SUSTAINABLE BIOFUELS

A TRANSITIONS APPROACH TO UNDERSTANDING THE GLOBAL EXPANSION OF ETHANOL AND BIODIESEL

by

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ABSTRACT

Between 1998 and 2008, the promise of biofuels to increase rural development, enhance energy security, and reduce greenhouse gas emissions stimulated their diffusion across international markets. This rapid expansion of ethanol and biodiesel encouraged many jurisdictions to implement biofuels expansion policies and programs. Global biofuels, characterised by mass production and international trade of ethanol and biodiesel, occurred despite their long history as marginal technologies on the fringe of the petroleum-based transportation energy regime. The first purpose of this dissertation is to examine the global expansion of ethanol and biodiesel to understand how these recurrent socio-technological failures co-evolved with petroleum transportation fuels.

Drawing from the field of socio-technical transitions, this dissertation also assesses the global expansion of ethanol and biodiesel to determine whether or not these first generation biofuels are sustainable. Numerous studies have assessed the technical effects of ethanol and biodiesel, but effects-based technical assessments of transport biofuels are unable to explain the interaction of wider system elements. The configuration of multi-level factors (i.e., niche development, the technological regime, and the socio-technical landscape) informs the present and emerging social functions of biofuels, which become relevant when determining how biofuels might become a sustainable energy option.

The biofuels regimes that evolved in Brazil, the United States, and the European

Union provide case studies show how ethanol and biodiesel expanded from fringe fuels to global commodities. The production infrastructures within these dominant biofuels regimes contribute to a persistence of unsustainable first generation biofuels that can inhibit the technical development and sustainability of biofuels. However, new and emerging ethanol and biodiesel markets are relatively small in comparison to the dominant regimes, and can readily adapt to technical and regulatory change.

This dissertation argues that dominant biofuels regimes have not produced a sustainable energy option. It explores the Canadian case to evaluate the opportunities for niche development, and suggests that small markets can develop niche innovations by regulating the insertion of sustainability criteria in order to de-align the dominant trajectory of global biofuels production regimes and encourage their re-alignment in a more sustainable configuration.

ACKNOWLEDGEMENTS

The United Nations Members States declared the year 2012 as the International Year of Sustainable Energy for All. It is fitting that this dissertation was completed at a time when the concept of sustainable energy has reached a global level of awareness and has been endorsed by the most international of all multilateral governance institutions.

Despite the global attention on biofuels, this dissertation has been a personal endeavour. At times, this pursuit verged on the quixotic, and only by stepping back now and again to gain perspective on my academic vocation was I able to maintain my commitment in the face of other challenges and opportunities. I can now conclude that this dissertation is indeed an important personal achievement that has fundamentally changed the way I view the world. Yet this influence occurred simultaneously with a number of other important events.

During the course of my research, my wife and I have lived in two provinces and three homes. We lived in both city and town, and now live on a small acreage of riparian areas, mixed forest, and farm land. We now have a daughter and a son. We also have a dozen or so new nieces, nephews and second cousins, and I have the privilege of being "uncle" to the children of close and personal friends. I lament the number of times I have received that body-numbing news of yet another loved one being diagnosed with cancer, but I consider myself lucky that I've only lost a handful of relatives and friends. Given the wonderful and sorrowful events that I proudly and dutifully embraced, I continued my academic pursuits while recognising the importance of my everyday reality.

I could not have completed this without the help, guidance, support and encouragement of so many people. My wife Andrea deserves the first and most credit. Her confidence in me exceeded all others, and without her support I might have fallen away from academia long ago. Our children, Ayla and Archer, reminded me on early weekend mornings as to why, in an ideal world, university education should be restricted to a five-day work week. My parents, Lawrence and Helen, always encouraged me to "get educated" so that I might achieve a better quality of life. They gave me a deep-rooted motivation that still inspires my desire to learn. My brother Jason and sister Jennifer always cheer me on, and I am lucky to have them in my corner. Likewise, Clare and Betty, Lorne, Sherry, Trèssa and Tobia were always there with words of encouragement and joyful distraction. Many have supported my research in various ways. I cannot name all of my colleagues, my students, my teachers, my friends, and my co-workers that have helped along the way, but I especially thank Lisa Erickson, Michael Cichon, and Natalie Moreno for taking the time to comment on early drafts. I also am grateful to those that helped with malfunctioning computer programs and other technical failures, particularly Rick Penner and Jen Peters of Emerge Knowledge, and my brother.

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Finally, I owe an endless debt of gratitude to my supervisor James Meadowcroft. He forewarned me that his job was to help me soar high on my ideas but to also bring me back to earth with as few broken bones as possible. True to his word, he afforded me the latitude to explore the literature at my discretion while delivering his most stringent criticisms during safe and friendly discussions. I wish to also thank my committee members Glen Toner and Stephan Schott, as well as external examiners Stephen Hill and Peter Andrée. Their challenging and provoking questions were delivered with a stern kindness that I've rarely experienced. I deeply value their input to, and interest in, my research. Their guidance and comments helped me to write the best possible dissertation that I could produce. Of course, all errors and omissions are my own.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ONE – Introduction

Fuelled by the promise of biofuels to accelerate rural development, boost energy security, and curb greenhouse gas emissions, countries around the world mapped a future in which ethanol and biodiesel would contribute to economic growth, stabilise and enhance national energy supplies, and improve environmental performance. Between 1998 and 2008, the biofuels industry exhibited an unprecedented rate of expansion. Annual global ethanol production jumped from 18 billion litres in 1998 to 30 billion litres by 2003[1], and jumped again to 52 billion litres annually by 2008.[2] Biodiesel followed a similar trajectory. In 1998, annual global biodiesel production was less than 500 million litres.[3] By 2003, installed capacity more than tripled to 1.75 billion litres, with actual production rates of about 65% (1.14 billion litres).[4] In 2008, global biodiesel production exceeded 10 billion litres; a 20-fold increase in a decade.[5]

Following Brazil's adoption of ethanol, the United States of America and the European Union expanded ethanol production. All three later embraced biodiesel, and have since become global leaders in the biofuels industry. The success of ethanol and biodiesel in these biofuels regimes suggested a bright future for biofuels as an alternative

[1] International Energy Agency, "Biofuels for Transport: An International Perspective," (Paris: International Energy Agency, 2004).
[2] Organisation for Economic Co-operation and Development, "Economic Assessment of Biofuel Support Policies," (Paris: Directorate for Trade and Agriculture, 2008).
[3] International Energy Agency, "Biofuels for Transport: An International Perspective." Production capacity, or installed capacity, refers to maximum possible productivity, which differs from actual yearly production levels.
[4] Ibid.
[5] Organisation for Economic Co-operation and Development, "Economic Assessment of Biofuel Support Policies."

to petroleum fuels, and one that could be achieved in a relatively short time frame. The International Energy Agency projected a combined global ethanol and biodiesel output exceeding 140 billion litres annually by 2020.[6] The United Nations Food and Agriculture Organisation similarly expected global biofuels production to grow and surpass 150 billion litres by 2017.[7] However, by 2008 the promise of biofuels to solve the problems associated with petroleum transport fuels seemed less feasible. Critics rallied against the dramatic acceleration of global production levels with warnings that adverse effects of biofuels production would negate many of the supposed benefits to energy markets, economic development opportunities, and greenhouse gas mitigation strategies.

Ethanol and biodiesel promised economic, social and environmental benefits, but it appears that the expansion of global biofuels has not been achieved in a sustainable way. The observation that biofuels have exhibited a significant diffusion throughout world markets with little confirmation on their contribution to sustainable development provides the impetus for this thesis. This chapter specifies two research questions and outlines the central argument of this dissertation. It then comments on the contribution of this thesis to the field of public policy, describes the methodology employed in this work, and concludes with an outline of subsequent chapters.

Research Questions

Since 2008, the excitement over ethanol and biodiesel has waned considerably and the promise of biofuels is much less certain. This warrants an investigation into some

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[6] International Energy Agency, "Biofuels for Transport: An International Perspective."
[7] Food and Agriculture Organization of the United Nations, *Biofuels: Prospects, Risks and Opportunities*, The State of Food and Agriculture (Rome: FAO, 2008).

fundamental questions about their rapid expansion and their potential as a sustainable energy option. The global expansion that marked the success of biofuels between 1998 and 2008 does not reflect the historical performance of ethanol and biodiesel, which can be characterised as suffering chronic misfires in their commercialisation and diffusion as transportation fuel products. The acceleration in global production comes after a long history of socio-technical stalls, which points us toward the first question of this dissertation: How did the global diffusion of ethanol and biodiesel succeed despite repeated failures over the past 150 years?

The second intent of this dissertation is to assess the sustainability of ethanol and biodiesel. This is a two-part question: (a) are first generation biofuels sustainable, and (b) if not, how might they be produced more sustainably? These questions are prompted by concerns with sustainable development, which the Brundtland Commission framed as a global challenge characterised by "interlocking crises" stemming from population growth and the resulting effects on food security, biodiversity, energy, and industry.[8] As this dissertation will show, these interlocking crises and their constituent issues appear prominently in the biofuels debate.

This dissertation employs a transitions approach to explain the diffusion of ethanol and biodiesel in the 21st century. It describes the emergence and strengthening of the biofuels regimes in three different jurisdictions, and shows how they contributed to the diffusion of first generation biofuels across global energy markets. It also investigates the sustainability of first generation ethanol and biodiesel to determine the extent to

[8] WCED, *Our Common Future* (Oxford: Oxford University Press, 1987).

which these biofuels can contribute to the transition toward a sustainable energy future.

Central Argument

The current oil-based transportation energy regime has provided substantial socio-economic benefits, but it is evident that global energy systems based on fossil fuels have reached a point at which adverse environmental effects have become pronounced. The emergence of a sustainable development paradigm (i.e., a trajectory of human development in which ecological limitations and intergenerational equity are included alongside economic growth as important indicators of successful societal progress) necessitates a reduction in the global reliance on oil products and petroleum fuels so as to mitigate resource scarcities that could threaten political, economic, and environmental security of nations in the present and the future.[9] There are three forms of scarcity that are at the root of these threats. *Demand-induced scarcity* involves increased population growth or higher per capita consumption. *Supply-induced scarcity* occurs where natural resources are used more quickly than they can be replenished or before adequate substitutes can be found. *Structural scarcity* appears when there is an unequal access to resources.[10] These resource scarcities can lead to social, economic, and political challenges, which may ultimately upset the balance of local, national and/or international communities.

Considering the connection between development trajectories and dominant

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[9] O.P. Dwivedi et al., *Sustainable Development and Canada: National and International Perspectives* (Peterborough: Broadview Press, 2001).

[10] Thomas Homer-Dixon, "Environmental Scarcities and Violent Conflict: Evidence from Cases," *International Security* 19, no. 2 (1994).

energy forms, sustainable development provides a conceptual direction on how to find new pathways for development that would address the pathologies of conventional development patterns. Sustainable development also provides a foundation for the ensuing discussion of sustainable energy. The development of sustainable energy resources and technologies can alleviate or avoid scarcities inherent to the present system of energy production and use. However, transportation energy systems present a unique challenge in that they rely almost entirely on oil and petroleum products. As such, the transportation sector is more likely to be subject to technological "lock-in" (i.e., a system-wide persistence toward a particular technical and economic trajectory). Moreover, most countries are dependent on foreign oil and incur higher import costs for transport fuels. This demand-induced scarcity will certainly increase over time as the world population grows and global economic development continues.

Aside from comparatively short-term economic considerations, the release of prehistoric carbon from the earth's crust is expected to affect humanity in the long-term.[11] The current socio-technological energy regime has succeeded because it is capable of exploiting fuel sources created over millennia, which are then harnessed, processed and distributed to consumers around the globe. The extraction of fossil fuels for energy production, distribution and use releases solid, liquid and gaseous waste into local and global ecosystems at comparatively high concentrations over relatively short time periods. In particular, greenhouse gas emissions from transport fuels have become a

[11] Nicolas Stern, *The Economics of Climate Change: The Stern Review* (Cambridge: Cambridge University Press, 2006).

pressing concern at national and international levels.[12] As populations and economies grow, we can expect a corresponding increase in the use of transportation vehicles and the consumption of petroleum products. These factors will exacerbate the supply-induced scarcity of oil products and petroleum fuels as well as increase the emission of greenhouse gases. In more specific terms, the problem of petroleum fuels is that the continued rate of greenhouse gas emissions will hasten the onset of climate change before we will be able to adapt to the declining ecological conditions that are anticipated with business-as-usual emissions levels under the conventional development trajectory.[13] Moreover, national concerns with demand- and supply-induced scarcities do not account for the global competition for oil and petroleum products, which entails a structural scarcity between the developed *north* and struggling *south*. Thus, all three forms of resource scarcity reveal unsustainable features of the production and distribution system presently in place for conventional energy. In these terms, fossil fuels and petroleum energy products do not appear to be sustainable.

The central argument of this thesis is that biofuels might be a partial solution to the problems associated with petroleum fuels, but that the mass production of first generation ethanol and biodiesel for distribution across international markets undermines the promise of biofuels as a form of sustainable energy. Nevertheless, first generation

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[12] Suzana Kahn Ribeiro et al., "Transport and Its Infrastructure," in *Climate Change 2007: Mitigation. Contribution of Working Group Iii to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. B. Metz, et al. (Cambridge and New York: Cambridge University Press, 2007).

[13] W. Neil Adger et al., "Assessment of Adaptation Practices, Options, Constraints and Capacity," in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. Martin L. Parry, et al. (Cambridge: Cambridge University Press, 2007).

biofuels are an important addition to the present energy system. Ethanol and biodiesel have contributed marginal changes to the dominant energy system and conventional development pattern. Although the trajectory of these niche products suggests they are not sustainable at a global level, small markets might stimulate the production and diffusion of sustainable biofuels through niche innovations supported by sustainability criteria that can help to de-align dominant production trajectories and to encourage a re-alignment of biofuels production in a more sustainable configuration.

Contribution

This dissertation explores the factors behind the recent increase in first generation ethanol and biodiesel production and assesses their potential as a form of sustainable energy. This investigation provides a timely examination of an emerging policy challenge. Public policy-makers have only recently approached the sustainability of biofuels as part of a broader interest in sustainable energy. The European Union has emphasised the importance of promoting sustainable renewable energy alternatives.[14] The United Nations developed a framework for decision-makers to encourage sustainable bioenergy production.[15] The United States outlined a "roadmap" for bioenergy and biomass production in the United States.[16] The recent popularity and government support for ethanol and biodiesel expansion strategies and the emergence of more sophisticated

[14] European Commission, "Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources," (Brussels: European Commission, 2008).

[15] UN-Energy, "Sustainable Bioenergy: A Framework for Decision Makers," (Food and Agriculture Organization, 2007).

[16] Biomass Research and Development Technical Advisory Committee, "Roadmap for Bioenergy and Biobased Products in the United States," (Washington, DC: Biomass Research and Development Initiative, 2007).

critiques on their sustainability merits closer study.

Canada has yet to address the sustainability of its biofuels industry. Existing studies on Canadian biofuels are few, and tend to focus on the technical potential for commercial advantage[17], policies and programs for economic feasibility[18], or their contribution to greenhouse gas emissions reduction strategies.[19] While recent studies have looked at biofuels policies in multi-nation comparisons[20], there are no studies on the social and technological aspects of the diffusion of biofuels in the Canadian context. Moreover, this thesis will be among the first to explore the public policy context of transport biofuels in Canada.

This dissertation also contributes to ongoing discussions on the broader transition toward sustainable energy. Understanding transport biofuels from a transitions perspective adds to a growing interest in the public policy implications of socio-technical change. In particular, this thesis contributes to the research on socio-technical change and transitions for sustainability. The multi-level perspective on transitions is a particular approach within the wider field of transitions studies, and is used in this thesis to examine

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[17] Michelle Heath, *Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels* (Calgary: University of Calgary Press, 1989).

[18] M. Olar et al., "Ethanol Industry in Canada," in *Research Series SR.04.08* (Québec City: Centre for Research in the Economics of Agrifood Laval University, 2004).

[19] Ewen Coxworth, "The Role of Renewable Liquid Transportation Fuels in Canada's Climate Action Plan: Pros and Cons, and Stages of Development of Ethanol, Biodiesel and Thermal Depolymerization Oil.," in *A Discussion Paper for the Saskatchewan Environmental Society and the Climate Action Network* (Saskatoon: 2003), Levelton Engineering Ltd., S&T Squared Consultants, and J.E. Associates, "Assessment of Net Emissions of Greenhouse Gases from Ethanol-Gasoline Blends in Southern Ontario," in *Report to Policy Branch, Agriculture and Agri-Food Canada* (Ottawa: Government of Canada, 1999), $(S\&T)^2$ Consultants Inc., "The Addition of Ethanol from Wheat to Ghgenius," in *Report to Office of Energy Efficiency, Natural Resources Canada* (Ottawa: Government of Canada, 2003).

[20] Thomas W. Hertel, Wallace E. Tyner, and Dileep K. Birur, "The Global Impacts of Biofuel Mandates," *Energy Journal* 31, no. 1 (2010), Giovanni Sorda, Martin Banse, and Claudia Kemfert, "An Overview of Biofuel Policies across the World," *Energy Policy* 38, no. 11 (2010).

the evolution of ethanol and biodiesel within the present socio-technical system. This perspective provides a basis for analysing the potential to achieve sustainable biofuels and strengthening niche development strategies with sustainability criteria.[21] The analytical focus on the multi-level perspective on transitions is later broadened to suggest potential areas of policy activity, but this dissertation does not advocate specific changes to government policies or programs. Where comparisons of other governance structures, such as those characterised by competitive markets or collaborative multilateralism, tend to seek to explain the differences or similarities between jurisdictions through comparison of select system variables[22], the multi-level perspective on transitions employed in this dissertation provides an alternate perspective on local and global energy systems. It seeks to "explain outcomes as a result of temporal sequences of events and the timing and conjunctures of event-chains".[23] These factors are not typically included in other approaches to public policy analysis, such as public choice, bureaucratic politics, policy networks, multiple streams, advocacy coalitions, or statistical-comparative

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[21] Thomas Buchholz, Valerie A. Luzadis, and Timothy A. Volk, "Sustainability Criteria for Bioenergy Systems: Results from an Expert Survey," *Journal of Cleaner Production* 17 (2009), B. M. Smyth et al., "Can We Meet Targets for Biofuels and Renewable Energy in Transport Given the Constraints Imposed by Policy in Agriculture and Energy?," *Journal of Cleaner Production* 18, no. 16/17 (2010).

[22] This is a persistent critique of comparative politics employing small-N analyses. David Collier and James E. Mahon Jr., "Conceptual "Stretching" Revisited: Adapting Categories in Comparative Analysis," *The American Political Science Review* 87, no. 4 (1993), Evan S. Lieberman, "Nested Analysis as a Mixed-Method Strategy for Comparative Research," *The American Political Science Review* 99, no. 3 (2005). For examples of comparative public policy, see Arnold Heidenheimer, Hugh Helco, and Carolyn Teich Adams, *Comparative Public Policy: The Politics of Social Choice in Europe and America* (New York: St. Martin's Press, 1975), Stella Z. Theodoulou, *Policy and Politics in Six Nations: A Comparative Perspective on Policy Making* (Upper Saddle River, New Jersey: Pearson Education, Inc., 2002).

[23] Frank W. Geels and Johan Schot, "The Dynamics of Transitions: A Socio-Technical Perspective," in *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*, ed. John Grin, Jan Rotmans, and Johan Schot (New York and London: Routledge, 2010), 93.

approaches.[24]

While advanced biofuels feedstocks and production processes are mentioned as part of the examination of first generation ethanol and biodiesel, this dissertation does not explore their potential as a sustainable energy option in detail. There is clearly an interest in developing advanced biofuels like cellulosic ethanol, algal biodiesel, as well as other alternative liquid transport fuels produced from biomass. These will surely become topics for future consideration, but there is not yet sufficient commercial activity to warrant their inclusion in the present discussion. Similarly, this dissertation does not examine other types of energy or transportation technology that might contribute to a sustainable energy future. Consequently, the potential for new automotive technologies[25] (in particular, hydrogen fuel cells[26] and electric vehicles[27]) in conjunction with other supporting alternative technologies (e.g., carbon capture and storage[28] or hybrid-electric vehicles[29]) or alternative consumption habits (energy efficiency[30], reducing energy

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[24] David Johnson, *Thinking Government: Public Sector Management in Canada*, 2nd ed. (Peterborough: Broadview Press, 2006), Paul A. Sabatier, ed., *Theories of the Policy Process, Theoretical Lenses on Public Policy* (Boulder, CO: Westview Press, 1999).

[25] Clovis Zapata and Paul Nieuwenhuis, "Exploring Innovation in the Automotive Industry: New Technologies for Cleaner Cars," *Journal of Cleaner Production* 18, no. 1 (2010).

[26] Seth Dunn, "Hydrogen Futures: Toward a Sustainable Energy System," *International Journal of Hydrogen Energy* 27, no. 3 (2002), Philip J. Vergragt, "Transition Management for Sustainable Personal Mobility: The Case of Hydrogen Fuel Cells," *Greener Management International* 47 (2004).

[27] Louise Poirier and Monique A. Hitchings, "Electric Vehicles and Biofuels Leading Clean Tech Investment," *Ethanol & Biodiesel News* 21, no. 27 (2009).

[28] $(S\&T)^2$ Consultants Inc., "An Examination of the Potential for Improving Carbon/Energy Balance of Bioethanol," in *IEA Bioenergy Task 39* (International Energy Agency, 2009).

[29] Valerie J. Karplus, Sergey Paltsev, and John M. Reilly, "Prospects for Plug-in Hybrid Electric Vehicles in the United States and Japan: A General Equilibrium Analysis," *Transportation Research Part A: Policy & Practice* 44, no. 8 (2010).

[30] Ernst von Weizsäcker, Amory B. Lovins, and L. Hunter Lovins, *Factor Four: Doubling Wealth, Halving Resource Use* (London: Earthscan Publications Ltd., 1997).

demand through mass transit[31], or sustainable cities[32]) are not the focus of this study. The exclusion of advanced biofuels, other alternative energy technologies, and alternative consumption habits from this dissertation should not imply any judgement over their long-term contribution to a future sustainable energy regime. Nor should their exclusion from this study suggest that they will not influence the future of sustainable biofuels. In fact, the research and development of these technological innovations suggest that the inclusion of these alternatives into a future energy system is closer than ever before. While this dissertation recognises that these alternatives are likely to affect the development of transportation technology and associated fuel sources in the future, this study remains focussed on the role of ethanol and biodiesel as commercially-available alternatives to gasoline and diesel fuels and their potential as a sustainable energy option.

Methodology

The main time period under consideration in this dissertation is 1998 through 2008. This is the period in which the diffusion and adoption of biofuels exceeded the expectations of supporters and critics alike. Yet the growth of global biofuels that occurred between 1998 and 2008 was built upon events that transpired much earlier, and it is therefore useful to revisit the history of ethanol and biodiesel. Historical comparisons figure prominently in this dissertation, and case studies are examined to reveal a larger

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[31] Rene Kemp and Jan Rotmans, "Managing the Transition to Sustainable Mobility," in *System Innovation and the Transition to Sustainability*, ed. B Elzen, Frank Geels, and K. Green (Cheltenham, UK: Edward Elgar, 2004), Vergragt, "Transition Management for Sustainable Personal Mobility: The Case of Hydrogen Fuel Cells."

[32] Peter Hall, "Sustainable Cities or Town Cramming?," in *Planning for a Sustainable Future*, ed. Antonia Layard, Simin Davoudi, and Susan Batty (London: Spon Press, 2001).

set of phenomena.[33] This thesis distinguishes characteristics of political jurisdictions (e.g., governments), economic structures (e.g., production systems), policy processes (including institutional structures and policy outcomes), and technologies (i.e., ethanol and biodiesel in relation to gasoline and petroleum diesel) in order to evaluate the growth of biofuels at the turn of the millennium. Recognising the challenges of using small-N case studies to infer causality, historical comparisons help to parse out the key differences and similarities in governance systems and socio-technological regimes with the aim of revealing the motivation, formation, and implementation of governance programs, such as biofuels expansion initiatives.[34]

In addition, case studies help to explore and reveal the current context of biofuels and sustainable energy resources and technologies. These include, first and foremost, ethanol and biodiesel as technical case studies from which to assess the potential application of these technological artefacts to the achievement of energy for sustainable development. As this dissertation reveals, the diffusion of ethanol and biodiesel to global markets was encouraged by the emergence and strengthening of biofuels regimes in Brazil, the United States, and the European Union. Consequently, this second category of case studies is used to investigate the degree to which these jurisdictions influenced the global trade in ethanol and biodiesel in order to reveal similarities and differences in the socio-technical context that shaped these biofuels regimes. Further, in terms of the role of small markets in promoting sustainable biofuels, studies of the federal and three

[33] Mark Irving Lichbach and Alan S. Zuckerman, "Research Traditions and Theory in Comparative Politics: An Introduction," in *Comparative Politics: Rationality, Culture, and Structure*, ed. Mark Irving Lichbach and Alan S. Zuckerman (New York: Cambridge University Press, 1997).

[34] Evan S. Lieberman, "Causal Inference in Historical Institutional Analysis: A Specification of Periodization Strategies," *Comparative Political Studies* 34, no. 9 (2001).

provincial biofuels expansion programs in Canada provide a third category of cases. These are considered and compared with the intent of identifying national and subnational governance structures, related biofuels policies and programs, and the degree to which these small markets were influenced by the global activity of dominant biofuels regimes.

These comparisons are useful to reveal variations and commonalities between cases, but comparisons do little to explain the processes involved in social transformations.[35] Employing a transitions approach as a theoretical framework helps to reveal dynamic interactions among social, political, economic, ecological and technical spheres of societal systems and; in so doing, can be used to overcome the static nature of historical observation.[36] Transitions approaches employ an heuristic model that investigate socio-technical changes over time by exploring historic turning points and the emergence of new societal contexts.[37] Transitions approaches also seek to provide insight into the characteristics of present socio-technical trajectories to identify ways that they might be adjusted to achieve more desirable outcomes.[38] This is a reflexive model that implies a bidirectional analysis; that is, it seeks to understand the context in which social

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[35] Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective."

[36] For example, see Philip Abrams, *Historical Sociology* (Ithaca, N.Y.: Cornell University Press, 1982), Robert Fox, ed., *Technological Change: Methods and Themes in the History of Technology, The History of Science, Technology and Medicine* (Amsterdam: Harwood Academic Publishers, 1996).

[37] Frank Geels, "Ontologies, Socio-Technical Transitions (to Sustainability), and Multi-Level Perspective," *Research Policy* 39 (2010).

[38] René Kemp, Saeed Parto, and Robert B. Gibson, "Governance for Sustainable Development: Moving from Theory to Practice," *International Journal of Sustainable Development* 8, no. 1/2 (2005).

actors choose technical pathways while revealing how technological artefacts shape the choices of social actors.[39]

In this thesis, the multi-level perspective on transitions is used to investigate the present and near-future implications for biofuels policy and sustainable energy. The multi-level perspective associated with transitions theory focuses on the linkages *across* analytical levels as well as the levels themselves.[40] In the case of biofuels, the socio-technical *regime* is the configuration of governance processes, trade and investment markets, objects, infrastructures, values and norms that frame the development of biofuels as a technological artefact.[41] The regime is identified as the meso-level, and the multi-level perspective seeks to identify connections of these meso-level elements with elements at other levels, such as engine technology at the *niche* (micro) level and the role of international organisations at the *landscape* (macro) level.

The multi-level perspective on transitions provides a "relatively straightforward way of ordering and simplifying the analysis of complex, large-scale structural transformations in production and consumption demanded by the normative goal of sustainable development".[42] This perspective helps to reveal the hidden roles and

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[39] Frank Geels, "The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860-1930)," *Technology Analysis & Strategic Management* 17, no. 4 (2005), Jan-Peter Voss and René Kemp, "Reflexive Governance for Sustainable Development – Incorporating Feedback in Social Problem Solving" (paper presented at the ESEE Conference - Special session on Transition Management, Lisbon, Portugal, June 14-17 2005).

[40] Frank W. Geels, "The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms," *Environmental Innovation and Societal Transitions* 1 (2011).

[41] René Kemp, "Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts," *Futures* 26, no. 10 (1994), Jan Rotmans, René Kemp, and Marjolein Asselt, "More Evolution Than Revolution," *Foresight* 3, no. 1 (2001).

[42] Adrian Smith, Jan-Peter Voss, and John Grin, "Innovation Studies and Sustainability Transitions: The Allure of the Multi-Level Perspective and Its Challenges," *Research Policy* 39 (2010).

interconnections within and between niches, regimes and landscapes. These differ from, but correspond in important ways with, the micro-, meso-, and macro-analytical levels. The interconnections between niche, regime and landscape are revealed through indicators of change as well as on direct observation of the activities of individuals or institutions. In order to bring together the different components that comprise this approach, this dissertation employs the multi-level perspective to augment the comparative methodology, rather than "stretch" the conceptual categorisation necessary for comparative analysis.[43] Where the comparative approaches tend to explain societal phenomena that are for the most part variations from the norm, the multi-level perspective on transitions involves a type of process theory that identifies the milestones of socio-technical change through explanatory concepts.[44] As is elaborated in chapter three, these concepts include alignment (between niches, regimes or landscapes), evolution (within these analytical levels), and the related pressures that arise from these process configurations. These processes are always contingent and tend to involve multiple generations, which makes *process tracing* a difficult exercise to portray in a parsimonious manner. This thesis utilises a narrative approach as a way to bring together various components of the multi-level perspective on transitions; that is, the historical circumstances, governance structures, politics, markets, socio-cultural milieu, and contingent processes are woven together to present a narrative of technological change,

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[43] Collier and Mahon Jr., "Conceptual "Stretching" Revisited: Adapting Categories in Comparative Analysis."

[44] Frank Geels and Johan Schot, "Typology of Sociotechnical Transition Pathways," *Research Policy* 36 (2007), Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective."

or "innovation journey"[45], that reveals the factors in the biofuels sector that might contribute to long-term socio-technical change.[46]

To investigate the activities and implications at each of the three levels of analysis within the multi-level perspective on transitions, the research procedures followed four progressive steps.[47] First, case studies were researched and presented in a narrative form. Based on primary data and secondary resources accumulated from historical journals and early publications, as well as newspaper articles, speeches, and production data, the case studies on Brazil, the United States, the European Union, as well as Canada and its provinces was necessarily drawn from various types of resources. In the case of Canada, information was provided by government documents, consultant reports, websites, corporate documents, and interviews with government employees, academics, and biofuels producers. Eight initial interviews were conducted with government employees identified as being responsible for, or otherwise actively involved in, developing biofuels policy. Interviewees were initially asked a broad range of questions that included technical considerations, history of biofuels in their respective jurisdiction, government policy objectives, and identities of relevant stakeholders. Government officials were asked to refer other potential interviewees. These referrals provided a snowball sampling

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[45] Frank Geels, "The Dynamics of Sustainable Innovation Journeys," *Technology Analysis & Strategic Management* 20, no. 5 (2008), Geert P.J. Verbong, Frank W. Geels, and Rob Raven, "Multi-Niche Analysis of Dynamics and Policies in Dutch Renewable Energy Innovation Journeys (1970-2006): Hype-Cycles, Closed Networks and Technology-Focused Learning," *Technology Analysis & Strategic Management* 20, no. 5 (2008).

[46] Geels, "The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms.", Smith, Voss, and Grin, "Innovation Studies and Sustainability Transitions: The Allure of the Multi-Level Perspective and Its Challenges."

[47] A.L. George and A. Bennett, *Case Studies and Theory Development in the Social Sciences* (Cambridge, MA: MIT Press, 2004). Quoted in Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective."

method, which was used to gain access to impenetrable groups, such as vulnerable sectors, large bureaucracies, and elites.[48] Questions on detailed aspects of policy processes, awareness of and or learning from other jurisdictions, and potential for first generation and advanced biofuels typically occurred during follow-up discussions. The pattern of questioning began with macro-level issues and concerns, and narrowed toward meso-level and micro-level considerations. This helped to categorise responses into landscape, regime, and niche level issues for further comparison and analysis. In a similar manner, semi-structured interviews were also conducted with representatives from other relevant social groups, including five with industry representatives, two with academics, and two with interest groups. As with the interviews with government employees, the aim was to discover aspects of biofuels that had not yet been revealed in existing documents, such as market potential, entrepreneurial expectations, or awareness of emerging environmental, social, and/or economic concerns.

Canadian data provided a wider selection than other jurisdictions, which necessitated alternative research procedures. Most information on the European Union was gleaned from European Commission Directives and related background papers. In the cases of Brazil and, albeit to a lesser extent, the United States, data was less available to the general public, a gap which was addressed by attending four conferences and public information sessions with government officials and industry professionals.[49] These

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[48] Winston Jackson, *Methods: Doing Social Research*, 2nd ed. (Scarborough, Ontario: Prentice-Hall Canada, 1999), 387-88.

[49] Conferences and public events attended included: University of Minnesota and INCAE Business School, "Biofuels, Carbon, and Trade: Leadership Challenges for the Interdependent Americas," (Minneapolis, MN: University of Minnesota, 2007), University of Winnipeg Environmental Studies Program, "Biofuels: Solution or Problem?," (Winnipeg, MB: University of Winnipeg,

events involved representatives from jurisdictions around the world, but were especially useful for gaining access to government officials, industry stakeholders, and academics from Brazil and the United States.

The intent of these narrative case studies was to provide the broad overview of each jurisdiction. The second stage of the research was to develop hypotheses and apply the theoretical mechanisms in order to explain the salient aspects of the narratives. In this stage, key turning points along the innovation journey of each case study were identified and further investigated. In total, interviews in the first two research stages involved semi-structured interviews with seventeen respondents (some of which participated in follow-up interviews), as well as additional research into particular aspects of a given event-chain.

The third stage of the research method employed was to analytically explain the case studies by identifying common patterns at the niche, regime, and landscape levels. Seven additional interviews were conducted with new interviewees (three government employees, two industry representatives, and two academics) and further research was conducted in this stage in order to clarify and confirm the accuracy and currency of the information. This stage brought together the research materials with the multi-level perspective on transitions approach, which provided the basis for comparing the three dominant biofuels production regimes in contrast with small markets in Canada.

2007), University of Winnipeg Environmental Studies Program and The Canadian Community Economic Development Network, "Crops, Cars and the Climate Crisis: The Global Impacts of Growing Biofuels on Food, Farmers and Human Rights," (Winnipeg, MB: University of Winnipeg, 2008), Young Environmental Professionals of the National Capital Region, "Biofuels and Green Transportation: Where Do They Fit?," (Ottawa, ON: YEP NCR, 2006).

Finally, the fourth stage of this research procedure was to elaborate on the general explanation from which to answer the main research questions regarding the global expansion of biofuels and their sustainability. Not only did this help to reveal indications of socio-technical change within niches, regimes and landscapes, it also helped to identify interpretations of technological artefacts and processes and to ascertain historical moments in the global expansion of biofuels. The research procedures leading to these generalised explanations parallel other studies on the technological evolution of other types of sustainable energy options.[50]

Outline

Chapter two outlines the expected benefits of biofuels and provides a technical overview of ethanol and biodiesel. Particular attention is given to the effects of biofuels in terms of their production and use. Chapter three presents the theoretical framework of this dissertation. It employs the principles of sustainable development in order to contrast "sustainable" energy with other depictions of energy (e.g., renewable, alternative, etc.). It discusses the need to define sustainable energy in a way that not only addresses their technical effects, but also fulfills their social functions. Chapter three then introduces the theoretical framework from which to understand the adoption and diffusion of technology and the stability and change of socio-technical systems. Finally, this chapter presents the multi-level perspective on transitions as a preferred way to understand the global expansion of ethanol and biodiesel.

The diffusion and adoption of ethanol and biodiesel have achieved a level of

[50] Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective."

commercial success, and biofuels expansion strategies have had both positive and negative short-term effects on energy systems. This expansion to global markets is covered in chapters four through six. Chapter four presents a history of ethanol and biodiesel and their application in North America and the European Union in the 19th and 20th centuries. It identifies socio-technical barriers that inhibited their diffusion and adoption over the past century and a half, which stabilised these technical artefacts as fringe fuels. Chapter five shows how Brazil, the United States, and the European Union established and strengthened their respective biofuels regimes, and how these regimes contributed to the diffusion of ethanol and biodiesel to global markets. This rediscovery of old technologies in new socio-technological contexts was an important stage in the diffusion of biofuels in which these biofuels regimes shaped the rapid global expansion of ethanol and biodiesel between 1998 and 2008. Since then, the rate of expansion has levelled off, and chapter six explains the factors that slowed their expansion.

Considering the diffusion of ethanol and biodiesel in terms of their contribution toward the achievement of sustainable energy, chapter seven investigates biofuels as "two-world" technologies that contain robust socio-technical characteristics that enable them to straddle regime shifts. The adaptive content contained within ethanol and biodiesel suggest that biofuels can act as petroleum substitutes, fuel extenders, or as vanguard artefacts that could trigger a technological revolution and a wider socio-technical shift toward sustainable energy. Chapter eight investigates the context of biofuels in Canada by examining biofuels policies of the federal and select provincial governments to reveal any apparent influence of the three dominant biofuels regimes and the global trade in biofuels on policy trajectories within small biofuels markets. It also suggests that small markets can contribute to the achievement of sustainable biofuels, but only if they can avoid the unsustainable technological "lock-in" experienced by dominant biofuels regimes. Niche development within small markets shows subnational variation, which may suggest an ability to resist the harmonising trajectory of global biofuels.

Chapter nine explores how the multi-level perspective can be used as an analytical tool to contribute to the overarching policy framework of small jurisdictions, and suggests areas for further exploration as to how small markets might avoid unsustainable technological "lock-in" of first generation ethanol and biodiesel and instead encourage the production of more sustainable biofuels. Sustainability criteria and certification standards have been suggested in the form of principles, guidelines and requirements, each of which provide a different focus for policy direction and different level of policy instruction. These variations hold implications for niche development strategies. Regulation can aid in the de-alignment of unsustainable biofuels production, but the process of regulatory development can take many forms, and can range from voluntary measures to compulsory requirements. The chapter emphasises the need for corrective measures that re-align biofuels production in a more sustainable configuration.

Chapter ten concludes this dissertation by summarising the main ideas developed in this thesis. It outlines the main arguments, and identifies the contribution of this work to the fields of sustainable energy, transition studies, and public policy.

TWO – A Primer on Ethanol and Biodiesel

Ethanol and biodiesel have an established pedigree. They interact almost seamlessly with petroleum fuels distribution systems. They involve relatively simple production processes and can be produced from a wide variety of feedstocks which make them almost universally accessible. Most importantly, ethanol and biodiesel have captured the attention of governments, investors, and entrepreneurs around the world.[1] These factors suggest that first generation biofuels might encourage a shift toward a sustainable development trajectory that would contribute to a wider socio-technical transition away from the current reliance on petroleum in global energy systems. The purpose of this chapter is to outline the basic characteristics of ethanol and biodiesel. After introducing the promise of these biofuels as alternative transportation fuels, this chapter provides the technical specifications of ethanol and biodiesel, and identifies the main environmental and social benefits of using biofuels instead of petroleum fuels. Although the focus on the technical effects is admittedly narrow, establishing these properties and characteristics are a necessary starting point from which to begin an assessment of their sustainability.

[1] Biopact, *EU, US, Brazil Release Report on Biofuels Specifications to Expand Trade* (February 4 2008 [cited February 5 2008]); available from http://biopact.com/2008/02/eu-us-brazil-release-report-on-biofuels.html, International Energy Agency, "Biofuels for Transport: An International Perspective.", W. Körbitz et al., "Worldwide Review on Biodiesel Production," in *IEA Bioenergy Task 39, "Liquid Biofuels", subtask "Biodiesel"*. ed. Austrian Biofuels Institute (Paris: International Energy Agency, 2003), Samantha Ölz, Ralph Sims, and Nicolai Kirchner, "Contribution of Renewables to Energy Security," in *IEA Information Paper* (Paris: International Energy Agency, 2007), Organisation for Economic Co-operation and Development, "Economic Assessment of Biofuel Support Policies."

The Promise of Biofuels

After a century of technological dormancy, transport biofuels have become politically, commercially, and environmentally attractive.[2] This renewed activity has rekindled the interest in extracting combustible liquid energy from agricultural crops.[3] The promise of biofuels has stimulated their technical advancement from simple alcohol fermentation or pressed oilseed transesterification processes toward more advanced biofuels production processes from non-traditional feedstocks.[4] The potential for second-generation cellulosic ethanol has further increased expectations that biofuels may be able to solve multiple policy challenges.[5] Where first generation biofuels production employs technologies that have remained fundamentally unchanged since the earliest experiments in the 1800s, there is no guarantee that second generation biofuels production process will succeed.[6] The move toward advanced biofuels is not certain, and "first generation" biofuels may be inherently unsustainable due to their direct and indirect effects on other issues, such as food security[7], land use patterns[8], and water.[9]

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[2] Christian Bomb et al., "Biofuels for Transport in Europe: Lessons from Germany and the Uk," *Energy Policy* 35 (2007), International Energy Agency, "Biofuels for Transport: An International Perspective."

[3] Luís A. B. Cortez et al., "Considerations on the Worldwide Use of Bioethanol as a Contribution for Sustainability," *Management of Environmental Quality: An International Journal* 14, no. 4 (2003), Alexander E. Farrell et al., "Ethanol Can Contribute to Energy and Environmental Goals," *Science* 311 (2006).

[4] Carlo Hamelinck and André P.C. Faaij, "Outlook for Advanced Biofuels," *Energy Policy* 34 (2006).

[5] Christian Azar, Kristian Lindgren, and Bjorn A. Andersson, "Global Energy Scenarios Meeting Stringent Co2 Constraints - Cost-Effective Fuel Choices in the Transportation Sector," *Energy Policy* 31 (2003), European Commission, "Promoting Biofuels in Europe: Securing a Cleaner Future for Transport," ed. The Directorate-General for Energy and Transport (Brussels: European Union, 2004).

[6] Bruce A. Babcock, Stéphan Marette, and David Tréguer, "Opportunity for Profitable Investments in Cellulosic Biofuels," *Energy Policy* 39, no. 2 (2011), Rethabile Melamu and Harro von Blottnitz, "2nd Generation Biofuels a Sure Bet? A Life Cycle Assessment of How Things Could Go Wrong," in *Journal of Cleaner Production* (2011).

[7] Food and Agriculture Organization of the United Nations, *Biofuels: Prospects, Risks and Opportunities.*

Of the limited renewable transportation energy options, ethanol and biodiesel seem to be the most likely candidates for a short-term policy direction in the long-term transition toward sustainable transportation energy. They are made from renewable feedstocks. They enhance energy security. Proponents describe these biofuels as a "low carbon" or "carbon neutral" energy source, where carbon dioxide emissions are absorbed by crops grown in the next season. They emit less greenhouse gases than petroleum fuels and alleviate associated environmental and air quality concerns. They also help local and regional economic development. As a result, governments have increased support for ethanol and biodiesel as a way to address declining oil reserves, rural development, greenhouse gas emission reductions, and urban air pollution.[10] Transport biofuels now have a larger role in national energy strategies in countries around the globe that seek to reduce dependency on foreign oil.

Although biofuels promised to solve these and other policy challenges, the emerging debate over liquid biofuels as an appropriate use of biomass has escalated. The main contested issues include economic costs, environmental performance, net energy

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[8] Richard J. Plevin et al., "Greenhouse Gas Emissions from Biofuels' Indirect Land Use Change Are Uncertain but May Be Much Greater Than Previously Estimated.," *Environmental Science & Technology* 44, no. 21 (2010). Jacinto F. Fabiosa et al., "Land Allocation Effects of the Global Ethanol Surge: Predictions from the International Fapri Model," *Land Economics* 86, no. 4 (2010).

[9] Christopher Harto, Robert Meyers, and Eric Williams, "Life Cycle Water Use of Low-Carbon Transport Fuels," *Energy Policy* 38, no. 9 (2010).

[10] Biofuels Research Advisory Council, "Biofuels in the European Union: A Vision for 2030 and Beyond," ed. European Commission (Brussels: European Union, 2006), Biopact, *An in-Depth Look at Brazil's "Social Fuel Seal"* (March 23, 2008 2007 [cited]); available from http://biopact.com/2007/03/in-depth-look-at-brazils-social-fuel.html, Lisa Ryan, Frank Convery, and Susana Ferreira, "Stimulating the Use of Biofuels in the European Union: Implications for Climate Change Policy," *Energy Policy* 34 (2006), John Sheehan et al., "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol," *Journal of Industrial Ecology* 7, no. 3-4 (2004).

ratio, and energy yield of biomass.[11] Some argue against their carbon neutrality, suggesting that the energy inputs required for biofuel production make this a somewhat tenuous claim.[12] Some blame biofuels for the rise in food prices and world grain shortages.[13] As will be addressed in greater detail in chapter six, critics have argued that biofuels are: increasing the stress put upon natural ecosystems and agricultural lands; encouraging the transformation of important natural ecological systems into cultivated tracts through human activity; contributing to the decline of biodiversity; adding to urban air quality problems though higher emissions of particulate matter; distorting markets through subsidies; enabling the concentration of ownership of land and crop varieties in the hands of a few large transnational corporations; and, threatening the basic human rights of people around the world. The promise of biofuels involves numerous effects, and these are subject to conflicting interpretations that will affect how societies envision the role of transport biofuels as a form of sustainable energy.

Defining Biofuels: Ethanol and Biodiesel

Liquid biofuels can take numerous forms depending on their chemical make-up. Many biofuels have been explored for their potential to achieve energy, economic and

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[11] Tim Lieuwen, George Richards, and Justin Weber, "Approaching Zero," *Mechanical Engineering* 132, no. 5 (2010), Tad. W. Patzek et al., "Ethanol from Corn: Clean Renewable Fuel for the Future, or Drain on Our Resources and Pockets?," *Environment, Development and Sustainability* 7 (2005), David Pimentel, "Energy and Dollar Costs of Ethanol Production with Corn," (Golden, CO: Colorado School of Mines, 1998), Louise Poirier and Jack Peckham, "Crops Will 'Never' Yield Enough to Replace Petroleum: Study," *Ethanol & Biofuels News* 22, no. 1 (2010), UN-Energy, "Sustainable Bioenergy: A Framework for Decision Makers."

[12] Aranya Venkatesh et al., "Uncertainty Analysis of Life Cycle Greenhouse Gas Emissions from Petroleum-Based Fuels and Impacts on Low Carbon Fuel Policies," *Environmental Science & Technology* 45, no. 1 (2011).

[13] Marcelo Fernandes Pacheco Dias, Eugenio Avila Pedrozo, and Tania Nunes da Silva, "Proposition of a Framework for Interpretation of Complex Problems and Initiatives Focused on Sustainability: The Food, Energy and Biofuel Crisis," *China-USA Business Review* 9, no. 4 (2010).

environmental goals. The two most popular biofuels are ethanol and biodiesel, and this section specifies their technical characteristics.

Ethanol is an alcohol alternative for gasoline. It can be produced from ethylene (a derivative of the oil refining process), catalytic hydration of ethane, or from the fermentation of sugars from biomass. The last of these was the first transport biofuel to achieve widespread commercialization, which relies upon the agricultural suitability of energy crops.

When assessing the effects of ethanol, it helps to divide the examination of its technical characteristics into the separate domains of production and consumption. In terms of *production effects*, most ethanol production facilities around the world are based on the fermentation and distillation of food crops into alcohol. This "first generation" biofuels technology is the most popular gasoline alternative. Ethanol production techniques have improved over the last few decades, and now include acid and enzyme hydrolysis to hasten or increase production. Acid hydrolysis involves a chemical reaction between acid and water that, when mixed with a feedstock, aides in its decomposition.[14] This process extracts the simple sugars from starches and cellulose, but it is an energy- and cost-intensive process that results in about 50% feedstock losses making it an inefficient process despite being a mature technology. Enzyme hydrolysis has been developed to extract fermentable sugar solutions directly from the feedstock. This avoids intermediate processing, and thereby reduces energy input costs. In addition, acid and

[14] Andy Aden and Thomas Foust, "Technoeconomic Analysis of the Dilute Sulfuric Acid and Enzymatic Hydrolysis Process for the Conversion of Corn Stover to Ethanol," *Cellulose* 16 (2009), Climate Change Central, *Closing the Loop on Biofuel Production* (October) (Climate Change Central, 2008 [cited 24 November 2008]); available from http://www.climatechangecentral.com/publications/c3-views/october-2008/closing-loop-biofuel-production.

enzyme hydrolysis also offer the possibility of producing ethanol from the xylose (sugars extracted from wood and straw) and lignin (an organic binding compound that supports plant tissue and provides tensile strength) portions of biomass that were previously waste products.[15] This innovation forms the basis for "second generation" ethanol, which can utilise non-food products like grasses and trees as biofuel feedstocks. These advanced biofuels promise to utilize more complex ligno-cellulosic biomass, thereby increasing the energy crop yield per acre, enhancing the efficiency of the cultivation and conversion process, and reducing the energy and resource requirements for their growth and transformation. However, cellulosic ethanol has not yet become commercially viable, and their current role in the global biofuels industry remains largely in the research and development stage.[16]

The most common feedstocks for first generation ethyl alcohol (C_2H_5OH) are sugar cane, corn, wheat and sugar beets. Ethanol production is a four-part process: (a) growth, harvest and delivery of feedstocks, (b) pre-treatment (physical conversion of raw material into hydrolysable substrate), (c) hydrolysis (the enzymatic reaction that converts starch and cellulose to sugar), and (d) fermentation (conversion of sugars to ethanol and CO_2) and distillation (separation of ethanol from by-products and water). Warmer climates are better suited for sugar cane, corn, and sorghum while colder climates are

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[15] Frank Rosillo-Calle, "Liquid Fuels," in *Bioenergy and the Environment*, ed. Janos Pasztor and Lars A. Kristoferson (Boulder, CO: Westview Press, Inc., 1990), 114-15.

[16] This is expected to change in the near future. See Babcock, Marette, and Tréguer, "Opportunity for Profitable Investments in Cellulosic Biofuels.", Climate Change Central, *Next Generation of Liquid Biofuels* (October) (Climate Change Central, 2008 [cited 24 November 2008]); available from http://www.climatechangecentral.com/publications/c3-views/october-2008/next-generation-liquid-biofuels, Hamelinck and Faaij, "Outlook for Advanced Biofuels.", Iogen Corporation, *Cellulose Ethanol Is Ready to Go: Iogen Producing World's First Cellulose Ethanol Fuel* [website] (Iogen Corporation, 2004 [cited 31 October 2006]); available from http://www.iogen.ca/news_events/press_releases/2004_04_21.html.

more favourable for sugar beets, wheat and corn. While the final product is virtually identical, different feedstocks have different yields, sugars, and energy potential that affect the social, economic and environmental effects of biofuels. Thus, the choice of feedstock can be important.[17]

Energy crops must first be reduced to simple sugars before fermentation can occur. This process is more or less the same for all ethanol feedstocks in the first generation production process and can be sub-divided into dry-mill and wet-mill techniques. Dry-mill processing is the simpler of the two, but produces less value-added co-products than wet-milling, which also produces germ, fibre, and gluten and starch components that can be used to produce ethanol or high fructose corn syrup.[18] Wet-milling processes result in more diverse by-products than dry-milling, but the feasibility of waste recapture depends upon the feedstock, the harvest method, type of pre-treatment, and the fermentation process.

While co-products can be captured, they require adequate infrastructure and capacity to do so. Otherwise they are released into proximate terrestrial, aquatic and atmospheric environs as unsalvaged by-products. In the early stages of Brazil's ethanol industry, waste products from sugar cane were disposed of in rivers and caused substantial water pollution. As Brazil's ethanol industry developed, numerous by-products have been retained and refined as value-added goods. Stillage can be recycled to reduce waste volumes, or it can be directly applied as a fertiliser or fermented into biogas (e.g., bagasse from sugar cane) for electricity production, as has become the practice on

[17] Rosillo-Calle, "Liquid Fuels," 119-21.
[18] Heath, *Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels*, 41-45.

Brazilian sugar cane fields.[19] Additional stages can be added to ethanol production streams in order to reduce pollution and recover by-products as value-added co-products such as low-solid liquid stillage, distilled dried grain with soluables for animal feed, and CO_2 for industrial and beverage use. There are numerous other potential co-products, but certain co-products require particular feedstocks, which are in turn dependent on location and marketability. Non-fuel value-added products obtained from ethanol production are not universally feasible, and ethanol from sugar cane provides fewer potential co-products than ethanol from corn, wheat, and other grains. Since feedstock prices and additional production costs affect the commercial viability of first generation ethanol, producers might rely more heavily on value-added co-products to supplement overall ethanol production costs. Early studies suggested that the success of ethanol fuel enterprises in small markets would likely depend on particular feedstocks, site locations, and the demand for ethanol and co-products for niche markets.[20] However, this has not occurred in the biofuels regimes that produce most of the world supply of biofuels.

Where some waste by-products can be converted into value-added co-products, pollutants and emissions are created as a result of the production process due to the high energy demand and associated particulate emissions, excess distillates (i.e., liquids) and organic vapours, toxic chemical use, dusts from raw material handling, and fermentation odours.[21] While indirect problems of land use and degradation (through monocultures, intense agro-industrial farming, and soil erosion) have been identified[22], the direct effects from fermentation and distillation are generally considered to be environmentally benign.

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[19] Rosillo-Calle, "Liquid Fuels," 126-27.
[20] Heath, *Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels*, 42-45.
[21] Rosillo-Calle, "Liquid Fuels," 124.
[22] Ibid., 122-23.

Depending on the source feedstock however, some products may be necessary that have adverse environmental effects. Feedstocks with higher percentages of ligno-cellulose fibres make the hydrolysis process more difficult. Biocatalysts and enzymes are ideal for starches, but cellulosic feedstocks require acid or more complex enzymatic hydrolysis processes. For instance, sugar- and starch-based feedstocks such as fruits, vegetables and grains contribute some biomass effluent to the waste stream, but these can be reclaimed as value-added co-products, composted or otherwise discarded with relatively minimal disposal requirements. However, the acid hydrolysis process used to draw the simple sugars from lignocellulosic feedstocks contributes acids and other chemicals, as well as the remaining non-sucrose components (e.g., residues, pulp, and other fibrous matter) to the waste stream. Although techno-economic improvements have reduced effluent, chemical and solid wastes require special disposal protocols to inhibit site contamination and other downstream effects.[23]

Consumption effects comprise the second domain that can be used to define the technical characteristics of ethanol, and include exhaust emissions from ethanol-gasoline blends include hydrocarbons, carbon monoxide (CO), nitrogen oxides (NOx), among other pollutants. Because oxygenates are partially combusted hydrocarbons, the amount of oxygen needed in combustion is less than in regular gasoline. Thus, blend emissions are less than normal gasoline, while emissions from unblended ethanol (E100) exhibit different emissions results. Evaporative emissions include hydrocarbons that, when combined with increased NOx emissions, could create air quality concerns (i.e., ozone

[23] Aden and Foust, "Technoeconomic Analysis of the Dilute Sulfuric Acid and Enzymatic Hydrolysis Process for the Conversion of Corn Stover to Ethanol."

attainment problems) in some areas during the summer months. However, proper blending for seasonal optimisation can avoid adverse effects on ambient ozone levels.[24] Exhaust emissions from ethanol blends depend largely on petroleum quality, and exhaust emissions decline as blend ratios increase (e.g., E85 burns cleaner than E10). Clean combustion also depends largely on improvements to engine technology and engine upkeep.

Early studies suggested that the use of pure alcohol as a gasoline substitute in a regular internal combustion engine had positive effects on exhaust emissions levels.[25] Where pollution from unburned fuels and most hydrocarbon emissions levels were about the same, emissions of some hydrocarbons (like polynuclear aromatics) were substantially lower. Similarly, carbon monoxide (CO) emissions were about the same (but could be controlled with cleaner engine technology), while nitrogen oxides (NO_x) emissions were also lower. Particulate emissions were near zero, and there were no sulphur emissions. Oxygenated compounds and aldehydes emissions were found to be higher in older gasoline automobiles without catalytic converters, but emissions levels improved significantly in vehicles designed to burn alcohol fuels.[26]

More recent assessments of ethanol focused on the amount of energy input it requires to produce a unit of energy output, or "net energy balance". Energy ratios are used as a comparative indicator for the net energy balance, and a positive net energy balance, for example, is said to occur when more energy per unit output is produced than

[24] Heath, *Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels*, 56.

[25] Ibid, Doann Houghton-Alico, *Alcohol Fuels: Policies, Production, and Potential* (Boulder, CO: Westview Press, 1982), Harry Rothman, Rod Greenshields, and Francisco Rosillo Callé, *Energy from Alcohol: The Brazilian Experience* (Lexington, USA: The University Press of Kentucky, 1983).

[26] Rosillo-Calle, "Liquid Fuels," 129, table.

the required energy per unit input. Table 2-1 compiles the research results of ten North American studies of ethanol between 1998 and 2005. This table shows that the net energy balance of ethanol ranges from .58 to 1.67 for corn ethanol, while the energy ratio for sugarcane is comparatively much higher at 3.66.

Table 2-1: Net Energy Balance of Ethanol (BTU/US Gallon)

Study	Energy Input+	Co-production Credits	Net Input	Total Output	Net Energy Balance	Energy Ratio*
Pimentel (1998)	129600	Nil	129600	76000	(53600)	.58
Levelton (1999)	68190	14055	54135	84750	30615	1.56
Shapouri and McAloon (2001)	72052+	26250	45802	76330	30528	1.67
Shapouri et al. (2002)	77228	14372	62856	83961	21105	1.34
Wang (2001)±	62746+	13284+	49462	76000	26538	1.54
Graboski (2002)	77497	14829	62668	76000	13332	1.21
S&T[2] Consultants (2003)±	61909 (wheat)	9530	52379	76000	23621	1.45
Patzek (2004)	58197	Nil	58197	76396	18199	1.31
Pimentel and Patzek (2005)	118909	6847	112062	77206	(34853)	.69
Dias de Oliveira (2005)	24676 (sc) 76797	864 (sc) Nil	23812 (sc) 76797	87287 (sc) 84395	63475 (sc) 7598	3.66 (sc) 1.09

Source: Author's compilation from the literature cited.

\+ weighted average was used for both dry and wet milling manufacturing process
sc sugar cane
± Source: Rillett, 2003
* Energy ratio = total output / net input

These studies argue that an energy content of biofuels that is equal to or less than petroleum is simply not economic, and that biofuels requiring an equal or greater amount of petroleum throughout its lifecycle (i.e., from feedstock cultivation to combustion emissions) entails unnecessary energy and dollar costs[27] that are a "drain on our resources and pockets".[28] In short, biofuels with a petroleum energy balance near parity are not worth the effort. They do not consider the long-term effects on other resources, including soil, water, and air quality.[29] Net energy ratios are often used to bridge the gap between different data measures, but "net energy ratios are extremely sensitive to specification and assumptions and can produce uninterpretable values in some important cases".[30] In addition to problems with variable specification, the calculation of these variables can also contribute to confusion over the net energy balances because the "calculation of net energy [is] highly sensitive to assumptions about both system boundaries and key parameter values".[31] Ultimately, net energy ratios provides a convenient metric, but such assessments are not suited to address the "confounding influences of gasoline" in blended fuels that make it difficult to attribute tailpipe emissions to either gasoline or ethanol.[32]

Although energy crops capture atmospheric carbon and biofuels have been proven to reduce CO_2 emissions into the atmosphere, other gases and pollutants increase with ethanol combustion. While CO_2 emissions from fossil fuel combustion comprises over 80% of the emitted greenhouse gases and has a global warming potential equal to one,

[27] Pimentel, "Energy and Dollar Costs of Ethanol Production with Corn."
[28] Patzek et al., "Ethanol from Corn: Clean Renewable Fuel for the Future, or Drain on Our Resources and Pockets?."
[29] T. W. Patzek, "Thermodynamics of the Corn-Ethanol Biofuel Cycle," *Critical Reviews in Plant Sciences* 23, no. 6 (2004): 319.
[30] Farrell et al., "Ethanol Can Contribute to Energy and Environmental Goals," 506.
[31] Ibid.
[32] Sheehan et al., "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol," 136.

methane (CH_4) and nitrous oxide (N_20) have significantly higher global warming potentials of 21 and 310, respectively. Therefore, small increases of greenhouse gases with higher global warming potentials have larger impacts.

Table 2-2: GHG Emissions from Gasoline and Ethanol Blends

Study	Fuel type		GHG emissions (grams/mile)	
	Baseline	Biofuel		
Wang (1996)	Gasoline (RFG)	Corn Ethanol (E85)	343	256 (↓25.4%)
Wang (1997)	Gasoline	Corn Ethanol (E10)	382.7	373.6 (↓2.4%)
Wang (1997)	Gasoline	Corn Ethanol (E85)	469.1	324.7 (↓30.8%)
Levelton (1999)	Gasoline	Corn Ethanol (E10)	510	491 (↓3.9%)
Levelton (1999)	Gasoline	Corn Ethanol (E85)	510	321 (↓37.1%)
Agriculture Canada (1999)	Gasoline	Corn Ethanol (E10)	-	↓3.9%
Kheshgi (2000)	Gasoline	Corn Ethanol (E10)	-	↓25%
Wang (2001)	Gasoline (RFG)	Corn Ethanol (E90)	-	↓29.4%
Wang (2001)	Gasoline (RFG)	Cellulosic Ethanol (E90)	-	↓78.4%
$S\&T^2$ Consultants (2003)	Gasoline	Wheat Ethanol (E10, coal)	525.6	502.9 (↓4.3%)
$S\&T^2$ Consultants (2003)	Gasoline	Wheat Ethanol (E10, hydro)	525.6	499.1 (↓5.0)
$S\&T^2$ Consultants (2003)	Gasoline	Wheat Ethanol (E85, coal)	525.6	288.9 (↓45.0%)
$S\&T^2$ Consultants (2003)	Gasoline	Wheat Ethanol (E85, hydro)	525.6	248.2 (↓52.8%)
IPCC (current methodology)	Gasoline	Corn Ethanol (E10)	-	↓4.7%
Sheehan et al. (2004)	Gasoline	Corn Stover Ethanol (E85)	382.4 (239 g/km)	62.4 (39 g/km) (↓83.6%)
Farrell et al. (2006)		Corn Ethanol (E10)	-	↓13%

Source: Author's compilation from the literature cited.

Table 2-2 synthesises studies from a ten-year period (1996 to 2006) that compared either conventional gasoline or reformulated gasoline (RFG) with high (E85, E90) and low (E10) ethanol blends made from corn, wheat and cellulose. Each study claims to adopt a life-cycle analysis approach, and, although methodologies differ, they all show a decrease in total greenhouse gas emissions. In particular, low ethanol content blends (E10) emitted between 2.4% and 25% less greenhouses gases than conventional gasoline.

Reformulated gasoline, which increases the oxygen content with petroleum-based products to reduce evaporation and improve combustion, emitted less greenhouse gases than both conventional gasoline and corn- and wheat-based E10 blends. High blends of corn ethanol reduced greenhouse gas emissions by 25.4% and 37.1% in comparison with conventional gasoline, while high blends of wheat ethanol performed between 20-50% better than corn ethanol. The 78.4% decrease in greenhouse gas emissions from ethanol produced from cellulosic biomass indicates substantial improvements over first generation ethanol. These results were similar for corn stover, which showed a comparative greenhouse gas emissions reduction of 83.6%. In short, first generation ethanol and reformulated gasoline provided small reductions in greenhouse gas emissions.

Table 2-3 compares fuel types and non-greenhouse gases emissions of carbon monoxide (CO), nitrous oxides (NO_x), sulphur oxides (SO_x), non-methane volatile organic compounds (VOC), and particulate matter (PM). These non-greenhouse gas emissions contribute to air pollution and climate change. For example, volatile organic compounds affect atmospheric ozone while particulate emissions (fine particles and aerosols) absorb or reflect ultraviolet light and can increase smog over specific areas.

Table 2-3: Non-GHG Emissions from Gasoline and Ethanol Blends

Study	Fuel Type		CO		NOx		SOx		VOC	PM
	Baseline	Biofuel								
Wang (1996)	RFG	Corn Ethanol (E85)	8.844	7.929 (↓10.3%)	.743	1.345 (↑81.1%)	.126	.588 (↑367.5%)	1.112	.714 (↓35.8%)
Levelton (1999)	Gasoline	Corn Ethanol (E10)	11.49	10.12 (↓11.9%)	1.89	1.90 (↑0.53%)	.39	.33 (↓15.4%)	1.61	1.50 (↓6.83%)
Levelton (1999)	Gasoline	Corn Ethanol (E85)	11.49	7.77 (↓32.4%)	1.89	1.94 (↑2.6%)	.39	.234 (↓40%)	1.61	1.74 (↑8.1%)
S&T^{2} Consultants (2003)	Gasoline	Wheat Ethanol (E10, coal)	21.99	17.28 (↓21.4%)	1.77	1.80 (↑1.7%)	.49	.48 (↓2.0%)	1.10	.94 (↓14.5%)
S&T^{2} Consultants (2003)	Gasoline	Wheat Ethanol (E10, hydro)	21.99	17.28 (↓21.4%)	1.77	1.80 (↑1.7%)	.49	.46 (↓2.0%)	1.10	.94 (↓14.5%)
Wang (2001)	RFG	Corn Ethanol (E90)	-	↑3.2%	-	↑155.2%	-	↑64.9%	-	↑99.1%
Wang (2001)	RFG	Cellulosic Ethanol (E90)	-	↑11.0%	-	↑221.0%	-	↓83.8%	-	↑10.5%
Sheehan et al. (2004) (gram/km)	Gasoline	Corn Stover Ethanol (E85)	.59	.69 (↑17%)	.093	.943 (↑924%)	.35	1.41 (↑305%)	.081	.056 (↓30.1%)

Source: Author's compilation from the literature cited.

Levelton and S&T^{2} Consultants both show decreases in high and low corn or wheat ethanol blends by a range of 11.9% to 21.4% for E10. Levelton estimates that an increase to an E85 blend would decrease CO emissions by 32.4% from gasoline.[33] These findings agree with Wang's early results, which show a decrease of 10.3%.[34] However,

[33] Levelton Engineering Ltd., S&T Squared Consultants, and J.E. Associates, "Assessment of Net Emissions of Greenhouse Gases from Ethanol-Gasoline Blends in Southern Ontario."

[34] Michael Q. Wang, "Greet 1.0 - Transportation Fuel Cycles Model: Methodology and Use," (Argonne, Illinois: Centre for Transportation Research, Argonne National Laboratory, 1996).

they conflict with Wang's later analyses as well as Sheehan's findings, which show an increase in CO emissions of 3.2% from high content corn ethanol (E90) and an increase between 11% and 17% for cellulosic biomass, respectively.[35] A similar pattern appears in sulphur oxide emissions. Levelton shows a decrease by 15.4% for E10 and 40% for E85. S&T² Consultants shows a moderate decrease of 2% for low content corn and wheat ethanol.[36]

Wang's initial study shows a 367.5% increase in SOx for corn-based E85, but later GREET studies reduced this increase to below 65%. Wang's study of E90 cellulosic ethanol showed much more favourable results at a decrease of 83.8% from reformulated gasoline.[37] Sheehan et al. show that SOx emissions from cellulosic E85 increasing by 305% over conventional gasoline.[38] While the results from these non-greenhouse gas emissions are mixed, there is a clear agreement in these studies that NOx emissions from ethanol blends are comparatively higher than from both reformulated and conventional gasoline ranging from less than one percent to as much as 924%. Despite different methodologies, these studies were consistent in their attempt to quantify pollutants from both gasoline and ethanol.

Volatile organic compounds like aldehydes and hydrocarbons are organic chemicals. They can enter the atmosphere as emissions from natural and human activity and are harmful to humans. Methane is the most common VOC, and is typically treated separately as a greenhouse gas and studies of other VOC emissions are distinguished as

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[35] Sheehan et al., "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol."
[36] (S&T)² Consultants Inc., "The Addition of Ethanol from Wheat to Ghgenius."
[37] Michael Q. Wang, "Development and Use of Greet 1.6 Fuel Cycle Model for Transportation Fuels and Vehicle Technologies," (Argonne, Illinois: Center for Transportation Research, Argonne National Laboratory, 2001).
[38] Sheehan et al., "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol."

non-methane volatile organic compounds (VOC). Wang's early findings show a one third decrease in VOC emissions from corn-based E85. However, he later concluded opposite results with corn-based E90 emitting almost double the amount in comparison with reformulated gasoline, while cellulosic E90 emissions of VOC increased 10%.[39]

Particulate matter is often specified as either PM_{10} or $PM_{2.5}$ to indicate particles measuring less than 10 and 2.5 micrometers in diameter, respectively. These can be solids or liquids suspended in a gas that enter the atmosphere to the extent that it alters atmospheric quality. Particulate matter emissions can be hazardous to humans in high enough levels, and have been linked to heart and respiratory disease. The expected effects to human health depend largely on the size of the particles. Particulates measured as PM_{10} or less can be inhaled and block lung function, while the smallest particles, measuring $PM_{2.5}$ or less, can enter the bloodstream through the respiratory system. Wang shows an increase of 120% for first generation ethanol and 620% for second generation E90 blends. Levelton shows a decrease in both E10 and E85 of 83% and 33%, respectively while $S\&T^2$ shows no change.[40]

These early evaluations of ethanol, and indeed many current analyses, tend to separate production and consumption effects. This approach may be adequate for understanding particular aspects of ethanol as a product, but these boundaries become less clear when one looks at the overall impact of the product throughout its life cycle. Where the effects of ethanol consumption are most often evaluated by the emissions at

[39] Wang, "Development and Use of Greet 1.6 Fuel Cycle Model for Transportation Fuels and Vehicle Technologies.", Wang, "Greet 1.0 - Transportation Fuel Cycles Model: Methodology and Use."

[40] Levelton Engineering Ltd., S&T Squared Consultants, and J.E. Associates, "Assessment of Net Emissions of Greenhouse Gases from Ethanol-Gasoline Blends in Southern Ontario.", $(S\&T)^2$ Consultants Inc., "The Addition of Ethanol from Wheat to GHGenius."

the tailpipe, there have been attempts to examine the effect of ethanol fuel over its lifecycle. Life cycle analyses have not yet fully studied the total effects of ethanol production and consumption. Although some have tried to include more variables, such as embedded energy in farm machines[41], the inclusion of these variables can be difficult to justify due to the inability to specify measurement parameters.[42] Later assessments have made progress in quantifying emissions in more detail, and the technical debate on the performance of ethanol helped to justify government support to expand and strengthen biofuels regimes.

Biodiesel can be a complement or substitute for petroleum diesel fuel. It is produced through the simple reconstitution of plant or animal oils and requires chemical pre-treatment. Unprocessed vegetable oil can be also used to fuel diesel engines without modification, but this is extremely hard on the engine. Early experiments concluded that using straight vegetable oil causes diesel engines to fail due to excess carbon build-up. This "coking" often occurs at the fuel injector nozzles and constant cleaning is necessary. Yet it also leads to more serious failures, such as seized engines caused by "excessive engine deposits, lubrication oil dilution, piston ring sticking, scuffing of the cylinder liners and even lubricant failure due to polymerisation of the vegetable oil".[43] These fuel problems caused by using unprocessed "biodiesel" (or "straight veggie") can be solved with simple technical adjustments to engine operation so as to use petroleum diesel to start the engine and to flush the fuel lines before turning off the vehicle. A preheating system is added to the engine in order to make the unprocessed vegetable oil less viscose

[41] Patzek, "Thermodynamics of the Corn-Ethanol Biofuel Cycle."
[42] Farrell et al., "Ethanol Can Contribute to Energy and Environmental Goals."
[43] M. L. Poulton, *Alternative Fuels for Road Vehicles* (Southhampton, UK: Computational Mechanics Publications, 1994).

shortly before it enters the combustion chamber. Thus, the main difference between processed and unprocessed biodiesel is the adjustment of engine technology rather than the chemical re-composition of the fuel itself. Both methods have been promoted by different segments of the biodiesel community. However, chemical conversion of oils into biodiesel is the only form supported by government policies and programs, and is the type of biodiesel discussed in this thesis.

The technical term for processed biodiesel is *fatty acid alkyl esters*, or more simply, *alkyl esters*. This fuel can be used wherever petrodiesel fuels are used. Biodiesel was largely a niche market fuel that has been used in experiments and some limited commercial use in passenger and heavy transport vehicles, corporate vehicle fleets, mass transit, heavy equipment, farm machinery, marine vessels, train engines, aircraft, electrical generation, as well as in some lanterns and cooking stoves. However, governments around the world have invested heavily to encourage its wider commercialization. Its high lubricating characteristics make it an ideal diesel engine lubricant to extend engine life – a B1 blend (one part biodiesel blended with 99 parts petrodiesel fuel) increases lubricity by 65%.[44] Its qualities as a solvent can be used to clean and degrease machine parts. It can also be used as both a fuel extender and substitute for commercial and home heating fuel.[45]

Alkyl ester is any alcohol-mixed biodiesel derived from vegetable oils drawn from a wide variety of oil-producing feedstocks. Palm oil, avocado, coconut, jatropha, ground nut (peanut), linseed, cottonseed, castor, sunflower, hemp, safflower, mustard,

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[44] Greg Pahl, *Biodiesel* (White River Junction, Vermont: Chelsea Green Publishing Company, 2005), 192.
[45] Ibid., 66-74.

soybean, corn, rapeseed/canola, and many others have been tested and evaluated. Other feedstocks include used cooking oil from restaurant deep fryers, animal fats, certain types of algae[46], fish waste, and some have even experimented with insects.[47]

The production process is much simpler than that used for ethanol. Vegetable oils are first pressed from plant seeds and fibres. The immediate by-product is the compressed cellulosic residuals that contain about 6-8% of the unextracted oil. Depending on the feedstock, this "oil cake" can be used as a high-quality, high-protein animal feed. The extracted vegetable oil is then pretreated to separate the oil components. Every type of vegetable oil is a triglyceride; that is, it has a molecular composition of three fatty acid chains and one molecule of glycerine. To transform vegetable oil into biodiesel, the thick and sticky glycerine molecule must be removed from the chemical structure of pure oil through a process of *alcoholysis*, which biodiesel producers refer to as *transesterification*. A catalyst, usually sodium hydroxide or potassium hydroxide (both are a type of lye) is added to "crack" the molecular structure of the triglyceride and separate the fatty acid chains from the glycerine molecules. During this process, ethyl or methyl alcohol is added, resulting in ethyl ester and methyl ester, respectively. The fatty acid chains bond to the alcohol molecules and create mono-alkyl esters and exclude the glycerine molecules from the compound. Once the glycerine (a by-product used in pharmaceutical and cosmetic products) is removed, the remaining mixture creates the fatty acid alkyl esters (biodiesel).[48]

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[46] Ibid, Poulton, *Alternative Fuels for Road Vehicles.*

[47] Lyle Estill, *Biodiesel Power: The Passion, the People, and the Politics of the Next Renewable Fuel* (Gabriola Island, BC, Canada: New Society Publishers, 2005), 84.

[48]Steve Anderson, 2006, William Kemp, *Biodiesel: Basics and Beyond* (Tamworth, Ontario: Axtext Press, 2006). Pahl, *Biodiesel*, 43.

Although biodiesel is chemically distinct from petrodiesel, their fuel properties are closely matched. In fact, biodiesel and petrodiesel can be used interchangeably as a complete substitute or as a fully miscible blend. Specific similarities and differences depend upon the type of vegetable feedstock used, but some general comparisons can be made. First, the physical characteristics display some relevant distinctions. Biodiesel has higher oxygen content, which gives it a higher mass than petrodiesel. Consequently, biodiesel is heavier than petrodiesel, and this weight penalty lowers the fuel economy of biodiesel. Also, the energy content of biodiesel is 10-12 percent lower than petroleum diesel. The higher weight and lower caloric content suggest that it is a poor alternative to petroleum diesel, but the caloric efficiency of biodiesel is higher than petrodiesel by about 7 percent, which offsets lower performance so that biodiesel contains about 3-5% less net energy than petrodiesel.[49] All real world tests will differ slightly due to uncontrollable variables, but most find no conclusive variation in fuel economy when comparing biodiesel to conventional petrodiesel.[50] Most trials and experiments have concluded that the difference between these energy levels is of little or no significance.[51] This is likely due to the variability involved in real world tests that remain controlled during bench tests in the laboratory. Unnecessary idling, heavy acceleration and erratic braking, engine maintenance schedules, different vehicle and engine types, uneven operating uses and conditions, irregular passenger and cargo load weights, weather and temperature fluctuations, and severity of terrain all affect fuel economy. The expected 3-5% reduction in power and fuel efficiency in biodiesel seems to be of minor

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[49] Pahl, *Biodiesel*, 57, Poulton, *Alternative Fuels for Road Vehicles*, 68.

[50] Lawrence Schmidt, "Biodiesel Vehicle Fuel: Ghg Reductions, Air Emissions, Supply and Economic Overview," in *Discussion Paper C3 - 015* (Climate Change Central, 2004).

[51] Poulton, *Alternative Fuels for Road Vehicles*.

consequence.

Spontaneous ignition temperature (i.e., the point at which fuel compression causes fuel combustion) varies between different types and grades of diesel fuels, and biodiesel has a better ignition quality than petrodiesel. High-speed diesel engines of the kind used in large transportation and passenger vehicles require cetane ratings (analogous to octane ratings for gasoline) of around 50, which is an average rating for premium (i.e., Type A or No. 1) diesel fuel.[52] Ideal cetane ratings for petrodiesel occur between 45 and 55.[53] The most common diesel fuel, Type B or No.2, has a cetane rating of 40-45[54], which is about 5 points lower than premium diesel fuel. Petrodiesel quality has been dropping for some time, notably in falling cetane levels and rising sulphur content.[55]

A higher cetane rating will reduce exhaust emissions by shortening ignition delay, thereby effectively increasing fuel combustion and improving fuel economy.[56] The combustion efficiency of petrodiesel can be improved to attain a higher cetane number through a number of methods. Selective refining can remove the poor quality fuel from the refining process, but this would simultaneously decrease supply and result in fewer petroleum components. Because the characteristics of crude oil differ depending on the source, some sources produce a higher quality fuel than others. As global supplies diminish, real prices can be expected to rise causing a drop in ability to select the best "cut" of diesel from ideal reserves. Thus, oil-based products are increasingly produced

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[52] D.S.D. Williams, ed., *The Modern Diesel*, 14 ed. (London: Newnes-Butterworths, 1972), 84.
[53] Houghton-Alico, *Alcohol Fuels: Policies, Production, and Potential*, 118.
[54] Jon Van Gerpen, "Cetane Number Testing of Biodiesel," (Jefferson City, MO: National Biodiesel Board, 1996).
[55] D. S. Moulton and N. R. Sefer, *Diesel Fuel Quality and Effects of Fuel Additives* (Washington, D.C.: Transportation Research Board, 1984).
[56] Poulton, *Alternative Fuels for Road Vehicles*, 19.

from lower quality crude, making selective refining an increasingly difficult and inherently temporary endeavour.

Hydrogenation can dramatically improve cetane ratings in the poorest quality petroleum feedstocks. This process converts aromatic hydrocarbons (a reactive and volatile petroleum constituent) to napthene hydrocarbons (a less reactive and more stable petroleum constituent) through a catalytic conversion that is effective but costly. The most common method of improving the cetane number of petrodiesel is through conditioning additives. They are comparatively inexpensive and can be easily reformulated in response to changes in specification requirements.[57] While blending agents and additives are often necessary to avoid fuel gelling and allow cold weather operation, they also dilute the fuel. This reduces the total energy content, and can reduce lubricity and overall engine performance.

Generally, both "neat" (B100 biodiesel) and petro-biodiesel blends have a better fuel ignition quality and higher cetane rating than pure diesel fuel. Some studies indicate that biodiesel cetane ratings can range widely from 48-67[58], with most averaging around mid- to high-50s.[59] Biodiesel and petrodiesel can be blended in any ratio, and diesel engines can easily operate on B100. The higher cetane rating of biodiesel makes it especially useful as a petrodiesel additive. Not only does it improve fuel ignition and lubricity, but it also reduces gaseous and particulate emissions. This factor makes biodiesel an attractive alternative in comparison to the negative reputation of petroleum

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[57] Ibid., 20.
[58] Van Gerpen, "Cetane Number Testing of Biodiesel."
[59] Poulton, *Alternative Fuels for Road Vehicles.*

diesel as a "dirty" fuel.[60]

Like all petroleum fuels, diesel exhaust contributes to acid rain, photochemical smog, and ozone depletion.[61] The noxious exhaust of petrodiesel, especially in confined work areas (e.g., tunnels, garages, and ferries), has been linked to an increased prevalence of medical symptoms afflicting the eyes, nose and throat, as well as causing "laboured breathing, coughing, phlegm, wheezing, and headache" and deteriorated lung function.[62] In comparison, the superior combustibility (i.e., higher cetane rating) of biodiesel dramatically reduces particulate emissions, is free of lead, and has only minuscule levels of sulphur and aromatic hydrocarbons such as benzene, toluene and xylene.[63] Its high combustion efficiency results in comparatively low emissions of unburned hydrocarbons, carbon monoxide, carbon dioxide, and particulate matter. However, due to these higher combustion levels, nitrogen oxide emissions are usually slighter higher in biodiesel than in petrodiesel. For example, Poulton's analysis of two categories of vehicles (light-duty and heavy-duty) showed that while nitrogen oxide emissions rose about 20% for both categories, hydrocarbon emissions dropped by 20-30% and 20-75%, carbon monoxide was variable or dropped by 10-50%, and particulate matter dropped by 20-40% and 5-40%, respectively.[64] The increased nitrogen oxide emissions can be partially offset by adjusting the engine specifically for biodiesel, while new nitrogen oxide-reducing additives have been tested with favourable results. Finally, the noxious exhaust smell of

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[60] Mikael Hard and Andrew Jamison, "Alternative Cars: The Contrasting Stories of Steam and Diesel Automotive Engines," *Technology in Society* 19, no. 2 (1997).

[61] Bang-Quan He et al., "The Effect of Ethanol Blended Diesel Fuels on Emissions from a Diesel Engine," *Atmospheric Environment* 37, no. 35 (2003).

[62] B. Rudell et al., "Efficiency of Automotive Cabin Air Filters to Reduce Acute Health Effects of Diesel Exhaust in Human Subjects," *Occupational and Environmental Medicine* 56, no. 4 (1999).

[63] Pahl, *Biodiesel*, 57.

[64] Poulton, *Alternative Fuels for Road Vehicles*, 79.

petrodiesel is reportedly replaced by the faint odour of french-fries or popcorn.[65] Pure biodiesel (B100) is as biodegradable as sugar and less toxic than table salt. Pahl notes one study[66] that showed biodiesel to be less irritating to skin than a four-percent water and soap solution.[67] It also degrades rapidly if accidentally spilled. On soil, 98% of biodiesel is decomposed within three weeks.[68] Due to the water-absorbing qualities of alkyls, water displaces the esters thereby breaking alkyl esters apart, so the decomposition process is even quicker in water. However, unprocessed oils can cause problems in marine ecosystems similar to crude oil spills, so it is advisable to process biodiesel close to feedstock supplies rather than ship vegetable oil to overseas production facilities.

Transporting processed biodiesel is also safer in comparison with petrodiesel due to its high flash point (i.e., the temperature at which a material will ignite). The ignition temperature of biodiesel is twice that of petrodiesel (126° C vs. 52° C), and is high enough for it to avoid consideration as a hazardous material and associated regulatory costs and requirements. Biodiesel can be stored very much like vegetable oil, can be used in the same way as petroleum diesel, and requires no significant changes to the distribution and supply infrastructure.[69] Biodiesel is also similar to petrodiesel in that storage should ideally be limited to six months[70], water contamination should be avoided, and tanks should be shielded from extreme temperature variations.[71] However, biodiesel's organic nature makes it more susceptible to bacteria and mould, therefore

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[65] Pahl, *Biodiesel*, 57.

[66] Unfortunately, this source is unquoted and does not appear in his bibliography. But the increasing evidence, both verified and anecdotal, suggests that biodiesel is significantly less harmful than petrodiesel.

[67] Pahl, *Biodiesel*, 58.

[68] Ibid., 59, Poulton, *Alternative Fuels for Road Vehicles*, 69.

[69] Pahl, *Biodiesel*, 59-60.

[70] Ibid., 59.

[71] Poulton, *Alternative Fuels for Road Vehicles.*

requiring biocide conditioning additives.[72]

Conclusion

These technical specifications help to define ethanol and biodiesel as referred throughout this dissertation. They appear to exhibit favourable qualities in terms of direct production and consumption effects. Specifically, they seem to be relatively benign for both ecosystems and humans. As discussed in chapter four, previous attempts to expand biofuels were limited within national and subnational jurisdictions, while the expansion of biofuels to global markets suggests that ethanol and biodiesel have overcome their historic commercial failures. The discussion of ethanol and biodiesel in this chapter focused on their technical effects rather than their sustainability. However, these "effects-based" characteristics do not address the wider context of biofuels within the current energy system. If biofuels are to provide a sustainable alternative to petroleum fuels, ethanol and biodiesel must somehow overcome present and emerging concerns with their social, economic and environmental performance. The remainder of this dissertation seeks to broaden the analysis of their performance by augmenting "effects-based" evaluation by revealing the socio-technical functions of ethanol and biodiesel. This broadening will help to identify long-term visions for sustainable biofuels, as well as reveal policy areas that can guide attempts to foster sustainable energy.

[72] Pahl, *Biodiesel*, 59.

THREE – Sustainability, Energy and Socio-Technical Transitions

The conventional understanding of development is based on the economic growth of nations (gross domestic product) and more recently on the global integration of markets.[1] This development model relies on finite natural resources, brings higher levels of environmental pollution, and involves growing tensions between the developed North and struggling South. Even though efforts to legitimise the pursuit of conventional patterns of economic growth persist, the challenges of scarcity, pollution, and equity have stimulated a growing criticism of the conventional wisdom. The concept of sustainable development provides a framework to balance environmental protection and economic growth, but the practice of sustainable development has not yet become a fundamental consideration for public or private decision-making structures and processes. For example, the concept and practice of sustainable development has not radically altered government policy-making, private sector innovation, individual consumption choices, or community-based action. Despite these challenges and other uncertainties with the application of the sustainable development paradigm to societal activity, "so far [the concept of] sustainable development has proven to be significant, and remarkably robust".[2]

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[1] Herman Daly, "Sustainable Development: Definitions, Principles, Policies," (Washington, D.C.: World Bank, 2002).

[2] William M. Lafferty and James Meadowcroft, "Concluding Perspectives," in *Implementing Sustainable Development: Strategies and Initiatives in High Consumption Societies*, ed. William M. Lafferty and James Meadowcroft (Oxford: Oxford University Press, 2000), 455.

Sustainable energy has been called the "engine of sustainable development", and is a prerequisite for achieving a sustainable society, economy and environment.[3] Considering the fundamental role of technological change involved in sustainable development and the achievement of sustainable energy, this chapter presents the conceptual models and theoretical approaches on the innovation and diffusion of technology for sustainability that informs this dissertation. These provide necessary insights into the present socio-technical system, helps us to understand the diffusion of biofuels that occurred between 1998 and 2008, and reveals useful lessons on the greater socio-technical transition required to achieve sustainable energy for sustainable development.

Sustainable Development

Following the stalemate in the "environment versus growth" debate in the 1980s, the notion of sustainable development provided a concept that helped "to [re]frame international debates about environment and development policy-making".[4] Defined by the Brundtland Commission as a form of "development that meets the needs of the present without compromising the ability of future generations to meet their own needs", sustainable development is based on the concepts of needs and limitations.[5] Needs are delineated as essential requirements, such as food, natural resources, energy and technology for industrial and urban design. Limitations refer to the scarcity, access and

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[3] Jefferson W. Tester et al., *Sustainable Energy Policy: Choosing among Options* (Cambridge and London: The MIT Press, 2005).

[4] William M. Lafferty and James Meadowcroft, "Introduction," in *Implementing Sustainable Development: Strategies and Initiatives in High Consumption Societies*, ed. William M. Lafferty and James Meadowcroft (Oxford: Oxford University Press, 2000), 1.

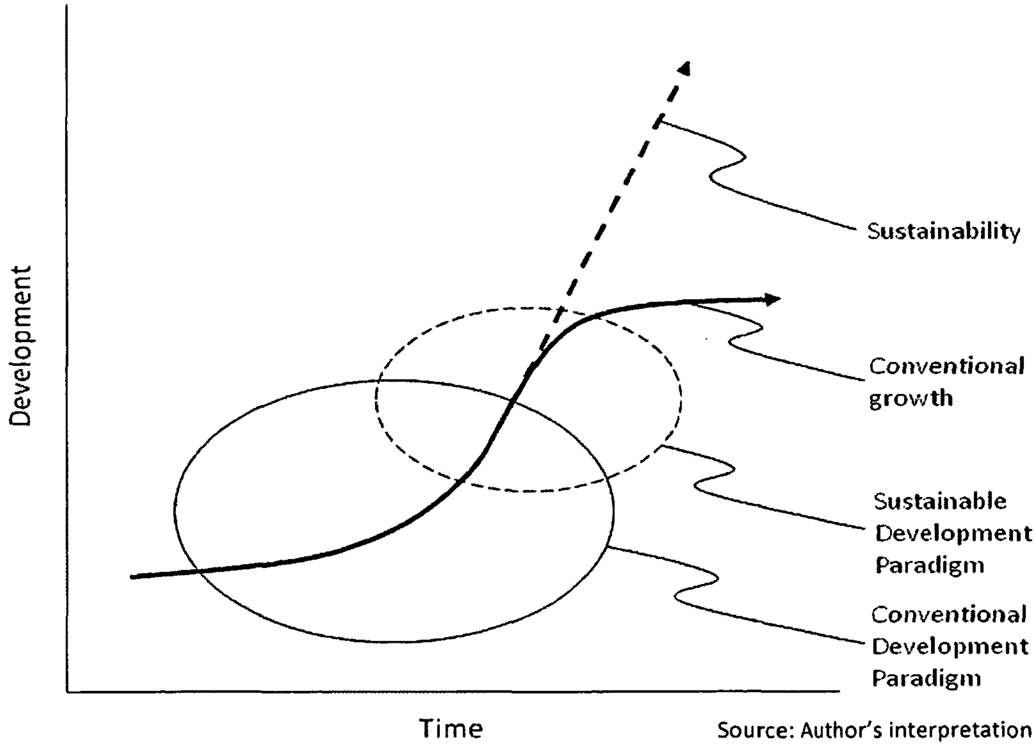
[5] WCED, *Our Common Future*, 43.

affordability of natural resources, as well as to institutional and technological capacities to achieve sustainability. Sustainable development emphasises mitigating environmental degradation, striving for present and future equity, international collaboration premised upon differentiated responsibility between countries, modernisation of governance structures, and the management of technological advancement. *Our Common Future* presented sustainable development as a global agenda for change that sought to identify common concerns, common challenges, and common endeavours. Its aim was to link environmental sustainability with social and economic development in order to overcome problems related to "business-as-usual" development patterns of conventional growth. Figure 3-1 provides a conceptual model depicting the potential for sustainable development to shift the present trajectory of conventional development toward one that is more sustainable.[6]

The concept of sustainable development has emerged to challenge the conventional development paradigm, and seeks to stimulate efforts to diverge from the conventional pathway of "business as usual" development (represented by the solid line) to another trajectory (represented by the dashed line) that is more sustainable in the future than the present. This model shows that marginal changes from the *status quo* (i.e., those that occur immediately after the bifurcation point) can lead to a significantly different pattern of development in the future.

[6] This two-dimensional model is necessarily limited. The horizontal access represents the passage of time, and the vertical access represents the upward progression of development (broadly considered to be those improvements to society as determined and re-interpreted by present and future generations). Also, it is worthwhile noting that the slotted line suggests an ideal direction of change toward a sustainable future, but the slope of the curve (i.e., speed of change) is uncertain.

Figure 3-1: Sustainable Development Paradigm



An important question is raised in relation to the type of change implied by the concept of sustainable development. As Robinson[7] noted, this debate was illustrated in the argument between Barry Commoner and Paul Ehrlich in the early 1970s. Ehrlich identified human overpopulation and overconsumption as key causes of environmental degradation that required "fundamental changes in underlying individual beliefs and behaviours".[8] In contrast, Commoner argued that the form and function of technology was often a more influential factor, which suggested that sustainability could be achieved through incremental measures. Later the Brundtland Commission suggested a managerial

[7] John Robinson, "Squaring the Circle? Some Thoughts on the Idea of Sustainable Development," *Ecological Economics* 48 (2004).

[8] Ibid.: 371.

and incremental approach that was in line with interests of governments and businesses.[9]

This is not to say that radical changes cannot or will not occur, but the sustainable development paradigm only requires incremental measures. In this way, undertaking marginal changes in a steady, long-term effort that is led or endorsed by governments, non-government organisations, corporations, groups, individuals and other actors that actively participate can bring forth the achievement of environmental integrity and social development alongside economic growth.[10] However, this emergent paradigm of sustainable development does not imply with any certainty that a successful shift toward a more sustainable trajectory would occur.[11] This uncertainty is due, in part, to the difficulty in defining what constitutes sustainable development. According to Hajer, within a half decade after the release of *Our Common Future* there were "at least forty working definitions of sustainable development".[12] Indeed, as Lafferty and Meadowcroft note, the term appears explicitly in the documents that resulted from the Rio Earth Summit in 1992, even though "sustainable development was never formally defined in any of the [United Nations Conference on Environment and Development] outputs".[13] In addition to the lack of definition, the uncertainty as to whether or not a shift toward sustainability will occur is also connected to at least two other controversial factors. First, and related to the concepts of needs and limitations, sustainable development conveys a notion of embedded constraints that guide decision-makers to address the challenges of both immediate physical constraints (especially ecological limitations) and ethical

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[9] Ibid.: 370.
[10] Dwivedi et al., *Sustainable Development and Canada: National and International Perspectives*, 221.
[11] Lafferty and Meadowcroft, "Introduction," 1.
[12] Maarten A. Hajer, *The Politics of Environmental Discourse* (Oxford: Oxford University Press, 1995), 1.
[13] Lafferty and Meadowcroft, "Introduction," 13.

constraints (inter- and intra-generational justice).[14] However, short-term responses to immediate physical constraints are typically more politically salient than long-term aspirations for fairness, and responses to embedded constraints tend to favour political expediency to "correct" such constraints with as little change as is possible in order to preserve the conventional growth trajectory. These short-term responses to embedded constraints rarely aspire toward a future state in which patterns of material growth and distribution are significantly different from those that presently exist. Consequently, long-term visions to successfully achieve bio-physical, institutional and ethical sustainability are virtually non-existent in most governments.

Second, sustainable development entails a policy orientation that puts the onus of leadership on governments. Just as they were instrumental in bringing forward a welfare state that provided social services to their populations, governments are uniquely situated to inspire and exhort public and private sector efforts to embrace the sustainable development paradigm.[15] National governments in particular have the resources, power and authority to institute changes for sustainability, and they are also the most influential link between local and global levels of social organisation. The structural-institutional approach inherent to Brundtland's depiction of sustainable development focussed on achieving a renewed multilateralism between nations, but subnational, international, non-governmental, and individual actions can contribute significantly to national sustainable development strategies. This policy orientation is linked to a broad vision of an ideal future of sustainability that involves the spread of environmentally-benign technologies

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[14] Ibid., 18.

[15] James Meadowcroft, "From Welfare State to Ecostate," in *The State and the Global Ecological Crisis*, ed. John Barry and Robyn Eckersley (Cambridge, Massachusetts: The MIT Press, 2005).

and socially-enlightened habits and practices throughout societal structures, across and between social groups, and even into individual psychology.[16] Yet the values that constitute this sustainable future are rarely internally consistent and often contradictory[17], and any policies and programs that might achieve these visions are more likely to fall through political and jurisdictional gaps rather than gain universal support.[18] Thus, even if the vision is broadly supported, the actions taken to achieve it may not be.

The lack of definition, embeddedness of constraints, and the implied policy orientation reveals substantial challenges for sustainable development. The next section considers other challenges that apply to sustainable energy, and shows how constraints tend to invoke a pre-occupation with short-term technical solutions to address immediate effects rather than aspire for long-term efforts to achieve sustainability. In the latter half of this chapter, the policy orientation implied by sustainable development is discussed in terms of technical change and socio-technical transitions for sustainability. To succeed, efforts to achieve sustainable energy need to satisfy long-term goals of sustainability by

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[16] S. A. Healy, "Science, Technology and Future Sustainability," *Futures* 27, no. 6 (1995), Kemp, "Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts.", Ingunn Moser, "The 'Technology Factor' in Sustainable Development," in *Towards Sustainable Development: On the Goals of Development - and the Conditions of Sustainability*, ed. William M. Lafferty and Oluf Langhelle (Hampshire, UK: MacMillan Press Ltd., 1999).

[17] Keith Pezzoli, "Sustainable Development: A Transdisciplinary Overview of the Literature," *Journal of Environmental Planning and Management* 40, no. 5 (1997).

[18] Kemp, Parto, and Gibson, "Governance for Sustainable Development: Moving from Theory to Practice.", James Meadowcroft and Francois Bregha, *Governance for Sustainable Development: Meeting the Challenge Ahead* (Ottawa: Policy Research Initiative, 2009), Ineke S.M. Meijer and Marko P. Hekkert, "Managing Uncertainties in the Transition Towards Sustainability: The Cases of Emerging Energy Technologies in the Netherlands" (paper presented at the Governance for Sustainable Development: Steering in Contexts of Ambivalence, Uncertainty, and Distributed Control, Berlin, 5-7 February 2006 2006).

re-arranging the core socio-technical functions of energy resources and technology.[19]

Sustainable Energy

The problems associated with the production and use of conventional energy involves both “effects” and “functions”. Effects are those outcomes revealed by performance indicators that are often used to identify policy and program success. In terms of technical or environmental performance, effects tend to refer to discrete changes or milestone achievements to confirm the presence of an improvement or decline from the status quo. Even though there is a wide recognition of the increasing scale, complexity and uncertainty of technical and environmental change[20], the requirement for quantitative assessment necessitates a focus on effects rather than functions.

Among others, the effects of biofuels might be to reduce greenhouse gas emissions, increase GDP, and augment energy supplies. In contrast, functions are socio-technical roles that contribute to how society is ordered or how a social order might change to accommodate an innovation in technologies or techniques.[21] A functionalist approach is only one of the foundational ontologies that have been identified to explain socio-technical transitions with the multi-level perspective. Geels points out that a functionalist ontology makes assumptions about causation that are based on a different

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[19] Josephine K. Musango and Alan C. Brent, "A Conceptual Framework for Energy Technology Sustainability Assessment," *Energy for Sustainable Development* 15 (2011). For a broader overview of energy transitions, see Geert P.J. Verbong and Derk Loorbach, eds., *Governing the Energy Transition: Reality, Illusion or Necessity?*, Routledge Studies on Sustainability Transitions (London and New York: Routledge, 2012).

[20] Matthew Gandy, "Rethinking the Ecological Leviathan: Environmental Regulation in an Age of Risk," *Global Environmental Change* 9 (1999).

[21] Timothy J. Foxon, Mark S. Reed, and Lindsay C. Stringer, "Governing Long-Term Social-Ecological Change: What Can the Adaptive Management and Transition Management Approaches Learn from Each Other?," *Environmental Policy and Governance* 19, no. 1 (2009).

understanding of the roles of agency and other causal mechanisms than would be the case under foundational ontologies based on rational choice, conflict and power struggle, interpretivism or structuralism. A functionalist ontology assumes, for example, a division of labour within a society in order to fulfill various social functions. While societal groups and subsystems hold different roles and tasks, they are collectively obliged to contribute to the overarching function of social stability, consensus and shared goals. Thus, a functionalist ontology relies heavily on external causation to explain socio-technical transitions, which in turn suggests that landscape changes may provide greater impetus to change a socio-technological trajectory than either regimes or niches.[22] This differs in ontologies based on rational choice or conflict and power struggle, which hold a greater emphasis on the role of causal agents.[23] Functionalism also differs from interpretivism and structuralism, which hold greater emphasis on cultural and/or social institutions as causal mechanisms.[24]

Understanding socio-technical functions of technologies and techniques helps to reveal the degree to which system elements are aligned to achieve societal expectations and aspirations, and how a given technology contributes to the continuity or change of

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[22] Frank W. Geels, "Foundational Ontologies and Multi-Paradigm Analysis, Applied to the Socio-Technical Transition from Mixed Farming to Intensive Pig Husbandry (1930-1980)," *Technology Analysis & Strategic Management* 21, no. 7 (2009).

[23] Frank Geels and Rob Raven, "Non-Linearity and Expectations in Niche-Development Trajectories: Ups and Downs in Dutch Biogas Development (1973-2003)," *Technology Analysis & Strategic Management* 18, no. 3/4 (2006), Frank W. Geels and Wim A. Smit, "Failed Technology Futures: Pitfalls and Lessons from a Historical Survey," *Futures* 32 (2000).

[24] Boelie Elzen et al., "Normative Contestation in Transitions 'in the Making': Animal Welfare Concerns and System Innovation in Pig Husbandry," *Research Policy* 40, no. 263-275 (2011), Frank Geels and B. Berhees, "Cultural Legitimacy and Framing Struggles in Innovation Journeys: A Cultural-Performative Perspective and a Case Study of Dutch Nuclear Energy (1945-1986)," *Technological Forecasting and Social Change* 78 (2011), R. P. J. M. Raven and F. W. Geels, "Socio-Cognitive Evolution in Niche Development: Comparative Analysis of Biogas Development in Denmark and the Netherlands (1973-2004)," *Technovation* 30 (2010).

societal relations, structures, and socio-technical systems.[25] Social functions are fulfilled within the context of larger socio-technical systems, and system innovations that contribute to the stability and change over the long-term process of socio-technical transitions are often responses to new functional requirements of evolving socio-technical systems.[26]

Examples of potential functions for biofuels can be as simple as providing energy. They might also be more ambitious, such as seeking to decentralise energy production, re-order property rights and attendant socio-economic relationships, integrate renewable energy resources to the global energy system, or stimulate a new vision of a bio-economy. As will be demonstrated through the remainder of this chapter, distinguishing technical effects from socio-technical functions is an important exercise, and is a necessary aspect of developing a guiding vision for biofuels as a sustainable energy option. Before exploring how a transitions approach employs socio-technical functions as articulations of guiding visions, this chapter presents some of the more common "effects-based" approaches that have been used to assess energy resources and technologies.

Different orientations and approaches to the management of energy resources and technologies have sought to address energy challenges in different ways, although most focus on effects rather than core socio-technical functions. For example, a predominant perspective in the natural resources literature employs a *management model*.[27] This

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[25] Frank W. Geels, "Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case Study," *Research Policy* 31 (2002).

[26] Frank Geels, "Processes and Patterns in Transitions and System Innovations: Refining the Co-Evolutionary Multi-Level Perspective," *Technological Forecasting and Social Change* 72 (2005).

[27] Alan Diduck, "Incorporating Participatory Approaches and Social Learning," in *Resource and Environmental Management in Canada*, ed. Bruce Mitchell (Don Mills, Ontario: Oxford University Press, 2004).

instrumentalist approach is oriented toward the traditional values, norms and practices associated with the conventional development trajectory. It emphasises the role for science and technology to provide solutions to problems associated with resource and environmental management. Typically, this model employs command-and-control type decision-making methods, which include rational planning, policy development, and implementation strategies. The primary goal of this approach is "progress" through wealth production and economic growth.[28] Although this model can seek to mitigate adverse economic effects of natural resource extraction, such mitigation efforts tend to be responsive to immediate challenges rather than to foster long-term structural change.

Neo-Malthusian approaches, such as are found, for example, in *Limits to Growth*[29] and *Tragedy of the Commons*[30], argue for a more interventionist approach to address the problems associated with economic growth, population expansion, finite resources, and environmental quality. The conception that humanity is on a growth trajectory that will exceed the capacity of the planet was not a new argument, but the Club of Rome report and subsequent book in 1972 reflected an emerging public discourse. Based on a computer model that analysed five trends of global concern and projected the implications of following a business-as-usual scenario, this report was "very much in the resource conservation school and sound[ed] the same warnings regarding global population growth as had a number of [preceding] publications".[31] Despite

[28] Ibid., 506.
[29] Donella H. Meadows et al., *The Limits to Growth* (New York: Universe Books, 1972).
[30] Garret Hardin, *Exploring New Ethics for Survival: The Voyage of the Spaceship Beagle* (Baltimore, MD, USA: Penguin Books, Inc., 1973).
[31] Doug Macdonald, *The Politics of Pollution: Why Canadians Are Failing Their Environment* (Toronto: McClelland and Stewart Inc., 1991), 102.

criticisms of the model itself[32], *Limits to Growth* presented a stark and convincing argument that if the five main trends (accelerating industrialisation, population growth, malnutrition, depletion of finite resources, and environmental decay) continued along the same trajectory, a collapse of the present system would occur by 2100 unless we find "a realistic, long-term goal that can guide mankind to the equilibrium society [i.e., a stable population in accordance with natural resources consumption patterns] and the human will to achieve that goal".[33]

The strength of *The Limits to Growth* argument also polarised the "environment vs. growth" debate between "doom-saying prophecy" on one side and "defence of the existing order" on the other.[34] It pointed to the need to alter social and economic practices to avoid environmental decay and recognised the link between exponential population growth with rates of production and consumption that doubled every generation (25 years). Most importantly, it highlighted the interconnectedness of the five trends of global concern and revealed how discrete changes in one area could have profound effects on the others.[35] In short, it presented a need to employ a holistic approach to significantly reduce resource use and pollution and develop new energy sources, among other activities.[36]

Where *Limits to Growth* identified the problems of population growth and

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[32] Critics questioned the veracity of computer-aided modelling, while others pointed that price effects, technological innovation, and humanity's long history of overcoming previous resource shortages. See, Paul Hawken, A. Lovins, and H. Lovins, *Natural Capitalism: Creating the Next Industrial Revolution* (New York: Little-Brown and Co., 1999), 145.

[33] Meadows et al. (1972) , quoted in Judith I. McKenzie, *Environmental Politics in Canada* (Don Mills, Ontario: Oxford University Press, 2002), 35.

[34] Macdonald, *The Politics of Pollution: Why Canadians Are Failing Their Environment*, 103.

[35] McKenzie, *Environmental Politics in Canada*, 36.

[36] Ibid.

scarcity of resources, *Tragedy of the Commons* took a closer look at the role of property rights in the management of public goods that suggested the need for either government regulation or private ownership.[37] It was concerned that population growth would out-pace natural resource extraction, but also recognised the importance of how social arrangements between populations and resources were managed. The greater role for regulation presented a policy orientation that exposed the potential for the intrusion on, or reallocation of, property rights as procedural methods to achieve desired outcomes and mitigate unwanted effects. For Hardin, it was necessary to secure "mutual coercion, mutually agreed upon" in order to create "responsible social arrangements" in order to protect and preserve human and ecological systems.[38]

More optimistic approaches such as *Small is Beautiful*[39] and *Human Scale*[40] sought to address increasing populations and ecological limits by suggesting a pursuit for an ideal balance between humanity and environment. These orientations are reflected by the notion of *appropriate technology*[41], defined as "a technology tailored to fit the psychosocial and biophysical context prevailing in a particular location and period".[42] In light of the various understandings of appropriate technology, two basic contrasting explanations have emerged. First, the "specific-characteristics interpretation" seeks to avoid unqualified abstractions. It is both a normative statement (in assuming the priority of some outcomes over others) and an empirical program (in that practical criteria of

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[37] Hardin, *Exploring New Ethics for Survival: The Voyage of the Spaceship Beagle.*
[38] Garret Hardin, "The Tragedy of the Commons," *Science* 162, no. 3859 (1968).
[39] E. F. Schumacher, *Small Is Beautiful: Economics as If People Mattered* (New York: Harper and Row, 1973).
[40] Kirkpatrick Sale, *Human Scale* (New York: Coward, McCann & Geoghegan, 1980).
[41] Schumacher, *Small Is Beautiful: Economics as If People Mattered.*
[42] Kelvin W. Willoughby, *Technology Choice: A Critique of the Appropriate Technology Movement* (Boulder, CO: Westview Press, 1990), 15.

what is appropriate must be based on some technical assessment in relation to the specified outcome). This interpretation seeks to ensure that specific technical "effects" are achieved, and tends to advocate the notion of *technological fit*, which requires the balancing of technological means (its function in relation to certain objectives) with technological niche (the psychosocial and biophysical context in which technological means are used) in order to determine the parameters and implications of alternative choices. Second, the "general-principles interpretation" contrasts with the first in that it employs normal conventions on the use of "appropriate" as an adjective. It does not seek to specify what exactly an appropriate technology might consist of, or what "effects" or outcomes might be achieved. Instead, the second interpretation looks for the overarching significance of a technology as a means to specific and well-articulated ends (i.e., the implications of technical change as a function of a more appropriate technology).[43]

These two interpretations contrast the value judgement of "appropriateness" based on "endogenous technological development" (i.e., local innovation, economic self-reliance, community development, and technological mix)[44] with a "practical holism" that situates individual action within the context of their relationship with society, environment, technology, and other factors in order to maintain a humanist view and so to avoid technocratic decision-making.[45] It is often easier to identify "appropriateness" than it is to account for "practical holism". Where the latter involves judgements on the context and functions of socio-cultural and techno-economic characteristics of a given community or society, the former is based on abstracted indicators that are chosen

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[43] Ibid., 20.
[44] Ibid., 285-93.
[45] Ibid., 294-305.

primarily to achieve economic effects. As such, there is a tendency for *appropriate technology* approaches to address problems of conventional energy by identifying "effects-based" rather than "functions-based" objectives as measures of success. Even if objectives are poorly defined, the act of achieving outcomes (however amorphous they might be) implies the realisation of specific milestones or technical performance indicators in order to justify policy decisions or assess policy-making success.[46]

Some approaches have become popular even though their stated indicators are limited, if not outright obscure. For instance, *Soft energy* is linked to the appropriate technology movement, and argues that we need to meet but not exceed the ideal requirements to fulfill human needs.[47] This involves a specific yet undefined balance between too little and too many energy resources and technologies. Inspiring as it might be, it provides little substance for policy developers and decision-makers. *Clean energy* often refers to clean-burning, and thus highlights energy emissions at the expense of system inputs or wasted by-products of energy production. It is closely related to the concept of clean technology[48], but there is a tendency to focus more on clean processes[49]. *Green energy* is often used vaguely to reflect indeterminate environmental impacts, and the difficulty in determining what constitutes "green energy" is illuminated by the debate

[46] Rodney Dobell and David Zussman, "An Evaluation System for Government: If Politics Is Theatre, Then Evalution Is (Mostly) Art," *Canadian Public Administration* 24, no. 3 (1981), Éric Montpetit, *Misplaced Distrust: Policy Networks and the Environment in France, the United States, and Canada* (Vancouver: UBC Press, 2003), 11-12.

[47] Hawken, Lovins, and Lovins, *Natural Capitalism: Creating the Next Industrial Revolution,* Amory B. Lovins, "Energy Strategy: The Road Not Taken?," *Foreign Affairs* 55, no. 1 (1976).

[48] Vanessa Oltra and Maider Saint Jean, "The Dynamics of Environmental Innovations: Three Stylised Trajectories of Clean Technology," *Economics of Innovation and New Technology* 14, no. 3 (2005).

[49] Rene Kemp and Massimiliano Volpi, "The Diffusion of Clean Technologies: A Review with Suggestions for Future Diffusion Analysis," *Journal of Cleaner Production* 16S1 (2008).

on whether or not nuclear power can be included in this category. Authors including James Lovelock[50] and George Monbiot[51] suggest that the world cannot wait for the diffusion of renewable energy to replace the effects of fossil fuels on global climatic change. In contrast to what Lovelock labels the "Green lobbies" (e.g., the Green Party, Greenpeace, etc.), both argue that nuclear power is the only safe, practical and immediate alternative to escape the amplification of adverse effects from greenhouse gas emissions on global warming. *Low-carbon energy* speaks to the challenges of greenhouse gas reduction and climate change mitigation, with a focus on low-carbon supply options (e.g., renewables, nuclear power, and fossil fuels attached to carbon capture and storage) and reduced demand of carbon intensive energy sources (e.g., load shifting, energy conservation and curtailment, and point-of-use electricity generation).[52] These "decarbonising options" may all be viable from a technical perspective, but they are inevitably subject to relative costs, ecological effects, conceptions of risk, and public acceptance.[53] Additionally, the focus on energy content can easily overshadow indirect environmental, social, and economic consequences. Thus, while each addresses certain problems of conventional energy, these "effects-based" approaches tend to obscure other important considerations inherent to the technological characteristics of the dominant

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[50] James Lovelock, "Nuclear Power Is the Only Green Solution," *The Independent* (2004).

[51] George Monbiot, "Why Fukushima Made Me Stop Worrying and Love Nuclear Power," *Guardian*, March 22 2011. George Monbiot did not always support nuclear power. See, George Monbiot, *Heat: How to Stop the Planet from Burning* (Double Day Canada, 2006).

[52] Alexander E. Farrell and Daniel Sperling, "A Low-Carbon Fuel Standard for California," (Berkeley and Davis, California: University of California, 2007), Timothy J. Foxon, Geoffrey P. Hammond, and Peter J. Pearson, "Transition Pathways for a Low Carbon Energy System in the Uk: Assessing the Compatibility of Large-Scale and Small-Scale Options" (paper presented at the 7th Academic Conference, St. Johns College, Oxford, 24-25 September 2008).

[53] Mark Jaccard, John Nyboer, and Bryn Sadownik, *The Cost of Climate Policy* (Vancouver: UBC Press, 2002), 34-37.

energy system.

The Brundtland report is unique in that it embraced a much broader approach by defining sustainable energy as containing four key elements: (1) sufficient energy supply to meet human needs, (2) minimal waste of primary resources (i.e., efficiency and conservation), (3) public health (i.e., safety), and (4) biospheric protection (i.e., pollution prevention).[54] The first element speaks to the ability of primary resources[55] to provide energy services to human populations. It is concerned, for example, with the growing world population and the increase of *per capita* consumption trends. This characterises sustainable energy as any energy form that enables long-term access. The second element aims to increase efficiency and conservation of energy resources to reduce consumption. These activities are often seen as a necessary step to address energy crises, but observations of such efforts suggest that conservation alone may not work. As early as 1865, British economist Stanley Jevons noted that efficiency in the use of coal resulted in increased levels of consumption.[56] This paradox has been cited as evidence that energy efficiency will not bring about sustainability.[57] Even though the effects are desirable, technical improvement for energy efficiency and conservation continue to focus on more efficient use of conventional sources rather than encourage the adoption of alternative

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[54] WCED, *Our Common Future*, 169.

[55] Primary energy occurs in natural resources that have not been converted or transformed by human processes. These include fossil, geothermal, nuclear, solar, as well as naturally occurring kinetic energy such as wave, wind, and water flow. Secondary energy involves the human transformation of primary energy into useable forms. Examples include liquid combustive fuels (petroleum and biofuels), electricity and some forms of heat. See, Tester et al., *Sustainable Energy Policy: Choosing among Options*.

[56] John M. Polimeni et al., *The Jevons Paradox and the Myth of Resource Efficiency Improvements* (London: Earthscan, 2008).

[57] Mark Jaccard, *Sustainable Fossil Fuels: The Unusual Suspect in the Quest for Clean and Enduring Energy* (New York: Cambridge University Press, 2006).

energy forms. The third and fourth elements identified in Brundtland's conception of sustainable energy seek to address the human and ecological effects of energy use. The risks associated with climate change and air pollution from fossil fuels, with accidents and radioactive waste associated with nuclear power generation, and with the collapse of wood fuel supplies in developing countries each reveal the unsustainability of conventional energy resources and the adverse effects on human health and the biosphere. The key elements of sufficiency, efficiency, human health and environmental protection aspire to address and overcome the economic, social and environmental effects of conventional energy systems.

Energy was not always linked directly to the concept of sustainable development, and the definition provided by the Brundtland report took some time to gain legitimacy. At the 1972 United Nations Conference on the Human Environment (Stockholm Summit), the emphasis was on the human-ecology interrelationship, with barely a mention of energy except to acknowledge the need to avoid energy resource depletion. However, the subsequent energy crises of that decade made energy resources a pressing international issue. By the time the Brundtland Commission's 1987 definition of sustainable energy was discussed at the 1992 United Nations Conference on Environment and Development (Rio Earth Summit), the socio-technical functions of energy were understood to be much more complex than merely to provide an input to growth. After the continued OPEC influence on global oil supplies, the geopolitical uncertainty after the fall of the Soviet empire, and the 1990 Persian Gulf War, the concern of energy debates have become much more acute as new issues came to the fore, such as the role of energy in the projection of military power, national security, and economic development.

The definition of sustainable energy presented in *Our Common* Future as entailing sufficiency, efficiency, human health and environmental protection continues to evolve. Debates on sustainable energy are increasingly prevalent at the international level and energy has "become more firmly rooted in the framework of sustainable development".[58] In terms of the economic, environmental and social dimensions of sustainable development, energy is considered to be a motor of macroeconomic growth, is a major source of environmental stresses at global and local levels, and is also a necessary element to satisfy basic human needs.[59] These dimensions were further institutionalised at the international level at the 2002 World Summit on Sustainable Development (Johannesburg Summit), which referred to energy for the first time as a human need on par with "clean water, sanitation, shelter, health care, food security and biodiversity".[60] The social dimension of sustainable energy was added to the long-standing preoccupations with economic and environmental concerns.

Energy is now widely considered to be a fundamental component of sustainable development. The evolution of these dimensions provides a socio-technical context that might signify a cognitive shift toward a more functional conception of energy resources and technologies. Despite the re-framing of sustainable energy at the international level and the associated shift in understanding the socio-technical functions of energy, a preoccupation with the achievement of sustainability continues through ongoing efforts to

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[58] Adil Najam and Cutler J. Cleveland, "Energy and Sustainable Development at Global Environmental Summits: An Evolving Agenda," *Environment, Development and Sustainability* 5 (2003): 117.
[59] Ibid.: 119.
[60] Ibid.: 131.

undertake evaluations of technical effects[61] at the expense of acknowledging new social functions that could contribute to and reinforce more sustainable socio-technical configurations. Yet there seems to be a continuing effort to move away from viewing technological assessment as providing "*the answer*" for policy-makers and program managers by augmenting effects-based assessment to include other considerations on the sustainability of energy technologies.[62]

Each of the approaches outlined above provide different articulations of the need to move away from the conventional growth trajectory. The *management model* focuses primarily on the rational stewardship of natural resources for economic gain and subsidiary social benefits. *Neo-malthusian* approaches often suggest technological solutions to scarcity, and both perspectives argue for conservation, efficiency and innovation. *Appropriate technology* and *soft energy* seek better environmental performance and improved living standards for the world's poor by encouraging environmental protection and social equity through technology innovation and transfer. *Clean energy* and *low-carbon energy* focus on mitigating greenhouse gases and particulate emissions, primarily from electricity production. *Green energy* can have numerous and often vague interpretations, many of which are used as part of marketing strategies. Even Brundtland's definition of "sustainable energy", which attempted to increase the scope of responses to the problems associated with dominant energy systems, seems to focus on technological effects of energy resources and technologies rather than address the deeper and broader socio-technical functions that are emerging

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[61] See Simon Bell and Stephen Morse, *Sustainability Indicators: Measuring the Immeasurable?*, 2nd ed. (London: Earthscan, 2008).
[62] Musango and Brent, "A Conceptual Framework for Energy Technology Sustainability Assessment."

with the progression of the sustainable development paradigm.

Effects-based evaluations are typically based on assessments of technical characteristics with the goal of identifying the impact of "current (or historical) production and the use of one unit of production or of minor product or process changes".[63] There are numerous examples of effects-based evaluations of environmental performance, such as environmental impact assessment, and cumulative impact assessment.[64] The parameters of these types of methods are determined by the scope of the project, which in turn establishes how the study is to address, for example, specified environmental components, ecosystems or wider socio-ecosystems.[65] Other effects-based evaluations employ more expansive study parameters in order to identify the impacts over the course of its production and use. Life-cycle assessments can vary according to system parameters (e.g., well-to-tank, well-to-wheel) and can sometimes identify direct and indirect impacts that would have been otherwise unknown.[66] In addition to environmental impact assessments and life-cycle assessments, other approaches rely on "effects-based" calculations and assessments. For example, ecological modelling, uncertainty analysis, and other risk-based approaches seek to evaluate the environmental effects of products and processes.[67]

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[63] Karl Jonasson and Bjorn Sanden, "Time and Scale Aspects in Life Cycle Assessment of Emerging Technologies: Case Study on Alternative Transport Fuels," (Goteborg, Sweden: Centre for Environmental Assessment of Product and Material Systems, 2004).

[64] Thomas Meredith, "Assessing Environmental Impacts in Canada," in *Resource and Environmental Management in Canada*, ed. Bruce Mitchell (Don Mills, Ontario: Oxford University Press, 2004), 474-79.

[65] Ibid., 470-71.

[66] Jonasson and Sanden, "Time and Scale Aspects in Life Cycle Assessment of Emerging Technologies: Case Study on Alternative Transport Fuels."

[67] Kathryn Harrison and George Hoberg, *Risk, Science, and Politics* (Montréal and Kingston: McGill-Queen's University Press, 1994), Musango and Brent, "A Conceptual Framework for Energy Technology Sustainability Assessment.", Venkatesh et al., "Uncertainty Analysis of Life Cycle

The intent of undertaking effects-based evaluations is to identify potential responses to readily identifiable problems with resource use and energy technologies. However, focussing on effects provides only a limited assessment of the actual and potential impacts of a given technological artefact or process, and does not identify or acknowledge social phenomena related to the artefact or process within the broader socio-technical context. Consequently, effects-based approaches are ill-suited to articulate a vision of a more desirable technological trajectory for sustainability. Put another way, addressing the negative effects of conventional energy with short-term responses to problems associated with current energy use focuses on symptoms instead of causes. A long-term focus on the alteration of energy systems and related socio-technical structures is needed to foster a sustainable energy regime. Most effects-based approaches tend to offer short-term "solutions" rather than address the core social-technical *functions* of conventional versus sustainable energy resources and technologies.

Understanding socio-technical functions can augment the constrained study parameters of effects-based assessments. Functions are the societal purposes or roles of artefacts and processes that are fulfilled by socio-technical systems (i.e., the alignment of elements that are actively created, reproduced and refined by multiple relevant social groups).[68] Functions-based approaches allow a deeper exploration of the interconnections between socio-technical landscapes and the configuration of energy regimes in ways not available to effects-based evaluations. They can help reveal the implications of

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Greenhouse Gas Emissions from Petroleum-Based Fuels and Impacts on Low Carbon Fuel Policies."

[68] Geels, "The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860-1930)."

technological niches on socio-technical systems, which might help to avoid unwanted externalities. Thus, distinguishing the effects of technologies from their socio-technical functions can reveal implications that would have otherwise remained concealed. This distinction becomes particularly relevant in societal efforts to encourage a transition away from the trajectory of dominant energy systems. In terms of energy resources and technologies, socio-technical functions might include basic services like mobility, illumination, heating and cooking. Yet these functions may also involve much more complex perceptions and aspirations, such as interpersonal relationships, moral-ethical stances, or the perceived value of one technological trajectory compared to another. Social functions of energy are not dependant on a given technology and can, in theory, be achieved through other socio-technical configurations. As one example, transportation is a social function that includes a number of constituent sub-functions (e.g., mobility, social status, economic growth, etc.) that are currently provided by the dominant energy regime of petroleum transport fuels. However, it is not unreasonable to suggest that these can also be achieved through any number of alternative fuel options, so long as the social function and constituent sub-functions are more or less maintained.

The traditional functionalist approach embraces four generic functions within social systems: *adaptation* to external contexts, *goal-attainment* through politics or markets, *integration* through shared values and norms, and *latency* by maintaining stability through socialisation (e.g., schools and communities).[69] Based on different perspectives that have appeared throughout the social sciences in numerous disciplines

[69] Geels, "Foundational Ontologies and Multi-Paradigm Analysis, Applied to the Socio-Technical Transition from Mixed Farming to Intensive Pig Husbandry (1930-1980)."

including sociology[70], political economy[71], political science[72], and even grand theories to explain general social phenomenon[73], identifying functions of technical artefacts and processes can help reveal the role of a particular social feature (e.g., laws, customs, practices, and technologies) and how it contributes to the maintenance of social relations and human systems.

While the attempt thus far has been to emphasise the importance of distinguishing effects from functions, the task at hand is to determine how this might be done for biofuels as a sustainable energy option. This part of the chapter draws from the works of Durkheim and Weber to provide a brief introduction to structural-functionalism, which is then linked to the more recent iterations of socio-technical functions as employed by transitions theorists.

Identifying societal functions as a way to understand social structures has a long history in the social sciences. Emile Durkheim showed that the effect of the division of labour in society was to increase economic productivity but that its function was to create social solidarity. This system of production created new social relationships that brought forward a different social and moral order. However, "[t]hese new conditions of industrial life naturally require a new [form of societal] organisation. Yet because these transformations [in systems of production] have been accomplished with extreme rapidity

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[70] Emile Durkheim, *The Division of Labour in Society*, ed. Lewis Coser, trans. W. D. Halls (New York: The Free Press, 1997).

[71] Max Weber, *The Methodology of the Social Sciences*, trans. Edward A. Shils and Henry A. Finch (New York: The Free Press of Glencoe, 1964), Max Weber, *The Protestant Ethic and the Spirit of Capitalism* (New York: Charles Scribner's Sons, 1976), Max Weber, *The Theory of Social and Economic Organization* (New York: The Free Press, 1964).

[72] Gabriel A. Almond and G. Bingham Powell Jr., *Comparative Politics: System, Process, and Policy*, 2nd ed. (Boston: Little, Brown and Company, 1978).

[73] For example, the structural-functionalism developed by Talcott Parsons. See Robert K. Merton, *Social Theory and Social Structures* (New York: The Free Press, 1968).

the conflicting interests have not had time to strike an equilibrium".[74] The continuation of this social solidarity and new social organisation is not self-sustaining, Durkheim argued, because it was subject to *anomie* (social dislocation), political oppression, or poor design. As such, the "division of labour cannot therefore be pushed too far without being a source of disintegration".[75] The new social and moral order requires a stabilising force to sustain this new system of production that creates a

> ...whole system of rights and duties joining [people] in a lasting way to one another...The division of labour does not present individuals to one another, but social functions. Society has an interest in the interplay of those functions: depending on whether they cooperate regularly or not, society will be healthy or sick.[76]

Achieving a stable system requires laws and other social rules, "[b]ut the mere existence of rules is not sufficient: they must also be just".[77] For Durkheim, the instrumentalist view held by classical economists on the effects of a new system of production was insufficient to explain its importance in social and moral terms. Since the real function of this new technique was to create social solidarity, the division of labour was not only an economic relationship but also a social and moral one that required a long-term vision of the future to avoid the destabilisation and disintegration of social relations.

In a similar way, Weber explored the functional changes brought about with bureaucratic organisation. He developed a typology of bureaucracy that "remains the single most influential statement and the point of departure for all further analyses of the

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[74] Durkheim, *The Division of Labour in Society*, 306.
[75] Ibid., 294.
[76] Ibid., 338.
[77] Ibid.

subject".[78] Defined as "a system of administration carried out on a continuous basis by trained professionals according to prescribed rules"[79], Weber identified four main features of bureaucracy. *Hierarchy* establishes a "firmly ordered system of super- and subordination in which there is supervision of the lower offices by the higher ones."[80] This clear chain of command ensures fulfilment of the assigned duty by officials. *Continuity* requires that the bureaucratic office be a full-time salaried career within a determined career structure. This allows for the replacement of personnel with the least amount of disturbance to the hierarchical order. *Impersonality* refers to an ordered set of rules, laws and administrative regulations using a written record so as ensure the effective transmission of orders downward and the collection of information upward. This ensures the "discharge of business according to *calculable rules* and 'without regard for persons'".[81] Finally, *expertise* becomes the main determinant of the vocation. Bureaucratic personnel are selected meritoriously and are expected to maintain a high level of knowledge of the files for which they are responsible, as well as the skill to carry out their duties as assigned.

Weber's bureaucracy highlights these four main features of the bureaucratic character in order to define its advantages (i.e., effects) as technique, and in so doing reveals the *function* of bureaucracy as a social institution. Typological theories like this help to represent the interrelationships between complex system variables that "goes

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[78] Jay M. Shafritz and J. Steven Ott, "Classical Organization Theory," in *Classics of Organization Theory*, ed. Jay M. Shafritz and J. Steven Ott (Orlando, Florida: Harcourt, Inc., 2001).

[79] David Beetham, *Bureaucracy*, 2nd ed. (Minneapolis: University of Minnesota Press, 1996), 3.

[80] Max Weber, "Bureaucracy," in *From Max Weber: Essays in Sociology*, ed. H. H. Gerth and C. Wright Mills (New York: Oxford University Press, 1946; reprint, 1958), 196.

[81] Ibid., 215., See also, Jon Elster, "Rationality, Economy, and Society," in *The Cambridge Companion to Weber*, ed. Stephen Turner (Cambridge, UK: Cambridge University Press, 2000), 22.

beyond historical descriptions, because they identify patterns and mechanisms" that may reveal a potential future trajectory.[82] When bound together these four features create a new social configuration that becomes a mechanism to fulfill a social function; in this case to instil social cohesion in pursuit of the guiding 'ideas' in society. However, the demand for the "purely technical superiority"[83] of bureaucracy necessitates a level of formalisation that ultimately discourages individual autonomy and adaptation in favour of a procedural acceptance of custom.[84] Consequently, "...the universal advance of bureaucratic forms of social and political organisation was bound to place the principles of individual liberty and personal creativity in jeopardy."[85] A procedural society based on "the rise of bureaucratic social structures...would eventually leave no more room for the spontaneous, creative activity of individuals..."[86] Giddens explains this transformation in the context of capitalism:

> Modern rational capitalism, measured in terms of substantive values of efficiency or productivity, is easily the most advanced economic system which man has developed. But the very rationalisation of social life which made this possible has consequences which contravene some of the most distinctive values of western civilisation, such as those which emphasise the importance of individual creativity and autonomy of action. The rationalisation of modern life...brings into being the 'cage' within which men are increasingly confined.[87]

Weber saw that economic, legal and government systems that seek higher levels of calculability and predictability according to "purely objective considerations" (i.e., without regard for persons) will tend to formalize rationality in the institutional structure

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[82] Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective," 100.
[83] Weber, "Bureaucracy," 215.
[84] Elster, "Rationality, Economy, and Society," 22.
[85] Wolfgang J. Mommsen, *The Age of Bureaucracy* (New York: Harper & Row, Publishers, 1974), xiii.
[86] Ibid., ix.
[87] Anthony Giddens, *Capitalism and Modern Social Theory* (Cambridge: Cambridge University Press, 1975), 184.

of administration.[88] In contrast to individual autonomy and substantive rationalisation, this form of rationality tends to make decision-making a habitual, procedure-driven system.

The functionalism employed by Durkheim and Weber demonstrate the importance of distinguishing technical effects from social function. Durkheim's division of labour showed how a more efficient system of economic production altered human relationships and created new forms of social solidarity. Weber's bureaucracy brought administrative efficiency to garner social cohesion but caged individual creativity and autonomy in the process. Effects and functions are different, and understanding the social function helps to identify societal ideals from which to embrace a long-term perspective and to guide social action.

The socio-technical significance of societal functions has been explored in terms of transport[89], communications[90], water supply[91], and energy[92]. These studies have investigated changes from one socio-technical system to another by examining social functions within socio-technical systems and how they are fulfilled by aligned system elements. Artefacts, knowledges, techniques, markets, regulations, cultural meaning, physical infrastructure, production systems, and supply networks are some examples of

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[88] Weber, "Bureaucracy," 215.

[89] Geels, "The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860-1930).", Kemp and Rotmans, "Managing the Transition to Sustainable Mobility.", Vergragt, "Transition Management for Sustainable Personal Mobility: The Case of Hydrogen Fuel Cells."

[90] Geels and Smit, "Failed Technology Futures: Pitfalls and Lessons from a Historical Survey."

[91] Frank Geels, "Co-Evolution of Technology and Society: The Transition in Water Supply and Personal Hygiene in the Netherlands (1850–1930) - a Case Study in Multi-Level Perspective," *Technology In Society* 27 (2005).

[92] Meijer and Hekkert, "Managing Uncertainties in the Transition Towards Sustainability: The Cases of Emerging Energy Technologies in the Netherlands", Verbong and Loorbach, eds., *Governing the Energy Transition: Reality, Illusion or Necessity?*

system elements that contribute to socio-technical functions. Technological artefacts "play an important role in fulfilling societal functions, but artefacts only fulfill functions in association with human agency and social structures".[93] Thus, the socio-technical function of energy resources and technologies provide a different level of analysis than one primarily concerned with their technical features, which is sometimes perceived as being autonomous and abstracted from human agency when the opposite is more likely the case. Technical features can be identified and recorded much like the attention afforded to ethanol and biodiesel provided in chapter two, but the socio-technical function of biofuels involves their implications for social relations, political power, economic distribution, ecological conditions, and more.

Distinguishing the effects from the functions of different kinds of energy systems help us envision a more desirable future by identifying the wider socio-technical changes that sustainable energy might entail. *Effects-based* approaches to assessing sustainable energy tend to focus on relatively short-term projections of change, whereas *functions-based* approaches search for sustainable energy as part of a broader societal trajectory and a fundamental shift in the socio-technical roles of energy. Instead of articulating the challenge to conventional energy in terms of mitigating negative effects, it is more advantageous to look instead at the socio-technical functions of energy resources and technologies. This is not to say that efforts to identify and achieve positive effects through marginal improvements to conventional energy are not needed, but it is also necessary to evaluate energy resources and technologies in relation to their socio-

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[93] Geels, "The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860-1930)," 445.

technical functions and how they might improve society as whole. Where the socio-technical functions of conventional energy is to maintain the current trajectory of growth and correlated social, political and economic structures, the functions of new types of sustainable energy would inspire a new development trajectory for economies, societies and environments.

To see how the focus on effects tends to limit our ability to achieve significant changes to the socio-technical system to encourage sustainability, we need only look at the two different energy types that have been suggested to replace conventional energy. *Alternative energy* offers one example of energy resources and technologies that are often portrayed as having improved environmental performance in comparison to conventional energy. However, "alternative" is a term often used in a broader sense that includes any energy resource or technology that might act as a complement or substitute for conventional energy. Natural gas and nuclear power are examples of alternatives to coal for electricity generation. It is possible that the socio-technical function of alternative energy could be to institute a dramatic shift in energy use and social structures, but it can just as easily involve a marginal shift that serves to bolster the present trajectory of conventional economic growth and maintenance of social relations. Thus, the socio-technical function of alternative energy to address the challenges of conventional energy is uncertain.

Renewable energy offers another substitute for conventional energy that is more specific than alternative energy. Renewable energy is any form of energy obtained from a renewable resource. According to Vanderburg, renewable resources can be distinguished from non-renewable resources

> ...on the basis of the time frame required for the cycles in the biosphere that involve the conversions that 'produce' the resource. If this time scale is in the order of geological time (as is the case for oil, natural gas, and coal, for example), the stocks of these resources are fixed relative to any human time frame. Renewable resources derive from natural cycles whose time scale is short enough that the rate of conversion 'producing' the resource is significant in comparison with human usage.[94]

Thus, even though renewable energy is drawn from renewable resources, it can still be depleted if human usage outpaces the natural rate of regeneration of the resource from which the energy is produced. Vanderburg also distinguishes non-renewable and renewable energy resources from *continuing resources*, which are energy resources not affected by the rate of human consumption.[95] They are largely independent of human activity and include solar, tidal and geothermal. However, most authors make no distinction between these energy resources and other types of renewable energy, such as biomass, wind, hydrologic[96], or hydrogen energy produced from renewable feedstocks.[97] The value of this distinction in relation to biofuels is that ethanol and biodiesel are forms of renewable energy, but they are not continuing energy resources and the land required for their cultivation can thus be depleted through overexploitation or become barren through desertification, salinisation, drought/flood, or other ecological changes.

Some socio-technical functions of renewable energy could include: slowing the depletion of finite and renewable resources, mitigating harmful pollution and waste, and reducing the amount of pollutants released into ecological systems in order to improve

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[94] Willem H. Vanderburg, *The Labyrinth of Technology* (Toronto: University of Toronto Press, 2000), 198.
[95] Ibid.
[96] Hydrologic energy is the power of water as kinetic energy to rotate a water mill for mechanical power or water turbines for electricity.
[97] Vaclav Smil, *Energy at the Crossroads: Global Perspectives and Uncertainties* (Cambridge and London: The MIT Press, 2003), Tester et al., *Sustainable Energy Policy: Choosing among Options.*

the quality of life for all of humanity.[98] However, it is not clear whether or not renewable energy resources and technologies will help to solve the challenges of conventional energy. The historic use of biomass (especially wood for cooking and heating) demonstrates that overconsumption of renewable resources is a possible outcome that would undermine the ability of renewable energy technologies to improve the energy system in social, economic and environmental terms. Renewable energy advocates tend to hold a *biocentric* assumption that renewable energy resources are superior to non-renewable resources in terms of environmental effects even though the ability of renewable resources to maintain the quality of life and standards of living achieved through conventional energy is not certain. Also, most renewable energy resources imply a decentralised system of energy production and use, which does not account for the potential role of large-scale and/or centralised renewable energy systems.[99] Further, the biocentric assumption implies a cyclical perspective regarding energy production, but rarely addresses significant system uncertainties, such as those associated with the intermittent supply characteristics of most fledgling energy technologies, or the development and refinement of renewable energy options before they are able to provide standardised energy products at levels sufficient to supply global demand. Thus, while the socio-technical function of renewable energy might apply to a partial substitution of conventional energy resources, it does not yet seem able to ensure a long-term transition

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[98] José Goldemberg, "The Case for Renewable Energies," in *Renewable Energy: A Global Review of Technologies, Policies and Markets*, ed. Dirk Aßmann, Ulrich Laumanns, and Dieter Uh (London: Earthscan, 2006).

[99] Babcock, Marette, and Tréguer, "Opportunity for Profitable Investments in Cellulosic Biofuels.", Organisation for Economic Co-operation and Development, "Economic Assessment of Biofuel Support Policies.", Heather L. Wakeley et al., "Economic and Environmental Transportation Effects of Large-Scale Ethanol Production and Distribution in the United States," *Environmental Science & Technology* 43, no. 7 (2009).

to a completely new socio-technical regime based on sustainable energy.

The effects and functions of alternative and renewable energy exhibit different understandings of how to address the challenges of conventional energy. However, effects and functions are not often distinguished in the literature. For example, in addition to environmental concerns, advocates for renewable energy describe potential social and economic benefits in terms of both effect and function, but do not distinguish one from the other. Goldemberg, for example, identifies climate change mitigation, employment, energy security, poverty reduction, and health issues as the five key beneficial outcomes from renewable energy technologies.[100] These involve both positive outcomes (effects) and the re-ordering of social relations (function). By replacing fossil fuels with renewable energy, the positive effects include the reduction of anthropogenic carbon emissions linked to climate change while the function is to preserve (as much as possible) existing social and ecological conditions. Similarly, he suggests that energy innovations would create and expand local markets and increase economic growth, which would generate the positive effects associated with wealth creation. However, the function of this economic growth from renewable energy is to increase employment and alleviate poverty by distributing benefits across socio-economic strata. He similarly conflates other effects and functions related to energy security, diversity and equity of access, as well as human health issues and quality of life in marginalised societies around the world. Like many other advocates of renewable energy[101], Goldemberg does not distinguish "effects" from

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[100] Goldemberg, "The Case for Renewable Energies."

[101] Carol Freedenthal, "Biofuels Have Questionable Path as New Fuels for Transportation," *Pipeline & Gas Journal* 236, no. 6 (2009), Howard Geller, *Energy Revolution: Policies for a Sustainable Future* (Washington: Island Press, 2003), Jaccard, *Sustainable Fossil Fuels: The Unusual Suspect in the*

"functions", thereby missing the opportunity to expand the focus from relatively short-term outcomes to include the identification of long-term visions for a new socio-technical trajectory. The tendency to conflate effects and functions glosses over the possibility that some renewable energy options might bring positive short-term outcomes that could lead to unforeseen perverse externalities. Likewise, any positive effects resulting from the adoption of renewable energy might cultivate negative discursive reactions or trigger the emergence of unfavourable socio-technical functions. These might result in renewable energy options being considered to be socially undesirable even though they may be economically and environmentally superior to the pre-existing technological regime.[102] Such interpretations have surfaced in the debate over biofuels either as unintended negative effects on ecosystems or the notion that biofuels contribute to food insecurity (see chapter six for more on these critiques).

Even though "alternative" and "renewable" are used to describe improved energy resources and technologies, social and environmental critiques of conventional energy suggests that technical merits alone are inadequate as indicators for sustainability. The parameters for renewable energy identified by Goldemberg, for example, includes local, site-specific benefits of renewable energy (effects) as well as global benefits of making the shift to renewable fuels (functions). In fact, Goldemberg's depiction of key benefits goes beyond the usual depictions of what alternative and renewable energy resources and

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Quest for Clean and Enduring Energy, William Kemp, *The Renewable Energy Handbook* (Tamworth, Ontario: Aztext Press, 2005).

[102] Brian Caulfield, Séona Farrell, and Brian McMahon, "Examining Individuals Preferences for Hybrid Electric and Alternatively Fuelled Vehicles," *Transport Policy* 17, no. 6 (2010), Geels and Smit, "Failed Technology Futures: Pitfalls and Lessons from a Historical Survey.", Rende J. Johnson and Michael J. Scicchitano, "Uncertainty, Risk, Trust, and Information: Public Perceptions of Environmental Issues and Willingness to Take Action," *Policy Studies Journal* 28, no. 3 (2000).

technologies can deliver. Yet he stops short of describing renewable energy systems as offering fundamentally different socio-technical functions. Perhaps this is because the full potential of renewable energy is not yet clear, and the total costs of fossil fuels are not reflected in the energy and economic systems we have today. Perhaps also because the subsidies, externalities, and political interests are not adequately reflected in the market price of fossil fuels. Whatever the reason, solutions to the negative attributes of the present conventional energy system continue to focus on effects rather than functions even though an increasing reliance on decentralized production, employment generation, and reduced environmental impacts suggest that energy innovations could encourage societal trajectories that would differ from the conventional energy system presently in place.[103] Like alternative energy, renewable energy may help to improve the current global energy system in a more ecologically, socially, and economically beneficial manner, but the short-term focus does not suggest a greater shift toward an energy system with a fundamentally different socio-technical function. Instead, the focus on "effects" instead of "functions" suggests that alternative and renewable energy forms would complement rather than substitute conventional energy. Sustainable energy, on the other hand, requires a fundamentally different perspective than is possible under conventional, alternative or renewable energy systems. Although the global depiction of sustainable energy evolved from Brundtland's emphasis on sufficiency, efficiency, human health, and environmental protection[104] to include economic, environmental and social

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[103] Goldemberg, "The Case for Renewable Energies."
[104] WCED, *Our Common Future*, ch.7.

dimensions as an institutionalised characterisation within the United Nations system[105], the international discourse on sustainable energy still falls short of addressing the fundamental changes to socio-technical functions that a more sustainable energy system would require.

Sustainable energy entails a breadth of factors. The term seems to necessitate that governance become a fundamental part of its definition. Governments around the world are reconsidering their scope of activity in terms of energy for sustainable development. This global shift in the policy frame correlates with the Brundtland commission, which holds a special role for governments to make sustainable energy choices for environment and development.[106] Government decision-making power becomes an integral component for making a transition away from the present trajectory of conventional energy, and to understand this as a new direction for public policy and administration requires a more stringent definition. *Sustainable energy policy* involves any government decision or action deliberately undertaken to encourage the production and use of energy that seeks a net economic benefit while maintaining ecological integrity and improving social conditions. The reality of trade-offs between these three areas as a necessary component of policy development is immediately apparent, and sustainability must seek to balance these trade-offs in ways that differ dramatically from the "business-as-usual" scenario. For instance, where traditional policy directions for conventional energy resources and technologies tend to discount social and/or environmental costs if the economic benefits

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[105] International Energy Agency, "Energy for All," (Paris: Organisation for Economic Cooperation and Development, 2011), United Nations, "Energy for a Sustainable Future," ed. The Secretary-General's Advisory Group on Energy and Climate Change (New York: United Nations, 2010).

[106] WCED, *Our Common Future*, ch.7.

are substantial enough, formulating policy in terms of sustainable energy requires the maintenance of high standards for environmental quality, social integrity, and economic performance even if they contravene short-term gain. This seems to challenge, if not contravene, the competitive, voluntary, market-based policy approaches that have become the standard since the advent of New Public Management.[107]

The search for sustainable energy will influence how governments around the world will face new and emerging multiple public policy challenges. The dilemma for the achievement of sustainable energy and sustainable development is how to maintain and extend energy-derived benefits for present and future generations while stewarding the use of natural resources to achieve "a dynamic harmony between the equitable availability of energy-intensive goods and services to all people and the preservation of the earth for future generations".[108] By referring to the achievement of a "dynamic harmony" rather that a different kind of "development", Tester et al. suggest a subtle yet important departure from the global perspective on sustainable energy by pointing to a new equilibrium of sustainability instead of a linear conception of improving development over time. In so doing, it suggests a vision of a future state of sustainability rather than an ongoing struggle for sustainable development.

Policy development must consider both technical effects and socio-technical functions when envisioning a sustainable future. The challenge is to simultaneously (1) engage a development strategy for sustainable energy to promote technological *change* that will produce positive effects and (2) construct a new socio-technical system in which

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[107] Richard C. Box et al., "New Public Management and Substantive Democracy," *Public Administration Review* 61, no. 5 (2001).

[108] Tester et al., *Sustainable Energy Policy: Choosing among Options*, 8.

the function of sustainable energy resources and technologies are stabilised in a "dynamic harmony". There is a necessary tension between stability and change, and the literature on technical innovation and transitions can provide a useful framework in which to assess the socio-technical changes needed to achieve sustainable energy. Technical effects are much simpler to identify, but more emphasis on functional changes are needed to address systemic constraints to technical change. The remainder of this chapter introduces the challenges of technology for sustainability, and provides the theoretical basis from which to refine the policy orientation for achieving sustainable energy.

Technological Stability and Change

Technology evolves in patterns shaped by the interrelated components of systems arranged by organisational configurations, production requirements, and market characteristics of technical artefacts.[109] Like Rosenberg's "focusing devices"[110] and Hughes' "reverse salients"[111], technical bottlenecks and product necessity stimulate the evolution of technology. Yet bottlenecks are not random, and instead appear within a particular technological framework.[112] A common technological framework shared across an industry or a society is central to the notion of a technological *paradigm* or "a 'model' and 'pattern' of solution of *selected* technological problems, based on *selected* principles

[109] Kemp, "Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts."
[110] Nathan Rosenberg, *Inside the Black Box: Technology and Economics* (Cambridge: Cambridge University Press, 1982).
[111] Thomas P. Hughes, "The Evolution of Large Technological Systems," in *The Social Construction of Technological Systems*, ed. Weibe E. Bijker, Thomas P. Hughes, and Trevor Pinch (Cambridge, Mass.: The MIT Press, 1987).
[112] René Kemp, *Environmental Policy and Technical Change: A Comparison of the Technological Impact of Policy Instruments* (Cheltenham: Edward Elgar, 1997), 265.

derived from natural sciences and on *selected* material technologies".[113] The choice to embrace or reject a particular technology is enabled or constrained by the social, economic and environmental contexts in which that technology is situated.

Technological stability occurs when dominant technologies based on a prolific and standardised technological framework provide a basis for further development along a technical trajectory. Standardisation of dominant technologies provides a reference point from which to make judgements on what is technically possible, and allows for increased production flows that can provide economies of scale. Nelson and Winter's *technological regime*[114] and Dosi's *technological paradigm*[115] both speak to dominant technologies as containing "a core technological framework that is shared by a community of technological and economic actors as the starting point for looking for improvements in product and process efficiency".[116] This serves to focus attention on certain aspects like engineering perspectives and market conditions, while excluding others (like ecological effects or social costs) that might be less salient to relevant social groups and individuals.

These *regimes* and *paradigms* account for some excluded factors in traditional economic analyses (such as the perceptions and value systems of engineers and entrepreneurs), but they tend to hold what MacKenzie calls "deterministic overtones", wherein the characteristics of the technology itself provide some level of stability over

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[113] Ibid., 267, quoting Dosi 1982:152.

[114] Richard R. Nelson and Sidney G. Winter, "In Search of Useful Theory of Innovation," *Research Policy* 6 (1977).

[115] Giovanni Dosi, "Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change," *Research Policy* 6 (1982).

[116] René Kemp, Johan Schot, and Remco Hoogma, "Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management," *Technology Analysis & Strategic Management* 10, no. 2 (1998): 176.

time and in a specific direction.[117] Relying heavily upon engineering beliefs and market conditions to explain the stability of technological regimes, they emphasise shared beliefs in economic supply and demand factors rather than on the cognitive limitations of imagination, and depend on exogenous factors to explain periods of technological destabilisation throughout history.[118]

A more compelling explanation of the role of technology in socio-technical transitions would incorporate endogenous factors, such as technological variation and selection environment. Technological variation involves the type and range of experimentation with technological heterogeneity to respond to actual or anticipated socio-technical uncertainties. The selection environment consists of all those factors associated with the creation, diffusion, and adoption of the technology in question. Technological variation and selection environment are linked together in the technological regime, and are influenced by "the whole complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures that make up the totality of a technology".[119] This "totality" is an important component of the dominant technological system as it addresses the "technology-specific context of a technology which prestructures the kind of problem-solving activities that engineers are likely to do,

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[117] Donald MacKenzie, "Economic and Sociological Explanations of Technological Change," in *Technological Change and Company Strategies: Economic and Sociological Perspectives*, ed. Rod Coombs, Paolo Saviotti, and Vivien Walsh (London: Academic Press, 1992).

[118] Kemp, *Environmental Policy and Technical Change: A Comparison of the Technological Impact of Policy Instruments*, 278.

[119] Kemp, Schot, and Hoogma, "Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management," 182.

a structure that both enables and constrains certain changes".[120] One would expect policymakers, entrepreneurs, consumers and other relevant actors to be similarly influenced by this "totality" as it sets the conditions of prestructuration in all societal spheres.

The stabilisation of technological change into regimes is brought on by broadly-defined societal "rules" that can include both formal commands and informal practices. These can occur within the dynamics of relative cost structure (i.e., when a new technology or technical input becomes inexpensive), perceived spaces for innovation (i.e., when producers and consumers embrace the possibilities promised by a new technology), and organisational criteria and principles (i.e., when the production regime alters to accommodate a new technology).[121] These create economic, cognitive, and institutional certainty that enable the adoption of new technologies as well as the stabilisation of new technological regimes. Technological stability is not static but rather a dynamic equilibrium[122], and within any given socio-technical regime there are continuous processes of incremental change[123] for technological optimisation. The regime provides a set of institutionalised design configurations that form a basis for competition, research activities, and agenda development of individual firms or business units.[124]

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[120] Ibid.

[121] Carlota Perez, "Technological Revolutions and Techno-Economic Paradigms," *Cambridge Journal of Economics* 34 (2010).

[122] Rotmans, Kemp, and Asselt, "More Evolution Than Revolution."

[123] Christopher Freeman, "The Economics of Technical Change," in *Trade, Growth, and Technical Change*, ed. Daniele Archibugi and Jonathan Michie (Cambridge: Cambridge University Press, 1998).

[124] Giovanni Dosi et al., *Technical Change and Economic Theory*, ed. Maastrict Economic Research Institute on Innovation and Technology (MERIT), *International Federation of Institutes for Advanced Study, Research Series Number 6* (London: Pinter Publishers, 1988), Kemp, "Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts."

In their discussion of the factors that contribute to the under-utilisation of sustainable transportation technologies, Kemp et al. suggest the following variation and selection environment elements that contribute to the continuity of unsustainable technologies and socio-technological stability:

- Technical characteristics are not synchronised with the existing system;
- Policy and regulatory frameworks favour existing technology;
- Cultural and psychological factors resist change;
- Uncertain consumer demand limits industry's willingness to introduce new products;
- Supply side barriers, such as sunk capital costs in current infrastructure;
- Uncertain infrastructure and maintenance requirements; and
- Perceived potential for undesirable social/environmental effects.[125]

These barriers do not act separately but are instead interrelated and feed back upon one another. The dynamics of their combined influence gives rise to relative inertia that can explain consistent technological trajectories or technical failures of innovative products. Technological stability helps to explain why some inefficient and/or unsustainable technologies remain dominant despite the existence of better ones that are less expensive, of superior design, or more closely aligned with societal structures.

Despite the tendency of technological variation and selection environment to stabilise socio-technical systems, innovation nevertheless occurs. Technical change is often conceived as occurring within a "black box"[126]; that is, we know it to see it but cannot explain its inner workings. Economic approaches tend to understand technological change as *innovation*, and define it as the commercialisation of a novel product or production process. Such approaches can concentrate on the individual, as with Adam

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[125] Kemp, Schot, and Hoogma, "Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management," 177-80.

[126] Rosenberg, *Inside the Black Box: Technology and Economics*.

Smith's seminal observations of the pin-maker.[127] It can occur at the level of the firm, as demonstrated by Henry Ford's production line or Frederick Taylor's "Scientific Management".[128] Innovation may also be understood from a macro-economic perspective to explore factors that contribute to national productivity.[129] Political approaches to understanding technological change tend to examine the power relationships affected when technologies are employed or controlled by some groups and not others. Karl Marx, Martin Heidegger and others have proclaimed fundamentally political arguments on the patterns that technology can imprint upon society.[130] Likewise, Harold Innis, Marshal McLuhan, and George Grant each provided arguments on the political implications of technological change in the Canadian context.[131]

Economic and political approaches can reveal much about the social implications of technical change. Where the former tend to view technical knowledge in light of increased productivity and higher profit margins, the latter presents technology as the entrenchment of (and challenges to) power relationships. Yet technological change bring more than just wealth and power, and the diffusion of technology affects the development of societal structures and cultural norms. Yet according to Rogers, the diffusion of innovations is simply the market uptake of a new or improved technology (Figure 3-2).[132]

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[127] Adam Smith, *The Wealth of Nations* (London: Penguin Books, 1997), 109-10.

[128] Frederick W. Taylor, *The Principles of Scientific Management* (New York: W. W. Norton & Company, Inc., 1911).

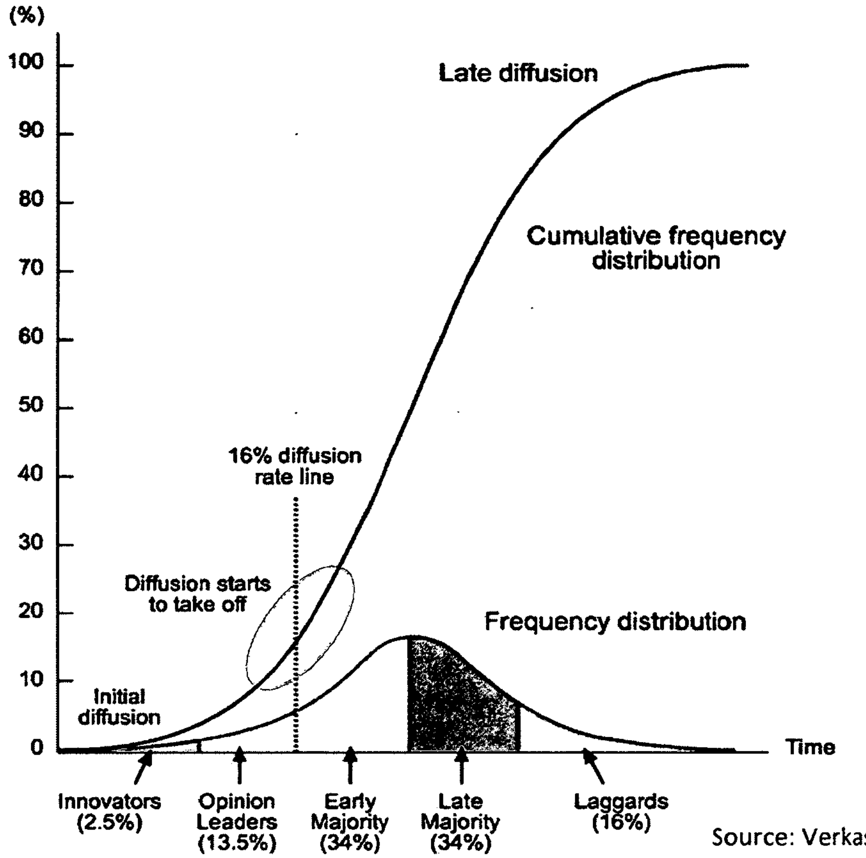
[129] Peter A. Hall and David Soskice, *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage* (Oxford: Oxford University Press, 2001), Bengt-Ake Lundvall, ed., *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (London: Pinter Publishers, 1992).

[130] Langdon Winner, "Upon Opening the Black Box and Finding It Empty: Social Constructivism and the Philosophy of Technology," *Science, Technology & Human Values* 18, no. 3 (1993).

[131] Arthur Kroker, *Technology and the Canadian Mind: Innis/Mcluhan/Grant* (Montreal: New World Perspectives, 1984).

[132] Everett M. Rogers, *Diffusion of Innovations*, 5th ed. (New York: The Free Press, 2003).

Figure 3-2: Rogers' Model of Technological Diffusion[133]



Source: Verkasalo, H. (2008)

This model of diffusion assumes that economically successful technologies will proliferate until complete market saturation. This model does not account for other effects resulting from technological diffusion. For example, the optimistic Lewis Mumford argued for continued technological progress and its potential to bring forth a more authentic life in which organic, humanist configurations would replace mechanistic technologies. The pious Jacques Ellul saw technology not as the end of humanity's "covenant with a forgiving God", but instead as a way to enable a resurgent religiosity to

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133 Hannu Verkasalo, "Handset-Based Measurement of Mobile Service Demand and Value," *Info* 10, no. 3 (2008).

correct the decline of the role of faith in the modern world.[134] These moral/ethical and religious approaches exhibit a desire to somehow make sense of the wider relationship between society and technology. Such approaches reveal how technology can create asymmetrical effects on various groups and individuals and even alter the very function of socio-technical systems in society. Whether from material, political, sociological, moral/ethical, religious, or other perspectives, all seem to agree that technology is not neutral: a change in a technological regime will change wealth distribution, power relations and/or cultural norms.

As a consequence, technological development is not a rational process. Despite this, however, the predominant systems of governance, including the institutional structures and policy processes that comprise the administrative apparatus, prefer technocratic solutions to immediate policy challenges[135], rather than acknowledging and addressing the role of technology as it affects long-term social relations, particularly those relationships involving societal institutions. By recognising the interaction between social actors and technical artefacts, social constructivists stipulate that technological change is fundamentally "a process in which there is no single dominant shaping force".[136] There is an "interpretative flexibility" of technology in which relevant social groups construct different understandings of technical artefacts and their

[134] Winner, "Upon Opening the Black Box and Finding It Empty: Social Constructivism and the Philosophy of Technology."
[135] Rudi Volti, *Society and Technological Change* (New York: St. Martin's Press, 1988), 29.
[136] Donald Mackenzie and Judy Wajcman, "Introductory Essay: The Social Shaping of Technology," in *The Social Shaping of Technology*, ed. Donald Mackenzie and Judy Wajcman (Buckingham, U.K.: Open University Press, 1999), 16.

characteristics.[137] In such cases, technologies 'work' only because they have been socially accepted by those relevant groups. For example, the automobile 'works' in North America as a whole, but does not 'work' for remote aboriginal communities, Amish townships, residents in severely congested areas, and the very poor.

Although social constructivism is criticised as overstating the deliberation of actors and understating "the extent to which technology always involves interaction between human beings and the material world", most would agree with the need to consider the fact that technologies 'work' as something to be explained rather than assumed.[138] Identifying the appropriate units of analysis is an important aspect of explaining technological change, as is determining the extent of the interactions between different analytical units. Not only must we decide, for example, if individuals, artefacts, institutions, systems of governance, market structures, or social processes are of primary importance, but we must also establish the extent of interaction between these units and the degree of influence of one unit in relation to another.[139] Where social constructivists located agency in individuals and their social groups[140], actor-network theory presents an example of a reciprocal relationship between artefacts and social actors, in which technologies influence social relations just as much as social relations influence technological development. Actor-network theory argues that technology and society are better understood as a socio-technical composition of "mutually constitutive" parts of

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[137] Trevor Pinch and Wiebe Bijker, "The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," *Social Studies of Science* 14 (1984).

[138] Mackenzie and Wajcman, "Introductory Essay: The Social Shaping of Technology," 22.

[139] Fox, ed., *Technological Change: Methods and Themes in the History of Technology.*

[140] Hans K. Klein and Daniel Lee Kleinman, "The Social Construction of Technology: Structural Considerations," *Science, Technology, & Human Values* 27, no. 1 (2002).

society rather than as separate spheres of social activity. This theory proposes that both society and technology are comprised of networks of human relationships with non-human entities, which requires a stringent "symmetry in the analytical treatment of human and non-human actors".[141] This differs significantly from the social construction of technology approach[142], as there is no dominant concern with the human condition at the expense of other non-human technological "actants".[143]

The innovation literature tends to focus less on individuals and groups and more on the historical succession of one technological paradigm over another. Figure 3-3 shows the progression of energy forms, materials, processes, and other features of socio-technical systems over time. Looking at successive waves of energy resources and technologies as regimes changed from water power, steam power, electricity, petroleum, and to renewable energy, it is much easier to describe these successive waves of innovation than explain them. Efforts to make sense of these socio-technical transitions have been undertaken in disciplines as diverse as ecology, psychology, technology studies, economics and demography, each of which have sought to understand the "punctuated equilibrium" between stable infrastructure and revolutionary upheaval.[144]

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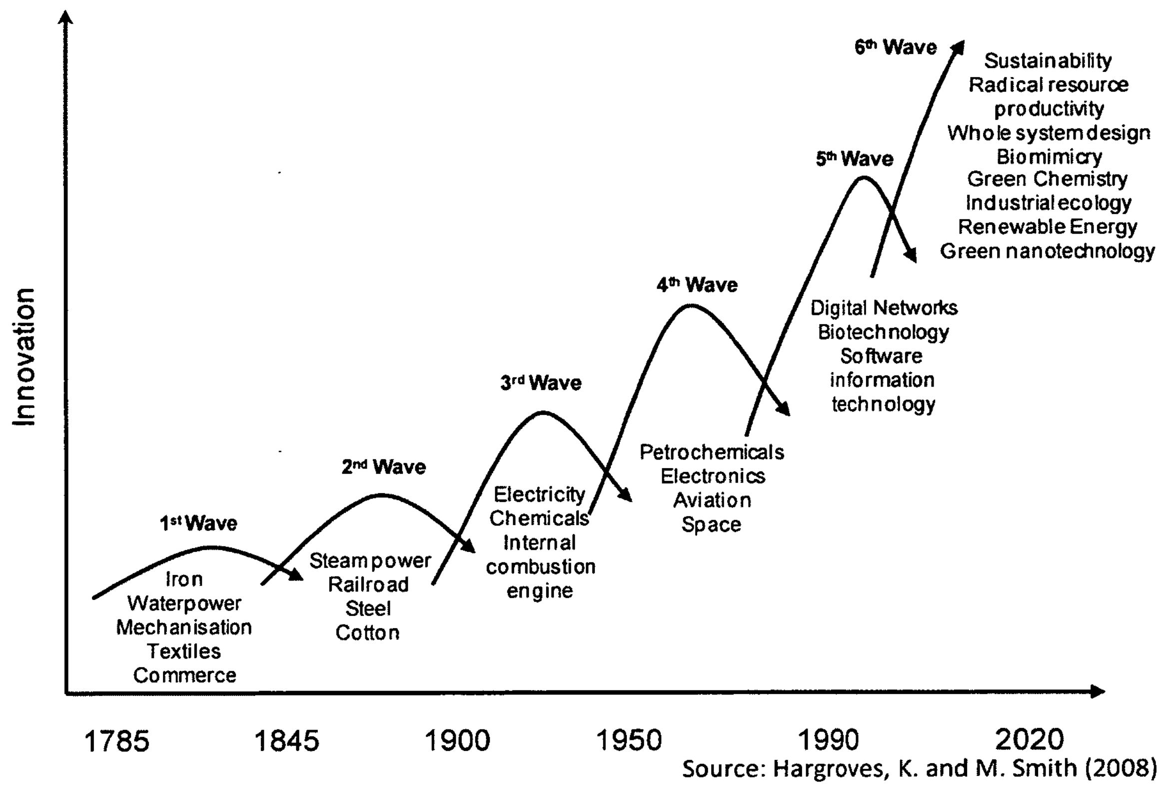
[141] Bruno Latour, "On Actor-Network Theory: A Few Clarifications," *Soziale Welt* 47 (1996).
[142] Mackenzie and Wajcman, "Introductory Essay: The Social Shaping of Technology," 24.
[143] Latour, "On Actor-Network Theory: A Few Clarifications."
[144] Connie J. G. Gersick, "Revolutionary Change Theories: A Multilevel Exploration of the Punctuated Equilibrium Paradigm," *Academy of Management Review* 16, no. 1 (1991).

Figure 3-3: Successive Waves of Innovation[145]



While the concept of successive waves of technological change is useful to describe the stages of historical development, they do not reveal why one particular wave was adopted instead of another potential alternative. In short, they do not explain why one technology succeeded or why another technology failed.

Transitions for Sustainability

The innovation and diffusion of modern technologies seem to be both the cause and solution to environmental crises.[146] Understanding the diffusion of technologies can help to address new and emerging global challenges. Technological diffusion has

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[145] Karlson Hargroves and Micheal H. Smith, *The Natural Advantage of Nations: Business Opportunities, Innovation and Governance in the 21st Century*, The Natural Edge Project (London: Earthscan, 2005).

[146] Moser, "The 'Technology Factor' in Sustainable Development."

economic, ecological and social implications, and each must be addressed if we are to understand technological change in terms of sustainable development. Thus, for technical change and stability to have practical utility, these explanations should also provide direction on how to influence the adoption of a socially preferred technological trajectory while avoiding other pathways that appear to be less favourable. The remainder of this chapter suggests an alternative analytical frame that may help to direct a policy orientation to encourage a fundamental shift in the socio-technical relationship between societal systems and their energy resources and technologies. Described broadly as a *transitions approach*, this analytical orientation provides a framework from which to understand innovations and technical change in the search for sustainable development. Further, this chapter specifies that a multi-level perspective on transitions is a useful analytical tool from which to gain insight on the role of biofuels and how they might contribute to a larger shift toward sustainable energy.

The concept of punctuated equilibrium that influenced the physical and social sciences also influenced the research on socio-technical innovation and sustainability since the 1990s. The field of 'transition studies' brings together research on socio-technical systems, public policy and administration, and sustainability studies.[147] Transitions involve "a gradual, continuous process of change where the structural character of a society (or complex subsystem of society) transforms".[148] Transitions involve long-term, large-scale transformations of social systems characterised by multiple causality and co-evolution. They include multi-actor processes within and between

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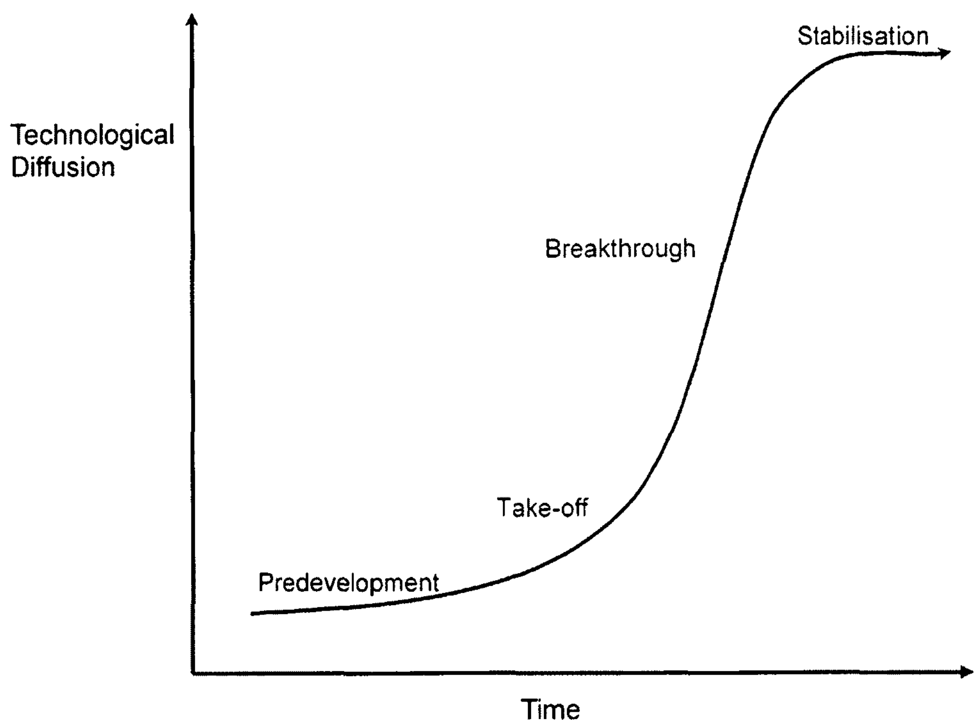
[147] Verbong and Loorbach, eds., *Governing the Energy Transition: Reality, Illusion or Necessity?*
[148] Rotmans, Kemp, and Asselt, "More Evolution Than Revolution," 16.

numerous social groups that actively participate in markets, networks, and institutions while engaged by new technologies, policy development, autonomous trends, as well as individual behaviours and preferences.[149] The objective of transition studies is to make sense of the stability and change that occurs within the progression of socio-technical systems, which is demonstrated through a four-stage model (Figure 3-4).

Figure 3-4: Four Stages of Socio-Technical Transitions[150]



Source: Author adaptation from Rotmans et al. (2001)

The first stage of *predevelopment* entails a dynamic transformation of the social context that does not yet appear as visible societal change. It can be characterised as an unpredictable conglomeration of tensions hidden beneath the surface that dislodge the current technological platform from its foundations without altering dominant social

[149] Verbong and Loorbach, eds., *Governing the Energy Transition: Reality, Illusion or Necessity?*
[150] Conceptual model adapted from Rotmans, Kemp, and Asselt, "More Evolution Than Revolution."

structures and institutions. The second stage, *take-off*, occurs when the first noticeable change of transition becomes visible in society. The innovations literature describe the take-off stage as the point at which an invention becomes an innovation; that is, when a novel product or process achieves commercial success.[151] In the transitions approach, *take-off* occurs when social structures are altered to accommodate the new technology. Examples of such accommodations include changes in policy frameworks, establishing new governance institutions, alterations to physical infrastructure, or shifting patterns of investment. The third stage of transition is *breakthrough*, in which accumulating changes reinforce each other to bring about an acceleration of learning, adoption, diffusion, and entrenchment of a new technological frame throughout society. Competition between the dominant regime and the emerging technological framework is at its height in this stage, and both can co-exist until one supplants the other. Eventually every successful transition reaches a period of *stabilisation*, where the speed of change decreases and a new dynamic equilibrium is reached.[152] It is necessary to realise that these stages can reach back and extend beyond the more linear *invention-innovation-diffusion* model presented by Rogers and other explanations of technical change.

Although stabilisation is the last stage of this model, Geels noted that a new dynamic equilibrium can be achieved via five pathways.[153] First, *transformation* of the socio-technical regime involves a change that does not result in one dominant

[151] Christopher Freeman and Carlota Perez, "Structural Crises of Adjustment, Business Cycles and Investment Behaviour," in *Technical Change and Economic Theory*, ed. Giovanni Dosi, et al. (London: Pinter Publishers Limited, 1988).
[152] Rotmans, Kemp, and Asselt, "More Evolution Than Revolution," 17.
[153] Geels and Schot, "Typology of Sociotechnical Transition Pathways."

technology, such as was the case of waste management in the Netherlands.[154] Second, *technological substitution* occurs when a radical technology replaces an existing technology to create a new socio-technical regime, as presented in Geels' case study of the replacement of sailing ships by steam-powered vessels for ocean transport.[155] *De-alignment and re-alignment* provides a third transition pathway that will be explored in greater detail in the penultimate chapter of this thesis. This pathway takes place when problems occur within existing regimes that enable new or marginal technologies to compete with dominant technologies to provide solutions, which in turn leads to the emergence of a winner.[156] A fourth pathway is possible when a new socio-technical domain is opened that requires the creation of a new socio-technical artefact that provides a new social function, such as the development of the aircraft industry. Fifth, system changes within and across many technologies alongside structural shifts in organisations can lead to the *reconfiguration* of a socio-technical regime, such as the transition from batch to mass production of bicycles and automobiles in the United States[157] or Dutch greenhouse horticulture.[158] In addition to these transition pathways, the multi-level perspective allows for incremental innovation through system *reproduction* that involves

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[154] Frank Geels, "The Hygienic Transition from Cesspools to Sewer Systems (1840-1930): The Dynamics of Regime Transformation," *Research Policy* 35 (2006).

[155] Geels, "Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case Study."

[156] Geels and Schot, "Typology of Sociotechnical Transition Pathways.", Geert P.J. Verbong and Frank Geels, "Exploring Sustainability Transitions in the Electricity Sector with Socio-Technical Pathways," *Technological Forecasting and Social Change* 77 (2010).

[157] Frank Geels, "Major System Change through Stepwise Reconfiguration: A Multi-Level Analysis of the Transformation of American Factory Production (1850-1930)," *Technology In Society* 28 (2006).

[158] Eric Berkers and Frank W. Geels, "System Innovation through Stepwise Reconfiguration: The Case of Technological Transitions in Dutch Greenhouse Horticulture (1930-1980)," *Technology Analysis & Strategic Management* 23, no. 3 (2011).

a process of renewal by dynamic and cumulative change along a stable trajectory.[159]

Transitions can therefore involve both 'radical' and 'incremental' change, and the identification of where along the transition pathway a socio-technological shift might be requires the consideration of three system dimensions: speed, size and time period of change. The speed and acceleration of change within transitions are relative to each other, and are mainly the result of positive feedback mechanisms; that is, outcomes that encourage repeated behaviour.[160] Technological regime change occurs over time[161]; as a consequence, the multi-level perspective relies on historical analysis to examine case studies of regime change to identify if a socio-technical transition occurred. Genus and Coles identify some important limitations of the multi-level perspective on transitions. The main item of critique is the lack of systematic approach. They also point to methodological problems associated with defining the parameters of a socio-technical transition, such as when politics and power struggle are more influential than evolution and structuration. For example, Meadowcroft critiques Transition Management as a reflection of the apparent lack of politics in transitions studies.[162] Although these critiques have merit, the theory is still in its infancy and its methodological apparatus is being continually refined. Geels, for example, addresses some of these critiques levied

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[159] Frank Geels and René Kemp, "Dynamics in Socio-Technical Systems: Typology of Change Process and Contrasting Case Studies," *Technology In Society* 29 (2007), Frank W. Geels, "Co-Evolutionary and Multi-Level Dynamics in Transitions: The Transformation of Aviation Systems and the Shift from Propeller to Turbojet (1930-1970)," *Technovation* 26 (2006).

[160] Rotmans, Kemp, and Asselt, "More Evolution Than Revolution," 18.

[161] In general, transitions theorists consider socio-technical transitions to require at least one generation (around 25-30 years) but multi-generational transitions are not uncommon.

[162] James Meadowcroft, "What About the Politics? Sustainable Development, Transition Management, and Long Term Energy Transitions," *Policy Sciences* 42 (2009).

against the multi-level perspective on transitions[163], although more work can be done to improve the rigour of this approach. In this thesis, for example, political struggle occurs at all heuristic levels and throughout the history of ethanol and biodiesel.

Genus and Coles also question the embedded assumptions on the 'needs' of technology within social contexts, and the acceptance of evidence and historic accounts, both of which would seem linked to an admitted preference by many transitions theorists for sustainability over conventional development. They also criticised the lack of agency within systems in transition and the bias of the examiner to favour "bottom-up" models of change. Evolutionary ontologies tend to "play down the role of agency… or strategy, and to emphasise more reactive and unreflective adaptive processes at work".[164] While Geels acknowledges that certain types of agency are less developed (such as rational choice and power struggle), the multi-level perspectives is "shot through with agency, because the trajectories and multi-level alignments are always enacted by social groups."[165]

In terms of examiner bias, critics argue that societal shifts are often conceived as beginning within niches and trickling upward to alter regimes. Geels notes that this was likely the case in early innovation studies and initial conceptualisations of socio-technical transitions.[166] More recent literature on transitions exhibits attempts to overcome such bias, and has developed to identify the event-chains as indicated by *timing* and *sequence* of multi-level interactions that reveal the differentiation between landscape, regime, and

[163] Geels, "Ontologies, Socio-Technical Transitions (to Sustainability), and Multi-Level Perspective.", Geels, "The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms."
[164] Audley Genus and Anne-Marie Coles, "Rethinking the Multi-Level Perspective on Technological Transitions," *Research Policy* 37, no. 9 (2008): 6.
[165] Geels, "The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms," 29.
[166] Ibid.

niche-based socio-technical change.[167]

Like all transitions theories, the multi-level perspective is a relatively new approach. Consequently, conceptual and empirical tools are continually being refined. Genus and Coles contribute to this challenge by identifying ways to improve the applicability of the multi-level perspective on transitions through more conscious methodological development. In particular, they note the importance of distinguishing between conceptual and empirical levels of analysis. They point to the subject of sustainable energy technologies as a way to analyse contemporaneous developments, and to utilise the multi-level perspective on transitions to examine socio-technological change as it unfolds. This not only enables testing of heuristic devices *in situ*, but it also helps to avoid uncritical adoption of historical interpretations.[168] This thesis on sustainable biofuels was researched in the midst of the proliferation of biofuels between 1998 and 2008, and provides one attempt to address this critique of the multi-level perspective on transitions and improve the distinction between the heuristic concepts of niches, regimes, and landscape and empirical analysis of micro-, meso-, and macro-levels of analysis. These methodological concerns with transitions approaches are recognised, but it is beyond the scope of this thesis to address critiques levied at all transitions approaches.

While transitions pathways can vary, it is useful to recognise that transitions can occur simultaneously at different levels of the social-technical system: micro (individuals, technologies, companies), meso (networks, communities, organisations, governments, industrial sectors), and macro (conglomerates of institutions and

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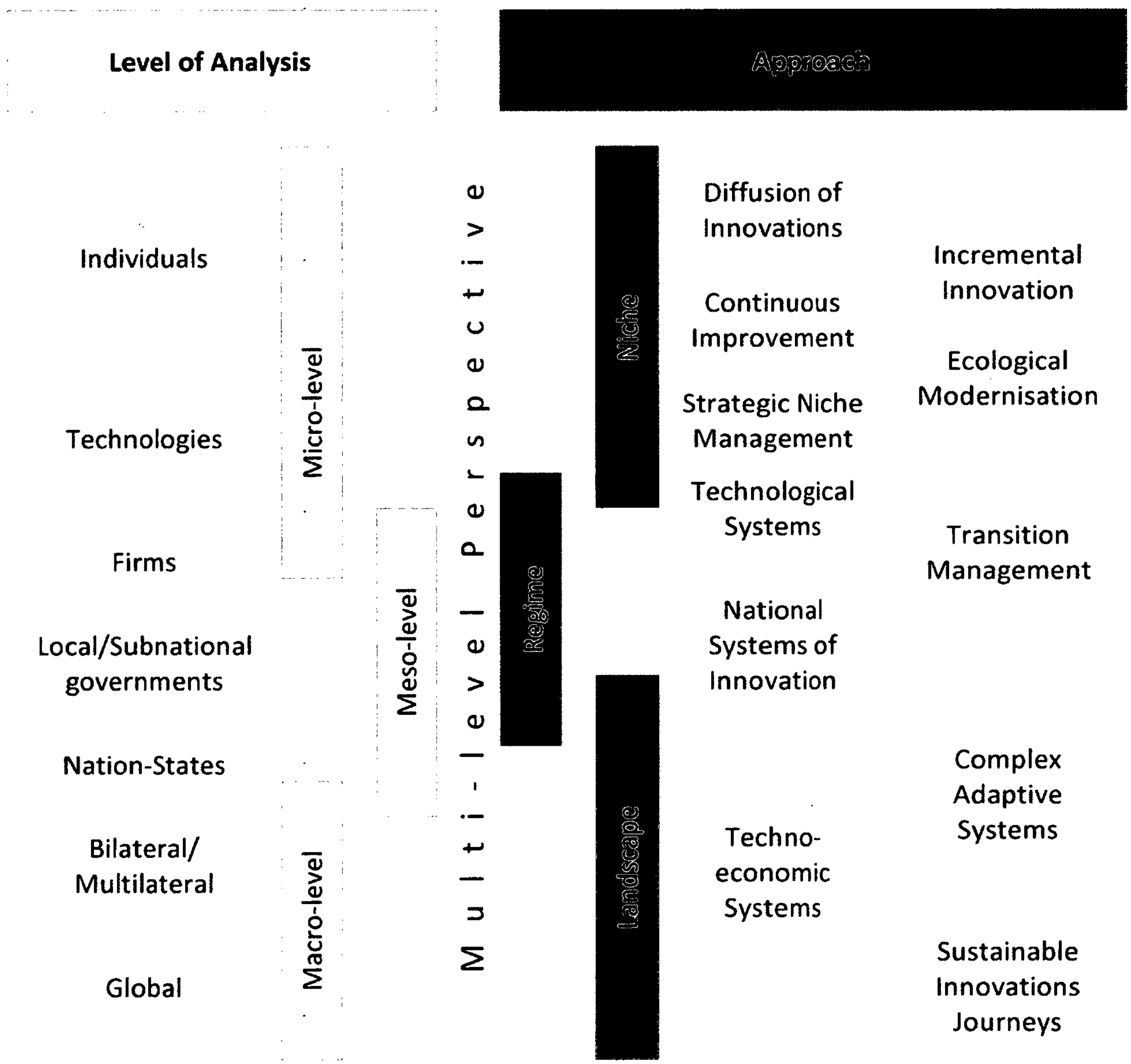
[167] Geels and Schot, "Typology of Sociotechnical Transition Pathways."

[168] Audley Genus and Anne-Marie Coles, *A Critique of Geels' Multi-Level Perspective of Technological Transition* (2007 [cited April 18 2012]).

organisations, nations, federations of nation-states, global systems), which correspond with the sites of socio-technical change and the actors involved (Figure 3-5).

Figure 3-5: Analytical Approaches to Transitions Theory



Source: Author's compilation and interpretation of the literature.

Figure 3-5 highlights some analytical approaches to understanding socio-technological transitions, which include three levels of analysis:

1. *niches* (local individuals, technologies, and practices with a high degree of flexibility)
2. *regimes* (dominant practices, rules and shared assumptions that guide public policy – geared toward optimising rather than transforming systems) and
3. *socio-technical landscapes* (material infrastructure, political culture and coalitions, social values, worldviews and paradigms, macro economy, demography, and the natural environment).[169]

A detailed discussion of each approach is beyond the scope of this thesis, but it is useful to note some pertinent aspects of the different levels of analyses within the field of socio-technical transitions.

Micro-levels of analysis explore individuals and technologies. The Diffusion of Innovations approach, for example, assumes that "laggards" will eventually follow "leaders" in the uptake of a new technology. This approach holds a significant role for human agency as the stimulus for technological change, but does not sufficiently explain how stable socio-technological regimes shape or constrain individual choice so that agency remains within the boundaries of a given trajectory.[170] Micro-level approaches can also explore the discrete improvement of individual technologies.[171] This level of analysis relates to the terminology used in transition theory as *niches*, defined as "...spaces in which radical novelties are tried out and developed further, while they are

[169] René Kemp, "Technology and Environmental Policy: Innovation Effects of Past Policies and Suggestions for Improvement," in *Innovation and the Environment* (Paris: OECD, 2000), 19, Arie Rip and Rene Kemp, "Technological Change," in *Human Choice and Climate Change - an International Assessment*, ed. S. Rayner and E.L. Malone (Washington DC: Batelle Press, 1998).

[170] Rogers, *Diffusion of Innovations*.

[171] Ad J. de Ron, "Sustainable Production: The Ultimate Result of Continuous Improvement," *International Journal of Production Economics* 56-57 (1998).

sheltered from mainstream competition".[172] Meso-level approaches look primarily at the activities of nation-states as indicators of societal organisation[173], but some include the contribution of large-scale firms[174] or local/subnational governments within this context.[175] Examples include the technological systems approach[176], strategic niche management[177], and transition management.[178] Instead of individuals or technical artefacts, these approaches address technological regimes that establish "boundaries for technological progress and indicates the direction in which progress is possible and worth doing".[179] Macro-level analyses seek to understand transitions from a multilateral or global perspective.[180] This is often motivated by the emergence of "global" concerns, such as international trade, multilateral agreements, climate change, energy security, health and disease, and a host of other global challenges. Examples of this approach include complex adaptive systems[181], techno-economic systems[182], and sustainable innovations journeys.[183] In the transitions literature, these are referred to metaphorically as *landscapes*, which "...form an exogenous environment beyond the direct influence of

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[172] Johan Schot and Frank Geels, "Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda, and Policy," *Technology Analysis & Strategic Management* 20, no. 5 (2008).

[173] Lundvall, ed., *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*.

[174] Freeman, "The Economics of Technical Change."

[175] Willoughby, *Technology Choice: A Critique of the Appropriate Technology Movement*.

[176] Thomas P. Hughes, *Networks of Power* (Baltimore, MD: John Hopkins University Press, 1983).

[177] Marlolein C. J. Caniels and Henny A. Romijn, "Strategic Niche Management: Towards a Policy Tool for Sustainable Development," *Technology Analysis & Strategic Management* 20, no. 2 (2008).

[178] Derk Loorbach and Jan Rotmans, "The Practice of Transition Management: Examples and Lessons from Four Distinct Cases," *Futures* 42 (2010).

[179] Kemp, *Environmental Policy and Technical Change: A Comparison of the Technological Impact of Policy Instruments*, 266.

[180] Daniele Archibugi and Jonathan Michie, "Technical Change, Growth and Trade: New Departures in Institutional Economics," *Journal of Economic Surveys* 12, no. 3 (1998), Dosi et al., *Technical Change and Economic Theory*.

[181] J. Stephen Lansing, "Complex Adaptive Systems," *Annual Review of Anthropology* 32 (2003).

[182] Perez, "Technological Revolutions and Techno-Economic Paradigms."

[183] Geels, "The Dynamics of Sustainable Innovation Journeys."

niche and regime actors."[184] Socio-technical landscapes provide structural contexts for niches and regimes, and involve "processes that span societal functions and...include environmental and demographic change, new social movements, shifts in general political ideology, broad economic restructuring, emerging scientific paradigms, and cultural developments."[185]

Of particular concern for transitions approaches are those social, economic and environmental goals associated with sustainability. In such transitions, there is a belief that the opportunity exists to encourage the "technology-economy-ecology linkages which may help to define and accomplish environmentally sustainable development".[186] Some suggest that there may be an obligation for socio-technical systems to embrace sustainability because "...present environmental problems call for more environmentally benign technology".[187] There is a strong symmetry between transitions theories and sustainable development. Where transitions are "made up of processes of co-evolution involving changes in needs, wants and the institutions that coordinate choices"[188], sustainable development is itself a process of co-evolution. Sustainability

> ...refers to a process and a standard – and not to an end state – each generation must take up the challenge anew, determining in what directions their development objectives lie, what constitutes the boundaries of the environmentally possible and the environmentally desirable, and what is their

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[184] Geels and Schot, "Typology of Sociotechnical Transition Pathways."
[185] Smith, Voss, and Grin, "Innovation Studies and Sustainability Transitions: The Allure of the Multi-Level Perspective and Its Challenges."
[186] René Kemp and Luc Soete, "The Greening of Technological Progress: An Evolutionary Perspective," *Futures* 24, no. 5 (1992): 437.
[187] Kemp, "Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts."
[188] James Meadowcroft, "Planning for Sustainable Development: What Can Be Learned from the Critics?," in *Planning Sustainability*, ed. Michael Kenny and James Meadowcroft (London and New York: Routledge, 1997).

understanding of the requirements of social justice".[189]

Because the "process" and "standard" of sustainability are co-evolutionary, subsequent definitions are subject to generational changes, which suggest potential problems with transitions that might require the stabilising force of institutions to override the lock-in of an unsustainable technology or political short-sightedness biased toward the electoral imperative.[190] Thus, there is a difference between the process envisioned by Brundtland as primarily multilateral and the transitions approach that sees a much broader engagement by society at all levels. The focus on multilateral treaties and accords that typically characterise sustainable development initiatives at the international level provide a degree of institutional stability (at least for participating nations) from which the transition approach can develop a process-driven operational model.

Transitions for sustainability differ from typical historical transitions in that the former are goal-oriented societal change while the latter involves historical changes emerging from blind exploration, accidental discovery, political ambition, economic activity, or other societal contexts. Sustainability transitions are intended as a deliberate achievement of socially-defined goals rather that merely stumbling on to a new frontier. Transitions for sustainability also differ from historical change in that the potential benefits from this new socio-technical system take the form of non-excludable, non-diminishable public goods. Therefore, technical innovations to improve environmental performance are not likely to replace dominant technological systems without changes to

[189] Ibid., quoted in René Kemp, Derk Loorbach, and Jan Rotmans, "Transition Management as a Model for Managing Processes of Co-Evolution Towards Sustainable Development," *The International Journal of Sustainable Development and World Ecology* 14, no. 1 (2007).

[190] Kemp, Loorbach, and Rotmans, "Transition Management as a Model for Managing Processes of Co-Evolution Towards Sustainable Development."

existing governance mechanisms, such as policy frameworks, public institutions, and political relationships. Established and powerful actors are likely to co-opt or resist changes to the *status quo*, which makes sustainability transitions even more difficult considering that the empirical domains of transportation, energy production, and other core areas of concern are dominated by large firms possessing 'complementary assets' (e.g., production processes, distribution systems, supply chains, service networks, and supplementary technologies) and a significant advantage over pioneer technologies at the frontier of environmental innovation. According to Geels,

> These considerations imply that sustainability transitions are necessarily about interactions between technology, policy/power/politics, economics/business/markets, and culture/discourse/public opinion...So, the core analytical puzzle is to understand how environmental innovations emerge and how these can replace, transform or reconfigure existing systems.[191]

This pursuit requires an analytical approach that includes multiple domains, multiple levels, and multiple actors.[192] The multi-level perspective integrates all three analytical units and levels with examinations of case-studies. In doing so, it offers a middle-range theory that combines theoretical understanding with empirical observation and avoids grand theories of societal change or micro-theories based on data-collection and analysis of variables abstracted from reality. In attempting to explain historical events rather than merely describing variations observed in dependent variables, the multi-level perspective investigates elaborate processes, their patterns, and the mechanisms that create stability and enable change.[193] It seeks to make sense of complex dynamic systems rather than describe simple cause-effect transactions.

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[191] Geels, "The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms."
[192] Rotmans, Kemp, and Asselt, "More Evolution Than Revolution," 22.
[193] Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective."

Most case studies explain societal phenomena by identifying how and why they are variations from the norm. In contrast, the multi-level perspective is a type of process theory that provides a way to understand the unfolding of socio-technical change rather than the uniqueness of a given context at a given time. There are different explanatory concepts that are used to convey the notion of *process* rather than *variation*. One concept employed in the multi-level perspective is *alignment*, which is an heuristic concept with which to explain the internal contexts and progression of activity within niches, regimes or landscapes. Alignment can reveal how, for example, a new tax structure or regulatory framework can encourage stability or contribute to change in the trajectory of a given socio-technical regime. It can also reveal a specific transition pathway described in the multi-level perspectives as "de-alignment and re-alignment" that occurs when internal tensions of a socio-technical regime or pressures from the socio-technical landscape destabilise a regime and "creates space for the emergence of multiple innovations in different niches".[194] Evolution is another concept used to explain the relationships *between* analytical levels, such as when a niche-innovation or altered landscape challenges the dominant regime with a viable re-configuration of the socio-technical system. Evolution is multi-dimensional "because it not only involves markets, but also regulations, cultural and social movements, infrastructure and legitimacy. So, evolution is the linkage process, which consists of making alignments between niche-variations and societal selection environments"[195] (Figure 3-6).

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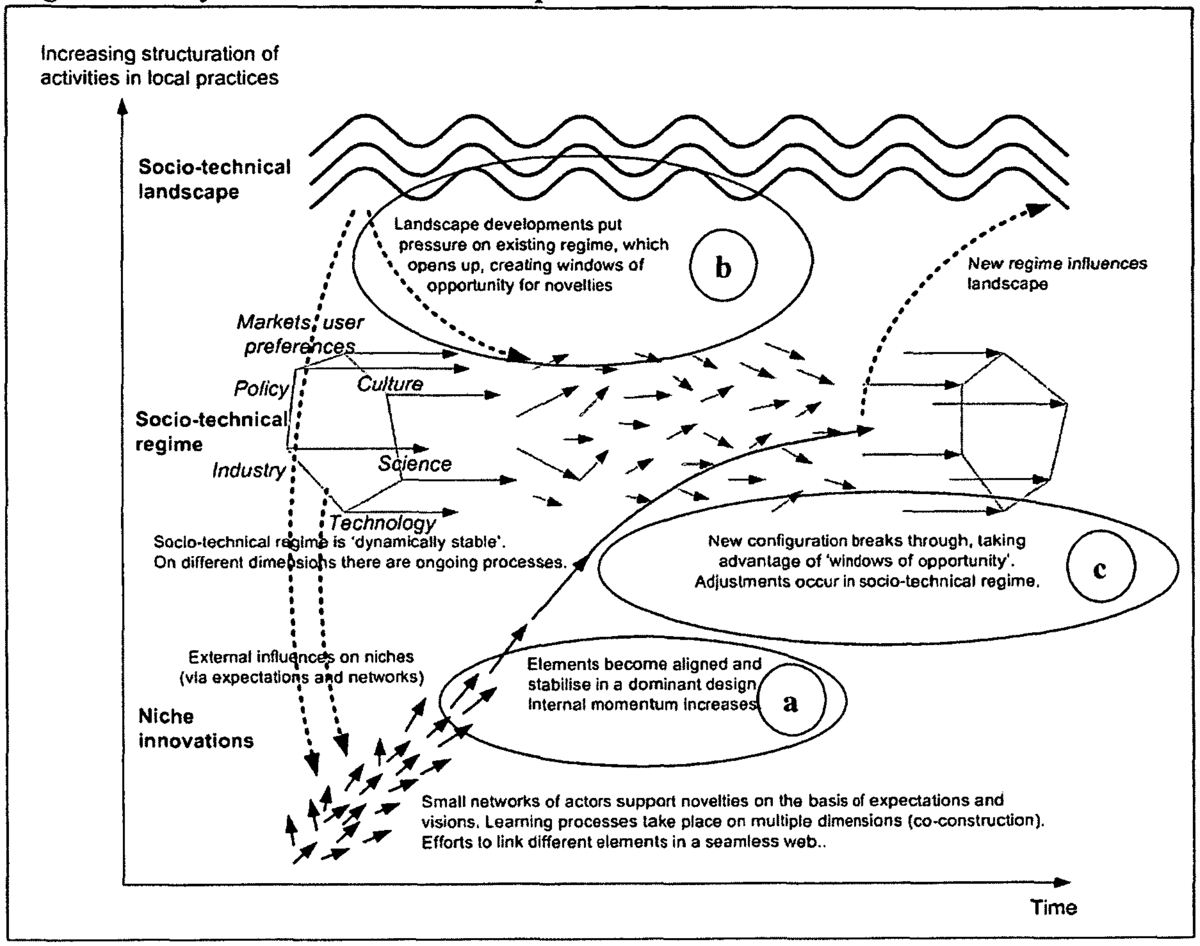
[194] Geels, "The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860-1930)," 472.
[195] Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective," 96.

Figure 3-6: Dynamic Multi-level Perspectives on Socio-technical Transitions[196]



Source: Author's adaptation from Geels (2005)

The multi-level perspective explains socio-technical transitions as resulting from processes occurring within and between niches, regimes, and landscapes. Alterations at the landscape level can exert 'pressure' that destabilises a dominant regime enough to provide an opportunity for transformative niches to break through long-standing barriers and thereby shift the trajectory of societal change. According to Schot and Geels,

> The core notion of multi-level perspective (MLP) is that transitions come about through interactions between processes at different levels: (a) niche innovations build up internal momentum, (b) changes at the landscape level create pressure on

[196] Adapted from Geels, "The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860-1930)."

> the regime, (c) destabilisation of the regime creates windows of opportunity for niche innovations.[197]

The multi-level perspective conceptualises the interactions of niches, regimes and landscapes and demonstrates through case studies and historical analysis how these interactions occur. Interactions between different analytical levels involve different types of actors making choices within changing contexts over time. The sequence of events, the strategic interaction among actors, the development of new societal ideas, institutions and identities, and other relationships involve a large number of agents and structures and are therefore difficult to convey. The alignment and evolution of socio-technical systems is therefore highly contingent on how these elements interact, and the multi-level perspective employs narrative as a way to capture historical events involving multiple actors over long periods of time. A narrative approach enables the depiction of larger socio-technical transitions as a way to articulate probable trajectories, and provides a way to identify and explore case studies that exemplify a larger socio-technical trajectory. The narrative approach enables a wider depiction of specific historical events, which can then be subjected to closer examination of its constituent parts in order to elucidate significant features and critical junctures. In the multi-level perspective, a narrative approach to exploring case studies aims to identify typologies as representations of complex interactions of innumerable variables and potential configurations.[198]

It is noteworthy that earlier iterations of the multi-level perspective presented niches, regimes and landscapes as a "nested hierarchy". However, the primary interest in

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[197] Schot and Geels, "Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda, and Policy."

[198] Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective," 100.

the stability of technological regimes and deliberate efforts to achieve sustainability has effectively relegated niches and landscapes as “derived concepts” defined only in relation to the regime in question.[199] Thus, the multi-level perspective suggests an important role for governments as legitimising institutions within a socio-technical regime. By recognising that multiple domains, levels and actors exist, a multi-level perspective to understanding transitions may help governments manage these transitions toward the achievement of socially-defined objectives. Employing a multi-level perspective as an analytical tool could help to align public policy analysis with the co-evolving visions, strategies, agendas and projects for sustainable development within and across generations.[200]

Transitions and the Multi-level Perspective on Biofuels

As a response to energy, climate, and rural economic decline, biofuels have attained a degree of prominence in national economies and for sustainable energy policy. By looking at the diffusion of biofuels through a multi-level perspective on transitions, we can better understand the factors that facilitated change and created stability for ethanol and biodiesel technologies and their potential contribution to sustainable energy. Biofuels are a “two-world” technology insofar as they “are viable both in the existing system and in a system that satisfies the transition objectives”.[201] Two-world technologies can fit into both pre- and post-transition societies with minimal socio-technical adjustments. They are distinguished from “one world” technologies that refine or

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[199] Geels, "The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms," 26.

[200] Kemp, Loorbach, and Rotmans, "Transition Management as a Model for Managing Processes of Co-Evolution Towards Sustainable Development."

[201] See Rotmans, Kemp, and Asselt, "More Evolution Than Revolution."

improve the present socio-technical system, but are inevitably defunct in a future energy regime. This capacity to straddle both current (i.e., present) and alternative (i.e., future) energy regimes makes ethanol and biodiesel transitionary technologies in two important ways. In the *present*, biofuels may be considered to be innovative products that are the first alternative transport fuels used on a relatively large-scale. They are pioneer technologies that must overcome economic, technical, political, social, cultural, environmental and ethical challenges before they can be considered "viable" options to complement or substitute petroleum fuels. While favourable, biofuels may simply refine the existing energy regime rather than contribute to broader socio-technical change.[202] In the *future*, biofuels might be considered as vanguard artefacts that helped trigger a technological revolution to bring about socio-technical shift toward a more sustainable energy regime. Here, they not only affect transport fuels, but they also inform the overarching debate on the extent to which we can rely on biomass as a material and energy resource base for human development. Niche-innovations in ethanol and biodiesel may influence the present petroleum-based socio-technical regime, but successful innovation with the commercialisation of ethanol and biodiesel as a complementary transportation fuel does not necessarily ensure a transition to a future free from fossil fuels.[203] Moreover, altered landscapes in which energy resources are less secure, greenhouse gas emissions are too high, and rural economies are stagnant can put pressure

[202] Nuno Bento, "Is Carbon Lock-in Blocking Investments in the Hydrogen Economy? A Survey of Actors' Strategies," *Energy Policy* 38, no. 11 (2010).

[203] Karplus, Paltsev, and Reilly, "Prospects for Plug-in Hybrid Electric Vehicles in the United States and Japan: A General Equilibrium Analysis.", Bjorn A. Sanden and Karl M. Hillman, "A Framework for Analysis of Multi-Mode Interaction among Technologies with Examples from the History of Alternative Transport Fuels in Sweden," *Research Policy* 40 (2011), Zapata and Nieuwenhuis, "Exploring Innovation in the Automotive Industry: New Technologies for Cleaner Cars."

on socio-technical regimes, but these may not be aligned in such a way as to encourage a successful transition toward sustainable energy development. Maintaining a multi-level perspective on the inter-connection between niches, regimes and landscapes of sustainable energy can shed light on the technological stability and change of biofuels.

Conclusion

This chapter introduced sustainable development in relation to sustainable energy, and suggested the need to facilitate a shift away from the conventional development trajectory and toward sustainability. It argued that sustainable energy cannot be achieved with effects-based approaches alone, but must also employ strategies to recognise the fundamental socio-technical functions of energy systems. The overview of different transitions approaches revealed numerous attempts to link the fields of technology studies, sustainability, public policy and administration, and other social sciences into an interdisciplinary analysis of socio-technical systems. This chapter argued in favour of a transitions approach based on the multi-level perspective as a way to encapsulate the factors and trends involved in understanding long-term historical change and to identify potential projections of a contingent future in the search for sustainability.

This chapter closed with an introduction of how the multi-level perspective on transitions can be applied to the global expansion of ethanol and biodiesel from 1998-2008. This analytical framework will inform the examination of the development of these two biofuel technologies from their earliest applications in combustion engines to their peak of popularity in the early 21st century, which begins in the next chapter with an historical account of ethanol and biodiesel in North America and Europe.

FOUR – Pioneer Technology and Old-World Innovation

The rapid expansion of first generation biofuels between 1998 and 2008 was based largely on the promise of ethanol and biodiesel to contribute to future fuel requirements that enhance energy security, improve rural economies, and reduce carbon emissions.[1] This expansion differs from their history, which is characterised by repeated cycles of marginal technical successes and almost total market failures. This chapter looks at technological, societal, and political factors that influenced the socio-technical stalls that inhibited the early diffusion of biofuels. History reveals that the promise of biofuels is not new, but that previous socio-technological contexts did not facilitate the adoption and diffusion of biofuels.

Ethanol: Pioneer Technology

Ethanol has been consumed since antiquity as an intoxicating beverage and medicinal treatment. It replaced whale oil as the lamp fuel of choice in the early 1800s. Today it is used in the production of chemical products such as antifreeze, synthetic rubber, plastics, solvents, acetates, resins and pesticides. Early inventors and producers of internal combustion engine designs considered ethanol to be a superior fuel type[2], and it has been used to propel chainsaws, automobiles, tractors, aeroplanes, submarines, torpedoes, rockets and more.

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[1] Kimberley A. Mullins, W. Michael Griffin, and H. Scott Matthews, "Policy Implications of Uncertainty in Modeled Life-Cycle Greenhouse Gas Emissions of Biofuels," *Environmental Science & Technology* 45, no. 1 (2011), Smyth et al., "Can We Meet Targets for Biofuels and Renewable Energy in Transport Given the Constraints Imposed by Policy in Agriculture and Energy?."

[2] Anon., "Ford Predicts Fuel from Vegetation," *New York Times*, Sept. 20 1925.

Since its first commercial applications, ethanol has had an irregular progression as a petroleum fuel alternative. As this historical case study demonstrates, ethanol has been considered a viable fuel since the mid-1800s, but serious considerations for the expanded use of ethanol arose only three times: before the American Civil War as a lamp fuel, in the early 20th century before petroleum reserves were quantified, and during the Second World War when petroleum use was prioritised. In each case, an uncertain fuel supply prompted the re-evaluation of ethanol as a viable alternative to gasoline.

Lamps, Industrial Machines, and Household Appliances

Until the mid-19th century, whale oil was a popular source of lamp fuel, but other types of fuels existed. Vegetable and animal oils, refined turpentine from pine trees, and methyl and ethyl alcohol fuels each had a share of the market for lamp fuel as the whale harvest declined.[3] During the half century before the 1859 discovery of petroleum in Pennsylvania, "camphene" was a popular alternative lamp fuel in the United States. A blend of high-proof ethyl alcohol with 20-50 percent turpentine and a few drops of camphor oil to mask the turpentine smell, "camphene" became a popular alternative to the increasingly expensive whale oil and the dirtier, although equitably priced, coal oil (kerosene).[4]

While kerosene gradually replaced camphene in Europe during the latter half of the 1800s, the market for kerosene as a lamp fuel in the United States shifted dramatically

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[3] Julian L. Simon, "Bright Global Future," *Bulletin of Atomic Sciences* (1984).

[4] Bill Kovarik, "Henry Ford, Charles Kettering and the 'Fuel of the Future," *Automotive History Review* 32 (1998).

after the introduction of petroleum products in 1859[5], and further accelerated between 1862-64 with the imposition of a tax on beverage alcohol that was implemented to help fund the American Civil War effort. The United States Internal Revenue Service made no distinction between industrial and potable alcohol, and a $2.08/gallon tax was applied universally to all alcohol sales. The price of camphene in the 1850s was $.50/gallon, and increased by 200 – 300% over the next decade after adjusting for the new tax.[6] This tax remained in effect until 1906, during which time kerosene became the primary lamp fuel in North America, while "the growth of the petroleum industry in the 1860s was greatly aided by the heavy tax on its primary competitor".[7]

The replacement of camphene with kerosene in the United States was stimulated by a shift in tax policy, but other factors also contributed to its decline. Lighting first shifted from oils and candles to liquid and *vapour* (natural gas) fuels around 1820. While many American homes continued using liquid fuels like camphene, street lighting and some urban residential and office buildings adopted a gas-based illumination infrastructure. As early as 1816 in New York, the gas industry attempted to establish itself as an alternative lighting source. From the 1820s to 1880s, gas illumination became the standard in New York city and a cadre of gas utilities cornered that market, benefiting from favourable regulatory rules that allowed for monopoly pricing.[8] Unveiled in 1882, Edison's electric light bulb and power supply system would eventually replace the $1.5

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[5] John McCollough and Henry F. Check Jr., "The Baleen Whales' Saving Grace: The Introduction of Petroleum Based Products in the Market and Its Impact on the Whaling Industry," *Sustainability* 2 (2010).

[6] Kovarik, "Henry Ford, Charles Kettering and the 'Fuel of the Future."

[7] Ibid.: 6.

[8] Andrew Hargadon and Yellowlees Douglas, "When Innovations Meet Institutions: Edison and the Design of the Electric Light," *Administrative Science Quarterly* 46, no. 3 (2001).

billion natural gas infrastructure and its "sputtering, yellowish light" with a clean, quiet, simple and fire-resistant source of illumination. Although gas utility companies, the municipally-employed lamplighters, and even the politicians that benefited from kickbacks for ensuring amenable regulatory policies clearly opposed this new technology, electricity replaced liquid and vapour fuel lighting for residences and offices in urban centres across western society.[9] Rural electrification programs followed shortly thereafter.[10] Weakened by the federal alcohol tax in the United States, ethanol-based camphene could not compete with natural gas or with the emerging electrical illumination systems.

The diffusion of ethanol biofuels in Europe was more gradual, and was aided by the first denaturing law in 1855 that allowed for the addition of a substance to make alcohol unfit for human consumption, thereby exempting ethanol from excise taxes on beverage alcohol.[11] By the turn of the century Britain, Germany and France were actively promoting alcohol fuel and numerous applications were suggested to increase the enthusiasm and distribution of the product. At the 1902 Paris alcohol fuel exposition, "the exhibit was devoted to alcohol powered automobiles, farm machinery and a wide variety of lamps, stoves, heaters, laundry irons, hair curlers, coffee roasters and every conceivable household appliance and agricultural engine powered by alcohol".[12] Similar expositions took place in France, Germany, Italy and Spain between 1901 and 1904. According to Kovarik's evidence, ethanol production in France rose from 2.7 million gallons in 1900 to 5.7 million gallons in 1903 to 8.3 million gallons in 1905. In Germany,

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[9] Ibid, Hughes, *Networks of Power*.
[10] Bob Patton, "History of the Rural Electrification Industry," *Management Quarterly* 37, no. 4 (1997).
[11] Houghton-Alico, *Alcohol Fuels: Policies, Production, and Potential*, 94.
[12] Kovarik, "Henry Ford, Charles Kettering and the 'Fuel of the Future."

ethanol production rose from 10 million gallons in 1887 to 26 million gallons in 1904.[13]

Until the expansion of electrical energy through large-scale coal and hydroelectric power stations, factories produced power independently; first through waterpower and later with steam engines that provided a mechanical drive system for industrial machinery. Electric utility companies competed with the gas companies and expanded their infrastructure, but industrial power systems (particularly those with large, expensive mechanical drive systems that had a reasonable level of thermal efficiency in comparison with the electrical generators that were available at the time) resisted an early shift to electrical power. The in-house power generators, which typically entailed a centralised, steam-powered mechanical system, used a complex system of cogs, sprockets, pulleys, and leather belts to turn iron shafts that transferred the energy to power equipment throughout the factory. The development of individual electric motors for each piece of industrial machinery replaced the large complex of mechanical drive production systems, which created a new end-use market for electricity. The increased availability of external electrical power allowed for the simple, flexible and comparatively more efficient electrical unit power drives, which brought down the operational costs of industrial operations. In addition, electric companies encouraged the adoption of electric motors because "daytime motor loads would complement night time illumination loads; since the marginal costs of serving these loads was relatively low, large profits were foreseen".[14]

Thus, the evolution and adoption of a separate electrical motor for each machine and tool allowed for both direct and indirect savings. Direct savings, such as energy use

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[13] Ibid.: 8.
[14] Warren D. Devine Jr., "From Shafts to Wires: Historical Perspective on Electrification," *The Journal of Economic History* 43, no. 2 (1983): 355.

and capital costs, were marginal but the indirect savings provided greater benefits and included: increased production flows and greater productive flexibility, better working environments, improved machine control, and less costly expansion of plant manufacturing facilities. An emerging socio-technical function of electrical energy enabled a technological division of mechanical processes that was not possible with in-house power generation. These were important factors that contributed to the transition from gas to electricity, which in turn enabled vast increases in productivity levels to be realised in the early 20th century.[15]

A similar progression of technological change occurred later in the household. The ethanol suppliers for the camphene industry could not resist the more powerful and better organised natural gas sector, which captured the larger public and commercial markets for illumination by providing large-scale lighting systems. Individual and decentralized households still relied on liquid fuels for illumination, but these too would eventually join the expanding grid of electrification provided by a more centralized energy system owned by private and public utility companies.[16] The emerging electrical energy market decimated consumer demand for liquid fuels by also capturing the household markets for lighting and appliances. The stoves, heaters, laundry irons, hair curlers, and coffee roasters featured at the 1902 Paris exposition were quickly overshadowed by their electric cousins. In short, lamps, industrial machinery, and household appliances all moved toward and evolved within the electrical power system, marginalising liquid fuels in the process.

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[15] Ibid.
[16] Patton, "History of the Rural Electrification Industry."

Automobiles, Tractors, Aeroplanes and Rockets

Samuel Moray invented the first internal combustion engine in 1826. It ran on ethanol and turpentine, a blend similar to the camphene lamp fuel that "offered the most logical starting point in the search for portable liquid fuels".[17] While technically successful, early attempts at commercialisation ended in economic failure. Moray was unable to attract investors because steam power was thought to be the better alternative for vehicle propulsion. In 1860, Nicolas August Otto used ethanol, abundantly available as a lamp fuel throughout Europe, to power his internal combustion engine. Subsequent versions of his engine could be powered by a variety of fuels with small adjustments, but the wide availability and cheap prices of gasoline made for an attractive alternative despite its highly volatile properties.[18]

In the late 1800s, the petroleum industry was still in its infancy and many governments around the world were concerned about the availability of oil resources. The extent of global oil reserves was unknown, and supplies from known reserves in Russia and America were unpredictable. Both Germany and France had low domestic oil reserves and consequently promoted liquid biofuel development. In the United States, the petroleum industry was growing due to domestic availability and the continuation of the alcohol tax. In 1906, the tax on ethanol fuel was repealed despite general opposition from the methyl alcohol producers that sought to avoid competition from other alcohol fuel types. Reportedly a "bitter foe of the oil industry"[19], President Theodore Roosevelt endorsed the removal of the tax, and his support for the farm lobby (which sought a

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[17] Kovarik, "Henry Ford, Charles Kettering and the 'Fuel of the Future," 5.
[18] Ibid.
[19] Ibid.

market in the context of falling grain prices and growing surpluses) and the Temperance movement (which finally found a noble use for the "wicked" beverage) elevated the likelihood of establishing an ethanol market for automobile fuels. American automobile manufacturers also supported the removal of the tax because ethanol could improve auto fuel quality and provide safer handling and storage while offering a cleaner burning fuel. These emerging socio-technical functions of ethanol provided a challenge to petroleum fuels.

With the removal of the alcohol tax, a fuel ethanol market seemed possible. Production costs plummeted and new uses and applications appeared. In 1907, ethanol prices in the United States were around \$0.25-\$0.30 per gallon while gasoline at \$0.18-\$0.22 was slightly cheaper. The Texas oil fields increased national production levels while Gulf and Texaco corporations bought out independent drilling companies, and the increased economies of scale resulted in a considerable drop in oil prices. Once again, the economic potential of ethanol was in question.[20] As the petroleum industry gained economic strength, the market share for an ethanol alternative declined considerably. However, a degree of the socio-technical functions of ethanol remained. The market for ethanol as an octane enhancer still had potential due to the relative inefficiency of automotive technology. The earliest vehicles had low compression ratios (4:1), and low-octane fuels were well suited for these comparatively inefficient machines.[21] Increased engine efficiency was most easily achieved by increasing compression ratios. The immediate result of higher engine compression was a pre-ignition of the fuel-air mixture

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[20] Ibid.
[21] Houghton-Alico, *Alcohol Fuels: Policies, Production, and Potential*, 95.

(engine knock). Ethanol was a known anti-knock agent and was used as a fuel additive.[22] For spark ignition engines, certain characteristics are needed for an ideal fuel: high energy content, high octane levels, high latent heat of vaporisation, rapid rate of flame propagation, phase stability throughout the range of local ambient temperatures and conditions, and low level of harmful emissions.[23] Although petroleum contained more energy by volume, ethanol provided more favourable characteristics overall.

General Motors researchers Charles Kettering and Thomas Midgely recognised that octane enhancement could be achieved via two paths: (1) benzene or alcohol-blended gasoline and (2) the development of alternative gasoline additives such as iodine or lead. Between 1916 and 1925, they pursued both paths, fully expecting that alcohol blends were the likely outcome. As Kovarik revealed, "Kettering came to believe that alcohol fuel from renewable resources would be the answer to the compression problem and the possibility of an oil shortage".[24] In response to potential grain-alcohol supply problems[25], research into possible additives continued. In December 1921, Kettering's General Motors research laboratories discovered anti-knock properties of adding tetraethyl lead to gasoline. Research continued into ethanol blends, and General Motors considered the possibility for two "ethyls": tetraethyl lead as a "transitional efficiency booster for gasoline, and ethyl alcohol, the 'fuel of the future' that would keep America's cars on the roads no matter what happened to domestic or world oil supply".[26] However, General Motors, supported by the DuPont family as powerful shareholders since 1920, entered a

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[22] Ibid.
[23] Ibid., 97.
[24] Kovarik, "Henry Ford, Charles Kettering and the 'Fuel of the Future," 14.
[25] Kettering estimated that over half the total farm area of the United States would be required for ethanol feedstocks. See Ibid.
[26] Ibid.: 17.

joint venture with Standard Oil (now Exxon) to create Ethyl Corporation in 1922. This new firm produced tetraethyl lead gasoline additive as its sole product, and could only succeed if it captured the market for octane enhancers. Shortly after its discovery in 1921, public concerns arose over the health effects of tetraethyl lead. Backed by GM-DuPont and Standard Oil, Ethyl Corp staunchly defended its proprietary product. Even though Kettering's new octane enhancer was temporarily removed from the market, the public health impacts were later deemed "groundless" by the U.S. Public Health Service and tetraethyl lead was re-admitted to the market in 1926. This outcome was further supported by the 1936 decision of the U.S. Federal Trade Commission to forbid health-based criticisms in the commercial market place by direct competitors.[27] Outspoken health officials and citizens-at-large continued to publicly criticise gasoline with tetraethyl lead additives, but the petroleum industry's support for leaded gasoline helped it to remain on the market by restricting the voices of competitors' and concerned citizens. Any competition from ethanol blends as an octane enhancer was effectively quashed.

Although brand name ethanol fuels such as Alcogas and Vegaline were commercially available in the 1920s, they were still "fringe fuels" (i.e., on the periphery of the automotive fuels market). Economic disadvantages of production costs and market price were important, but Prohibition and concerted opposition from the oil industry also contributed to the failure of ethanol as a transport fuel. Even though Henry Ford presumed ethanol to be the "fuel of choice" for his vehicles, ethanol was quickly

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[27] Ibid.: 18.

supplanted by the relative abundance and minimal cost of petroleum.[28] In the 1930s, the Farm Chemurgy movement in the United States led the charge against the petroleum monopoly on auto fuels. A "mixture of agronomy, chemistry and Prairie Populism", the Farm Chemurgy movement was a "populist, Republican alternative to Democratic President F. D. Roosevelt's agricultural policies".[29] Supporters considered it as a form of farm relief, and challenged the oil industry by urging motorists to use Agrol (an early brand of ethanol-blended gasoline). Although its pump price was the same as leaded gasoline, special handling requirements to keep water out of the holding tanks cost distributors an extra penny per gallon. By 1939, viable markets disappeared and most producers closed their doors. Also, suspected sabotage and collusion in the oil industry contributed to Agrol's declining market share.[30]

During the 1930s, the growing economies of scale of the oil companies eventually led to a tight oligopoly. Some, like Gulf and Texaco, benefited from early advantages in economic competition and public relations. Other tactics would also prove successful to secure the market share for petroleum products during the Great Depression. For instance, Standard Oil (which would later collaborate with General Motors, DuPont and the German chemical company I.G. Farben to develop petroleum-based chemical products) became a strong force in the petroleum industry. The American Petroleum Institute lobbied against ethanol with claims that it was technically inferior despite strong evidence to the contrary. Oil companies paid for radio announcements that corroborated ethanol's inferiority, and compared alcohol filling stations with illegal "speakeasies" and

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[28] Houghton-Alico, *Alcohol Fuels: Policies, Production, and Potential*, 94.
[29] Kovarik, "Henry Ford, Charles Kettering and the 'Fuel of the Future."
[30] Ibid.: 20-23.

bootleggers. Sun Oil Company went so far as to investigate the private lives of ethanol producers. Ethyl Corporation refused dealer contracts to gasoline wholesalers in order to increase pressure on dealers to sign exclusive sales contracts on only Ethyl Corp products.[31]

The two World Wars strained world oil supplies, and ethanol-based fuels were revived to supplement domestic fuel consumption in American farming communities, as well as in oil-poor nations like Germany, France and Brazil. However, the Second World War also established a need for more powerful engines. Although this could be achieved either by increasing combustion levels through higher fuel flow or by increasing the engine fuel efficiency, refinery technology at the time was limited to 25% petroleum output from crude oil and gasoline demand exceeded supply. Octane enhancement was the only viable way to increase engine power within the conditions of scarcity during the war. Ethanol was again used as a gasoline substitute/extender during the Second World War. It was used in special applications, such as aeroplanes, submarines, torpedoes[32] and later rockets[33], which performed much better with the higher combustion efficiency of ethanol. By 1945, new oil reserves were discovered and petroleum supplies became more certain. The interest in ethanol declined, although alcohol fuels remained available in a handful of countries with uncertain oil supplies. Still, the automobile became a petroleum-powered machine, and ethanol producers either returned to potable alcohol distillation or shifted their production to other agricultural commodities.

[31] Ibid. See also: Curtis Moore, "Dupont's Duplicity: Profiting at the Planet's Expense," *Multinational Monitor* 11, no. 3 (1990), Joseph C. Robert, *Ethyl: A History of the Corporation and the People Who Made It* (Charlottesville: University Press of Virginia, 1983).

[32] Houghton-Alico, *Alcohol Fuels: Policies, Production, and Potential.*

[33] Anon., "Blast Off of a New Era," *New York Times*, 28 November 1965, Anon., "Plane in a Minute Climbs 13,000 Feet," *New York Times*, 8 January 1949.

The oil and automobile industries mutually adapted and, in the process, formed a technological system that effectively excluded ethanol until adverse conditions once again stimulated their revival. The rising surplus of agricultural production in the post-World War II era motivated some countries, most notably Brazil and the United States, to create or expand alcohol fuel programs to support farming communities as well as to avoid future fuel shortages and rising oil prices. Where Brazil looked to ethanol as an answer to financial crises brought about by the international political economy, the United States realised for the first time that its dependence on foreign petroleum supplies could be exploited by other countries. Moreover, the public health concerns first identified in the 1920s later culminated in national bans on leaded gasoline in the 1980s. The environmental benefits of ethanol to local air quality and global climate change in the 1990s rekindled interest in the potential for ethanol.[34] These factors become relevant in the more recent history of ethanol and biodiesel, which is explored in more detail in the next chapter. Before examining these factors and their contribution to the emergence of global biofuels, it is worth reflecting on this history of ethanol as a fringe fuel.

The Marginalisation of Ethanol

The domination of transport fuels by the petroleum industry involved four main factors. First, market competition played a significant role in securing the success of one fuel technology over another. Prices were always a primary concern. Yet market competition was as political as it was economic. In its simplest form, the political economy of transport fuels involved the use of political tools to achieve economic gain.

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[34] Houghton-Alico, *Alcohol Fuels: Policies, Production, and Potential.*

The American Petroleum Institute's aggressive marketing techniques and Ethyl Corporation's demand for "exclusive" sales agreements politically overpowered the Farm Chemurgy movement's appeal to farmers' sense of local and regional solidarity.[35]

A second factor was the demand for certain technological features. While quantitative data can show the actual sales of various fuels, it cannot explain why one fuel was preferred over another. Ethanol offered a clean, efficient and stable automotive fuel while petroleum required lower ratio compression engines or octane enhancement, emitted considerably higher levels of chemicals and particulate matter in its exhaust, and was subject to intermittent supply problems. Petroleum producers overcame this through repeated questioning of ethanol's performance and viability, as well as consistent claims to the superiority of petroleum. Oil companies were able to reduce public confidence in alcohol fuels by reconstructing the perception of both fuel technologies. Social constructivists view this as a deliberate re-manufacturing of a cultural reality or, according to Bijker and Pinch[36] , a "rhetorical closure" that simultaneously redefined ethanol as a discredited alternative while marketing gasoline as a superior fuel.

Third, the more effective organisational capacity of the oil companies overpowered the disparate efforts of alcohol fuel supporters. Individual farmers, Henry Ford, Theodore Roosevelt, the Temperance movement, the Farm Chemurgy movement, Kettering and Midgley, and even some levels of government and their officials could not (or would not) resist the organisational capacities of the oil oligopoly. The bureaucratic

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[35] David E. Wright, "Alcohol Wrecks a Marriage: The Farm Chemurgic Movement and the Usda in the Alcohol Fuels Campaign in the Spring of 1933," *Agricultural History* 67, no. 1 (1993).

[36] Trevor J. Pinch and Weibe E. Bijker, "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," in *The Social Construction of Technological Systems*, ed. Weibe E. Bijker, Thomas P. Hughes, and Trevor Pinch (Cambridge, Mass.: The MIT Press, 1987), 44.

power of the multinational firm was in its infancy, but it already had concentrated enough capacity to overcome a decentralised and fragmented opposition regardless of any technological benefits, health and safety concerns, social advantages and ecological rewards that ethanol might offer, or any socio-technical functions that ethanol could potentially fulfill.

A fourth factor explaining the dominance of the petroleum regime involved a favourable policy environment for some technologies which adversely affected others. For instance, although ethanol was the technically superior alternative for lamp fuel, the federal tax on alcohol in the United States caused a hasty shift to kerosene. After forty-four years of taxation, the alcohol-based lamp fuel industry could not catch up to the competitive advantage of fuel alternatives developed by the petroleum industry and electrical power utilities. Inadequate product standards and trade regulations further undermined ethanol. While the health and safety concerns of tetraethyl lead were identified in 1924, they were deemed "groundless" and the product was subsequently re-admitted to the market. Although leaded gasoline was banned in the United States in 1986 and many other countries soon followed, Ethyl Corp continues to exploit weak national health and safety regulations.[37]

Thus, ethyl alcohol was seriously considered as a viable alternative fuel for illumination before the American Civil War, as an engine fuel before the adoption of petroleum fuels in the early 20th century, and in response to resource constraints during

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[37] Ethyl Corporation continues to sell methylcyclopentadienyl manganese tricarbonyl (MMT), a suspected neurotoxin that was at the centre of a 1998 NAFTA tribunal, to unregulated countries. See, International Institute of Sustainable Development, *Nafta Tribunal: Canada, U.S. Give Formal Support to Iisd Bid for Unprecedented Intervener Status* (International Institute of Sustainable Development (IISD), November 22 2000 [cited 1 February 2007]); available from http://www.iisd.org/media/2000/nov_22_2000.asp.

the Second World War. In each case, a combination of economic, political and social considerations influenced the trajectory of fuel technologies to favour petroleum. As a consequence, the status of ethanol was repeatedly relegated to a fringe fuel.

Biodiesel: Old World Innovation

While ethanol can be considered a pioneer technology with multiple applications, biodiesel was developed alongside the evolution of the diesel engine. Biodiesel is tied to the evolution of the diesel engine and to petroleum-based diesel fuel, and the expansion of biodiesel to world markets required two prestructuring conditions. First, the market share of the diesel engine had to reach a critical level in order to encourage sufficient demand for diesel fuel. Second, the regulated demand for cleaner petrodiesel (e.g., low sulphur content) triggered a supply problem for diesel markets that resulted in higher prices and a search for better fuels. The sufficient diffusion of the diesel engine, along with concerns with supply, quality and emissions enabled biodiesel to become a viable biofuel by the start of the 21st century.

The co-evolution between the diesel engine and diesel fuel is much more apparent than with spark-ignition engines and ethanol. Thus, a basic understanding of diesel engine technology is required before a full discussion of biodiesel can occur. The successes and failures of this old world innovation more often resulted from decisions of individual actors rather than changing industrial, sectoral, or market conditions.

The Diesel Engine and its Fuel

Invented by Rudolf Diesel[38], diesel engines are also known as compression ignition engines or oil engines after the method of fuel ignition or fuel type, respectively. The term 'diesel' is the most common descriptor, but critics suggest this gives Rudolf Diesel undue credit. Some historians suggest that Diesel's invention of the compression ignition engine was not original "but in effect a transcript of theories propounded by Professor Linde [Diesel's teacher] of Munich University".[39] Others point out that Diesel could not have invented this type of engine but only developed his theory from previous attempts, such as the 1890 patent granted to the British engineer Ackroyd-Stuart two years before Diesel's first patent.[40] Rudolf Diesel's inability to produce a working engine without a significant departure from his theory and substantial redesign for overall improvements and specific applications suggests that each stage of development "really amounts to a new species of engine, and each species [had] to go through its own independent evolutionary process".[41] Despite the debate over the legitimacy of Diesel's patents, Williams suggests that "there is no reason to quarrel with the general adoption of the name 'diesel' as a generic term for all engines in which pure intake air is compressed to a pressure sufficient to achieve self-ignition of an injected, non-volatile fuel".[42]

Diesel originally designed his engine as a replacement for the steam engines used for large-scale power generation in industrial applications. Early on, however, he envisioned the technology as flexible and versatile enough to be used in all sorts of

[38] Diesel refers to the inventor when capitalised. The engine technology is not capitalised.
[39] Williams, ed., *The Modern Diesel*, 9.
[40] Ibid., 11.
[41] Lynwood Bryant, "The Development of the Diesel Engine," *Technology and Culture* 17, no. 3 (1976): 446.
[42] Williams, ed., *The Modern Diesel*, 11.

applications from sewing machines to ocean liners. Diesel technology was applied commercially to marine use in the 1920s, heavy transport trucking in the 1930s, and train engines in the 1950s.[43] Each of these diesel applications can be interpreted as discrete inventions or as innovation stages within a larger evolutionary process. Bryant notes that such distinctions between invention, development and innovation are heuristic constructs that help differentiate the messy interplay of all three factors in the creation of technology. He suggests that it "may be better to regard them not as chronological stages but as different kinds of forces operating in an evolutionary process, or different types of human interest and activity, all more or less involved in all stages of technological progress".[44] To defend this approach, he divides his analysis of the diesel engine into four periods, all of which occurred between 1890 and 1908: invention, prototype, premature innovation, incremental development.

The first period of invention begins in 1890 with Diesel's plan for the rational development of a superior alternative form of the internal combustion engine. His expert knowledge of thermodynamics allowed Diesel to conceive of an isothermal combustion process in which fuel burned at a constant temperature in order to more efficiently convert excess heat energy into the movement of the piston. This had the effect of increasing fuel combustion (and power) without raising the temperature of the engine itself. Bryant suggests that this first period concludes when Diesel applied for and received the patent for his engine in 1892.

The second period involved the five-year task of building a working prototype. The first engine never ran under its own power. Although an unqualified failure, it helped

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[43] Bryant, "The Development of the Diesel Engine," 446.
[44] Ibid.: 433-4.

identify the major problems and stimulated a partial reconsideration of his theory. The second prototype was constructed in 1894 and idled for only a minute. For the two years following, Diesel experimented with fuel types, fuel injection systems, and carburetion and ignition systems. He chose kerosene as his experimental fuel source because it was both plentiful and inexpensive. It was not until 1897 that he built an engine that ran smoothly, at which point he eagerly (and prematurely) announced the end of the development period. For a diesel engine to run, a good mixture of fuel and air must enter the cylinder in the short time available between piston strokes. While a mechanical delivery system was Diesel's first choice, it proved to be very unpredictable. Diesel once considered it "impossible", and instead used a compressed-air injection system. Although technically feasible, this added considerable size, weight and cost to the engine, which made it "unable to compete in the market for small powers".[45]

The high thermal efficiency needed for superior fuel economy was the chief advantage of diesel over steam power, but the diesel engine was also intended to be versatile, adaptable to any fuel (solid, liquid, or gas), and practical at any size. Nevertheless, the high sensitivity to different fuel types made Diesel's engine fuel-specific, while the requirement for compressed-air injection systems made it uneconomical in small sizes. Although Diesel continued to promote his engine as versatile at any scale, businessmen viewed the uncertain development process as too risky. Only with the development of the direct fuel injection system were diesel engines designed for smaller applications.

Bryant describes Diesel's third period of the development of the diesel engine

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[45] Ibid.: 439.

(1897-1902) as "premature innovation" because the marketing of the engine began before the technology was stable. Diesel shifted his efforts from invention and development to promotion. He began to market the engine and sold patent rights to established machine manufacturing firms in industrial countries around the world. In addition to his native Germany, Diesel negotiated contracts in a dozen other countries, usually with its leading engine makers. Diesel sold the rights in the United States to Adolphus Busch, co-founder of the Anheuser-Busch brewing company, who intended to echo Diesel's strategy and negotiate patent sales throughout the American market. The licensees immediately began to develop diesel engines and very few built successful demonstration models. None of the licensees, however, were able to build a reliable engine that would work properly for the customer - not even with copies of the master blueprints and with assistance from the German mechanics who had already built working engines. "Diesel's own manufacturing firm took back every engine it made and went bankrupt. The diesel got a bad name that set back development by several years and made innovation difficult".[46]

Diesel turned his focus on public relations to rekindle interest in his engine. His direct contact with European licensees enabled him to reassure manufacturers on the benefits of the technology. However, in the United States the Busch control of the patent rights effectively limited Diesel's efforts to control the damage to both technical and professional reputation. From 1897-1899, Diesel found some time for experimental work on different fuels including powdered coal, blast-furnace gas, and peanut oil. However, his experimentation was cut short in order to focus on developing a reliable oil-fuelled engine.

[46] Ibid.: 443.

A two-cylinder, 60 horsepower engine was built and sold to a match factory in Kempten, Germany that was run by a brother of Heinrich Buz, the well-established industrial statesman and head of *Machinenfabrik Augsburg* that supported Diesel throughout the development of his engine. The weakest link of the immature technology was the injection system, which tended to clog. But the engine worked well so long as it was taken apart, cleaned and reassembled every night. After a year trial, the machine was brought back to the factory, stripped, examined, and completely redesigned and rebuilt. From the perspective of technical reliability, the redesigned engine produced from this trial was considered the first successful diesel engine.[47] However, this proclamation was also premature:

> ...the judgement that the 1897 engine was fully developed, ready to be sold, was a disastrous mistake. Such an error of judgement might be expected from an overoptimistic inventor, but in this case the hard-headed businessman, the practical mechanic, the professor of engineering, and many of the expert observers agreed. It is extraordinary that so many good people could be so wrong.[48]

In Bryant's view, the lesson for future innovators is that development can take longer than expected, even when favourable results from bench trials are achieved.

The fourth period Bryant identifies as "incremental development". This period saw steady technical progress and slow growth of engine use along a parallel path of diffusion and innovation. The first reliable engines were offered for sale in 1902 and the patent monopoly ended in 1908, opening up the door to imitators and innovators alike. By 1908, roughly one thousand engines were sold and running, most of them replacing steam engines in small stationary power plants. Former licensees who were unable to

[47] Ibid.: 443-4.
[48] Ibid.: 444.

build reliable diesel engines rekindled their interest and began manufacturing once again. This diffusion and innovation encouraged new pathways for the form and function of the diesel engine, which spurred its refinement and evolution into new applications.

The evolution of the engine reveals important features of technical innovation and niche development. Diesel initially sought to develop an engine that could run on multiple feedstocks, but chose kerosene for economic efficiencies during the experimentation process. This influenced future pathways, as subsequent commercial engines did not use gaseous or solid fuels. The patent monopoly began five years before the first working prototype in 1897 and a decade before the first reliable engine was constructed in 1902. The duration of the niche market in which Diesel could maximise his patent monopoly by offering a reliable engine was drastically cut short, thereby prohibiting him from controlling the development of future models that might have enabled him to realize his dream of a multi-fuel isothermal combustion engine. Bryant observed that the transfer of diesel technology to America was slowed considerably because the commercial success of diesel technology was limited by the protectionist approach undertaken by the American rights holder, Adolphus Busch.[49]

These observations are supported and elaborated by Lytle, who also argued that centralized control of an alternative technology can considerably slow its technical diffusion and effectively hamper its wider adoption by society. Lytle points out that Busch's strategy of focussing on selling patent licenses across the United States rather than manufacturing the diesel engine stymied development across the country. Upon the expiration of the patent, Lytle states that "the Busch companies had seriously thwarted

[49] Ibid.

implementation of diesel power".[50] Where European firms reorganised to overcome engineering obstacles and to speed technical development, the Busch companies were suspicious of these new arrangements. As major contract-holders they felt they should have been consulted regarding any changes in the design. Busch held steady and waited for the technical development in Europe to progress, but the lack of technical development in the United States stunted the adoption of diesel technology in the New World.

Although disillusioned by Rudolf Diesel and, more generally, with efforts in Europe, Busch sought to create a larger network that would connect engineers to the manufacturing process and, in turn, help to focus both the design and production processes toward developing a better product. This network did not materialise, and his company was falling farther out of touch with Europe. Where the existing contracts in the United States were becoming less effective, "European manufactures were attempting to increase cooperation with the diesel industry" and were able to establish an industry network to facilitate their common goal.[51] While technically part of this network, the American diesel industry grew increasingly isolated from 1899-1903 and partnerships with European companies had disintegrated by 1906.

The European diesel industry progressed significantly between 1902 and 1909. Various applications were realised, especially for marine use, which required increased engine speed, lightweight construction, shorter piston strokes, and other modifications. These improvements were transferred to early attempts for land transportation. By 1908,

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[50] Richard H. Lytle, "The Introduction of Diesel Power in the United States, 1897-1912," *The Business History Review* 42, no. 2 (1968): 115.
[51] Ibid.: 128.

Busch had re-established a partnership with Rudolf Diesel and sought to reinvigorate the network of engineers and engine manufacturers. However, by the summer Busch's health had declined, and his son August suggested that his father drop the diesel business to concentrate on the family brewery. Adolphus remained determined to continue, but eventually the Busch family interest in diesel technology disappeared. Diesel's patents expired in 1907 and 1908 and Busch's licensing control withered shortly thereafter.

Lytle suggests four reasons for the stalled diffusion of the diesel engine in America. First, entrepreneurial short-sightedness was to blame for missed opportunities. Second, technological development of a reliable product faced much greater obstacles than expected. Third, Busch was unable to secure adequate investment to secure large-scale introduction of the engine in the United States. Fourth, Busch was unwilling to risk the necessary capital to establish manufacturing plants that would have enabled quicker technical problem-solving.[52] Lytle suggests that these shortcomings occurred because of Busch's antiquated business philosophy, which sought to create a personal empire based on absolute control rather than a logical collection of enterprises each administrated by an appropriate manager.[53]

Lytle's examination shows that the connection between entrepreneurial capacity and technical innovation and diffusion is an important one. However, it is also notable that the diesel engine appeared during the era of national electrification between 1880 and 1930.[54] Diesel engines were intended as stationary power units that would replace steam power and its shared, mechanical drive system based on shafts and belts. Even

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[52] Ibid.: 143-5.
[53] Ibid.: 145-6.
[54] Devine Jr., "From Shafts to Wires: Historical Perspective on Electrification."

though Busch's activity surely contributed to the low adoption of diesel technology in America, Lytle acknowledges that factory power, centred on water mills and steam engines, was overtaken by the flexibility of small electrical motors and individual and dispersed power units. The diesel had measured success as an electrical power generator, and was used primarily in large-scale stationary applications. The increasing grid service provided by the electric power industry meant that smaller businesses did not have to purchase the more expensive diesel generators while plentiful fuel supplies reduced the need for fuel efficiency, which was one of the primary benefits of diesel power. In addition, technical and professional uncertainty in Diesel's engine and his reputation further reduced demand, and small- to mid-size businesses were not willing to invest the large sums for a completely new infrastructure. Lytle maintains, however, that

> [n]otwithstanding other deterrents to early American acceptance of the diesel, however, Adolphus Busch and his patent monopoly bear primary responsibility for the engine's tardy acceptance. Busch's inability or unwillingness to establish the industrial liaison in America which could have developed the engine – his determination to use the patent monopoly as he had originally intended – prevented the marketing of more than one diesel type, while in Europe many types were available. Moreover, the peculiar history of the Busch companies inhibited introduction of even this one engine type. Thus under the Busch patent monopoly the diesel engine was penalized some ten years in its competition with steam power.[55]

These factors combined to inhibit the technical innovation required to encourage the adoption of diesel technology, and it was not until decades later when the transportation industry adopted diesel engines that they achieved the necessary critical mass to stimulate interest in alternative fuels.

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[55] Lytle, "The Introduction of Diesel Power in the United States, 1897-1912," 148.

Modern Diesel Technology and the Biodiesel Alternative

Because of the co-evolution between engine technologies and fuels types, the development of alternative fuels required the successful diffusion of compression engine technology. Early decisions undoubtedly affected the development process. For example, the choice to use kerosene in experiments rather than other fuel types put the diesel engine on a particular pathway that persists today. However, the search for cleaner and renewable alternatives has resurfaced. By using vegetable oil or processing this feedstock into biodiesel, some proponents have achieved a small part of Rudolf Diesel's vision of a multi-fuel compression engine. Now that diesel technology has stabilised and improved over the course of the century, an interest in biodiesel (and in other petrodiesel alternatives) has appeared.

Higher gasoline prices and collaboration between large producers resulted in stronger commercial success of diesel automotive vehicles in Europe.[56] In North America, the wide availability of cheap gasoline, early technical problems, a risk-averse patent holder, and the wide-spread association of diesel engines with large-scale applications, gave diesel engines a long-standing reputation as a superfluous technology that was "slow, large, heavy, and inflexible".[57] The poor reputation of the diesel engine persists, but the potential for diesel fuel for use in aeroplane fuels and jet propulsion has since shown promise. Its high fuel efficiency gives it some advantage for increasing the range of flight while the compression ignition technology removed the difficulty of

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[56] Hard and Jamison, "Alternative Cars: The Contrasting Stories of Steam and Diesel Automotive Engines," 154.
[57] Ibid.

ensuring a consistent fuel-air mixture by carburetted gasoline engines.[58] In addition to the wide variety of diesel engines, diesel fuel is used in the manufacture of gasoline (where diesel and other heavy crude components are transformed through catalytic "cracking"), and for domestic heating with oil-burning furnaces. This variety of specialised applications for both mobile and stationary purposes across sea, land, and air in commercial, personal, and military sectors required the development of distinct improvements for each type of diesel engine. Along with the technical improvement of engine technology, an ongoing concern was improving the combustibility of diesel fuel for each application and working conditions. Fuel type is as critical to high-speed, high mobility diesel engines as it is to gasoline engines. Diesel fuel is produced from the same crude as gasoline. It is similar to kerosene but with a small addition of lubricating oil. According to Williams, "such specifically prepared fuels have contributed in no small measure to the progress of the modern [high-speed] diesel".[59] This co-evolution of the fuel and the engine is an important aspect for this development of niches for alternative diesel fuels and their specialty applications.

Biodiesel technology is in its infancy and must still overcome numerous challenges in order to offer a viable sustainable energy option. Promoting the diffusion and adoption of biodiesel must be regionally sensitive and locally aware, and consumer perceptions of diesel technology as inferior will likely be the most important challenge for North America. For Europe, it is reasonable to assume that the amount of land area required for a ten percent biofuel content blend (B10) might be entirely prohibitive without higher yields per acre, higher levels of fuel output per feedstock input, or

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[58] Williams, ed., *The Modern Diesel*, 3.
[59] Ibid., 82.

substantially more efficient vehicles. Although estimates vary, some suggest that a B5.75 blend could require up to 19% of the arable land in Europe, which would involve a considerable shift in agricultural production from food to biofuel feedstocks.[60]

The design of the diesel engine involved a succession of niche market products (i.e., stationary power generation and marine, train, and transport trucks) that shaped the development trajectory of diesel fuel. Consequently, biodiesel can be considered to be a niche market within a niche market. Although it has found other applications as heating oil or degreasing solvents, biodiesel has demonstrated equivalent or superior technical characteristics in comparison to petrodiesel. Nevertheless, biodiesel remains a marginal fuel product that is still in a state of relative infancy. There are various feedstocks, and new production processes are being explored. This suggests that first generation biodiesel will face competition from advanced biofuels from other feedstocks and novel production processes. More importantly, these can only achieve commercial success alongside the diffusion and adoption of diesel engines. Inhibition of diesel technology or a concentrated shift to another engine platform (e.g., electric or hydrogen fuel cell vehicles) would likely undermine any benefits of biodiesel as a sustainable energy option.

Conclusion

Niche markets for ethanol and biodiesel are slowly but steadily developing and technical improvements are continually being sought. The history of biofuels shows us that the integration of biofuels as part of existing petroleum transportation systems requires much more than technical superiority or competitive pricing. Just as ethanol and

[60] James Mackintosh, "Elusive Cornucopia: Why It Will Be Hard to Reap the Benefit of Biofuel," *Financial Times*, 21 June 2006.

biodiesel have been overpowered by socio-technical, political and economic conditions in the past, they continued to hold a small market share as a petroleum complement in their respective energy systems. Currently, biofuels are considered to be a fuel extender rather than a substitute, which make them less of a threat to the interests of oil companies than if they were to hold the potential to completely replace petroleum fuels. However, the history of ethanol and biodiesel reveal that technological pathways are not inevitable but are shaped by social decisions made within particular contexts. This survey also revealed that voluntary free-market mechanisms do not always result in technically, socially, or ecologically favourable outcomes, while government decisions can have substantial effects on the success of niche technologies within socio-technical systems.

The establishment of ethanol and biodiesel as partial responses to energy security concerns and rural development initiatives contributed moderately to their diffusion across national markets, but in many respect they are still fringe fuels in comparison to the petroleum industry. For biofuels to take on a larger role in the search for sustainable energy, government regulation is required to facilitate the diffusion of biofuels in socially-desirable directions. This dissertation now turns to the governance of biofuels expansion strategies in Brazil, the United States, and the European Union.

FIVE – Rediscovering Ethanol and Biodiesel

This chapter examines the rediscovery of ethanol and biodiesel and their diffusion to global markets. Providing an overview of the largest and most successful biofuels expansion strategies, this chapter looks at the efforts of Brazil, the United States, and the European Union to increase biofuels production. It shows how the transportation fuel regimes in these jurisdictions shifted along distinct yet converging policy trajectories to include ethanol and biodiesel, which later contributed to the expansion of first generation biofuels production on a global scale. The de-alignment of these petroleum-based transportation regimes occurred within very different socio-political and economic landscapes, and the internationalisation of ethanol and biodiesel as niche market products contributed to trilateral cooperation, centralisation of production, and a convergence of their respective biofuels regimes.

Brazil

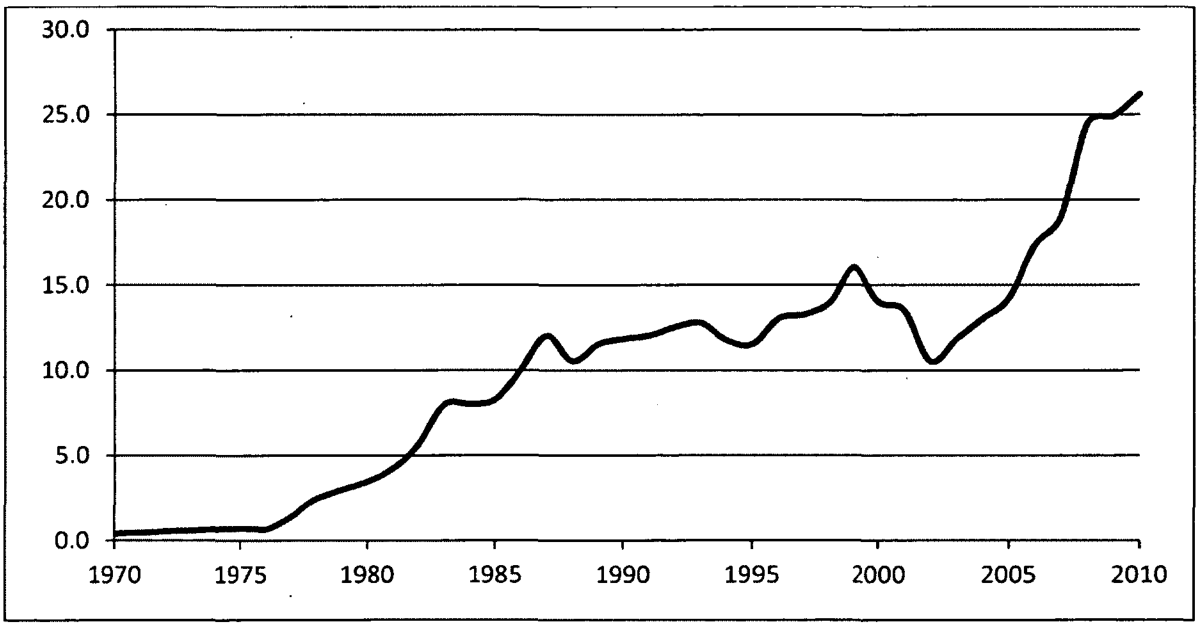
Created by a military government in response to dire energy shortages, Brazil's biofuels regime is notably different than those that developed much later in the United States and the European Union. Brazil's centralised approach to governing its highly regulated ethanol industry provides a well-researched case of an early shift to biofuels.[1]

[1] For an early example that still provides useful insights, see F. Joseph Demetrius, *Brazil's National Alcohol Program: Technology and Development in an Authoritarian Regime* (New York: Praeger Publishers, 1990), Houghton-Alico, *Alcohol Fuels: Policies, Production, and Potential,* Rothman, Greenshields, and Rosillo Callé, *Energy from Alcohol: The Brazilian Experience*.

The importance of the case of Brazilian biofuels is not only that they occurred decades earlier than the other dominant regimes, but also that they have achieved the most significant market penetration of each of the three biofuels regimes.

From 1960 to the early 1970s, ethanol production in Brazil varied between 400 and 700 million litres annually. Despite being displaced as the world's largest ethanol producer in 2005, ethanol production in Brazil exceeded 26 billion litres in 2010 and continues to grow (Figure 5-1).

Figure 5-1: Ethanol Production in Brazil, 1970-2010 (billions of litres)



(Source: Author's compilation of data from Geller 1985; De Almeida, Bomtempto, et al. 2007; Renewable Fuels Association 2011)

While the early rediscoveries of biofuels in other jurisdictions suffered from a series of starts and stalls, Brazil's uninterrupted evolution of its biofuels expansion efforts spans over four decades. This makes it a unique case from which to evaluate the changing socio-technical system that played an important role in the global expansion of ethanol and biodiesel.

The largest country in South America and the fifth largest country in the world, Brazil had long used its sugarcane industry to produce sugar for international markets. In an effort to stabilise its sugar industry during volatile world sugar markets, Brazil's sugar producers increased production capacity of its alcohol sector to diversify its product line. In fact, ethanol was a by-product of the sugar industry. In the midst of a steady decline in world sugar prices during the 1970s, Brazil sought a way to rationalise the country's large sugar sector so as to capitalise on the country's abundant land, suitable climate, agricultural capacity, and historical experience.[2] These factors made Brazil an ideal alcohol producer, and the existing experience with ethanol encouraged Brazil to deliberately shift the content of its transportation fuels regime.

The National Alcohol Program (PNA) was first implemented in 1975 as a national program to extract energy from alcohol as a response to multiple challenges.[3] Since the 1964 coup that installed the military junta in power, the authoritarian government sought to implement a nationalist program of rapid industrialisation alongside its agricultural base. Brazil's dependence on foreign oil made it highly sensitive to the fluctuations of international energy markets. It also had the largest debt in the developing world, substantial internal socio-economic and regional contrasts, large tracts of arable land, a concentrated reliance on road transit (versus rail or air), and rising inflation.[4] Like most

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[2] José Goldemberg et al., "Ethanol Learning Curve - the Brazilian Experience," *Biomass and Bioenergy* 26 (2004).
[3] Rothman, Greenshields, and Rosillo Callé, *Energy from Alcohol: The Brazilian Experience*, 16.
[4] Ibid., 8-11.

countries at the time, Brazil's political and economic difficulties were further exacerbated by the international economic shocks resulting from the OPEC oil embargoes in the 1970s. In response to these escalating landscape pressures, Brazil's national alcohol program was simultaneously a political, economic and social response to expand a local niche product in order to alleviate larger development problems in an era of uncertain energy supply. For the first time, Brazil considered alcohol as a resource substitute for petroleum rather than a revenue substitute for sugar.[5] This shift in perspective introduced a promise that ethanol would alleviate Brazil's economic hardship and it offered a new vision of the future.

During the 1970s, Brazil responded to this new socio-technical landscape with an aggressive national policy of agricultural improvement at a time when the country's high dependency on foreign energy sources made a domestic biofuels industry seem like an ideal alternative. Many countries entertained the idea of biomass fuels to enhance energy security, but few continued their pursuit of a national biofuels agenda when oil began to flow more freely and prices dropped. According to Rothman et al. (1983), there were a variety of reasons that Brazil's ethanol program continued while other national programs were reduced or cancelled. First and foremost, the ethanol industry was created by a military dictatorship, and the authoritarian rule provided a strong interventionist policy platform based on sugarcane ethanol production. Although the implementation of the National Alcohol Program was a clear and deliberate political strategy, the second reason for the continuation of Brazil's ethanol industry was economic. In an attempt to foster

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[5] Ibid., 13.

economic certainty through currency savings, military rulers sought to stabilise domestic energy supplies by lessening the import of petroleum.[6] The political and economic promise of ethanol was to reduce the country's reliance on foreign power and influence, while increased production capacity was expected to establish local energy resources and ancillary products.[7] Sugar cane ethanol became an opportunity for Brazil to escape a financial crisis and reduce its dependency on foreign powers. In doing so, the military government also hoped that the National Alcohol Program would enhance national pride and broaden political support for the dictatorship. These new factors open the possibility of new functions for sugar cane ethanol, which included: economic independence, stable national politics, and stronger geopolitical stature in South America.

Brazil's first legislation requiring the use of ethanol in gasoline was passed in 1931, and its policy framework has since expanded to facilitate the adoption and diffusion of ethanol throughout the country.[8] From the 1930s to 1974, production quotas and standards were developed by the Sugar and Ethanol Institute, an arm's length body formed to regulate the mandatory use of ethanol in gasoline. While the government continued to promote ethanol as a transportation fuel, the national focus continued to rely on ethanol to flatten fluctuations in the sugar market.[9] The implementation of Brazil's National Alcohol Program identified four key objectives regarding the expansion of ethanol as a transportation fuel: (1) to intensify primary and abundant domestic sources; (2) to increase available resources; (3) to rationalise consumption and production of

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[6] Ibid., 38.
[7] Ibid., 39.
[8] Howard Geller, "Ethanol Fuel from Sugar Cane in Brazil," *Annual Review of Energy* 10 (1985).
[9] USDA Foreign Agricultural Service, "Brazil: Biofuels Annual 2010," ed. Fred Giles (Sao Paulo, Brazil: US Department of Agriculture, 2010).

energy; and, (4) to reduce dependence on imported petroleum. Ethanol was expected to replace gasoline and diesel oil and increase production capacity to reduce oil imports, but it also become a feedstock for the international sucrochemical industry.[10] In the first phase of the program from 1975 to 1979, the National Alcohol Program focused on the expansion of ethanol distillery capacity at existing sugar mills and began to increase ethanol blend requirements. The first ethanol mandate in 1977 required a moderate blend requirement of 4.5%, and the program established a goal of 20% blend content by 1980. However, the nascent regime fell short of this target with an estimated 17% of national ethanol content in transportation fuels.[11]

Phase II of Brazil's National Alcohol Program (1980-1989) was driven by the second global oil crisis in 1979, and expanded the country's ethanol production infrastructure by providing state subsidies and government loans to develop independent distilleries. In addition, the government supported the research and development of alcohol-fueled vehicles. Consumer purchases of E100 vehicles reached 90% of all automotive sales in 1983, and an estimated 1.5 million alcohol-fueled automobiles were on the road the following year.[12] In addition to state subsidies for production infrastructure, the government provided other subsidies by setting wholesale and retail prices for ethanol below cost.[13] The success of this expansion brought forward the first environmental concerns, which focussed primarily on local environmental pollution

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[10] Rothman, Greenshields, and Rosillo Callé, *Energy from Alcohol: The Brazilian Experience*, 39.
[11] USDA Foreign Agricultural Service, "Brazil: Biofuels Annual 2010."
[12] Geller, "Ethanol Fuel from Sugar Cane in Brazil."
[13] Ibid.

(especially in waterways).[14]

By 1989, most of the subsidies and incentives provided to the ethanol industry were gone, which signified the virtual end of the national program. The Sugar and Ethanol Institute was transferred to the federal government in 1990. Between 1990 and 2002, ethanol producers were unable to keep up with consumer demand, and "erratic supply shortages of ethanol at the pump...led to a loss of confidence in the product and a drastic drop in sales of ethanol-fueled cars".[15]

Despite the conclusion of Brazil's National Alcohol Program and the drop in consumer confidence in ethanol, Brazil maintained the blend requirement of gasoline to contain 20-25% while further deregulating the industry. The overarching emphasis on ethanol as a rural development strategy continued, but the policy concerns of energy scarcity and rural development evolved into a national economic development strategy that would improve the balance of trade. After the 1997 legislation that established the National Agency of Petroleum, Natural Gas and Biofuels (ANP), private firms could now enter the biofuels industry.[16] Between 2001 and 2007, ethanol prices relative to gasoline reached a low of around 50% in 2004 and a high of 120% in 2006, suggesting continued uncertainty in the market. In order to maintain consumer interest in ethanol, Brazil needed to maintain taxation rules that favoured local biofuels over imported petroleum

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[14] Frank Rosillo-Callé, "Liquid Fuels," in *Bioenergy and the Environment*, ed. Janos Pasztor and Lars A. Kristoferson (Boulder, CO: Westview Press, Inc., 1990).
[15] USDA Foreign Agricultural Service, "Brazil: Biofuels Annual 2010," no page.
[16] *The Regulation of Petroleum in Brazil*, Law No. 9478, (August 6).

fuels.[17] Brazil increasingly used its significant regulatory and spending powers to coordinate its biofuel production strategy as a national economic development program, although the more populous southern regions received most of the benefit.[18]

In 2003, Brazil's ethanol industry was re-invigorated by the introduction of *flexfuel* vehicles and the efforts in other jurisdictions to expand biofuels to global markets. In this era after the 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change, Brazil occasionally mentioned the benefits of ethanol on the international stage, highlighting its potential to contribute to greenhouse gas emissions reduction strategies. However, climate change was a minor consideration during the emergence of Brazil's biofuels regime.[19]

Brazil developed its ethanol industry far earlier than other nations, and employs a very different system of production based on a simultaneous political, economic, and social response to facilitate national development. As Brazil's biofuel regime evolved, it became increasingly integrated, more technically efficient, and purportedly a more socially equitable production system. By utilising by-products to develop value-added co-products, this regime was said to increase economic and energy efficiency throughout the production chain, reduce dependency on foreign energy, reduce carbon emissions, and

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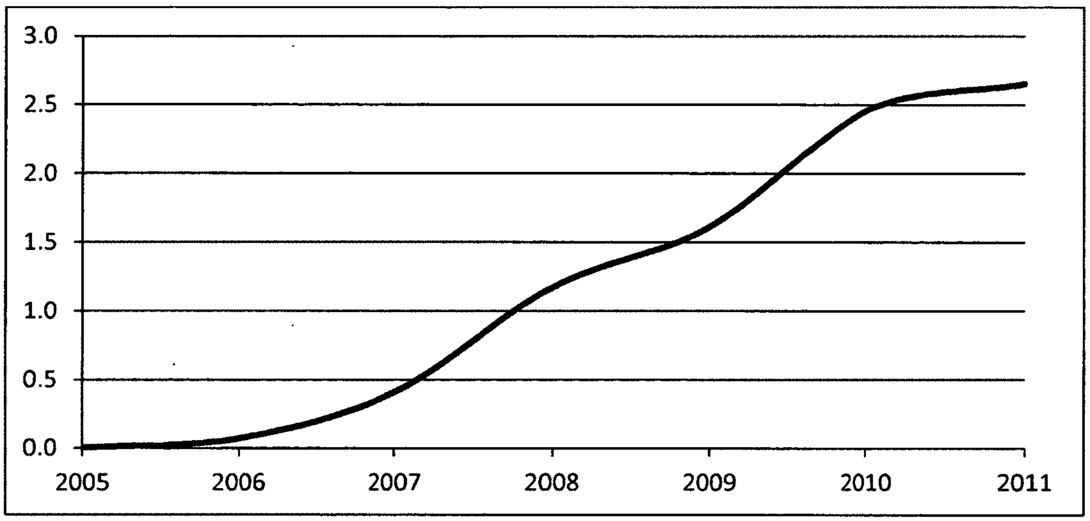
[17] Edmar Fagundes De Almeida, Jose Vitor Bomtempo, and Carla Maria De Souza E Silva, "The Performance of Brazilian Biofuels: An Economic, Environmental and Social Analysis," in *Discussion Paper No. 2007-5* (Rio de Janeiro: Federal University of Rio de Janeiro, 2007).
[18] Silvia Blajberg Schaffel and Emilio LÃ¨bre La Rovere, "The Quest for Eco-Social Efficiency in Biofuels Production in Brazil," *Journal of Cleaner Production* 18, no. 16/17 (2010).
[19] Biopact, *Eu, Us, Brazil Release Report on Biofuels Specifications to Expand Trade* ([cited).

create new local and international markets for domestic products.[20] The lessons Brazil learned from its national ethanol program have since been applied to the country's emerging biodiesel sector, which has grown from 736 thousand litres in 2005 to over 2.6 billion litres in 2011 (Figure 5-2).

Figure 5-2: Biodiesel Production in Brazil, 2005-2011 (billions of litres)



(Source: Author's compilation of data from USDA Foreign Agricultural Service 2010; Padula, Santos, et al. 2012)

Since January 2008, all diesel fuel sold in Brazil contains 2% biodiesel. But the trajectory of Brazil's biofuels policy has shifted slightly, as the biodiesel program also aims to improve the quality of life on small family farms in the poorest regions. The Ministry for Agricultural Development announced that 99% of the biodiesel required by the new mandate would come from "social fuel"[21], and Brazilian biodiesel companies

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[20] Miquel J. Dabdoub, "Biodiesel: Brazilian and South American Current State and Perspectives. New and Future Feedstocks for Its Production," in *Biofuels, Carbon and Trade Conference* (Minneapolis, Minnesota: 2007).

[21] Biopact, *Brazil's Biodiesel Mandate Comes in Effect* (Biopact, 2008 [cited January 11 2008]); available from http://www.checkbiotech.org/green_News_Biofuels.aspx?infoId=16539.

supplying the national mandate must obtain a "social seal" to certify that biodiesel feedstocks were purchased from small, family-run farms located in poor regions. Similar to Brazil's position on ethanol as a climate change mitigation strategy, the creation of a "social fuel" program to develop a more equitable biodiesel industry seems to be tailored in part for an international audience.[22]

Many analyses of Brazil's ethanol program focus on the government response to the international and domestic pressures, but relatively few studies explore the structural shifts made by governments to maximise scientific-technical development and acquisition in order to achieve national interests of economic growth and societal development. Demetrius was one of the few to explore the stability and de-alignment of socio-technological interactions, and the political implications of a shift in the transportation fuels regime. The scientific and technological pathways that shaped Brazil's political culture were based on decisions made by the military government to expand ethanol production in the early 1970s. While these decisions were intended to secure the continuation of the political system, the authoritarian command to embrace Brazilian ethanol also shifted the socio-technical transportation fuel regime.[23]

Demetrius' study of Brazil's national alcohol program helps to reveal how scientific-technical responses to international and domestic landscape pressures contributed to Brazil's shifting transportation fuels regime by de-aligning the existing system and re-aligning it to meet the needs of the military government. First, stability in

[22] Biopact, *An in-Depth Look at Brazil's "Social Fuel Seal".*
[23] Demetrius, *Brazil's National Alcohol Program: Technology and Development in an Authoritarian Regime*, 2.

the energy system was a priority even though the technology chosen for large-scale ethanol production facilities was technically inefficient. The continued dependence on sugarcane as the primary feedstock with little research into other viable feedstocks suggests that production efficiency and profit maximisation were not primary considerations of the military government.[24] Second, stability was also secured through structural re-alignment, wherein sugarcane production was centralised in close proximity to urban centres to maximise job creation, even though agricultural land was more expensive near cities than in the frontier regions. This made overall start-up costs higher than necessary. To overcome higher land costs, new distilleries were designed to have very large production capacities which, in combination with a plantation-style production regime, exceeded the economies of scale suitable for the sugarcane industry.[25] As a result, the economic costs of Brazil's national system of industrialised ethanol production were comparatively large.[26] Moreover, stabilising the political and economic governance structures required a de-stabilisation of the transportation fuel regime and quick re-alignment of ethanol productivity. The national program followed a technological trajectory that would continue even when periods of high operating costs and low economic competitiveness with fossil fuels brought conflicting landscape pressures.

Demetrius' assertion that the national alcohol program would remain a public industry was astute.[27] Even though the conversion to democracy in 1995 ended twenty-one years of authoritarian government, the public ownership that forms the core of the

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[24] Ibid., 76-81.
[25] Ibid., 83-7.
[26] Ibid., 81-7. See also, Goldemberg et al., "Ethanol Learning Curve - the Brazilian Experience."
[27] Demetrius, *Brazil's National Alcohol Program: Technology and Development in an Authoritarian Regime*, 128.

Brazilian biofuels regime continues. Although in a different form, the national alcohol program is still in force and has increased its activity. Direct subsidies and price controls were lifted in the mid-1990s, but the Brazilian ethanol industry requires

> ...close coordination among all sectors involved: the Ministry of Agriculture and sugarcane planters, the Ministry of Science and Technology and research centres, the Ministry of Industry and Commerce, the automobile industry, Ministry of Mines and Energy, PETROBRÁS, the fuel distributors, and the gas stations, the Ministries of Finance and Planning, the Ministry of Environment and automobile owners.[28]

Brazil's biofuels regime follows a government-controlled, systems-based approach in which regulators and consumers are as important as feedstock harvesters and biofuels facilities. Rather than a complete shift from public governance to the private sector, the Brazil regime retained a smaller, yet highly coordinated, regulatory system that included society-wide changes to property rights, production techniques, distribution chains, automobile engine technology, and consumption choices. These changes were re-enforced by high ethanol production quotas at sugar mills, large subsidies to refineries and auto producers, and mandatory sales at all pumps in the country. The biofuels regime in Brazil included micro-, meso- and macro-level policy measures that ranged from individual tax-breaks to national mandates to international agreements, all of which sought to encourage a diffusion of ethanol and related technologies (Table 5-3).

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[28] World Resources Institute, *Sd-Pams Database - Brazil: National Alcohol Program (Proalcool)* (2007 [cited January 14 2008]); available from http://projects.wri.org/sd-pams-database/brazil/national-alcohol-program-proalcool.

Table 5-3: Key Components of Transportation Fuels Regime Shift in Brazil

Function	Policy concerns	Micro-level action	Meso-level action	Macro-level action
Energy security	National energy development		Reduce dependence on foreign energy	
Rural Development	Developing production & distribution	Expand sugarcane industry	National Alcohol Program	
		Subsidies for refineries & auto producers	Capital investment for large facilities	
	Expand feedstock supplies	Intensify use of primary and abundant domestic resources	Expand agri-industry for biofuels feedstocks	Increase available energy resources
	Support Research & Development	ethanol-only vehicle production	Coordinate involved sectors and government departments	
	Stimulating technical diffusion	Automobile retrofit; Consumer tax breaks	Mandatory ethanol sales; price controls	
Trade	Enhancing Trade	Increase sucro-chemical production for global markets	Transform sugar industry from food to energy products	Ethanol Alliance with United States; International ethanol standards
	Supporting developing countries			Energy agreements across Latin America
Environment	Capture benefits to environment	Utilising ethanol by-products	Reduce effluent and material waste	Reduce greenhouse gas emissions
Society	Capture benefits to society	Create new products for local markets		Develop "social seal" for biodiesel; create new products for global markets

Source: Author's interpretation.

Although the rates of technical diffusion varied, there were undeniable socio-technical shifts as consumers first adopted E100 vehicles and, later, flexfuel vehicles. Social functions of ethanol also changed as consumer confidence rose and fell, environmental concerns emerged, and social effects of large-scale sugarcane and ethanol production became more prevalent. While Brazil's biofuels regime succeeded in meeting many of its goals, ethanol and biodiesel have different overall program characteristics. The sunk costs in the ethanol infrastructure "locked in" Brazil's sugarcane ethanol fuel program, thereby necessitating a continuation of large-scale facilities aimed at mass production of ethanol for domestic and international markets. In contrast, the early recognition of environmental and social problems associated with biodiesel encouraged Brazil to incorporate production requirements. Despite significant increases in production, Brazil's biodiesel industry seems to be more flexible than it ethanol sector.

The government of Brazil transformed a highly-regulated policy environment to one that is smaller, relies more on market measures, and improves the environmental and social performance of biofuels.[29] This emergent socio-technical regime has been the subject of much criticism over time[30], but it has begun to inspire other jurisdictions for its economic potential[31] and sustainability.[32] The policy shift within Brazil's biofuels regime that began with rural development and energy security grew to include other policy

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[29] Goldemberg, "The Case for Renewable Energies."

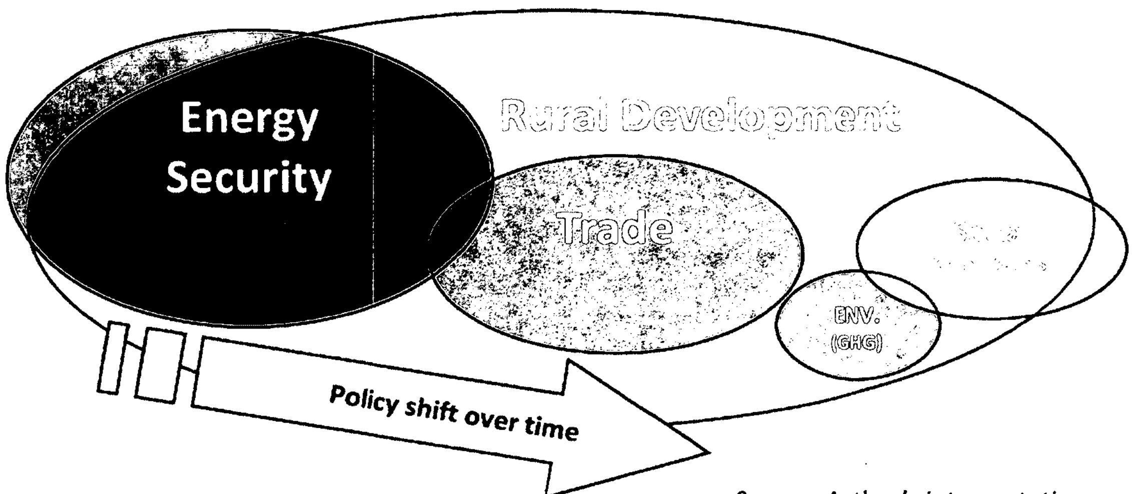
[30] Folke Dovring, *Farming for Fuel: The Political Economy of Energy Sources in the United States* (New York: Praeger Publishers, 1988), Melamu and von Blottnitz, "2nd Generation Biofuels a Sure Bet? A Life Cycle Assessment of How Things Could Go Wrong.", Patzek, "Thermodynamics of the Corn-Ethanol Biofuel Cycle.", Pimentel, "Energy and Dollar Costs of Ethanol Production with Corn."

[31] Bob Moser, *Brazil Model Could Give Louisiana's Farmers Hope* (Shreveport Times, November 2, 2007 2007 [cited January 11 2008]); available from http://www.checkbiotech.org/green_News_Biofuels.aspx?Name=biofuels&infoId=16052.

[32] José Goldemberg, "Ethanol for a Sustainable Energy Future," *Science* 315 (2007).

concerns. The most prevalent was the search for international markets, but also included shifts in environmental and social policy areas (Figure 5-4).

Figure 5-4: Biofuels Regime Shift in Brazil



Source: Author's interpretation.

Demetrius noted that "[b]ureaucratic authoritarianism has ebbed, but the model of development or pattern of resource allocation [i.e., socio-technical regime] it facilitated persists".[33] This trajectory continues with the evolution of Brazil's biofuel regime, which is a highly instructive example of the difficulty in making a large-scale shift in the petroleum transportation fuel regime to one that includes non-petroleum alternatives. Biofuels production in Brazil was stimulated by volatile market conditions that revealed its significant dependence on foreign oil. Other landscape features (i.e., low level of industrialisation, large foreign debt and rising inflation, reliance on road-based transport

[33] Demetrius, *Brazil's National Alcohol Program: Technology and Development in an Authoritarian Regime*, 133.

infrastructure, and agricultural surplus in an era of uncertain global energy supply[34]) contributed additional pressure upon the country's transportation fuel regime. Brazil's first concern was OPEC-induced price rises, but what began as a path toward energy security evolved into an attempt to expand the benefits of their emerging biofuels regime to other policy areas.

Despite this evolution from authoritarian governance toward a comparatively deregulated biofuels industry, Brazil's regime will continue to experience challenges. For example, the changing land use patterns that were identified early in the growth of the ethanol industry[35] are likely to increase the demand for arable land due to the trajectory of first generation biofuels to transform existing ecosystems for sugarcane and soy bean plantations. The economic benefits of the lumber industry for tropical regions, combined with the potential need for increased agricultural production on newly available land, makes the transformation from marginal into cultivated land a difficult outcome to prevent.[36] Similarly, the 2007 discovery by Brazil of offshore oil reserves, and the expectation of subsequent discoveries that may be large enough to catapult Brazil to become one of the world's top ten oil producers[37], will provide new options for national energy production that might shift the transportation fuel regime in a completely different direction. These and other future challenges will bring a stringent series of tests for Brazil that will affect the trajectory of biofuels.

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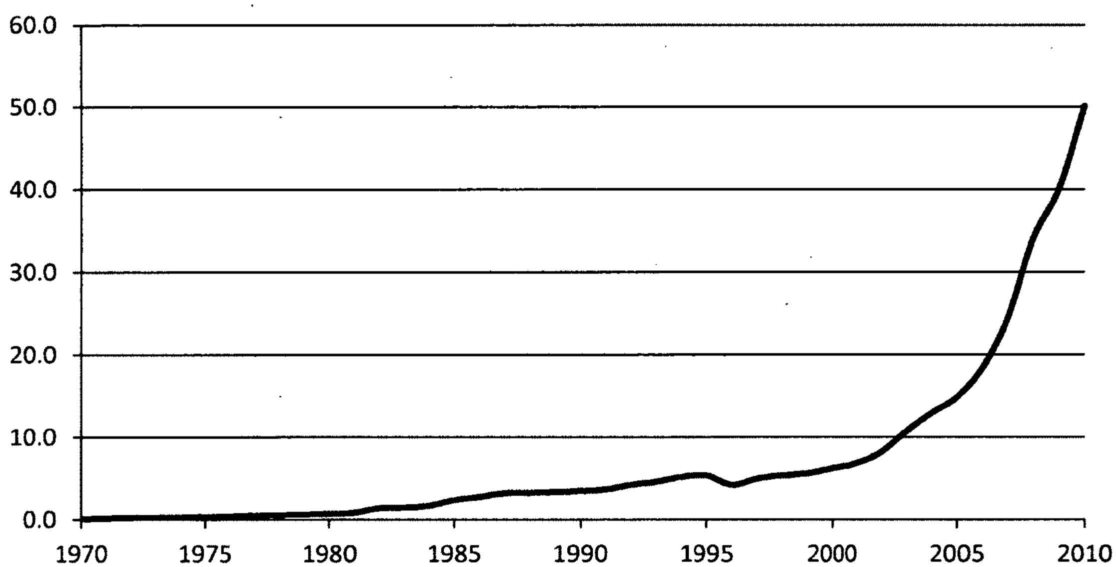
[34] Rothman, Greenshields, and Rosillo Callé, *Energy from Alcohol: The Brazilian Experience.*
[35] Geller, "Ethanol Fuel from Sugar Cane in Brazil."
[36] Joseph E. Fargione, Richard J. Plevin, and Jason D. Hill, "The Ecological Impact of Biofuels," *Annual Review of Ecology, Evolution, and Systematics* 41 (2010).
[37] BBC Staff Reporter, *Brazil Finds Massive Oil Field* (BBC, October 30, 2010 2010 [cited April 9 2011]); available from http://www.bbc.co.uk/news/world-latin-america-11659582.

The United States of America

In 2005, the United States surpassed Brazil to become the world's leading ethanol producer. This is an excellent example of how quickly national energy production technologies can develop with public and private support to mobilise resources. The biofuels regime that developed in the United States of America helped to increase ethanol production from only a few million litres in the 1970s to over 50 billion litres in 2010 (Figure 5-5).[38]

Figure 5-5: Ethanol Production in the US, 1970-2010 (billions of litres)



(Source: Author's compilation of data from USDA Foreign Agricultural Service 2010; Padula, Santos, et al. 2012)

This rapid expansion began around 2003, and was stimulated in large part by Federal government support for state-led programs. As in most other ethanol producing

[38] Renewable Fuels Association, *Industry Statistics* (Renewable Fuels Association, 2011 [cited April 3 2011]); available from http://www.ethanolrfa.org/pages/statistics, Hosein Shapouri, James A. Duffield, and Michael Wang, "The Energy Balance of Corn Ethanol: An Update," (Washington, D.C.: United States Department of Agriculture, 2002).

countries, commercial ethanol production expanded in response to a changing landscape in which the 1970s oil embargoes figured prominently. The United States realised that its energy supplies made it vulnerable to manipulation by foreign powers. As discussed in chapter four, ethanol was a niche product that many considered to be an ideal gasoline extender, which could increase domestic fuel production capacity and help to stabilise its transportation fuel regime. In the 1980s, environmental concerns, particularly urban air pollution, emerged on the landscape. The Environmental Protection Agency identified ethanol blends as a preferred alternative to leaded gasoline. Ethanol was swiftly recognised by many states as an octane enhancer that was superior to the existing lead-based additives, and "became a popular method for gasoline producers to meet the oxygen requirements mandated by the act".[39] These landscape pressures encouraged a shift in the United States' transportation fuel regime over time, such as when the 1990 *Clean Air Act* assisted the adoption of fuel ethanol as a gasoline additive.

The American domestic biofuels market was developed through private investment facilitated by federal regulatory initiatives, incentive programs, and capital investment support, all of which created a system of production intended to satisfy "high priority" objectives to improve air quality, to improve energy security, and to stabilise farm incomes.[40] Ethanol production was highly concentrated in the American mid-West, with Illinois, Indiana, Iowa, Minnesota, Michigan, Nebraska, Ohio, South Dakota and Wisconsin producing about 80% of the country's corn and over 90% of ethanol in the

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[39] Shapouri, Duffield, and Wang, "The Energy Balance of Corn Ethanol: An Update," 5.
[40] Ibid., 1.

United States.[41] As of January 2011, there were 204 operating ethanol plants in 29 states and 10 more were either under construction or expanding.[42] A few of these facilities use feedstocks other than corn, including cheese whey, beverage waste, brewery waste, and sugar cane bagasse. However, non-corn ethanol accounts for a very small portion of total domestic biofuel production, and all facilities utilising alternative feedstocks for ethanol production are comparatively small.

The United States biofuels regime achieved its position as the global leader in ethanol production, and has reached important milestones to satisfy national demand. By 2005, ethanol was sold across the country, blended in a variety of ratios, and was mixed with 30% of all gasoline sold in the United States. In 2005 alone, this growth added US$32.2 billion to the country's GDP from annual operating costs and capital investment, created over 150,000 jobs, and increased total household income by an additional US$5.7 billion. In addition, over US$1.9 billion went to federal tax revenues and almost US$1.6 billion to State revenues.[43] As a gasoline additive and fuel extender, the 50 billion litres of ethanol produced in 2010 accounts for about 9.5% of the 524.1 billion litres of gasoline consumed that year, which helped reduce the dependence on foreign petroleum by offsetting petroleum imports for gasoline[44] by 9.5%.[45]

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[41] Ibid., 5.
[42] Renewable Fuels Association, *Industry Statistics*.
[43] Renewable Fuels Association, "From Niche to Nation: Ethanol Industry Outook 2006," (Washington, DC: Renewable Fuels Association, 2006).
[44] Energy Information Administration, *Petroleum and Other Liquids* (Government of the United States of America, 2011 [cited April 9 2011]); available from http://www.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=mgfupus1&f=a. In 2007, total production equalled 4.6% of the 538 billion litres of gasoline consumed.
[45] This calculation does not adjust for the import of ethanol. In 2009 (the most recent data available), approximately 732 million litres of ethanol was imported. In 2010, ethanol imports were estimated to be less than 38 million litres. Renewable Fuels Association, *Industry Statistics*.

The United States' biofuels regime includes different scales of ownership and different types of operators including small producers[46], locally-owned businesses, farmer's co-operatives, and internationally-owned corporate agri-business. As of March 31, 2011, there were 115 small ethanol producers with an aggregate production capacity of over 17 billion litres. Small producers constituted 31.5% of ethanol production by volume, although this trend shows a recent decline, most of which can be attributed to the increase of new large-scale production facilities and the concentrated ownership of production in large multinational corporations.[47]

The strengthening of the biofuels regime in the United States over the past few decades encouraged proponents of other liquid biofuels, and none have been more successful than biodiesel advocates. With a large industry association backed by the soybean lobby, biodiesel production has grown from small batch production for limited and personal use by "homebrewers" to large-scale, continuous production, commercial manufacture intended for national distribution and export markets. Biodiesel production capacity in the Unites States rose from about 1.9 million litres in 1999 to about 285 million litres in 2005. In 2009, U.S. national production was over 2 billion litres, and more than 35% was for export.[48]

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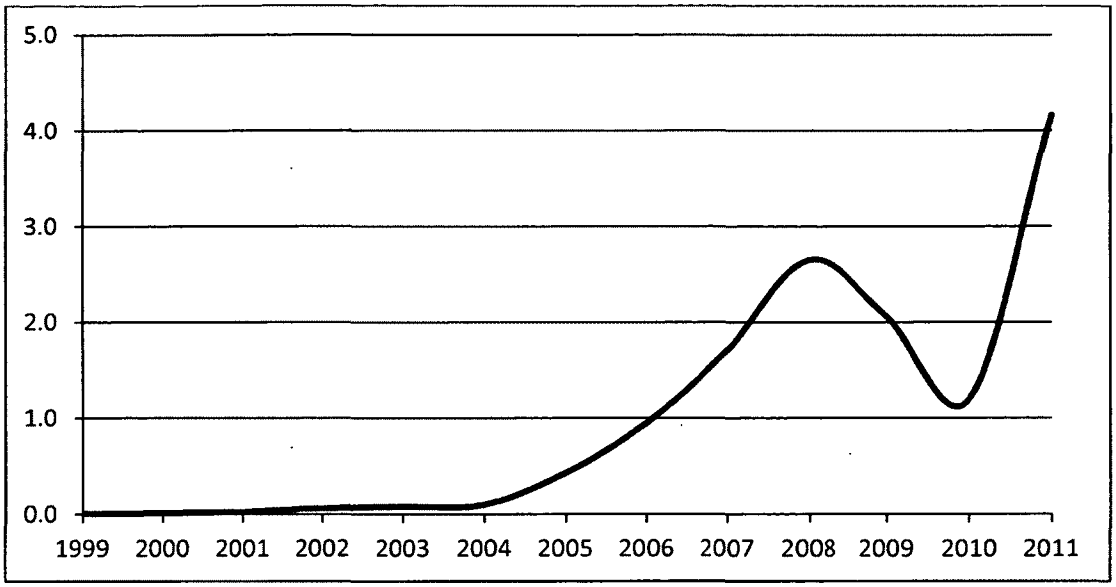
[46] Small producers are defined by the US Federal Regulation on Small Ethanol Producer Tax Credit as any plant producing up to 60 million gallons per year (227.12 million litres annually). See: Renewable Fuels Association, *Federal Regulations: Small Ethanol Producer Tax Credit* (Renewable Fuels Association, 2005 [cited 8 December 2006]); available from http://www.ethanolrfa.org/policy/regulations/federal/septc/.

[47] There were 38 locally-owned facilities in early 2011, down from 53 locally-owned plants in 2005. Renewable Fuels Association, *Biorefinery Locations* (Renewable Fuels Association, March 31, 2011 2011 [cited April 3 2011]); available from http://www.ethanolrfa.org/bio-refinery-locations/.

[48] Energy Information Administration, *Biofuels: Ethanol and Biodiesel Explained* (Government of the United States of America, October 25, 2010 2011 [cited April 9 2011]); available from http://www.eia.doe.gov/energyexplained/index.cfm?page=biofuel_home#tab2.

Figure 5-6: Biodiesel Production in the US, 1999-2011 (billions of litres)



(Source: National Biodiesel Board 2012)

With rising diesel fuel prices and recent renewable fuel content mandates by federal and state governments, consumer demand for biodiesel in the United States was expected to increase from 285 million litres in 2005 to almost 2.5 billion litres in 2015.[49] This projection was tempered somewhat by the economic downturn during the 2008 recession, when the National Biodiesel Board explained that "due to current economic conditions, the capacity utilization at many of these facilities is extremely low".[50] Despite these shifting landscape pressures, biodiesel production capacity in the United States approached 1.2 billion litres in 2010[51] and exceeded approximately four billion litres in 2011 (Figure 5-6). All but a few biodiesel producers use oil-seeds, with alternative

[49] John M. Urbanchuk, "Contribution of the Biodiesel Industry to the Economy of the United States," (National Biodiesel Board and the LECG Corporation, 2006).

[50] National Biodiesel Board, *Commercial Biodiesel Production Plants* (National Biodiesel Board, September 28 2008 [cited 4 January 2009]); available from http://www.biodiesel.org/buyingbiodiesel/producers_marketers/Producers%20Map-Existing.pdf.

[51] National Biodiesel Board, *Biodiesel Faqs* (National Biodiesel Board, 2011 2011 [cited May 10 2011]); available from http://www.biodiesel.org/resources/faqs/.

feedstocks consisting of recycled cooking oil, poultry fat, tallow, or trap grease.[52]

The emergence of the biofuels regime in the United States deserves attention due to its rapid expansion, due in large part to federal government efforts to unify the various subnational policies and program initiatives in order to strengthen its biofuels regime. The evolution of the regime from voluntary to regulatory is also significant. At the outset, the United States maintained a voluntary approach supported by limited legislation and tax expenditures. Biofuels blends were later mandated on a wider scale to create more certainty for a stable national market with the expectation of increased production levels and expansion of advanced biofuels technology.

The progression from voluntary to regulatory measures involved a continuous refinement of the regime through the adoption of key policy measures. First, *The Clean Air Act* (1990) addressed some of the worst areas of urban air pollution by identifying them as ozone "nonattainment areas". Since 1995, these areas were required to use reformulated gasoline (RFG), which consists of a minimum of 2% oxygen by weight to reduce smog and air pollution.[53] The *Act* did not specify, however, which additive was to be used in reformulated gasoline. Thus, refiners had a choice between ethanol and methyl tertiary butyl ether (MTBE). These were the most common gasoline additives used for RFG compliance, but the appearance of environmental and health-related landscape

[52] National Biodiesel Board, *Commercial Biodiesel Production Plants (November 14, 2006)* (National Biodiesel Board, 2006 [cited 8 December 2006]); available from http://www.biodiesel.org/buyingbiodiesel/producers_marketers/ProducersMap-Existing.pdf.

[53] Renewable Fuels Association, *Federal Regulations: RFG Required Areas* (Renewable Fuels Association, 2005 [cited 8 December 2006]); available from http://www.ethanolrfa.org/policy/regulations/federal/rfg/.

pressures motivated many states to ban the use of MTBE.[54] While this legislation was not directly related to ethanol production, it had a clear effect in promoting ethanol as the preferred additive to increase oxygen levels in gasoline. Also as part of *The Clean Air Act,* a winter oxygenated fuels mandate for carbon monoxide "nonattainment areas" was established in 1992, which specified that all gasoline sold in these areas must contain a minimum of 2.7% oxygen by weight (although many areas have increased this to 3-3.5% by weight).[55]

Second, the Department of Agriculture's *Commodity Credit Corporation Bioenergy Program* was established in 2001 to encourage bioenergy producers (mainly those that produced ethanol and biodiesel) to purchase agricultural products for feedstocks and to encourage the construction of new production capacity. The five year program focussed on a limited set of eligible commodities[56] and was designed for new facilities so as to overcome low profits and operating difficulties in the early stages of production.[57]

Third, tax credits supported biofuel production and use. Biofuels production was encouraged by the removal of the federal excise tax on gasoline at the pumps by the percentage of ethanol content. As of January 2011 (assuming the maximum allowable

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[54] American Coalition for Ethanol, *Mtba Bans* (American Coalition for Ethanol, 2006 [cited 8 December 2006]); available from http://www.ethanol.org/mtbebans.html#.

[55] Renewable Fuels Association, *Federal Regulations: Winter Oxygenated Fuels Areas* (Renewable Fuels Association, 2005 [cited 8 December 2006]); available from http://www.ethanolrfa.org/policy/regulations/federal/wofa/.

[56] These were limited to barley, corn, grain sorghum, wheat, oats, rice, soybeans, canola, sunflower seed, rapeseed, safflower, flaxseed, mustard, crambe, sesame seed and cottonseed; fats, oils and greases; and cellulosic commodities such as switchgrass and hybrid poplars.

[57] Renewable Fuels Association, *Federal Regulations: Ccc Bioenergy Program* (Renewable Fuels Association, 2005 [cited 8 December 2006]); available from http://www.ethanolrfa.org/policy/regulations/federal/ccc/.

content of 10%) this tax credit amounted to $0.0119 per litre of E10, which translates into $0.12 per litre of fuel ethanol produced.[58] The *Volumetric Ethanol Excise Tax Credit* (VEETC) was created as part of the *American Jobs Creation Act* (2004) in October of that year. The VEETC replaced the existing ethanol tax credit at the refinery to simplify the tax regime. Among other things, it eliminated restrictive blending requirements (of 5.7%, 7.7% and 10%) to allow greater flexibility to refineries, allows rack blenders to receive $0.135 per litre, and enlarged the regime by removing tax barriers restricting other ethanol markets, such as E-85 in off-road and other non-taxable markets.[59] The VEETC also contained tax credits for biodiesel according to its feedstock. Agri-Biodiesel (specified in the legislation as any diesel fuel made from virgin oils derived from agricultural commodities and animal fats) and renewable diesel (derived from biomass through a thermal depolymerisation process) both received a tax credit of about $0.264 per litre. Other biodiesel (defined as non-virgin agricultural products and animal fats, such as recycled cooking oil, fish oil, etc.) were eligible for a $0.132 per litre tax credit.[60]

Small ethanol producers were eligible to receive $0.026 per litre production income tax credit on up to 56.85 million litres of production annually up to a maximum of U$1.5 million per year. This was extended to include farmer cooperatives in 2004. The 2005 *Energy Policy Act* redefined "small ethanol producer" as any a plant that produced

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[58] Federation of Tax Administrators, *State Motor Fuel Tax Rates* (Federation of Tax Administrators, 1 January 2011 [cited April 9 2011]); available from http://www.taxadmin.org/FTA/rate/mf.pdf.

[59] Renewable Fuels Association, *Federal Regulations: Volumetric Ethanol Excise Tax Credit (Veetc)* (Renewable Fuels Association, 2005 [cited 8 December 2006]); available from http://www.ethanolrfa.org/policy/regulations/federal/veetc/.

[60] Renewable Fuels Association, *Federal Regulations: Biodiesel Tax Credits* (Renewable Fuels Association, 2005 [cited 8 December 2006]); available from http://www.ethanolrfa.org/policy/regulations/federal/biodiesel/.

up to 227.4 million litres (60 million gallons) annually, which is double the previous amount.[61] The *Energy Policy Act* also created a similar tax credit for small producers of agri-biodiesel of about $0.264 per litre for the first 56.85 million litres of biodiesel produced from virgin agricultural products. Like the small ethanol producers tax credit, a virtually identical program was developed for small biodiesel producers. The small biodiesel producer tax credit is subject to a sunset clause, which was supposed to end on December 31, 2008. It was extended to December 31, 2010 and extended again for another year.

A fourth key measure was the federal Renewable Fuels Standard (RFS), which may be one of the most important components in the evolution of the U.S. biofuels regime. The *Energy Policy Act* (2005) provided comprehensive legislation to increase the use of ethanol and biodiesel to 7.5 billion gallons by 2012 (Table 5-7). After 2012, a new RFS based on commercial sales will be developed that will not be less than the percentage of 7.5 billion gallons to the total consumption levels in 2012.

Table 5-7: Legislated Renewable Fuels Standard (billion gallons/litres), 2005

Year	Annual Mandate	Actual
2006	4.0 / 15.14	4.855 / 18.38
2007	4.7 / 17.79	6.5 / 24.61
2008	5.4 / 20.44	9.0 / 34.07
2009	6.1 / 23.09	10.6 / 40.13
2010	6.8 / 25.74	13.23 / 50.08
2011	7.4 / 28.01	-
2012	7.5 / 28.39	-

Source: U.S. Energy Policy Act (2005),
Renewable Fuels Association (2011)

[61] Renewable Fuels Association, *Federal Regulations: Small Ethanol Producer Tax Credit.*

Starting in 2013, the *Energy Policy Act* requires 250 million gallons of cellulosic-based ethanol to replace national gasoline use.[62] According to the federal Energy Information Agency, the 2012 RFS target of 7.5 million gallons will reduce national oil consumption by 4.65 billion litres in that year alone. Because different regions of the country may have geographic or economic difficulties in meeting the minimum use levels, the RFS created a credit-based trading program. Ethanol refiners and other regulated entities can generate credits when they consume ethanol, and would receive one credit for each gallon of corn ethanol and 2.5 credits for each gallon of cellulosic ethanol that they use. The preferential credit assignment for cellulosic ethanol will be removed when cellulosic ethanol quotas are instituted after 2012. These credits last for 12 months from the date they were generated, and may be bought and sold without geographic restriction. The value of these credits was expected to be linked to ethanol shipping costs.[63] In addition, credits were proposed for biobutanol (1.3), biodiesel (1.5), and non-ester renewable diesel (1.7)[64], which provide an opportunity to augment the transportation fuel regime by including other non-petroleum transport fuels. In September 2006, the Environmental Protection Agency (EPA) proposed implementation mechanisms and credit trading compliance and enforcement mechanisms that stipulated

[62] Renewable Fuels Association, *Federal Regulations: Renewable Fuels Standard* (Renewable Fuels Association, 2005 [cited 8 December 2006]); available from http://www.ethanolrfa.org/policy/regulations/federal/standard/.

[63] Eric Washburn and Brian Jennings, "Summary of the Ethanol-Related Provisions in H.R. 6, the Energy Security Act of 2005," (Sioux Fall, SD: American Coalition for Ethanol (ACE), 2005).

[64] United States Environmental Protection Agency, *Regulation of Fuels and Fuel Additives: Renewable Fuel Standard Program - Notice of Proposed Rulemaking* (Government of the United States of America, 7 September 2006 [cited 9 December 2006]); available from http://www.epa.gov/otaq/renewablefuels/renewablefuel-nprm.pdf.

how and when these goals would be achieved.[65] In 2009, the EPA proposed a new and accelerated renewable fuel standard (RFS2), which established a trajectory for the U.S. biofuels regime for the next 10-15 years (Table 5-8).

Table 5-8: Revised Projected Biofuels Use (2009) [66]

Renewable Fuel Volume Requirements for RFS2 (billion gallons)				
Year	Cellulosic biofuel requirement	Biomass-based diesel requirement	Advanced biofuel requirement	Total renewable fuel requirement
2008	n/a	n/a	n/a	9.0
2009	n/a	0.5	0.6	11.1
2010	0.1	0.65	0.95	12.95
2011	0.25	0.80	1.35	13.95
2012	0.5	1.0	2.0	15.2
2013	1.0	a	2.75	16.55
2014	1.75	a	3.75	18.15
2015	3.0	a	5.5	20.5
2016	4.25	a	7.25	22.25
2017	5.5	a	9.0	24.0
2018	7.0	a	11.0	26.0
2019	8.5	a	13.0	28.0
2020	10.5	a	15.0	30.0
2021	13.5	a	18.0	33.0
2022	16.0	a	21.0	36.0
2023+	b	b	b	b

(Source: U.S. Environmental Protection Agency 2009)

The RFS2 biofuels production objectives were premised on a linear relationship between benefits and consumption, and that it was "not necessary to repeat detailed energy and GHG assessments. Depending on crop and geographical information, in many

[65] United States Environmental Protection Agency, *Epa Proposes Regulations for a Renewable Fuel Standard Program for 2007 and Beyond* (Government of the United States of America, September 2006 2006 [cited 9 December 2006 2006]); available from http://www.epa.gov/otaq/renewablefuels/420f06060.pdf.

[66] The letter "a" indicates that the amount will be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons, and "b" indicates amounts will be determined by EPA through a future rulemaking.

cases it will be possible to obtain a sufficiently reliable estimate from previous work".[67] As discussed further in chapter six, these assumptions did not account for the growing critique on the periphery of the biofuels regime that grew alongside the accumulation of data on the effects of ethanol throughout its life-cycle.

To conform with the 2007 *Energy Independence and Security Act* (EISA), the revised *Renewable Fuel Standard* (RFS2) included minimum greenhouse gas emissions reduction thresholds (from 2005) that would be used to determine whether or not biomass-based fuels qualified as "renewable" under the RFS2 program, with renewable fuels set at 20%, advanced biofuels at 50%, biomass-based diesel at 50%, and cellulosic biofuels at 60%.[68] The evolving United States biofuels regime accelerated its micro-, meso-, and macro-level policy actions in the 1990s and 2000s to promote its first generation ethanol sector (Table 5-9).[69]

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[67] Harro von Blotttnitz and Mary Ann Curran, "A Review of Assessments Conducted on Bio-Ethanol as a Transportation Fuel from a Net Energy, Greenhouse Gas, and Environmental Life Cycle Perspective," *Journal of Cleaner Production* 15 (2007): 616. This article often points the reader toward the more extensive findings of a report by the Institute for Energy and Environmental Research (IFEU), see: M. Quirin et al., "Co2 Mitigation through Biofuels in the Transport Sector - Status and Perspectives," (Heidelberg, Germany: Institute for Energy and Environmental Research, 2004).

[68] U.S. Environmental Protection Agency, *Epa Lays out a Plan for the Nation'S Increase in Renewable Fuels* (May 5 2009 [cited May 11 2009]); available from http://yosemite.epa.gov/opa/admpress.nsf/d0cf6618525a9efb85257359003fb69d/028f14f22a5224ad852575ad00607923!OpenDocument.

[69] U.S. Environmental Protection Agency, *Epa Proposes New Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond* (U.S. Environmental Protection Agency, May 2009 2009 [cited April 17 2011]); available from http://www.epa.gov/otaq/renewablefuels/420f09023.htm. NOTE: For "a" the 20% criterion generally applies to renewable fuel from new facilities that commenced construction after December 19, 2007, while "b" indicates that the EPA is proposing to exercise the 10% adjustment allowance provided for in EISA for the advanced biofuels threshold to as low as 40%.

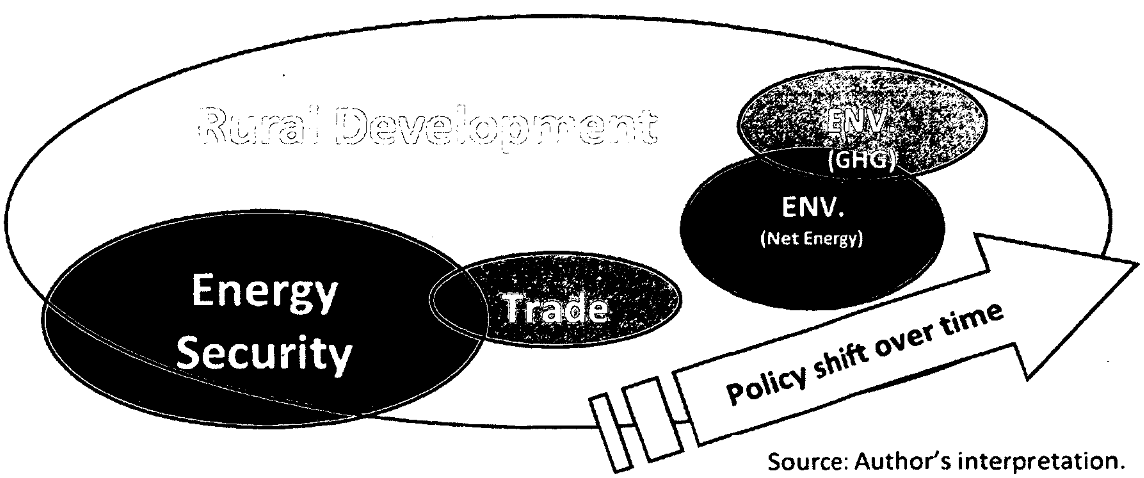
Table 5-9: Key Components of Transportation Fuels Regime Shift in the US

Function	Policy concerns	Micro-level action	Meso-level action	Macro-level action
Energy security	National energy development		Legislation (Energy Policy Act; Energy Independence adn Security Act)	Reduce national oil consumption
Rural Development	Developing production & distribution	Increasing biofuels production	Increasing feedstock production	
		Tax credit for small ethanol producers		
	Expand feedstock supplies	Increase support for biodiesel feedstocks	Capital investment for new feedstocks and new production capacity	
	Support Research & Development	Support cellulosic and advanced biofuels technology	Federal grants for industry-led R&D programs	
	Stimulating technical diffusion	Tax exemptions; tradable credits	Mandatory biofuels content requirements	Legislation (Clean Air Act)
Trade	Enhancing Trade			Ethanol Alliance with Brazil; International ethanol standards
	Supporting developing countries			
Environment	Capture benefits to environment	Fuel quality standards	Low-carbon greenhouse gas emissions thresholds	
Society	Capture benefits to society			

Source: Author's interpretation.

Between 1998 and 2008, the United States made a concerted effort to strengthen its biofuels regime and to become an international leader in ethanol production. By surpassing Brazil, the United States staked a sizeable claim in the global biofuels market. The history of ethanol in the United States presented in chapter four of this thesis revealed most power holders and decision makers resisted biofuels expansion policies and programs. Although federal and state governments in the United States offered minimal support for ethanol in select niche markets (primarily in the upper mid-west "corn-belt" states), ethanol was typically ignored or undermined during most of the 20th century.[70] Yet the sudden and rapid change in policy direction strengthened the United States' biofuels regime by leveraging newfound domestic support due to escalating concerns with national energy security and from environmentalists seeking to address air pollution and, later, to reduce greenhouse gas emissions. The U.S. biofuels regime evolved to accommodate shifting policy challenges (Figure 5-10).

Figure 5-10: Biofuels Regime Shift in the US



Source: Author's interpretation.

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[70] Kovarik, "Henry Ford, Charles Kettering and the 'Fuel of the Future."

In addition to addressing the landscape pressures of domestic energy concerns, the new biofuels regime was also used as a geopolitical tactic to challenge energy competitors in Central and South America. For example, the restoration of "fast track"[71] trade agreements in the 2002 U.S. federal "Trade Act"[72] and the pursuit of bilateral or trilateral trade agreements during a period of growing multilateralism helped to secure the 2007 ethanol agreement between the United States and Brazil. Although not the "fast track" trade agreement that Brazil's President Silva had hoped for, the hastily constructed "ethanol accord" (discussed further in chapter six) provides a good example of how the United States responded to the socio-technical landscape to secure agreements that bolstered its biofuels regime. In this case, the bilateral agreement seems to have been designed to maintain American influence in Latin American politics, which will be explored in the next chapter of this dissertation with a look at how interactions among dominant biofuels regimes have contributed to the institutionalisation of the global biofuels market.

The European Union

The European Union biofuels regime began with concerns over agricultural and energy systems, and evolved to include other issue-areas, including environment, climate change, social cohesion (job creation), and international development.[73] Although

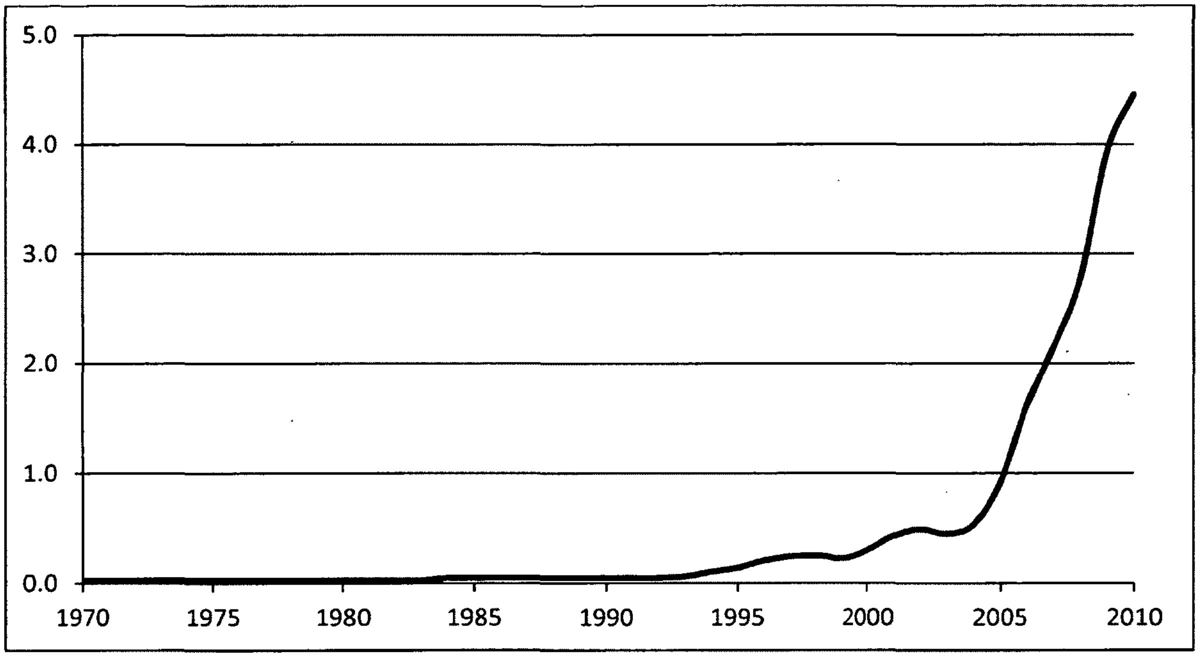
[71] "Fast track" refers to US bilateral trade agreements negotiated by the President that the House of Representatives can approve or disapprove without amendment. The first period allowing "fast track" trade agreements occurred from 1975 to 1994, which built upon the Canada-US Free Trade Agreement that eventually led to the North American Free Trade Agreement.

[72] *USTrade Promotion Authority Act*, 107–210, (August 6).

[73] Neill Nugent, *The Government and Politics of the European Union*, 5th ed. (Durham, North Carolina: Duke University Press, 2003).

identified early as a potential area for niche development, ethanol expansion in the European Union occurred much later than in Brazil and the United States (Figure 5-11).

Figure 5-11: Ethanol Production in the EU, 1970-2010 (billions of litres)



(Source: Author's compilation of data from Biofuels Platform 2010; Renewable Fuels Association 2011)

Rural development and energy provided initial landscape pressures after the 1957 Treaty of Rome and the creation of the European Economic Community. In terms of rural development, the 1962 Common Agricultural Policy (CAP) was intended to modernise Europe's agricultural sector by enabling economic integration while maintaining Europe's rural "social tissue" amidst dramatic techno-economic change and the migration of farm labourers to other economic sectors in urban areas.[74] The CAP has been reformed periodically to address emerging challenges, such as regulating agricultural price mechanisms, conserving natural spaces in rural areas, or protecting employment

[74] Ibid.

opportunities for less developed incoming members to the European Economic Community.[75] By the 1980s, the European Commission exhorted the agricultural industry to diversify in order to secure future benefits for all of the European Union. Wood, wool, cotton, hemp and flax were traditional non-food uses, but the industry had begun developing organic chemicals and other non-food products, while biotechnology promised a new future that might improve traditional feedstocks.[76]

Energy production from biomass linked rural development and energy policy areas, and first generation ethanol became a potential non-food agricultural product that promised multiple benefits. Transport biofuels were identified as an opportunity for agricultural diversification as the European Economic Community sought to reform farming in all Member States. In its 1985 "green paper", the European Commission stated that, in addition to acting as an alternative octane-enhancer for gasoline,

> [m]arketing large quantities of bio-ethanol by incorporating it in motor fuel would, however, present a number of advantages for agriculture. It would provide fresh outlets for products which are often in surplus. Although the new biofuel industry's raw materials would initially consist of sugar beet and, to a lesser extent, cereals and potatoes, they could at a later stage be replaced by vegetable products which can yield more alcohol and which can be grown in regions situated further to the south.[77]

The attractiveness of increasing ethanol production was recognised at an early stage to address both economic and environmental considerations, yet the limited potential for output at the time suggested that higher yield feedstocks were necessary. Changes in feedstock, along with associated technological changes, were necessary if energy crops

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[75] European Commission, "A Long-Term Policy Perspective for Sustainable Agriculture," in *Explanatory Memorandum* (Brussels: European Union, 2003).
[76] European Commission, "Perspectives on the Common Agricultural Policy," in *Communication of the Commission* (Brussels: European Union, 1985).
[77] Ibid., 34.

were to become a viable alternative to increase European agricultural diversity. Diversification of energy crops for liquid biofuels would require significant investment to construct new processing facilities, while the associated legislation, regulations, incentives, and budget allocations were still in their infancy. Moreover, the cost of producing ethanol was much higher than the market price, which would necessitate either full or partial subsidies while seeking to avoid market distortions.[78] Thus, while the landscape factors suggested that biofuels could be a socially-desirable objective, the European transportation fuels regime did not yet have the technical capacity to respond.

While the development of agricultural products and the search for new markets were a priority for economic integration and stability in Europe, other landscape pressures related to agriculture compelled the European Union to coordinate its agricultural policy with other policy areas. For instance, oversupplies of popular farm products were depressing prices and de-stabilising rural economies, which threatened the goal of market integration across the European Economic Community. One response was to establish "set-aside lands" that would leave some agricultural areas fallow in order to reduce surplus crops without penalising farmers with lower income levels from forced reductions.[79] Later, these dormant lands would be used to cultivate energy feedstocks as a non-food crop, a development that coincided nicely with the European Union's nascent renewable energy policy. Not only did ethanol fulfil the mandates of the CAP, but it also was recognised as a renewable energy source that could address the impending regulation

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[78] Ibid.
[79] Körbitz et al., "Worldwide Review on Biodiesel Production."

that would restrict leaded gasoline in 1989.[80]

While landscape changes to agriculture in Europe inspired some niche changes that would shape the emerging biofuels production regime, other landscape factors emerged related to energy access and security of supply, as well as an emerging awareness of energy-related environmental problems. Europe, and indeed the rest of the world, was faced with a "new geopolitical context".[81] The fall of the Soviet Union and rise of new political realities in Europe and Asia, as well as the cycles of conflict and peace in the Middle East, provided a new era of international relations. This new landscape included increased economic integration and the institutionalisation of trade alignments around the globe (including the GATT, NAFTA and Mercosur, not to mention the growing European Economic Community). While international trade was supported as enabling more choice from larger and more diverse supply chains, "[p]aradoxically, in the energy sector, these changes [did] not necessarily result in greater security of supply for the [European] Community".[82] In addition, a cooperative energy policy for the European Union became important because of "increasing [global] pollution due to the growth of consumption, notably in developing countries; the role of energy in contributing to the stability of countries, be they producer or consumer nations; the increasing energy dependence of the Community; [and] the growth of the world markets in production, transport, distribution and consumption technologies".[83]

While different energy markets responded differently, a 1994 green paper stated

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[80] European Commission, "Perspectives on the Common Agricultural Policy."
[81] European Commission, "For a European Union Energy Policy," in *Communication from the Commission* (Brussels: European Union, 1994), 43.
[82] Ibid.
[83] Ibid.

that the level of "[o]il consumption will be determined by the transport sector; as long as fundamental changes do not occur in this sector, efforts to reduce dependency on oil will be in vain".[84] Moreover, "[r]enewable energy's contribution will increase as a function of specific conditions connected with the type of energy and with increased decentralisation of production installations", while "[t]he future development and use of different fuels development will be influenced principally by the aims of environmental protection and by the need to diversify to limit import dependence".[85] Transportation was presented as the single greatest challenge affecting Europe's energy supply; one that was subject to a continually increasing demand with the corollary issues of traffic congestion and environmental pollution.[86] New biofuels production technologies opened up "interesting possibilities", yet despite first generation biofuels being a "mature" technology, liquid biofuels were not yet cost competitive.[87] Nevertheless, a new energy policy for Europe was seen as a necessary response to a new geopolitical landscape, and

> ...must pursue aims that reconcile competitiveness, security of supplies and protection of the environment while bearing in mind that the Union's central concerns are, on the one hand job creation and the quest for greater efficiency in the general business environment that also includes the organisation of energy systems, and on the other hand the protection of the environment.[88]

While agriculture and energy were the primary landscape changes to influence the transportation fuel regime in the European Union, the climate change issue was becoming a global policy challenge. In 1995, the Commission identified three key energy policy

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[84] Ibid., 46.
[85] Ibid.
[86] Ibid., 48.
[87] Ibid., 60.
[88] European Commission, "An Energy Policy for the European Union," in *White Paper* (Brussels: European Union, 1995), 2-3.

objectives: to increase overall competitiveness, ensure of energy supply, and protect the environment.[89] However, they also recognised that a Community energy policy must address social cohesion and quality of life issues, and economic development and job creation. In general, renewable energy was identified as an important factor for achieving these goals, although this emerging industry would require "supportive market regulation" at the outset. Transport biofuels provided an ideal product with which to satisfy these five objectives for a new Community energy policy.

Climate change appeared as a landscape pressure emanating from commitments made at the 1992 Rio Earth Summit. A common effort to encourage renewable energy as a greenhouse gas emissions reduction strategy would help overcome non-technical barriers. Also, since conventional energy prices had been stable at "historically low levels", a long-term program consisting of "political, legislative, administrative, economic and marketing aspects" was necessary to assist their development. Moreover, the overall success of the European Economic Community's internal market necessitated a diverse energy mix, which included indigenous renewable energy sources in order to "avoid imbalances between Member States or distortion of energy markets".[90] The 1997 white paper outlining a renewable energy strategy for the European Union offered one of the earliest indications of the move toward mandating biofuels for use in motor fuels at 2% content[91], which later became the reference value used as the content mandate in the 2003 *Biofuels for Transport Directive*. The European Union consistently supported the

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[89] Ibid., 14.
[90] European Commission, "Energy for the Future: Renewable Sources of Energy," in *White Paper for a Community Strategy and Action Plan* (Brussels: European Union, 1997), 7.
[91] Ibid., 17.

Kyoto Protocol, which it ratified in May 2002 with a commitment to reduce emissions by 8% from 1990 levels. Considering that oil consumption and emissions from transportation was one of the most difficult challenges to address, the European Union strengthened its biofuels regime by producing policy statements, EU commitments, and other institutional mechanisms to reduce carbon emissions.[92]

While seen as an early opportunity to diversify agricultural production, secure energy supplies, and address climate change, the European Commission was unable to convince its Member States to embrace the new biofuels regime and voluntarily expand their respective biofuels production systems. The demand for petroleum fuels for transport represented 67% of all the oil used in the EU in 1998, and was expected to grow at a consistent pace of 2% per annum to supply the 189 million public and private vehicles. Passenger road traffic was expected to increase by 16% by 2010, while the use of road vehicles for the transport of goods was expected to increase by more than 50%.[93] In 1998, liquid biofuels comprised only 0.15% of the motor fuels market and was still far from meeting Europe's immediate needs, let alone the expected increases. Despite the direction of the evolving European Union biofuels regime, Member States responded slowly to the shifting transportation fuels regime. Nevertheless, the socio-technical landscape continued to change, and soon additional pressures would arise in other policy areas, including a desire to increase energy diversity and renewable technologies.[94] Despite an effort to mandate biofuel content in transportation fuels, Member States

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[92] Körbitz et al., "Worldwide Review on Biodiesel Production."

[93] European Commission, "Towards a European Strategy for the Security of Energy Supply," in *Communication from the Commission* (Brussels: European Union, 2000), 14.

[94] European Commission, "Promoting Biofuels in Europe: Securing a Cleaner Future for Transport."

responded to the *2003 Biofuels Directive*[95] in various ways. Most did not meet the requirements of the European Commission Directive by the 2005 deadline, with some explaining why they could not meet the minimum reference values (Table 5-12).[96]

Table 5-12: Explanations for Production Shortfall from EU References Values [97]

Argument \ Country	Denmark	Estonia	Finland	Hungary	Ireland	Malta	Netherlands	Portugal	United Kingdom
Loss of government revenue	✓								
Allocation of resources to other bio-energy uses	✓		✓						
Limited national potential for production of biofuels from biomass		✓	✓	✓	✓	✓	✓	✓	
High production cost	✓		✓						
Low technological/knowledge capacity		✓	✓					✓	✓
Vehicles not technically ready		✓							
Emissions of other greenhouse gas emissions	✓				✓				
Second-generation biofuels projects							✓		

Source: PricewatershouseCoopers (2005)

At the time, however, most Member States supported the principles of the European Union biofuels policy and many implemented multiple policy measures in their attempt to achieve national targets (Table 5-13). The most progressive countries included Sweden, which offered the highest policy mix with five supporting measures. Germany and the United Kingdom also embraced a number of policy tools, which suggested a good deal of commitment to biofuels expansion.[98] Of the policy options identified to

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[95] European Commission, *Directive 2003/30/Ec of the European Parliament and of the Council of 8 May 2003 on the Promotion of the Use of Biofuels or Other Renewable Fuels for Transport* (European Union, 17 May 2003 [cited 10 December 2006]); available from http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_123/l_12320030517en00420046.pdf.

[96] PricewaterhouseCoopers, "Analysis of Biofuel Policies in a Selection of Eu Member States," (Brussels: Ministry of the Environment (Climate change division), Government of Belgium, 2005).

[97] Ibid., 8.

[98] Ibid.

develop biofuels as niche products within the existing petroleum-dominant transportation fuels regime, most Member States simply offered tax exemptions and established research and development programs.

Table 5-13: Policy Tools Employed by EU Member States [99]

Measures \ Member State	Austria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Latvia	Lithuania	Malta	Netherlands	Portugal	Slovak Republic	Spain	Sweden	United Kingdom	Total
Excise duty exemption	✓		✓	✓	✓	✓	✓	✓		✓	✓		✓			✓	✓	✓	✓	✓	14
CO2 tax exemption				✓																	1
Rebates for low carbon vehicles																			✓		1
R&D programs		✓	✓	✓		✓		✓		✓	✓				✓				✓	✓	10
Biofuels content mandates	✓																				1
Quality Measurements			✓					✓													2
Public Awareness								✓								✓				✓	3
Voluntary Agreements																✓					1
Technology Procurement																			✓		1
Greening of Government Fleet																			✓		1
Capital allowances for biofuels facility construction																				✓	1
State Aid			✓																		1

Source: PricewatershouseCoopers (2005)

In addition to the biofuels content mandates required by the *2003 Biofuels Directive*, the *2005 Biomass Action Plan* identified five other niche-level activities to encourage biofuels production and use:

1. Regulate the vehicle market to provide more biofuel-ready models.
2. Balance biofuels use between domestic production and import.
3. Enable fuel standards to accommodate new biofuels technology.
4. Remove technical barriers and ensure no discrimination against biofuels.
5. Increase ethanol use as substitute for diesel fuel and methanol in biodiesel.[100]

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[99] Ibid., 8-10.

[100] European Commission, "Biomass Action Plan," in *Communication from the Commission* (Brussels: European Union, 2005), 9-11.

The European Commission encouraged Member States to pursue these other measures, and also offered broader objectives for biofuels in the *2006 Biofuels Strategy*, which favoured a "regulated market-based approach"[101] instead of either a "business-as-usual" or a "deregulated market-based" scenarios.[102] Yet rather than implement these niche-level activities or embrace these broader objectives, most Member States still preferred to use simple taxation policy as the main measure of their expansion strategies. This suggests a potential disconnection between the more ambitious multinational "vision" held by the European Commission and the national "visions" of European Union Member States. Declining infrastructure, higher energy demand and rising prices, increasing reliance on imported energy, and changing climate all were cited as reasons to develop renewable fuels as part of Europe's "new energy landscape". This necessitated a "common European response" in six key areas, each supported by concrete proposals on how they might be achieved as well as detailed impact analyses of the likely results of inaction.[103]

1. the competitiveness of the internal energy market,
2. diversification of the energy mix,
3. solidarity in the face of potential energy crises,
4. addressing sustainable development,
5. encouraging innovation and technology, and
6. an external energy policy for future bilateral and multilateral relationships.[104]

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[101] European Commission, "An Eu Strategy for Biofuels," in *Communication from the Commission* (Brussels: European Union, 2006), 4.

[102] European Commission, "An Eu Strategy for Biofuels (Annex - Impact Assessment)," in *Communication from the Commission*, ed. Commission Staff Working Document (Brussels: European Union, 2006).

[103] European Commission, "Annex to the Green Paper: A European Strategy for Sustainable, Competitive and Secure Energy - What Is at Stake - Background Document," in *COMMISSION STAFF WORKING DOCUMENT* (Brussels: European Union, 2006).

[104] European Commission, "Green Paper: A European Strategy for Sustainable, Competitive and Secure Energy," in *Communication from the Commission* (Brussels: European Union, 2006).

The broader objectives offered in the 2006 Strategy provided a foundation for a new vision for biofuels in Europe, which included "...reducing greenhouse gas emissions, boosting the decarbonisation of transport fuels, diversifying fuel supply sources and developing long-term replacements for fossil oil...to offer new opportunities to diversify income and employment in rural areas.[105] By the mid-2000s, the "ambitious and realistic vision" for Europe was a cost-competitive and healthy European biofuels industry[106], where transportation fuels contained up to 25% of clean and CO_2-efficient biofuels supplied by a "competitive European industry" that used various biomass resources and "sustainable and innovative technologies".[107] Ethanol and biodiesel offered a renewable energy option that would shift the existing transportation fuels regime to become more competitive, increase security of supply, and foster sustainability in the energy sector.

The key components of the shifting European Union transportation fuels regime involved a wide array of micro-, meso-, and macro-level policy initiatives and regulatory changes that strengthened the biofuels regime (Table 5-14).

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[105] European Commission, "An Eu Strategy for Biofuels," 3, European Commission, "An Eu Strategy for Biofuels (Annex - Impact Assessment)."

[106] European Biofuels Technology Platform, *European Biofuels Technology Platform* (European Union, 8 June 2006 [cited 13 December 2006]); available from http://www.biofuelstp.eu/downloads/Steps_to_TP_LCJS.pdf.

[107] Biofuels Research Advisory Council, "Biofuels in the European Union: A Vision for 2030 and Beyond," 3.

Table 5-14: Key Components of Transportation Fuel Regime Shift in the EU [108]

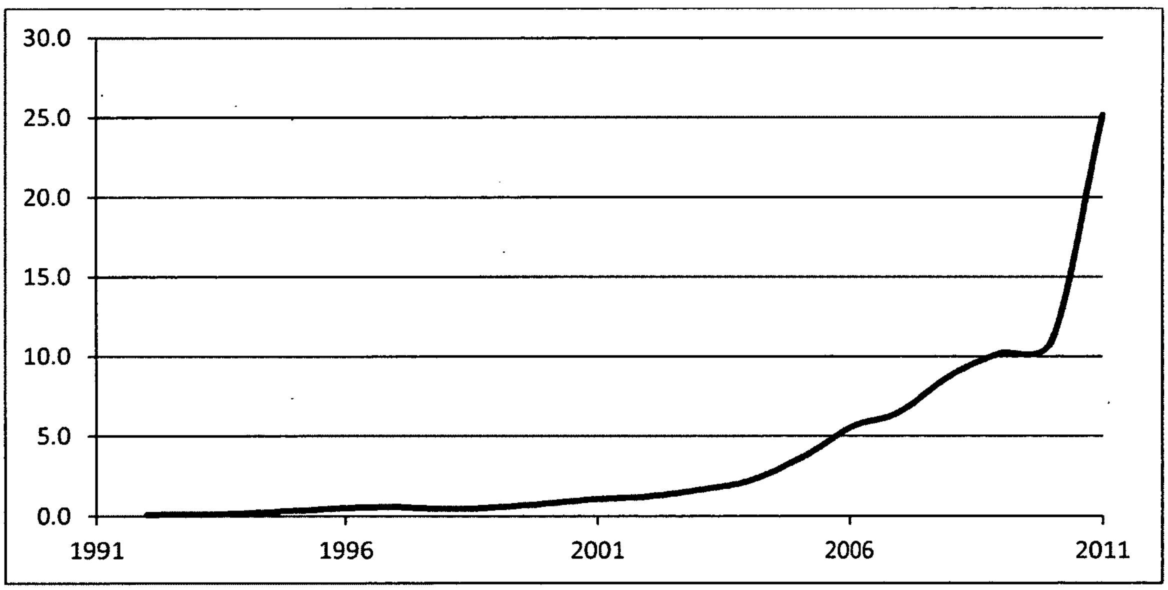
Function	Policy concerns	Micro-level action	Meso-level action	Macro-level action
Energy security	National energy development			Policy goals of sustainable, competitive and secure energy
Rural Development	Developing production & distribution		Concerted national efforts for biofuels development	
			Biofuels policies for rural development	
	Expand feedstock supplies		Sector-based development (forestry, organic waste)	Common Agricultural Policy Reform
	Support Research & Development	Joint ventures with industry	Research funding; cooperation between energy and agriculture	
	Stimulating technical diffusion	Assisting market introduction; tax and subsidy incentives	Mandatory biofuels content requirements	
Trade	Enhancing Trade	Assisting biofuels exporters; adjusting tariffs	Creating customs codes for biofuels to distinguish from other fuel and food products	International ethanol standards
	Supporting developing countries	Assisting international cooperation	Cooperation with sugar-producers affected by EU reforms	
Environment	Capture benefits to environment	Sustainable production	Fuel quality standards	Greenhouse gas emissions reduction
Society	Capture benefits to society			

Source: Author's interpretation.

[108] European Commission, "An EU Strategy for Biofuels." See also, European Commission, "An EU Strategy for Biofuels (Annex - Impact Assessment)."

This vision for the future of the European biofuels regime included improvements to first generation biofuel, advanced biofuels, and fully integrated bio-refineries to produce chemicals, biofuels and other energy forms.[109] Particular emphasis was put upon biodiesel. Like the other dominant biofuels regimes, the European Union transferred much of its policy experience from early ethanol expansion strategies to biodiesel. In the span of only two decades, the European Union biodiesel niche grew from virtually no production to over 25 billion litres annually (Figure 5-15).

Figure 5-15: Biodiesel Production in the EU, 1991-2011 (billions of litres)



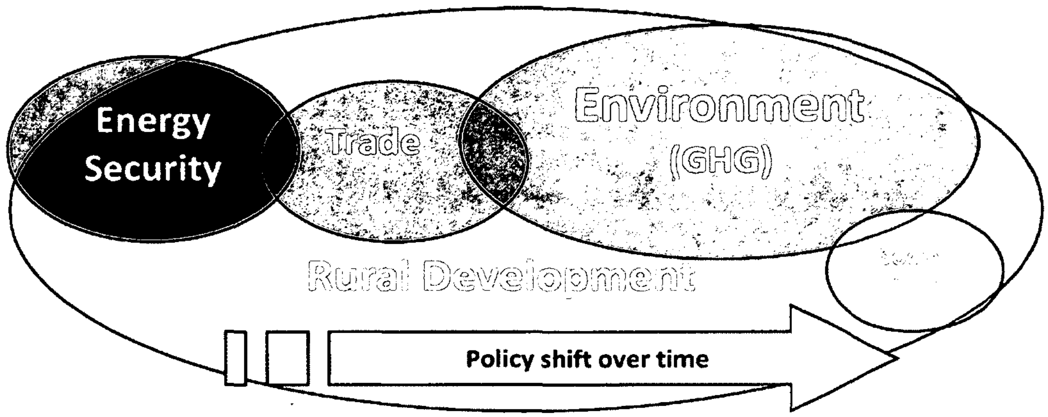
(Source: Author's compilation of data from Biofuels Platform 2010; European Biodiesel Board 2012)

This vision for European biofuels included research and development to avoid technological "lock-in", improving conversion technologies to enhance the carbon reduction benefit, accessing alternative feedstocks with an effort to maximise their

[109] Biofuels Research Advisory Council, "Biofuels in the European Union: A Vision for 2030 and Beyond," 4.

efficient use, as well as development of fuels testing and standards. This vision also included greater inter-organisational coordination efforts by all stakeholders regarding their policies and programs, as well as for the inter-operability of various sectors and their artefacts, such as the various types of vehicles and their operations.[110]

Figure 5-16: Biofuels Regime Shift in the EU



Source: Author's interpretation.

Between 2000 and 2008, the development of biofuels policy in the European Union became increasingly interconnected with other policy issue-areas both within and outside of the European Union. While it started with rural development and energy security concerns, it grew to include international trade, environmental concerns focussed primarily on greenhouse gas emissions reduction, and eventually to the use of biofuels technology transfer for international development and assistance (Figure 5-16).

This policy shift over time necessitated an enlargement of the biofuels regime to accommodate and involve more Member States, more social actors, and more societal institutions in the development of strategies and visions to guide the biofuels regime in

[110] Ibid., 28-9.

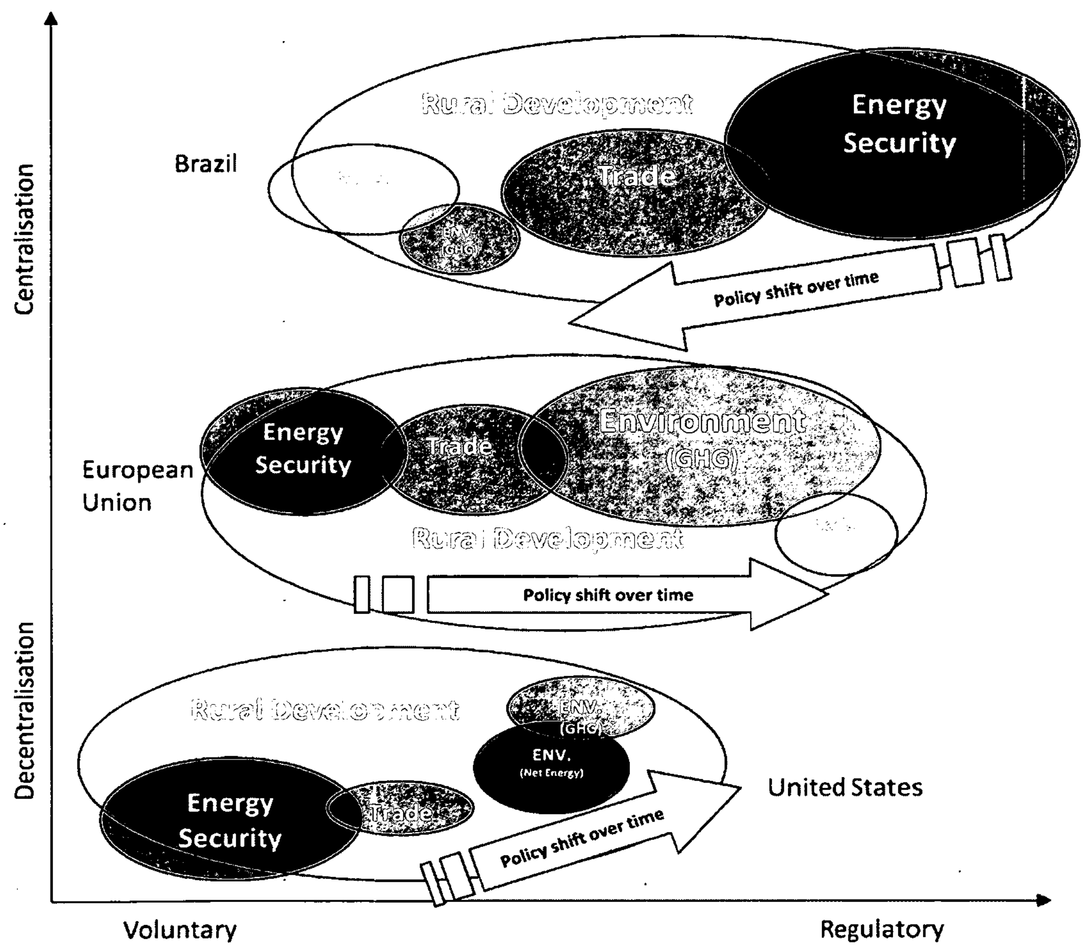
the European Union. Ethanol and biodiesel grew from niche considerations as a non-food agricultural product to a mainstream commodities The evolution and strengthening of the European Union biofuels regime moved toward a more regulatory-interventionist approach in order to shift the larger transportation fuels regime to include non-petroleum transportation fuels. Yet despite significant efforts at the supra-national level, the activities of Member States did not meet the aspirations and overarching vision of biofuels for the European Community.

Conclusion

The evolution of the biofuels regimes in Brazil, the United States, and the European Union occurred during different historical eras, at different speeds, and with varying emphasis on rural stability, energy security, trade, and environmental concerns. While these regimes supported the growth of biofuels from niche products, to national programs, to international markets, the way they were configured within their respective jurisdictions varies significantly. The biofuels regime in Brazil is based on centralised, large scale, state-run production facilities. The United States regime can be described as a market-centred, firm-based regime in which government incentives were directed at privately owned operators of various scales of production. The European Union regime differs significantly from both Brazil and the United States. It employs a supra-national governance structure to facilitate the adoption of an administrative, multi-sectoral biofuels regime.

These biofuels regimes evolved within different socio-technical landscapes. As this chapter has demonstrated, they shared overlapping landscape pressures and used a host of similar niche-level initiatives to expand biofuels production and consumption. Moreover, they all eventually sought to expand domestic biofuels production capacity in order to develop ethanol and biodiesel as commodities for international markets. This common milestone in otherwise unique trajectories reveals a degree of convergence among these three biofuels regimes that appeared even though their respective landscapes, regimes and niches were qualitatively different.

Figure 5-17: Socio-Technical Convergence of Biofuels Regimes



Source: Author's interpretation.

Figure 5-17 provides a conceptual depiction of this convergence. The vertical axis reflects the level of government control ranging from a decentralised governance system (in which numerous individuals, social groups, corporations, and levels of governments actively participated in multiple decision-making processes), to a centralised and highly concentrated group of power holders (represented by the executive decision-makers in government institutions). The horizontal axis captures the degree of government intervention ranging from completely voluntary to highly regulatory. Based upon the preceding discussion of Brazil, the United States and the European Union, each bubble represents the importance of different social functions within the socio-technical regime.

Brazil moved only slightly away from its centralised and highly regulated approach. The biofuels regime retained or expanded standards for production and consumption, but voluntary policy tools were later utilised and supported by fiscal incentives, such as producer subsidies and biofuel tax exemptions. Energy security concerns and economic crisis helped to expedite the shift toward biofuels, and rural development quickly became a primary concern. However, expanding biofuels to export markets in order to offset high costs and reliance on foreign petroleum meant that international trade of biofuels was a high priority. Other policy issues emerged, including mitigating environmental pollution and biodiesel production standards.

The market-centred, firm-based United States biofuel regime was based on government incentives in which early subnational activity spurred national programs to unify and strengthen efforts to expand American ethanol and biodiesel production capacity. Rural development was the first policy driver, but energy security later entered the policy framework as a significant concern. Environmental concerns related mostly to air quality and, to a lesser extent, to net energy ratios and greenhouse gas emissions, but these issues were not significant for the configuration of this biofuels regime.

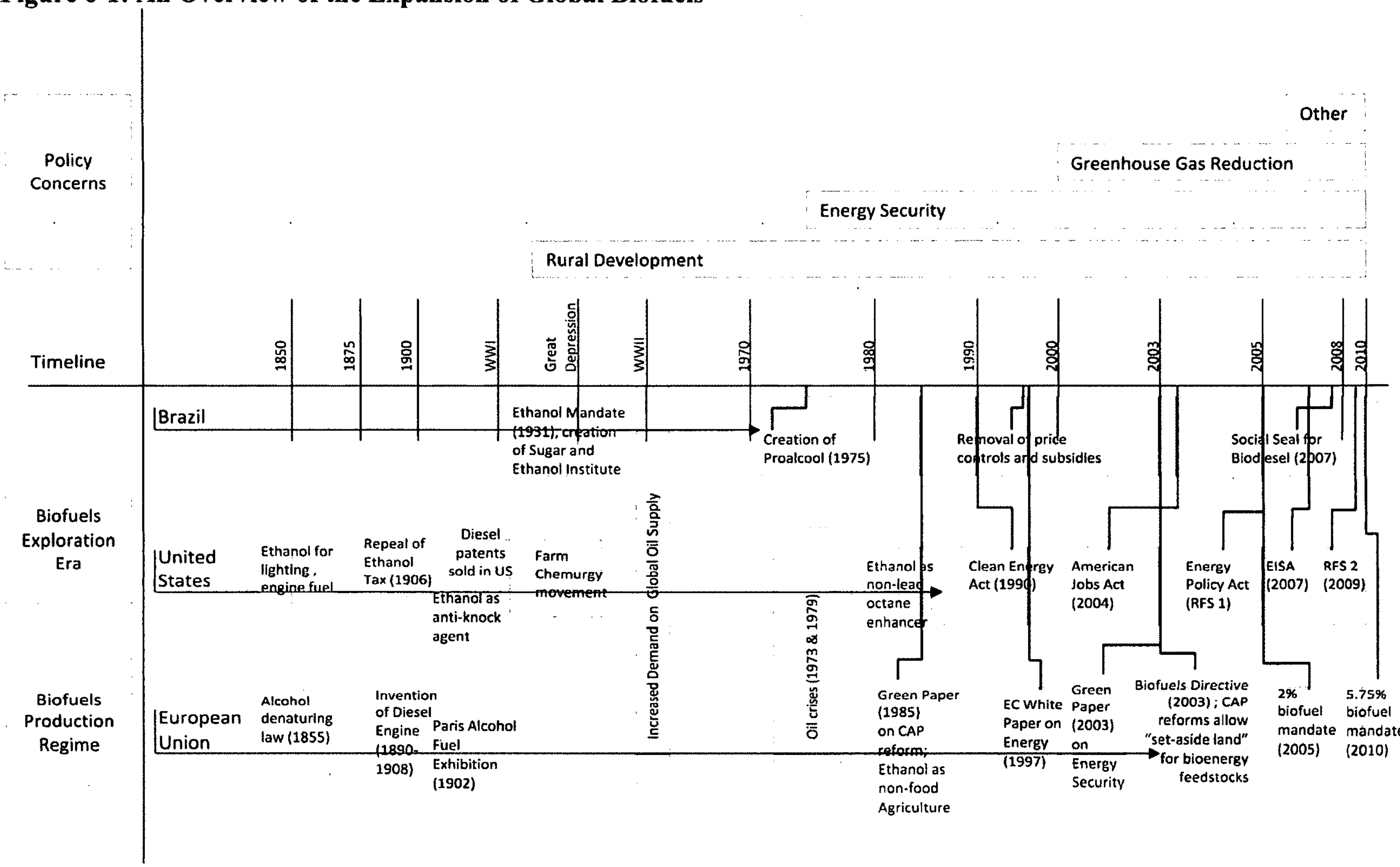
Finally, more and more landscape factors exerted an increasing amount of pressure on the transportation fuels regime in Europe. Rural development was the initial driver, and energy security emerged earlier as a landscape pressure. However, energy security (particularly the certainty of supply achieved through trade agreements) was complemented by growing concerns with greenhouse gas emissions and climate change. Eventually, the social dimension of biofuels was included in the biofuels regime. The appearance of new policy considerations contributed to a greater degree of uncertainty with the technical and environmental effects of ethanol and biodiesel. Although the level of regulatory intervention rose, the European Union biofuels regime maintains an administrative, multi-sectoral approach that was consistent with other European Union governance structures. As the next chapter demonstrates, these biofuels regimes shifted the function of ethanol and biodiesel from agricultural development and energy security, to include other social functions. Brazil and the United States exhibited marginal interest in the associated properties of reducing emissions or addressing unwanted environmental or social effects. Emerging social functions in the European Union embraced biofuels as a climate change mitigation strategy, and recognised that biofuels development strategies may adversely affect socio-economic conditions in developing countries. By the mid-2000s, the regimes were already international, and they were on the cusp of developing transportation biofuels as a "global" commodity.

SIX – Global Biofuels and Local Sustainability

Rural development and energy security were key social functions that motivated the expansion of biofuels production for national programs during the 1970s and 1980s. In the 1990s and early 2000s, ethanol and biodiesel were also considered environmental technologies that were to reduce air pollution and greenhouse gas emissions. This new social function held a promise for countries around the world that transportation biofuels would provide a renewable energy option. In addition to these three social functions, the diffusion of biofuels would also create more jobs, more wealth, and increase gross domestic product. By 2008, as this chapter will demonstrate, the global expansion of biofuels would not prove sustainable. However, the dominant biofuels regimes were not concerned with the social functions of ethanol and biodiesel, nor were they concerned with the sustainability of biofuels. Ethanol and biodiesel were now international commodities that held the most potential as products for an emerging global marketplace for renewable energy.

By this measure, the biofuels expansion strategies in each of the three dominant regimes succeeded (Figure 6-1). Between 1998 and 2008, transportation biofuels had exhibited a rapid commercialisation that led to the global diffusion of ethanol and biodiesel. However, despite their global diffusion across national and international markets, ethanol and biodiesel were increasingly criticised for their adverse local social and environmental effects.

Figure 6-1: An Overview of the Expansion of Global Biofuels



Source: Compiled by Author.

This chapter continues to explore the global diffusion of biofuels. First, it examines the trade regulations for ethanol established by the three major biofuels regimes through a trilateral agreement. Second, it considers the disapproval of this trade strategy from the international community by looking at Venezuela as a notable example of the response to the global diffusion of ethanol and biodiesel. In particular, it shows how a technological artefact can embody latent political tensions. Third, this chapter identifies environmental and social critiques in order to identify the interconnection between the global diffusion of biofuels and the implications for "local" production.

Global Biofuels

The evolution of dominant biofuels regimes in Brazil, the United States, and the European Union involved the construction of large capacity national systems of biofuels production and created international trade agreements and product standards. Mass production and international trade shifted national transportation fuels regimes by including more ethanol and biodiesel. The transformation of these national systems is an important point in the evolution of biofuels, because this is the point at which biofuels became a global commodity. This increased emphasis on the economic potential of transportation biofuels shifted the policy concerns from predominantly "local" matters of rural development, energy security, and environmental performance and toward "global" concerns of comparative advantage and product harmonisation. Despite their differences in terms of historical period, speed of adoption, and direction of technological development, these dominant regimes all evolved to prioritise biofuels as a global commodity. International markets for biofuels provided further motivation for the expansion of national production, but it also brought concerns over the effects of globally-available first generation biofuels.

As discussed in the latter half of this chapter, the economic opportunities provided by global biofuels came with important trade-offs for government decision-makers as they refine their biofuels policy strategies.[1] The proliferation of global biofuels will require countries to address their national context in relation to both global markets and local ecological requirements. We can already see some of the trade-offs that each of the three dominant biofuels regimes might have to reconcile in the near future. The European Union, for example, faces the likelihood that its biofuels directives are undermining international development efforts.[2] The United States is exploring the implication of regulating large agribusiness and independent farmers in order to ensure proper soil and water management.[3] Brazil has tried to balance the benefits of an increased balance of trade with the threats to habitat and biodiversity caused by the transformation of tropical forest into soy plantations.[4] In the same way, subnational governments will need to align "local" biofuels production systems with international agreements between multilateral institutions while also enforcing regulations on behalf of their national governments.

The convergence of the biofuels regimes that evolved in Brazil, the United States, and the European Union coincided with the expansion of ethanol and biodiesel as

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[1] J. E. Cambell and E. Block, "Land-Use and Alternative Bioenergy Pathways for Waste Biomass," *Environmental Science & Technology* 44, no. 22 (2010).

[2] Lorenzo Cotula, Nat Dyer, and Sonja Vermeulen, "Fuelling Exclusion? The Biofuels Boom and Poor People's Access to Land," (London: Food and Agriculture Organisation and the International Institute for Environment and Development, 2008).

[3] Plevin et al., "Greenhouse Gas Emissions from Biofuels' Indirect Land Use Change Are Uncertain but May Be Much Greater Than Previously Estimated."

[4] Schaffel and La Rovere, "The Quest for Eco-Social Efficiency in Biofuels Production in Brazil."

commodities for international markets. As the diffusion of ethanol and biodiesel reached global markets, Brazil, the United States, and the European Union sought to establish more deliberate cooperation, and negotiated important agreements to facilitate the international trade of biofuels.

The Tripartite Strategy

In March 2007, the United States and Brazil signed a bilateral "alliance" on ethanol in order to promote production and development of "next generation" biofuels, to create international quality standards, to expand biofuel production in developing countries, and to regulate the global trade in ethanol. This partnership encouraged the development of international standards through the International Biofuels Forum (IBF). At the end of the same year, the Tripartite Task Force (representing Brazil, the United States, and the European Union) released a strategy paper entitled the *White Paper on Internationally Compatible Biofuels Standards*.[5] This joint declaration provided a common point of reference from which to engage the other IBF members (China, India and South Africa) to facilitate global biofuels trade. Focussing solely on ethanol and biodiesel, the White Paper stated that product standards were a necessary component of an international biofuels market. Product "compatibility would not only facilitate the increasing use of biofuels in each of the regional markets, but also would support both exporters and importers of biofuels by helping to avoid adverse trade implications in a

[5] Tripartite Task Force, "White Paper on Internationally Compatible Biofuel Standards," (Brazil, European Union, United States of America, 2007).

global market"[6]. The Tripartite Task Force presented a strategy that identified the most promising product standards, and outlined three categories assessing the likelihood of harmonised product standards for international trade – "easily achievable", "eventually achievable", and "not deemed achievable".[7]

"Easily achievable" ethanol standards included colour, total alcohol content, density, hydrocarbons, sulfates, copper, sodium and iron, sulphur, appearance, and electrical conductivity. Specifications deemed "eventually achievable" were identified as purity, residue by evaporation, maximum chloride content, acidity, sulphate limits, and phosphorous content. Due to the differences in phase separation in low ethanol blends (E5, E10) compared to higher water absorption rates in high content blends, water content specifications were "not deemed achievable". Even though additional drying time for high water content ethanol at production facilities might address the issue, the diffusion of high content blends in Brazil in comparison to other biofuels regimes meant that policy symmetry on this area was not only unlikely, but water content standards were identified as possibly the "greatest deterrent to trade" for the global ethanol market.[8]

For biodiesel, "easily achievable" standards included sulphated ash, alkali and alkaline earth metals, free glycerol, copper strip corrosion, methanol or ethanol content, and acid number. Those areas of product specification requiring additional harmonisation but considered "eventually achievable" included total glycerol (both free and bound mono-, bi-, and triglycerides), phosphorous content, carbon residue, ester content,

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[6] Ibid.
[7] Ibid.
[8] Ibid.

distillation temperature (to identify product adulterated with heavy petroleum products), flash point, total contamination by solids, water content and sediment. The third category on which agreement was "not deemed reachable" concerned a number of areas, including sulphur content, cold climate operability, cetane number, oxidation stability, presence of mono-, di-, and triglycerides, density, kinematic viscosity (fluidity of biodiesel during operation), as well as iodine number, linolenic acid and polyunsaturated methyl ester (causing polymerisation and deposit build-up when heated).

The technical certainty achieved through these product quality standards are a necessary element for the international trade in biofuels. However, the intent of this White Paper was limited solely to product interoperability across national markets, and does not address broader questions of sustainability. The Trilateral White Paper followed the bilateral trade agreement by the United States and Brazil, and the applicability of such operability standards may be insufficient for countries that were excluded from these agreements and that experience more extreme climatic conditions, such as Canada, the Nordic countries, Russia, Chile or Argentina. Moreover, this does not address non-technical barriers such as ethics or environmental requirements.

The intent of the White Paper was, first and foremost, to specify technical requirements for global trade of bioethanol and biodiesel.[9] The results were then shared with other members of the International Biofuels Forum as "a basis for ongoing discussions on more closely aligning their respective specifications and prioritizing future

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[9] Tamás Kenessey, "Transatlantic Cooperation for a Competitive and Sustainable Biofuel Industry," in *Transatlantic Energy Future: Strategic Perspectives on Energy Security, Climate Change, and New Technologies in Europe and the United States*, ed. David Koranyi (Washington, DC: Center for Transatlantic Relations, 2011).

efforts for maximum impact".[10] This limited multinational policy formation provided direction to emerging producers, but the political and policy considerations of global biofuels favoured the dominant producers. Also, it further entrenched first generation ethanol and biodiesel as the leading biofuel alternatives. The theory of technological stability and change discussed in chapter three suggests that the configuration of a dominant socio-technical regime tends to inhibit the adoption of other similar technologies. Thus, the evolution and convergence of dominant biofuels regimes that favour ethanol and biodiesel can be expected to inhibit other liquid biofuels. The socio-technical acceptance of ethanol and biodiesel and their respective technical qualities and characteristics has prompted little discussion on whether or not they are sustainable. Similarly, little discussion or reflection has occurred on the changing socio-technical functions associated with their global expansion.

The Tripartite Task Force attempted to foster a harmonized global biofuels market through a trilateral agreement. This approach excluded small producers in other markets, and reveals how technical and economic considerations are often inseparable from wider political considerations. The Tripartite strategy resulted with an agreement to harmonise fuel for interoperability, rather than other production standards on feedstocks, manufacturing processes, or environmental effects. Thus, international standards were established as a way to facilitate trade, rather than to protect consumers, standardise production process, or achieve environmental or social objectives. While the Tripartite strategy complements the activities of the dominant biofuels regimes, it also acts as a

[10] Tripartite Task Force, "White Paper on Internationally Compatible Biofuel Standards," 11.

voluntary regulatory layer placed upon existing and future production systems. A significant effect of this added structure is an increased reliance on the existing capabilities of the dominant biofuels regimes that intend to harmonise the international biofuels market in their image.[11]

The international harmonisation of trade rules for biofuels enabled the expansion of ethanol and biodiesel into global markets without requiring complicated national or subnational statutory frameworks. However, the premature institutionalisation of unsustainable biofuels through trade-based product standards can be expected to reduce innovation in ethanol and biodiesel. For example, the White Paper did not address the effects of establishing and enforcing international production criteria. While favourable to its signatories, these product standards institutionalised the market in ways that may have adversely influenced the evolution of biofuels production systems in other markets. In particular, small markets seeking to enter the global biofuels sector must now adjust local production systems to harmonise with dominant regimes rather than set locally-relevant objectives to realise other goals, such as sustainability. The omission of sustainability standards from international economic agreements on biofuels specifications might result in future sustainability standards being viewed as impediments to trade. This could shift the trajectory of technological innovation for sustainable development away from ethanol and biodiesel and toward other related technologies,

[11] J. van Dam, M. Junginger, and A.P.C. Faaij, "From the Global Efforts on Certification of Bioenergy Towards an Integrated Approach Based on Sustainable Land Use Planning," *Renewable and Sustainable Energy Reviews* 14 (2010).

such hybrid vehicles, electric vehicles, and other low-carbon fuel technologies.[12]

The influence of the dominant biofuels regimes can be either transformative or retrenching. Although not intended to transform society and encourage a new socio-technical configuration of sustainable biofuels, the choice by governments to harmonise and institutionalise their respective biofuels regimes within the Trilateral Task Force will adversely affect socio-economic development and ecological integrity associated with ethanol and biodiesel production.

The expansion of biofuels to global markets reveals how national interest and political expedience for economic advantage can stultify the trajectory of new technologies. For example, the international agreement between the three dominant biofuels regimes to standardise trade rules has bolstered the market for first generation biofuels. The Tripartite Task Force focus on technical performance rather than social and environmental concerns affects all biofuels production systems regardless of their exclusion from the agreement. Although more stable, this policy environment favours dominant biofuels regimes while other producers must either comply with the new rules or oppose them from the outside. This strategic trilateral agreement not only limits niche development but also alters the landscape pressures associated with the diffusion of ethanol and biodiesel to global markets.

Opposing Global Biofuels

The diffusion of biofuels and the tripartite strategy elicited a range of responses

[12] Sonia Yeh and Daniel Sperling, "Low Carbon Fuel Standards: Implementation Scenarios and Challenges," *Energy Policy* 38, no. 11 (2010).

from countries around the world. Where some countries supported biofuels as a valid pathway to address energy and environmental problems, other countries were vocally opposed to biofuels. While not the most influential factor in the cooling off period in the story of biofuels since 2008, Venezuela interpreted the Trilateral Agreement as yet another threat to the balance of power in Latin America, and President Hugo Chavez's response to global biofuels provides a vivid example of how technological artefacts in different socio-technical systems can reflect contradictory political meanings.

Venezuela has good relations with other South and Latin American nations and has long been considered a friend of the United States. Massive oil reserves accelerated its economic development and it quickly became one of the wealthiest countries in Latin America, making it a political and economic leader in the region for most of the 20th century.[13] During the 1970s, the high price of oil enabled significant increases in public spending through the accumulation of external debt, but the resolution of the oil crises and fall of oil prices in the 1980s diminished the value of its currency.[14] This quick and unexpected increase in the countries debt burden led to a major financial crisis as Venezuelan currency values and standards of living fell while government corruption, street crimes, and poverty rose.[15] With support from the International Monetary Fund, Venezuela was required to comply with the Fund's policy of Structural Adjustment. Like many other countries, including Argentina and Mexico, austerity measures had

[13] Mark Weisbrot and Luis Sandoval, "The Venezuelan Economy in the Chavez Years," (Washington, DC: Center fof Economic Policy and Research, 2007).
[14] Roberto Briceño-León, "Violence in Venezuela: Oil Rent and Political Crisis," *Ciência & Saúde Coletiva* 11, no. 2 (2006).
[15] Weisbrot and Sandoval, "The Venezuelan Economy in the Chavez Years."

significant domestic ramifications[16], not the least of which was the radicalisation of political culture.

The United States' imports around 12% of its domestic consumption of oil and petroleum products from Venezuela, and the two countries have a clear interest to maintain positive trade relations. Venezuela's economy is dominated by its wealth of oil resources, and the country's foreign policy is aligned with its trade relations with other oil-producing countries. Bolivia, Ecuador, and Cuba are notable recipients of the financial assistance from Venezuela, and Brazilian and Argentine Presidents Silva and Kirchner both agreed to Venezuelan President Hugo Chavez's plan to build a $20 billion, 5000-mile natural gas pipeline across South America. The appearance of Chavez and his search for an alternative to western neoliberalism in Latin America seems based on popular support, and includes policies for the social distribution of wealth and economic growth that potentially "marks the beginning of a new epoch".[17] This new dynamic challenged the United States' regional influence, and coincided with a standstill on the Free Trade Agreement of the Americas (FTAA).

In order to dilute the power of Chavez's petro-diplomacy, the United States attempted to weaken Venezuela's efforts to secure multilateral agreements by establishing discrete bilateral treaties with key partners. The bilateral ethanol accord between the United States and Brazil improves trade relations between these two countries. Discussed briefly in chapter five, the ethanol accord addresses Brazil's interest

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[16] Victoria Marie Jackson, "The Imf and Latin America: A Comparative Case Study Analysis of Mexico, Argentina, and Venezuela," *The Penn State McNair Journal* 15 (2008).

[17] Sue Branford, "Biofuel Power Games," *New Statesman* 136, no. 4830 (2007): 18.

in increasing its exports while opening its borders to importing ethanol from the United States.[18] This agreement must have seemed to be a challenge to his integration plans for South America, and Chavez characterised the accord as a "cartel". With the principled support of Fidel Castro who decried the use of food crops for fuel as a "sinister idea"[19], Chavez announced the creation of an alternative proposal to "overthrow" the United States-Brazil agreement, which he described as "true craziness" that would exhaust agricultural production, monopolize arable land, starve the poor, and tighten the United States' grip on Latin American resources.[20]

Chavez's stance increased the diplomatic distance between Brazil and Venezuela at the South American Energy Summit in April 2007. Although Silva and Chavez downplayed any friction over the ethanol accord[21], the national leaders were embroiled in a two-day impasse, which was later resolved with an agreement by both countries to promote biofuels production as a supplement to the South American oil industry.[22] In the end, Chavez supported biofuel-blended transportation fuels as a way to boost both oil and agriculture sectors. In response to comments on the noticeable regional friction on this issue, Chavez stated, "The press is saying there's an ethanol war. No. Ethanol is a valid

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[18] The US imported advanced ethanol in order to meet its RFS2 mandate. In the latter half of 2011, the US imported almost 1 million litres of ethanol per day from Brazil, and exported almost 4.1 million barrels per day in the same period. See: Crooks, *Us Rules Boost Imports of Brazilian Ethanol* (Financial Times, April 9 2011 [cited June 11, 2012 2012]); available from http://www.ft.com/intl/cms/s/0/5564f822-8252-11e1-9242-00144feab49a.html#axzz1xibQgicb.

[19] Lauren Etter, *Ethanol Craze Cools as Doubts Multiply* (The Wall Street Journal, November 29 2007 [cited February 5 2007]); available from http://www.checkbiotech.org/green_News_Biofuels.aspx?Name=biofuels&infoId=16293.

[20] Hemscott Group Ltd, Alan Clendenning, and Eva Vergara, *Friction between Chavez, Silva on Ethanol* (Hemscott, April 16, 2007 2007 [cited February 4 2008]); available from http://www.checkbiotech.org/green_News_Genetics.aspx?Name=genetics&infoId=14453.

[21] Ibid.

[22] Theresa Bradley and Alex Kennedy, "South American Leaders Agree to Promote Biofuels," *Houston Chronicle*, April 18, 2007 2007.

strategy as long as it doesn't affect food production".[23]

While Chavez criticized American ethanol, Venezuela was quietly planning to expand its own ethanol industry with a U$900 million project to cultivate 740,000 acres of sugar cane, manioc and rice to supply over one dozen large-scale ethanol distilleries. With this, Venezuela was expected to build up to 17 ethanol processing plants by 2012.[24] Venezuela's vast oil reserves will continue to play the dominant role in its energy future, and the planned construction of 13 new oil refineries includes the integration of fuel ethanol distilleries in order to incorporate on-site blending with the refinery process. The collaboration of Latin American oil and ethanol production facilities lessens the region's dependency on United States-owned oil refineries and biofuels production facilities. It also increases the total output of Venezuelan fuel products.[25]

Despite the agreement with Brazil during the April 2007 energy summit and creation of a domestic biofuels strategy for Venezuela, Chavez's biofuels critique continued. As a vivid example, Chavez's used a national address as an opportunity to decry the use of food to produce more biofuels as a scenario in which "illogical, absurd, and stupid capitalism can continue its voracious growth...That would be a disaster".[26] Despite his agreement and concession to include ethanol as part of its energy policy, Chavez held the position that any biofuel regime using agricultural produce as energy feedstocks instead of food empowers capitalist exploitation.

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[23] Ibid.
[24] Hemscott Group Ltd, Clendenning, and Vergara, *Friction between Chavez, Silva on Ethanol.*
[25] Bradley and Kennedy, "South American Leaders Agree to Promote Biofuels."
[26] Carmen Gentile, *Chavez Warns of Biofuel Disaster* (August 9 2007); available from http://www.upi.com/International_Security/Energy/Analysis/2007/08/09/analysis_chavez_warns_of_biofuel_disaster/5011/.

Venezuela's resistance to the emerging global biofuels regimes reveals the importance of politics, national resources, and international relations as socio-technical regimes reach beyond national borders. Latin America is a prime location for growing sugar cane as an ethanol feedstock, and although Brazil has been a leader in biofuels production for three decades, other countries are only now entering the biofuels market. The reasons for this delay can mostly be attributed to low population densities and higher poverty levels, slow uptake of global environmental trends, and influence of American foreign policy directions. There are forty-one countries in this region that, for the most part, tend to follow American leadership in many political and economic policy areas. The United States has implemented a strong interventionist foreign policy platform in the region, and has a colourful history of funding political counter-forces in many Latin American countries.[27] This history has shaped the political and economic development of the region, and the socio-technical landscape of the region must be seen through these contexts. Even though Brazil's early activity in ethanol and the success of its biofuels regime suggests higher potential for sustainable energy in the region, biofuels as a sustainable energy option is a minor factor in relation to local concerns of most Latin American countries. However, local concerns with ethanol and biodiesel in the dominant regimes have increased alongside the global diffusion of biofuels to international markets. In particular, these concerns focussed on the local effects of biofuels production which, when considered together, reflect a growing critique of their sustainability.

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[27] Richard L. Harris, "The Global Context of Contemporary Latin American Affairs," in *Capital, Power, and Inequality in Latin America*, ed. Sandor Halebsky and Richard L. Harris (Boulder, CO: Westview Press, 1995).

Local Sustainability

The expectation of sustainability at a "local" level often differs from sustainability in a "global" sense. Sustainability can be viewed in terms of individual identity[28] or global perceptions.[29] In terms of spatial and temporal considerations, sustainability can be measured in terms of *here and now* as well as *everywhere and forever*.[30] "Local" sustainability can also imply local governance, such as the routing of decision-making activities through community-based, municipal, or regional administration[31] rather than national or international leadership.[32] In a similar manner, local environmental administration can either be centralised or de-centralised, and might include voluntary actors, public-private partnerships, or other non-conventional forms of governance.[33] "Local" can define what constitutes the relevant and appropriate level of knowledge held by actors, such as localised traditional knowledge vs. universal scientific knowledge.[34] In short, determining "local" sustainability requires more than measuring discrete effects on economic, environmental or social policy areas, but must also assess sustainability in terms that may be neither universally understood as "global", nor transferable beyond

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[28] Mitchell Thomashow, *Ecological Identity: Becoming a Reflective Environmentalist* (Cambridge: The MIT Press, 1995).
[29] Mitchell Thomashow, *Bringing the Biosphere Home: Learning to Perceive Global Environmental Change* (Cambridge: The MIT Press, 2002).
[30] Mathis Wackernagel and William Rees, *Our Ecological Footprint: Reducing Human Impact on the Earth* (Gabriola Island, BC: New Society Publishers, 1996).
[31] Susan Batty, "The Politics of Sustainable Development," in *Planning for a Sustainable Future*, ed. Antonia Layard, Simin Davoudi, and Susan Batty (New York: Spon Press, 2001), David Gordon, *Green Cities: Ecologically Sound Approaches to Urban Space* (Montréal: Black Rose Books, 1990).
[32] Dwivedi et al., *Sustainable Development and Canada: National and International Perspectives*.
[33] Mary Louise McAllister, *Governing Ourselves? The Politics of Canadian Communities* (Vancouver: UBC Press, 2004).
[34] Marybeth Long Martello and Sheila Jasanoff, "Globalization and Environmental Governance," in *Earthy Politics: Local and Global in Environmental Governance*, ed. Sheila Jasanoff and Marybeth Long Martello (London: The MIT Press, 2004).

"local" perspectives.

Identifying and evaluating sustainability is problematic, as some indicators lend themselves more readily to measurement and can be accurately calculated, such as water availability and consumption. Other indicators, such as those reflecting the success of local decision-making or changing consumption patterns cannot always be definitively demonstrated. Governments can employ any number of reasons to enact local regulations and guidelines. For instance, justifications for allowing unsustainable water consumption can include increasing tax revenues by attracting or retaining investment and development.[35] Governments can also include reactive decisions stemming from a lack of awareness of the availability of local water resources or a focus on short-term gain rather than long-term implications.[36] The development of these decisions and rules are more often influenced by local needs rather than global factors, but distinguishing the "local" from the "global" is becoming increasingly difficult.

The characteristics of biofuels are such that "local" and "global" factors are often intertwined. For example, the limited availability of arable land and related crop competition has been intensified by the global interest in first generation biofuels.[37] Other considerations, such as co-product saturation[38], limited environmental benefits[39], and

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[35] Harto, Meyers, and Williams, "Life Cycle Water Use of Low-Carbon Transport Fuels.", Jerald L. Schnoor et al., *Water Implications of Biofuels Production in the United States* (Washington, DC: National Academy of Sciences, 2008).

[36] Gaile Whelan Ens, *Town of Minnedosa Water Supply Upgrade Project (Husky Ethanol Plant) - Public Registry File #5205.00* (Manitoba Wildlands, 2006 [cited 13 November 2006]); available from http://manitobawildlands.org/water_projects.htm, Gregory Yamamoto, "Besides Water, There Are Other Issues," *The Honolulu Advertiser*, 5 October 2006 2006.

[37] Fabiosa et al., "Land Allocation Effects of the Global Ethanol Surge: Predictions from the International Fapri Model."

[38] Jean-Christophe Bureau et al., "A Quantitative Assessment of the Determinants of the Net Energy Value of Biofuels," *Energy Policy* 38, no. 5 (2010).

increasing demand for transport fuel[40] have contributed to the appearance of adverse consequences from the global trade in first generation biofuels. This is particularly the case when biofuels entrepreneurs attempt to squeeze out further productivity under poor conditions. Some crops, such as grains for ethanol or vegetables and oil seeds for biodiesel, require ideal soil conditions to maximise limited growing seasons.[41] While this is less of a problem in regions with longer growing seasons or more productive feedstocks like sugarcane or palm oil, achieving high ratios of energy input to biomass output is a challenge for most jurisdictions.

Large-scale production methods of first generation biofuels are ultimately limited by the availability of land and water and the ability of the ecosystem to bear the brunt of additional energy input required for cultivation, chemicals application, harvesting rates, etc.[42] While Brazil, the United States, and the European Union currently produce enough biofuels for use as a petroleum complement (i.e., as an additive or fuel extender) for domestic markets, significantly higher production levels to meet higher blend mandates or to supply more or larger export markets would rapidly negate economic and

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[39] D. Rajagopal, G. Hochman, and D. Zilberman, "Indirect Fuel Use Change (Ifuc) and the Lifecycle Environmental Impact of Biofuel Policies," *Energy Policy* 39, no. 1 (2011), Nicolas Vuichard, Philippe Ciais, and Adam Wolf, "Soil Carbon Sequestration or Biofuel Production: New Land-Use Opportunities for Mitigating Climate over Abandoned Soviet Farmlands," *Environmental Science & Technology* 43, no. 22 (2009).

[40] P.W. Tittmann et al., "A Spatially Explicit Techno-Economic Model of Bioenergy and Biofuels Production in California," *Journal of Transport Geography* 18, no. 6 (2010).

[41] Warren Mabee, *Ethanol Backlash Masks a Bigger Energy Problem* (Globe and Mail, March 31, 2011 2011 [cited April 17 2011]); available from http://www.theglobeandmail.com/report-on-business/economy/economy-lab/daily-mix/ethanol-backlash-masks-a-bigger-energy-problem/article1964509/, Dennis Rogoza, *Biofuels and Commodity Turbulence* (Climate Change Central, 2008 [cited 24 November 2008]); available from http://www.climatechangecentral.com/publications/c3-views/october-2008/biofuels-and-commodity-turbulence.

[42] Poirier and Peckham, "Crops Will 'Never' Yield Enough to Replace Petroleum: Study."

environmental benefits.[43] For example, the recent shift to higher production levels has already increased land prices and encouraged some countries to allow the transformation of forests and wetlands to cultivated land. It has also shifted farming practices from rotational to static planting and from mixed agriculture to homogeneous crops, the effects of which include diminished soil quality, increased use of water resources, and higher rates of fertiliser, pesticide, and herbicide applications.[44]

There are numerous examples of the consequences of large scale production to local sustainability, such as: the deforestation of tropical forests to create more cropland for palm oil in Indonesia and soya production in Brazil[45]; environmental problems in developing countries caused by higher biofuels imports by European Union Member States[46]; and the threat to biodiversity caused by the United States corn sector.[47] Although the policy goals of accelerating rural development and enhancing energy security are met, the transformation of these natural ecosystems is so dramatic that they may be irreplaceable in an anthropocentric time frame. Thus, even though these benefits and consequences occur in "local" geographic locations, their impacts are of a significantly larger scale. "Local" effects have become "global" concerns that extend beyond national boundaries and across generations. As a result, the large scale production of first

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[43] Wakeley et al., "Economic and Environmental Transportation Effects of Large-Scale Ethanol Production and Distribution in the United States."

[44] François Cardinal, *Québec Abandons Ethanol* (La Presse, November 9 2007 [cited December 4 2008]); available from http://www.fcpp.org/main/publication_detail.php?PubID=2046, Hertel, Tyner, and Birur, "The Global Impacts of Biofuel Mandates.", Organisation for Economic Co-operation and Development, "Economic Assessment of Biofuel Support Policies."

[45] Organisation for Economic Co-operation and Development, "Economic Assessment of Biofuel Support Policies."

[46] Paul Taylor, "Eu to Toughen Environment Criteria for Biofuels," *Reuters*, January 15 2008.

[47] Organisation for Economic Co-operation and Development, "Economic Assessment of Biofuel Support Policies."

generation ethanol and biodiesel have become increasingly criticised from both "local" and "global" perspectives as not being sustainable.

Government decision-makers in the three biofuels regimes continue to present these production regimes as beneficial in terms of rural development, energy security, and climate change, but they have not yet determined whether or not the benefits of biofuels are worth the risk to local ecosystems and communities. For example, the debate over fossil fuel content, energy balance, and greenhouse gas emissions is still unsettled[48], and some still argue the need to utilise biofuels as "low carbon" transport fuels.[49] The concern with fossil energy inputs, net energy balance, and greenhouse gas emissions are fundamentally "global" issues. Transportation biofuels may help achieve the long term aspiration of mitigating climate change, but the immediate effects of large scale biofuels production on local communities will change current land-use patterns, affect water quality, and alter property rights. These local sustainability issues are more immediate than concerns with climatic change, and "local" communities will be affected long before the "global" community stabilises greenhouse gas emissions levels. As such, local issues can be expected to become more politically and economically salient as resources are depleted and social structures are transformed. Cattle producers, environmentalists, social justice and human rights activists, and others maintain that biomass transportation fuels are neither renewable nor economical, and they continue to oppose biofuels production in

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[48] Robert K. Niven, "Ethanol in Gasoline: Environmental Impacts and Sustainability Review Article," *Renewable and Sustainable Energy Reviews* 9 (2004).

[49] Farrell et al., "Ethanol Can Contribute to Energy and Environmental Goals." Many studies concur that corn ethanol requires between 60-80% of fossil energy units, with most of the 17% of fossil energy input comes from natural gas and coal from the electricity used during production. See International Energy Agency, "Biofuels for Transport: An International Perspective," 58.

their communities.[50]

The matter of sustainability, therefore, is connected with the scale of effects. The contestation over the sustainability of biofuels is primarily due to the perspectives and values of relevant social groups. Both advocates and critics tend to conflate "local" knowledge with "global" application. For instance, advocates too often dismiss opposition with arguments that adverse "local" effects are unique cases that do not describe the larger experience, or that "local" social, environmental and economic costs are necessary in order to secure the "global" benefits that biofuels will provide. Similarly, critics tend to evaluate biofuels production from one perspective (e.g., ethanol produced from subsidised corn feedstocks grown in the American mid-west) and apply this model as an argument against all scales of biofuels production.

The distinction between "local" effects and "global" application is necessary if we are to achieve sustainable biofuels. Given the failure to meet international greenhouse gas reduction targets, it seems that the "only practical path to achieving significant emissions reductions is to find an alternative to gasoline as a fuel".[51] The evaluations of net energy balance discussed in chapter two argued that biofuels reduced greenhouse gas emissions, and this view was supported by biofuel advocates who agreed that "[b]ioethanol is perhaps the most attractive short- to medium-term alternative for gasoline in cars and

[50] For example, a local activist cited numerous academic, public and private industry studies cautioned against transportation biofuels. See, Ken Sigurdson, "Ethanol: A Costly Misadventure," (Winnipeg, MB: National Farmers' Union, 2007). Presented at University of Winnipeg Environmental Studies Program, "Biofuels: Solution or Problem?."

[51] Lester B. Lave, Michael W. Griffin, and Heather MacLean, "The Ethanol Answer to Carbon Emissions," *Issues in Science and Technology* Winter (2001): 74.

light trucks…"[52] However, this "global" application has been challenged by strengthening critiques against first generation biofuels during the 2000s, which seems to have encouraged the biofuels industry to re-evaluate large scale production processes by seeking different energy feedstocks, better production technology, increased cost effectiveness promised by advanced biofuels[53], and the development of high-density feedstock production through genetic modification.[54]

These "local" critiques involve emerging issues that have not yet been subjected to the same degree of analysis as the technical performance, economic considerations, energy content, and emissions levels. Yet these emerging concerns have become more sophisticated insofar as they seek to understand the implications for sustainability at both local and global levels. The critiques extend beyond energy security, rural development, and climate change to explore other issues with the sustainable development of biofuels. These include land use patterns, soil quality, water use patterns and quality, biodiversity and air pollution. The remainder of this chapter provides an overview of each of these areas of concern, and suggests that these emerging criticisms need to be addressed in order to achieve sustainable biofuels.

Land Use Patterns

One of main obstacles to sustainable global biofuels is finding enough land to

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[52] Cortez et al., "Considerations on the Worldwide Use of Bioethanol as a Contribution for Sustainability," 509.

[53] Iogen Corporation, *Cellulose Ethanol Is Ready to Go: Iogen Producing World's First Cellulose Ethanol Fuel.*

[54] Bill Tomson, *Monsanto Making Progress on the Perfect Corn for Ethanol* [company news] (OsterDowJones, 17 December 2002 [cited 13 November 2006]); available from http://www.monsanto.co.uk/news/ukshowlib.phtml?uid=6897.

grow biofuel feedstocks.[55] Land use is not constant but evolves over time. The settlement of the North American prairies, for example, demonstrates how large tracts can be dramatically transformed in a relatively short period. Land has multiple uses that, in addition to the many different forms of human activity, also include providing animal and plant habitat.[56] While projections on changing land use patterns from food crops to energy crops is inexact, assumptions are based on *established* technologies instead of *leading* or *pilot* technologies. As such, projections on land use patterns tend to exclude the newest technologies and most recent developments in biofuels production, but they do offer a basis for analysis using accumulated data to assess the *type* and *intensity* of land use patterns.

According to the International Energy Agency, in order to achieve 2020 scenarios in which 10% of gasoline is displaced by biofuels in the United States, 14% of total cropland (i.e., the amount of land area expected to be planted with field crops) would have to be converted to ethanol energy crops.[57] In the European Union, 8% of arable land for ethanol would be required by 2020.[58] The projections for biodiesel are generally higher: both Europe and America would have to dedicate about 30% of total cropland to displace 10% of diesel fuel consumption by 2020. To achieve 10% biofuel content in both gasoline and diesel fuels by 2020, the United States would require up to 45% of its cropland to be dedicated to biofuels feedstocks. Although it is not expected to overly

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[55] The Royal Society, "Sustainable Biofuels: Prospects and Challenges," (London: The Royal Society, 2008).

[56] Art Wilson and Allen Tyrchniewicz, "Agriculture and Sustainable Development: Policy Analysis on the Great Plains," (Winnipeg: International Institute for Sustainable Development, 1995).

[57] International Energy Agency, "Biofuels for Transport: An International Perspective."

[58] Ibid., 130.

influence land availability and would not lead to intensified production[59], the European Union would still require almost 40% of its land to achieve a 10% blend with both biofuels.[60] However, estimates for land use vary widely depending upon feedstock types, fuel blend, cultivation practices, conversion processes, types of energy input sources, and benefits of biofuel co-products. For instance, to achieve a 5% ethanol blend from sugar beets would require the full use of 10% of the arable land. In contrast, a 5% blend made from cellulosic biomass through second generation conversion processes would utilise all the straw from wheat grown on up to 45% of the arable land in the European Union.[61] Like most effects-based assessments, these measures differ depending on research assumptions. The key point, however, is that the amount of land required for biofuels feedstock production will rise significantly as the global biofuels industry expands to supply larger markets for ethanol and biodiesel.

The Organisation for Economic Co-Operation and Development predicted that the short term changes in land use will be driven by private landowners as they seek to maximize profits.[62] As energy crop prices rise, more land is likely to be shifted toward energy crops. For the same reasons, producers will look toward fallow lands or the cultivation of marginal areas by draining wetlands or opening up tracts of forest. Around the world, national governments have already had to address dramatic shifts in land use patterns caused by increased biofuels production. Deforestation of tropical forests in

[59] European Commission, "The Impact of a Minimum 10% Obligation for Biofuels Use in the Eu-27 on Agriculatural Markets," in *Impact Assessment of the Renewable Energy Roadmap - March 2007* (Brussels: Directorate-General for Agriculture and Rural Development, 2007).
[60] International Energy Agency, "Biofuels for Transport: An International Perspective."
[61] The Royal Society, "Sustainable Biofuels: Prospects and Challenges,", from Woods and Bauen, 2003.
[62] Richard Doornbosch and Ronald Steenblik, "Biofuels: Is the Cure Worse Than the Disease?," (Paris: Organisation for Economic Co-Operation and Development, 2007).

Brazil and Indonesia has prompted the global community to question the viability of biofuels production in those countries. The European Commission proposed in a 2008 Directive to restrict biofuels production from materials gleaned from land with "high carbon stock", including wetlands, peat lands, or "continuously forested areas" of more than one hectare with trees higher than 5 meters and a canopy cover of more than 30%.[63]

The *type* of land use is only one part of land use patterns and environmental sustainability. The *intensity* of crop production is another important consideration that is revealed most readily through rising expectations of the potential for crop yields. Strong economic performance of energy crops will motivate agricultural producers to plant successive years of the same energy crop. Also, climate change and uncertain precipitation patterns are expected to affect the global food supply, while the competition between agriculture, forestry, and urban growth will physically transform the function of land. Attempts to increase productivity will similarly transform our expectations from land use[64], which bring forth an important set of environmental problems. While some crops are perennial and relatively maintenance free, most first generation feedstocks require substantial nutrients and irrigation. The reliance on chemicals application in agricultural practices has already increased crop yield dramatically in the last century, and a degradation of soil nutrients by repeated chemicals applications could stimulate a continual increase in the intensity in the use of fertilisers, herbicides and pesticides. Genetically modified varieties could be an alternative solution to chemicals as a way to

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[63] European Commission, "Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources."

[64] Danielle Murray, *Ethanol's Potential: Looking Beyond Corn* (Earth Policy Institute, 2005 [cited 10 November 2006]); available from http://www.earth-policy.org/Updates/2005/Update49.htm.

maintain or increase yields.[65] The type of use and the intensity of use are integral considerations of land use patterns, and are important indicators of sustainability of both locally produced and imported biofuels.

Soil Quality

Nutrient loss, contamination, and erosion are major influences on soil quality from increased production levels of energy crops. In order to ensure arable lands are available for food and energy crops, soil must be used efficiently and sustainably. The 2007 *Roadmap for Bioenergy and Biobased Products in the United States* highlights sustainable feedstock production as an integral element for a bioenergy economy, and calls for further research to reduce energy inputs, maintain soil fertility, develop methods for residue removal and cultivation practices, and to increase productivity.[66]

Intensive agricultural practices cause over-extraction of soil nutrients, erosion and siltation, and increased salinity. These may ultimately contribute to desertification, which is a likely outcome from unsustainable biofuel production. This argument has been part of the biofuels debate for a generation.[67] The effects of increased biofuel production vary according the feedstock. Corn production contributes more to soil erosion in the United States than any other crop.[68] Moreover, intensive use of herbicides, pesticides and fertilisers are required to achieve successive, high-yield corn production. The application of high rates of chemicals increases soil acidity and the need to add lime to de-acidify

[65] Tomson, *Monsanto Making Progress on the Perfect Corn for Ethanol.*
[66] Biomass Research and Development Technical Advisory Committee, "Roadmap for Bioenergy and Biobased Products in the United States."
[67] Dovring, *Farming for Fuel: The Political Economy of Energy Sources in the United States*, 33-4.
[68] David Pimentel and Tad W. Patzek, "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower," *Natural Resources Research* 14, no. 1 (2005).

soil. Also, *humus*, a soil component composed of decomposing organic matter, declines as biomass residues are extracted. An insufficient amount of humus in soil exacerbates nutrient loss and increases the propensity for erosion. To ensure adequate soil composition, critics maintain that non-starch plant parts "should be decomposed and recycled to recover their [minerals and nutrients], and diminish the degree of unsustainability in...farming."[69] Residues left on the field after harvesting are an important form of surface cover that protect the soil from erosion by water and wind, but any activity disturbing ground cover will result in some degree of erosion. The challenge is to determine how much erosion can be tolerated. According to Sheehan et al., for example, in order to avoid "adverse effects on soil and water resources...approximately 40% of the residue can be collected under continuous corn production and mulch till, compared with 70% under no-till [farming methods]".[70] Nevertheless, as first generation ethanol production increased in the United States more land has been used for corn, either through crop substitution or from newly cultivated land.[71]

Incorporating crop residues back into the soil helps to maintain and improve soil quality. The question, however, is how much needs to be tilled back into the soil? That is, at which point does nutrient extraction outstrip soil regeneration? More critical opponents argue that the long-term needs of improving soil quality exceed any short-term benefit

[69] Patzek, "Thermodynamics of the Corn-Ethanol Biofuel Cycle."

[70] Sheehan et al., "Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol."

[71] Crop substitution occurs more often than cultivating new land, but causes higher rates of nutrient depletion and soil degradation. See: Liz Marshall and Suzie Greenhalgh, "Beyond the Rfs: The Environmental and Economic Impacts of Increased Grain Ethanol Production in the Us," in *WRI Policy Note* (Washington, DC: World Resources Institute, 2006).

from residue extraction for biofuel crops.[72] Others hold a more pragmatic perspective, and argue that some degree of erosion is inevitable. In short, a large corn ethanol market will exacerbate soil quality problems in the United States, but these problems may fall within "acceptable" limits. Lal and Stewart show that the debate on acceptable balance between agricultural production and soil degradation is contentious, and is caused primarily by a predominance of "an emotional rhetoric rather than a precise and quantifiable scientific entity".[73] Human use, primarily through agriculture, causes varying degrees of soil erosion, decline in organic matter, salinity, and acidification. Soil degradation can be reduced by changes in agricultural practices, but without economic incentives such changes are unlikely to occur before extensive decline in soil resources.[74] The requirements of local ecosystems tend to be a secondary concern when producers face the prospects of increased production and potential access to global biofuels markets.

Water Resources

Unsustainable water use by biofuels production facilities can degrade and deplete ground and surface water resources. Degradation can occur when surface water and aquifers are subject to over-application of fertilisers, herbicides and pesticides. Water quality is also affected by untreated effluent from biofuels production facilities. Water resources can be depleted due to over-extraction for irrigation of energy crops or for

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[72] R. Lal, "Crop Residues as Soil Amendments and Feedstock for Bioethanol Production," *Waste Management* 28, no. 4 (2008).

[73] Lal, R. and B. A. Stewart. "Need for Action: Research and Development Priorities", Advances in Soil Science. Vol. 11. 1990, quoted in Wilson and Tyrchniewicz, "Agriculture and Sustainable Development: Policy Analysis on the Great Plains."

[74] Ibid.

water-intensive biofuel conversion processes. Sugarcane operations require significant water resources. Irrigation is not needed in areas with sufficient rainfall[75], but establishing sugarcane farms in drought-prone regions can be a politically sensitive issue, as they divert local water use from current applications to industrial agriculture.[76] In the United States, around 15% of all corn crops were irrigated in 1997.[77] In 2003, corn for grain or seed continued to be the most heavily irrigated crop at 19% of all irrigated land in the United States. This translates into about 10 million acres (one quarter of 1% of the total arable land in the United States) that required upwards of 16.5 million acre-feet[78] of water per year.[79] Extrapolating for an increase in energy crop growth and additional farmland, any increase in irrigation levels will require a proportionate increase of water extraction.[80] This may prove to be unsustainable for on-farm wells, causing farmers to turn to off-farm water suppliers, which negatively alters the economics of energy crops by increasing input costs.

Aside from the increased draw upon water resources through irrigation or effects on water resources from chemical application, water consumption for ethanol manufacture is high. This leads to concern over actual or potential water shortages in

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[75] Francisco Rosillo-Callé and Arnaldo Walter, "Global Market for Bioethanol: Historical Trends and Future Prospects," *Energy for Sustainable Development* 10, no. 1 (2006): 29.

[76] Yamamoto, "Besides Water, There Are Other Issues."

[77] Pimentel and Patzek, "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower."

[78] acre-foot = the volume of water that will cover an area of one acre to a depth of one foot; equal to 43,560 cubic feet or 7,758 barrels or 325,829 US gallons.

[79] USDA, "2002 Census of Agriculture," in *Farm and Ranch Irrigation Survey (2003), Vol. 3, Special Studies Part 1* (United States Department of Agriculture, 2004), xx.

[80] T. W. Patzek, *The Real Corn-Ethanol Transportation System* (2006 [cited 13 November 2006]); available from http://petroleum.berkeley.edu/patzek/BiofuelQA/Materials/TrueCostofEtOH.pdf.

places as diverse as Hawaii[81] and Manitoba[82]. In addition, excess biomass is flushed with water to produce stillage as a co-product from grain-based ethanol production. Water use for this process has been measured as being between 6 to 15 times higher than would occur during sugar cane production[83], which has had its own water pollution problems in the past.[84] Recent attempts have been made to recapture stillage and other effluent to produce fertilisers as a value-added co-product[85], while grain-based stillage has been transformed into high-protein animal feed.[86]

Increased biofuel production will have demonstrable effects on water resources and their availability, as "[i]ncreased usage of biofuels will raise demand for water, which could, in turn, negatively impact on water availability for other uses."[87] Efficient water use will be an important area for technological improvement, and success in this largely will depend on the type of feedstocks used for biofuels. Access and availability of water resources will undoubtedly constrain how, and where, biofuels will appear as a viable energy alternative. Although current biofuels production in the United States has only marginally increased stress on water supplies, "significant acceleration of biofuels production could cause much greater water quantity problems depending on where the crops are grown. Growing biofuel crops in areas requiring additional irrigation water

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[81] Sean Hao, "Enough Water for Ethanol?," *The Honolulu Advertiser*, 5 October 2006 2006.

[82] Ens, *Town of Minnedosa Water Supply Upgrade Project (Husky Ethanol Plant) - Public Registry File #5205.00.*

[83] Rosillo-Callé and Walter, "Global Market for Bioethanol: Historical Trends and Future Prospects."

[84] Rosillo-Calle, "Liquid Fuels."

[85] Rosillo-Callé and Walter, "Global Market for Bioethanol: Historical Trends and Future Prospects."

[86] Heath, *Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels,* Husky Energy Inc., *Minnedosa Ethanol* (Husky Energy Inc., 2006 [cited 31 October 2006]); available from http://www.huskyenergy.ca/majorinitiatives/minnedosaethanol/.

[87] The Royal Society, "Sustainable Biofuels: Prospects and Challenges."

from already depleted aquifers is a major concern".[88] In fact, the "growth of biofuels in the United States has probably already affected water quality because of the large amount of [nitrogen and phosphorous] required to produce corn...If projected future increases in the use of corn for ethanol production do occur, the increase in harm to water quality could be considerable".[89] This is particularly true for irrigated crops in Midwestern states, where "groundwater is being mined much faster than the recharge rate".[90] As discussed in further detail below, the effects of biofuels production on water resources is closely related to concerns with global food supply and food security.

Biodiversity

Land, soil and water are the foundations of ecosystems, and changes in these components will alter the diversity and population levels of plants and animals. Biofuels production entails two potential threats to biodiversity. First, there can be an overall decline in the population levels of native plant and animal species. This can result from three causes that are often interrelated: changes to land use (discussed above), the replacement of diverse plants by industrial-scale monoculture, and the impact of chemicals on the reproductive abilities of existing plant and animal species. Second, the potential alteration of existing energy crops via genetic modification could introduce novel species to local ecosystems, the impact of which has not yet been sufficiently explored. While the 2007 United States "Roadmap for Bioenergy..." stresses the

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[88] Schnoor et al., *Water Implications of Biofuels Production in the United States.*
[89] Ibid.
[90] Patzek et al., "Ethanol from Corn: Clean Renewable Fuel for the Future, or Drain on Our Resources and Pockets?."

importance of identifying and developing energy crops suitable to biofuel production with special consideration to yield rates, feedstock properties, and growth cycles, it also recognises that the "lack of plant breeders willing to assume the associated risk is inhibiting major advances in plant sciences and new crop development".[91] There are both threats and benefits from the use of genetically-modified organisms, and the literature on genetic modification is extensive, uncertain and rife with rhetoric on both sides of the argument.[92] The ensuing discussion in this section concentrates on ecosystem integrity as it relates to biodiversity, but sets aside the debate over genetic modification.

A large portion of the accelerated decline of biodiversity around the globe is due to the conversion of habitat by agriculture and forestry sectors.[93] Because land use patterns are continually evolving with human societies, new practices invariably affect natural systems. Biofuels production, as a new form of "agro-ecosystem"[94], can be expected to affect biodiversity and population levels of natural species. The outcome will depend upon the type of feedstock, density, duration and intensity of growth, and overall distribution effects on the landscape. Recognising the multiple drawbacks of deforestation and monoculture farming, Brazil has already legislated that 10% of all new sugarcane fields must be dedicated to non-cane uses and this target could be increased to 15-20%.[95] Such efforts to maintain biodiversity may limit monocultural industrial farming practices, but may also increase the total area of land required for energy crop

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[91] Biomass Research and Development Technical Advisory Committee, "Roadmap for Bioenergy and Biobased Products in the United States."

[92] Henry Miller and Gregory Conko, *The Frankenfood Myth: How Protest and Politics Threaten the Biotech Revolution* (Westport, CT: Praeger Publishers, 2004).

[93] The Royal Society, "Sustainable Biofuels: Prospects and Challenges."

[94] Ibid.

[95] Rosillo-Callé and Walter, "Global Market for Bioethanol: Historical Trends and Future Prospects," 29.

production.

In other cases, biofuels production might be able to mitigate or halt the decline of biodiversity in local ecosystems. For instance, biodiesel can provide an alternative energy source for heating and cooking, which could reduce the need for wood. In India, Sri Lanka, and Thailand, wood harvesting for heating and cooking have "produced a halo of deforestation around roads, towns, and cities".[96] Transforming these deforested woodlots into energy crops could reduce further deforestation in other areas, but most discussions on biofuels and biodiversity tend to focus on real and observed threats. Sustainable agriculture practices emphasise the need to reserve sufficient habitat for biodiversity, minimise the ecological footprint of biofuel production, and to choose biofuels feedstocks that sequester high amounts of carbon or that possess a proven negative carbon balance. Groom, Gray and Townsend use these principles to evaluate the corn-based ethanol industry in the United States, and find it to be "the worst among the alternatives... [although it] is most advanced for commercial production in the United States".[97]

Air Pollution

Planting and harvesting energy crops requires farm machinery, and the biofuels production process requires energy to convert biomass into liquid fuel. Energy consumption results in emissions from the vehicles and machinery used in crop production and their conversion. Adverse effects on air quality can be reduced by using biofuels in farm equipment and by restricting the burning of biomass left over after

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[96] UN-Energy, "Sustainable Bioenergy: A Framework for Decision Makers."

[97] Martha J. Groom, Elizabeth M. Gray, and Patricia A. Townsend, "Biofuels and Biodiversity: Principles for Creating Better Policies for Biofuel Production," *Conservation Biology* 22, no. 3 (2008).

harvest.[98]

During the conversion process, biofuels production facilities relying on petroleum or coal for energy input contribute higher levels of air pollution than facilities employing non-combustible forms of energy, such as hydroelectricity or nuclear power. Thus, air quality effects from biofuels depend on numerous factors that can differ along the production chain. Where early technical assessments of biofuels focussed primarily on emissions at the tailpipe, they tended to avoid analyses of most upstream effects (i.e., from energy inputs) and downstream emissions. Even though assessments and outcomes will vary, most agree that biofuels tend to perform better than petroleum transport fuels at the tailpipe but still contribute to air pollution, emit greenhouse gases, as well as formaldehydes, acetaldehydes, and others.[99]

Other Sustainability Issues

The above considerations on the environmental effects of biofuels are linked to other issues with a broader effect on societies and economies. The "food vs. fuel" debate and the threat to food security was perhaps the most contentious socio-economic issue, but the potential re-arrangement of land ownership might have even greater long-term effects. Thus, food security and property rights suggest an emergence of new socio-technical functions associated with the expansion of global biofuels.

Food security

One of the most public and emotional aspect of the biofuels debate, the rise of

[98] UN-Energy, "Sustainable Bioenergy: A Framework for Decision Makers."
[99] The Royal Society, "Sustainable Biofuels: Prospects and Challenges."

global biofuels and the concern with food security juxtaposes the transformation and use of agricultural resources. Advocates claim that first generation biofuels use grains, fruits and vegetables as alternative products that increase farm incomes and contribute to national policy objectives. Critics argue that the shift of food resources away from poor and hungry people toward satisfying the mechanical appetites of high-consumption societies is unethical. This critique of the industrialisation of the food industry is exacerbated by the perception of biofuels facilities as industrial (i.e., non-agricultural) rather than as part of an integrated agricultural production system.[100] In short, the emerging biomass energy market encroaches upon the traditional emphasis of food production for nourishment and health while re-assigning the socio-technical function of farming from food production to energy production. Moreover, this seems to occur mainly at the expense of people in the developing world.

The United Nations identifies four dimensions of food security. *Availability* involves ensuring that an adequate supply of food is produced to sustain the global population. *Access* can be reduced if the price of food exceeds the ability of lower-income food purchasers to pay. *Stability* refers to the continuity of food production over a long period of time. *Utilisation* of food entails the nutritional components of food production and consumption, and is closely linked to the health of individuals.[101] Food security is threatened wherever the integrity of any one of these dimensions is diminished. The concern with biofuels within these parameters is that a shift away from

[100] Henry Lee, William C. Clark, and Charan Devereaux, "Biofuels and Sustainable Development: Report of an Executive Session on the Grand Challenges of a Sustainability Transition," (San Servolo Island, Venice, Italy: Sustainability Science Program, Centre for International Development, Harvard University, 2008).

[101] UN-Energy, "Sustainable Bioenergy: A Framework for Decision Makers."

food production and toward energy feedstocks could undermine the performance of the global food system and contribute to world hunger.

One of initial challenges for first-generation biofuels was the "entangling" of energy and agricultural markets. The Organisation for Economic Co-Operation and Development suggested that biofuels feedstocks and food products will face related price effects due to crop substitutability because all crops "tend to compete for the same inputs".[102] Furthermore, a larger biofuels market would likely increase the net effect of rising oil prices on agricultural markets. Higher oil prices would increase the overall cost of agricultural operations, causing increased prices for both food and biofuels. As oil prices climb, biofuels are expected to become a more desirable option that would stimulate a shift away from food production and toward biofuel production. This would place differential market pressure on food products and make them even more expensive.[103] As the price of food increases alongside a large expansion of biofuels production, it is very possible that all four dimensions of food security could be compromised.

While it is true that food and biofuels compete for the same inputs, there are other causes for food insecurity.[104] The United Nations Food and Agriculture Organisation noted a 40% increase in food prices in 2002 alone, attributing this to a variety of factors such as adverse weather, agricultural input costs (fuel, fertilisers, chemicals), higher aggregate demand, out-dated production practices, lagging research and development,

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[102] Doornbosch and Steenblik, "Biofuels: Is the Cure Worse Than the Disease?."
[103] Ibid.
[104] Mabee, *Ethanol Backlash Masks a Bigger Energy Problem.*

decaying infrastructure (roads and irrigation), as well as regulatory standards for energy use and environmental protection.

One can assume that inefficient distribution systems are equally as challenging as substitution effects between food and energy crops. Nevertheless, although biofuels are not the sole threat to food security, the expansion of biofuels production via first generation methods affects agricultural food production, distribution and consumption. The emerging socio-technical function of food as an energy feedstock is considered by many to be unjust, and therefore incongruent with significant aspects of social structures and socio-technical systems.

Property Rights

The development of global biofuels has tended to alter the structure of agricultural production by concentrating ownership in the hands of a few large corporate entities. Biofuels production can contribute to local development, but they can also "drive the world's poorest farmers off their land and into deeper poverty".[105] While some countries have sought to foster local and/or alternative forms of ownership, such as small-scale operations or co-operative ventures, the fastest growing components of the biofuels industry are large multinational corporations. The access to large amounts of investment capital, organisational capacity, and international markets enables large corporations to exercise their advantage over small local biofuels producers.

The ability of large corporations to control a large share of the market enables an intensification of production in ways that limit or undermine some forms of participation

[105] UN-Energy, "Sustainable Bioenergy: A Framework for Decision Makers," 24.

in the industrial and family farm operations of the biofuels sector.[106] The mobilisation of investment and government support to purchase land, or to mechanise agricultural production of energy feedstocks, can similarly exclude small farmers from participating in or benefitting from the expansion of biofuels. For example, Hall et al. compare the concentration of ethanol production with the dispersed biodiesel production in Brazil in the 1990s and 2000s.[107] They found that the large-scale ethanol exacerbated poverty and social exclusion. Although a more dispersed model of biodiesel production was designed to avoid these problems, it is nonetheless vulnerable to international pressures that re-direct social programs and environmental incentives toward mass production to achieve economies of scale.[108] Large corporations can also exclude local access by farmers through economic measures, such as the land speculation and rising real estate prices in Africa, Latin America, Central Asia and Southeast Asia that gained media attention in 2008-2009.[109]

The global biofuels industry will involve a mix of production types and vary from small to large scale operations, but the inclusion or exclusion of small farms and the emerging challenges to traditional access and legal property rights will influence sustainable local ownership. In this way, global biofuels may further divide rural populations from their land base, effectively exacerbating rural instability and

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[106] Bernardo Mancano Fernandes, Clifford Andrew Welch, and Elienai Constantino Goncalves, "Agrofuel Policies in Brazil: Paradigmatic and Territorial Disputes," *Journal of Peasant Studies* 37, no. 4 (2010).

[107] Jeremy Hall et al., "Brazilian Biofuels and Social Exclusion: Established and Concentrated Ethanol Versus Emerging and Dispersed Biodiesel," *Journal of Cleaner Production* 17 (2009).

[108] Foxon, Reed, and Stringer, "Governing Long-Term Social-Ecological Change: What Can the Adaptive Management and Transition Management Approaches Learn from Each Other?."

[109] Lorenzo Cotula et al., "Land Grab or Development Opportunity? Agricultural Investment and International Land Deals in Africa," (London/Rome: IIED/FAO/IFAD, 2009).

contravening the goals of a rural development and social cohesion as key policy concerns.[110]

Conclusion

Alongside the diffusion of global biofuels between 1998 and 2008, the opposition to first generation biofuels regimes became more international, while local criticism of ethanol and biodiesel became more sophisticated. The global diffusion of biofuels shifted the emphasis from national policy concerns (rural development, energy security, and greenhouse gas emissions) to the growth of international markets and trade harmonisation of ethanol and biodiesel. The trilateral pursuit of internationally tradable biofuels entails a more rigid institutional structure that could impede innovation for sustainable biofuels and prematurely stabilise the advancement of first generation biofuels technology.

The shift from a "local" solution for numerous policy goals to a "global" commodity indicates that 2007 was a watershed year for transportation biofuels. The US-Brazil ethanol accord and the Trilateral Task Force White Paper strengthened trade relationships between the dominant biofuels regimes, harmonised product standards for internationally tradable biofuels, and politicised biofuels on the international stage. Around this time, a wider debate on their sustainability increased while arguments against the adverse local environmental and social effects became more vigorous.[111]

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[110] Cotula, Dyer, and Vermeulen, "Fuelling Exclusion? The Biofuels Boom and Poor People's Access to Land."

[111] Biopact, *An in-Depth Look at Brazil's "Social Fuel Seal"* , Canadian Press Staff Reporter, "Bodiesel (Sic) Labelled Biggest Change in History of Farming," *Fort Frances Times*, 12 September 2006 2006, Etter, *Ethanol Craze Cools as Doubts Multiply* , University of Minnesota and INCAE Business School, "Biofuels, Carbon, and Trade: Leadership Challenges for the Interdependent

These critiques of global biofuels have preceded European Union and Brazilian efforts to re-define their biofuels strategy and address environmental and social sustainability. Similarly, the United States improved the federal Renewable Fuel Standard and has begun to address some of these same concerns. Nevertheless, sustainable biofuels requires a broader integration of economic, social and ecological sustainability of biofuels production as a core component of a long-term sustainable energy strategy. The main benefit of biofuels is that they are supposed to mitigate many of the unsustainable practices associated with conventional energy sources, such as the extraction of non-renewable materials (e.g., oil and gas, coal, nuclear material) and the irreparable transformation of natural ecosystems (e.g., hydro electricity, oil sands). Conventional energy involves a cycle of exploration, extraction, exhaustion and evacuation that is unsustainable, non-renewable, and degrades local economic, social, and environmental foundations. The promise of biofuels included the avoidance of these unsustainable activities.

Pursuing sustainable biofuels in the present global market will be difficult, and will require a more sophisticated approach to understanding the adverse effects on local ecologies by the international trade in biofuels. All three biofuels regimes invested large amounts of financial and administrative resources into their biofuels production strategies and the development of a multilateral regulatory framework on internationally compatible biofuels. As the next chapter will show, it is likely that these biofuels giants will seek to retain their existing production infrastructures in order to capitalise on these sunk costs,

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Americas.", University of Winnipeg Environmental Studies Program, "Biofuels: Solution or Problem?."

which can be expected to entrench first generation biofuels and inhibit the achievement of sustainable biofuels. Yet it is possible that the global diffusion of first generation biofuels is merely another stage along the trajectory of socio-technical evolution of ethanol and biodiesel toward becoming more sustainable in the future.

SEVEN – Trajectory of "Two World" Technologies

The biofuels regimes in Brazil, the United States, and the European Union mobilised substantial resources to significantly increase the production and consumption of first generation biofuels, but these biofuels expansion strategies followed different pathways based on different contexts and needs. However all three eventually sought access to global markets rather than ways to improve the configuration of biofuels in their own socio-technical systems. The focus on economic growth at the expense of environmental or social improvements motivated other countries to stimulate domestic production in order to pursue international trade and increase biofuels exports.[1] Yet the trajectory of first generation biofuels suggests that food-based ethanol and biodiesel are intrinsically limited in their capacity to supply large markets.[2]

As this chapter will show, current policy objectives have contributed to an unsustainable technological trajectory for biofuels in which the expansion of national biofuels programs created production infrastructures that will continue to supply a significant percentage of the biofuels market with first generation technology. This persistence of first generation biofuels favours large multinational producers, utilises traditional food crops and existing arable land, and employs production processes that require a considerable input of petroleum products. As such, the expansion of ethanol and biodiesel production may have been successful from commercial and public policy

[1] Sorda, Banse, and Kemfert, "An Overview of Biofuel Policies across the World."
[2] Babcock, Marette, and Tréguer, "Opportunity for Profitable Investments in Cellulosic Biofuels.", Hertel, Tyner, and Birur, "The Global Impacts of Biofuel Mandates."

perspectives, but the emergent socio-technical system based on the global diffusion of first generation biofuels is not sustainable.

This chapter argues that the biofuels regimes in Brazil, the United States, and the European Union have ultimately hindered the technological development of sustainable transportation biofuels. After evaluating the biofuels trajectory, this chapter asks if present socio-technical systems of first generation biofuels can be shifted to encourage sustainable biofuels. This prepares the discussion for the following chapter, which examines the Canadian case to reveal the challenges and opportunities for sustainable biofuels in the future.

The Persistence of First Generation Biofuels

The rapid expansion of biofuels production levels to supply global markets has resulted in an unsustainable technological pathway. The major biofuels regimes sought to develop export opportunities and create harmonious international markets. In the process, first generation biofuels became entrenched as the industry standard. While biofuels regimes varied in approach, they each focussed on the importance of the immediate economic benefits of international trade, which outweighed earlier considerations of rural development, energy security, and greenhouse gas emissions reduction. Although first generation biofuels technologies still required further refinement, the focus on internationally tradable biofuels created greater market certainty and technological stability. The transitions approach helps explain the primary role of the biofuels regimes and the technological "lock in" of unsustainable first generation ethanol and biodiesel.

The primary implication arising from the aggressive development of domestic industries by dominant producers is that first generation biofuels will retain a significant portion of the global market for renewable transportation fuel in the short term. This means that the development of sustainable biofuels will have to address and overcome the inefficiencies and other shortfalls of first generation biofuels while simultaneously developing advanced production methods. However, as established by the preceding discussion on the Trilateral Task Force and efforts to establish internationally tradable biofuels, the focus on trade instead of sustainability reduces the likelihood of incorporating specifications for social and/or environmental sustainability. The advantages gained from early diffusion of first generation biofuels in niche markets were largely economic, and initially overshadowed environmental and social considerations. Since first generation biofuels production processes rely on traditional food crops using existing arable land, they often compete with food production. Only a small percentage of the plant is used in distillation and oil extraction processes and much of the biomass is excluded. Only the kernels of corn are used to make ethanol, while the husks, cobs, stalks and leaves are discarded. Similarly, biodiesel feedstocks from canola/rape and soy are obtained from the seeds, while the plant matter is not usable in these production processes. Thus, there is a substantial amount of biomass throughput in the production process that increases the overall material flow.

The volumes of waste biomass to useful input increases with higher production levels, and a consistent profit margin is needed to absorb the costs associated with the processing and disposal of excess biomass. As production levels increase, the imperative for economic gain tends to occlude other social and environmental considerations in the short term. To do otherwise risks facing higher production costs and this can threaten the profitability of a niche technology that prematurely enters an established competitive market. First generation biofuels are successful under niche market conditions because the burdens associated with unsustainable production processes were alleviated by public resources, and they have not yet accounted for their full social and environmental costs. As they move to unprotected markets and compete with other transportation fuels, these costs must be included in the total cost of production if biofuels are to be sustainable. Biofuels produced sustainably would account for the use of public goods, such as environmental services or social effects. If these goods, services and effects are not included in the market price, their environmental and social costs will continue to be offset by state resources, such as direct monetary subsidies, through foregone revenue (i.e., tax incentives), or *de facto* subsidies from undervalued public goods. Thus far, most governments have chosen to partially displace the costs of biofuels production.[3]

Despite the negative effects associated with first generation biofuels production, companies have been able to leverage state resources and public goods in order to assist biofuels entering the global marketplace. However, these incentives have encouraged a premature expansion of first generation biofuels, and production facilities can be expected to either: 1) continue to contribute to the biomass energy market for decades to come, or 2) close production facilities as incentives are removed. Both scenarios are unsustainable.

We can find a prime example of the first scenario in the United States. The federal

[3] It is worthwhile to note that the offset of these costs with public resources follows the precedent set by other major energy sectors, including coal, oil and gas, nuclear, and large-scale hydroelectric.

Renewable Fuel Standard requires that a minimum of 250 million gallons of cellulosic ethanol will contribute about 3.3% of the 7.5 billion gallon production goal by 2013.[4] The United States "Twenty in Ten" initiative amended the Renewable Fuel Standard to require that 35 billion gallons of renewable and alternative fuels contribute to the domestic transport fuel market by 2017.[5] This target includes 9.5 billion gallons of first generation biofuels, which ensures that 40% of the total renewable fuel standard will continue to be supplied by existing technologies.[6] The United States produced over 13 billion gallons (50 billion litres) in 2010. This supply of first generation transportation biofuels will compete with advanced biofuels which will be hampered by lower market share, higher production costs, and more growing pains associated with technical development and refinement. By establishing a significant corn-based ethanol infrastructure, the United States can expect its first generation biofuel production infrastructure to continue for the lifespan of these production facilities.

While the intent was to move toward second generation biofuels as a replacement strategy for first generation production, the initiative entrenched 50 billion litres of unsustainable first generation biofuels in the market. First generation biofuels will continue to hold a large share of the biofuels market well beyond 2020. Assuming a 30 to 50-year lifespan for a fully-operational industrial biofuels production facility, first generation biofuels could provide unsustainable biofuels until around 2050. Given the

[4] United States Environmental Protection Agency, *Epa Proposes Regulations for a Renewable Fuel Standard Program for 2007 and Beyond.*

[5] Government of the United States of America, *Twenty in Ten: Strengthen America's Energy Security* (The White House, 2007 [cited June 18 2008]); available from http://www.whitehouse.gov/stateoftheunion/2007/initiatives/energy.html.

[6] Renewable Fuels Association, *Renewable Fuels Standard* (Renewable Fuels Association, 2008 [cited June 28 2008]); available from http://www.ethanolrfa.org/resource/standard/.

comparatively easy access and technical simplicity of current first generation biofuels production processes, the cost of entry to the second generation biofuels market may simply be too high for new producers to compete with larger, well-established firms.

Rising demand for biofuels would encourage farmers in countries around the world to grow energy crops in order to benefit from higher prices to increase farm-level profits. Current conditions hold no market standards or production criteria for sustainability, and increases in production levels will use proven technology in order to capitalise with greater certainty on growing foreign markets. The immediate result of a further expansion of first generation biofuels by private firms will be the persistence of first generation biofuels in the global market. The effects of these changes will vary depending on geography, perceived necessity, market incentives, and political will. However, in the absence of guiding regulations supported by appropriate administrative infrastructure, biofuels producers are likely to employ existing first generation facilities as long as possible to recoup their investment. These attempts to recapture sunk costs will also impede the adoption of new biofuels technologies and delay the commercialisation of advanced biofuels. In this first scenario, advanced biofuels are unlikely to replace first generation biofuels as the industry standard until the existing industrial infrastructure exceeds its useful life. Companies would seek to recover their sunk costs before investing in advanced generation biofuels technologies. While advanced biofuels may offer sustainable alternatives in certain niches, first generation biofuels will remain as the dominant, albeit unsustainable, complements to petroleum fuels.

The second scenario in which first generation biofuels producers shut down facilities is possible if the industry infrastructure becomes overcapitalised so that the economic rate of return is insufficient to justify production. While rapid industry development provides a good example of state-led innovation, it has also encouraged the development of large scale production facilities based on minimal sustainability requirements. Given the expected continuation of first generation biofuels production levels, regulation of biofuels production to become more sustainable will likely create significant hurdles for the existing biofuels production infrastructure. If the biofuels regimes impose escalating restrictions on first generation biofuels in the future, the existing stock of production facilities will require substantial technical upgrades to accommodate the very different production processes required for advanced biofuels. This will threaten existing market conditions to the point that significant improvements would be necessary to escape shutdown conditions. Firms could respond by investing in costly improvements to retrofit existing facilities, constructing entire new production plants, selling or repurposing existing facilities[7], or total facility closure. Given the precedent set by states investing public monies in biofuels production through expansion programs that formed the core of the three biofuels regimes, it is not unreasonable to expect that public funds would again be used to support the shift from first generation to advanced biofuels. Relying upon first generation technologies to address current and future challenges to sustainable transport energy is not sustainable. Nevertheless, first generation biofuels are the baseline from which to evaluate sustainable biofuels, as they

[7] None have yet done this in North America, and any ethanol producers that have expanded their product line to include advanced biofuels have built brand new facilities adjacent to first generation biofuels distilleries. Syed Ayub, interview, May 10 2011.

will continue to supply global markets in the foreseeable future.

Sustainable Biofuels in the 21st Century?

The persistence of first generation biofuels will continue. Although firmly entrenched, their technological trajectory is not immutable. The transformation of ethanol and biodiesel from a fringe fuel to a government mandated petroleum additive speaks volumes on how the prospects for biofuels have changed. Ethanol influenced the expansion of biodiesel, and the success of dominant biofuels regimes motivated scientists and entrepreneurs to search for other biofuels, including methanol, biobutanol, Fischer-Troph Diesel, and BioOil, to name a few.[8]

The international commercialisation of biofuels and the recent critiques on their local sustainability identified in the preceding chapter raise the important question as to whether or not biofuels can become a sustainable energy option. While under present conditions ethanol and biodiesel are not sustainable, it is possible that these biofuels can be produced in a more sustainable way under a different biofuels regime. Biofuels have co-existed with petroleum-based transportation fuels for the past century and a half, and they have remained on the fringe of the dominant regime as a marginal product. The long history of biofuels shows that ethanol and, to a lesser extent, biodiesel have been able to straddle a number of socio-technical regime shifts. As presented in chapters four through six, the marginalisation of ethanol occurred numerous times in history. None of these

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[8] Dynamotive, *Biooil and Other Products* (Dynamotive, 2006 [cited 29 November 2006]); available from http://www.dynamotive.com/english/biooil/biooil.html, Hamelinck and Faaij, "Outlook for Advanced Biofuels.", Mullins, Griffin, and Matthews, "Policy Implications of Uncertainty in Modeled Life-Cycle Greenhouse Gas Emissions of Biofuels."

failures were caused by an inherent technical shortcoming, but instead were shaped by the abundance of oil and the creation of policy frameworks that favoured petroleum over other transportation fuels. Nevertheless, ethanol exhibited a substantial degree of adaptability, and was able to satisfy different niches at different times; first for lighting, industrial machines, household appliances; then as transportation fuels for automobiles, tractors, aeroplanes and rockets; and later as octane enhancers and petroleum emissions reduction technology. While ethanol may be considered to be a "failed innovation", this perception cannot be attributed to the technical characteristics inherent to the artefact. Instead, biofuels repeatedly failed due to shifting socio-technical landscapes in which the regime was not prepared to respond.

Each venture into a new niche represents a robustness and flexibility that enables technical variation to match emerging social functions. This variation allowed relevant social groups to foster a re-alignment of biofuels to meet new landscape contexts, which in turn enabled a co-evolution between the development of biofuels, their application, and their socio-technical function. It seems that ethanol and biodiesel are able to absorb pressures from changing contexts brought on by different energy regimes. This provides them with an "interpretive flexibility"[9] that allows different system actors to exploit the technical variability of biofuels. In so doing, actors have been able to revive the relevancy of biofuels within and across different socio-technical regimes. This capacity for variation has enabled biofuels to remain relevant despite different niche developments, regime shifts, and changing landscapes. Recognising this co-evolutionary variability

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[9] Pinch and Bijker, "The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other."

throughout the history of these biofuels provides a chance to explore how they might contribute to the achievement of sustainable biofuels in the future.

The co-evolutionary variability of biofuels suggests they are "two world" technologies; that is, they hold the potential to straddle the chasm between the decline of one regime and rise of another. Biofuels exhibit both adaptive and revolutionary properties. In some aspects, biofuels have adapted to become a symbiotic variation of petroleum fuels. In fact, since biofuels can be used in existing internal combustion engines, their attractiveness as a petroleum alternative is based on their ability to be used within the existing transportation infrastructure with very little technical adjustment. They can be distributed in the same manner as petroleum fuels. Consumers are not required to alter behaviour patterns in purchasing, their use of fuel stations, general auto maintenance, or distance of travel, while repair shops can continue to service engines with existing mechanical knowledge. In many ways, biofuels technology has been seamlessly embedded within the existing energy regime, and adaptation presents few consequences to the social functions of energy resources and technologies.

When viewed within these parameters, biofuels may be considered to be a marginal variation to the economically viable and technically proven petroleum fuels that dominate the present transportation fuels regime. However, resource scarcity, market shocks, and other criticisms of petroleum fuels have presented a growing concern with the environmental and social challenges of continuing along a petroleum trajectory. Air pollution, greenhouse gas emissions, oil and fuel spills and the resulting contamination of soil and water, effects on wildlife, and individual health concerns are just a few environmental criticisms. Social challenges include concerns over energy security, increasing national dependency on foreign oil, rising energy costs to firms and individuals, volatile oil and gas prices and the effect on energy inputs to industry. Within this context, biofuels are seen by some to be a favourable technical variation that can help stabilise the current petroleum transportation regime. In this way, incremental innovation can support the continuing dominance of current petroleum-based transportation systems.

As a fuel extender, biofuels reduce the need for a more radical technological transition by prolonging the use of the present oil-based transport energy regime. However, ethanol and biodiesel might also contribute to the socio-technical change of current transportation systems by laying a foundation for other technical contenders to complement or substitute petroleum transport fuels, such as E85 "flexfuel" vehicles, "homebrew" biodiesel techniques, or even advanced biofuels production methods such as cellulosic ethanol, algae-based biodiesel, or direct cellulose fermentation processes for ethanol.[10] Biofuels may also have a more radical effect on innovation, in which their diffusion precedes a large scale transformation of transport energy systems or introduces the possibility of a post-petroleum bioenergy economy. From this perspective, biofuels are a potentially revolutionary technology; a vanguard artefact that could stimulate the shift toward a dramatically altered energy regime.

As discussed in chapter three, most theories of radical technological change rely on exogenous factors to explain technical regime shifts, "...when paradigms change, there are usually significant shifts in the criteria determining the legitimacy both of

[10] Carlo R. Carere et al., "Third Generation Biofuels Via Direct Cellulose Fermentation," *International Journal of Molecular Sciences*, no. 9 (2008).

problems and of proposed solutions".[11] This shift in legitimacy involves the reordering of ideas and values, and is therefore fundamentally a shift in perception. From this perspective, biofuels are potentially revolutionary because they can alter societal perceptions of the role of oil and offer the possibility of an alternative socio-technical system to the present petroleum-based transportation fuels regime. Shifts in perception are a pre-requisite for technical revolution because ideational landscape pressures can identify the limits of existing technologies, envision organisational changes in market structure, justify the inclusion of formerly excluded actors, or precipitate the emergence of new products to satisfy new socio-technical functions of energy resources and technologies. Each of these characteristics is present when examining biofuels from a transitions approach.[12] Air pollution and greenhouse gas emissions, human health and safety issues, intense land use patterns, resource scarcity, increasing consumption, high production costs, traffic congestion, the costs of infrastructure investment and maintenance, the decentralisation of transport fuel production away from oil companies, and a host of other factors suggest that the technical benefits of petroleum fuels are reaching their limits.[13]

Technological stability in the dominant transportation fuels regimes is based on the widespread use and dependence on oil and petroleum, and the global economy and multilateral trade rules that govern international energy markets provides a context for

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[11] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (Chicago and London: University of Chicago Press, 1996), 109.

[12] Wouter Van der Laak, Rob Raven, and Geert Verbong, "Strategic Niche Management for Biofuels: Analysing Past Experiments for Developing New Biofuels Policies," *Energy Policy* 35, no. 6 (2007).

[13] Joseph Romm, "End This Addiction Immediately," *U.S. News & World Report*, 2008/07/21/ 2008.

biofuels that "prestructures the kind of problem-solving activities that engineers are likely to do, a structure that both enables and constrains certain changes".[14] Similarly, this context pre-structures the activity of national and subnational governments. The public administration of state resources to solve social problems and achieve society-wide change is limited by the persistent technical trajectory of the present socio-technical systems. This configuration is not easy to redirect, and it is difficult to introduce new types of uses, improve energy production processes, and encourage more efficient energy consumption. In the future, improving energy systems will require that they be more sustainable by minimising the level of social dislocation and environmental degradation caused by energy consumption.[15] Altering existing energy systems today requires a deliberate state presence because the current energy regime is maintained by entrenched rules and regulations that govern the administration and enforcement of product standards, property rights, taxation rules, and other policy concerns.

While the co-evolutionary variability of biofuels enable them to be used within the existing petroleum transportation fuels regime, the shifting perceptions on the promise of biofuels suggests a new social function of ethanol and biodiesel to provide a sustainable energy option. Acknowledging the persistence of unsustainable first generation biofuels and the growth of global markets, the achievement of sustainable biofuels will require a deliberate effort to understand the following: (1) how biofuels interact with social values and government policies; (2) how niche markets affect

[14] Kemp, Schot, and Hoogma, "Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management," 182.
[15] Ulrich Steger et al., *Sustainable Development and Innovation in the Energy Sector* (Berlin Heidelberg: Springer-Verlag, 2005).

technical pathways; (3) how biofuels co-evolve with existing transportation and bioenergy systems; and (4) how the social framing of biofuels creates new socio-technical functions. In the next chapter, it appears that these factors are present (albeit in limited ways) in biofuels expansion strategies in small markets. Furthermore, these four factors suggest areas of consideration not typically identified in policy analysis, market research, or evaluations of technical performance. As discussed in more detail in chapter nine, these factors identify necessary aspects of change if biofuels regimes are to be re-aligned toward sustainable production of ethanol and biodiesel.

Conclusion

The evolution of the three major biofuels regimes led to the structuring of international markets and global trade flows that favoured first generation biofuels. This contributed to their socio-technical persistence as the industry standard for the global diffusion of transportation biofuels. This persistence will have important implications for biofuels as a sustainable energy option, particularly as nations seek to increase export opportunities from biofuels. Moreover, this persistence will constrain technological development for sustainable energy as biofuels production responds to the demands of global transport energy markets.

However, ethanol and biodiesel are "two world" technologies insofar as they have evolved and remained relevant within and across socio-technical systems. Biofuels have a history of technical variation and hold the potential to become vanguard artefacts in a technological revolution toward a sustainable transportation fuels regime. Global biofuels diffused to international markets, but the concern with the effects of first generation biofuels is growing. If sustainable biofuels are not possible within the context of the dominant biofuels regimes, the question arises as to whether or not sustainable biofuels can be achieved at all. If the largest biofuels producers do not adequately address the issue of sustainable energy in these biofuels sectors, is it possible to avoid the persistence of first generation biofuels and encourage the technological innovation needed to encourage sustainable biofuels?

As the next chapter suggests, small markets with established biofuels production capacities may be able to redirect the biofuels production strategies in dominant regimes in order to incorporate the principles of sustainable development and achieve sustainable biofuels. Employing a transitions approach as another analytical tool within existing policy frameworks might help to encourage the adoption of sustainable biofuels by strengthening sustainability criteria. Before exploring the potential for sustainability criteria and certification and how these would help to overcome the problems associated with first generation biofuels, the next chapter investigates Canada as a small market with the potential to contribute to the diffusion of sustainable biofuels to other jurisdictions.

EIGHT – Niche Development in Small Markets

Canada has the potential to become a significant biofuels producer, but it is still comparatively small in relation to the dominant biofuels regimes. Similar to China, Indonesia, South Africa and other nations with established biofuels production infrastructure, the Canadian biofuels industry has adjusted its national biofuels strategies to align with international market conditions and biofuels trajectories pursued by dominant regimes. Beginning with an overview of energy governance in Canada, this chapter explores the Canadian case to understand the impact of the diffusion of global biofuels and the effects on small markets. It looks at the progression of federal and three provincial biofuels strategies, and shows how niche development strategies in the provinces were influenced by the diffusion of global biofuels.

Energy and Transportation Fuels in Canada

Energy governance in Canada is divided between the federal government and the provinces. While an extensive analysis of energy in Canada is not possible here[1], a few key factors are helpful to reveal the context in which federal and provincial biofuels policy developed over time. The federal government holds broad powers of taxation and spending. It also holds jurisdiction over inter-provincial and international trade and

[1] For a good description of the energy governance in Canada, see: G. Bruce Doern, ed., *Canadian Energy Policy and the Struggle for Sustainable Development* (Toronto: University of Toronto Press, 2005), G. Bruce Doern and Monica Gattinger, *Power Switch: Energy Regulatory Governance in the Twenty-First Century* (Toronto: University of Toronto Press, 2003).

commerce, trans-boundary environmental effects, national policies (e.g., energy security), nuclear power and associated resources, as well as matters requiring resource management in the North and offshore. The federal government also has strong residual powers, which allow it to act in areas unspecified by the constitution. Provinces and Territories hold jurisdiction over all trade and commerce and environmental protection within their boundaries, which includes the development of natural resources and energy policy.[2] The governance of energy in Canada is complex and fluid, and is shaped by the constitutional division of powers between fourteen energy jurisdictions.

Where most other countries discussed in this thesis have centralised and authoritative government agencies, energy in Canada involves divided and decentralised jurisdictions over energy resources. According to Doern and Gattinger, there is always an element of federal-provincial bargaining over energy issues, which has created a complex system of regulatory governance. Regulations are those state-sponsored rules that influence the public administration and private operation of any sector. They involve formal rules, such as constitutions, trade agreements, statutes and orders. They also involve informal rules, such as guidelines, directives, standards and codes, past practices, and the habits of institutions and individuals. All of these contribute to the concept of regulatory governance, which "involves not just regulations themselves, but the processes and structures through which regulations are developed and implemented, and the ideas and ideals underpinning decision-making".[3]

The government of Canada sought to diversify its energy resources by exploring

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[2] Doern and Gattinger, *Power Switch: Energy Regulatory Governance in the Twenty-First Century.*
[3] Ibid., 13.

different forms and applications. Early efforts to secure conventional energy resources were followed by the search for new oil and gas reserves, as well as the development of oil sands, hydroelectricity and nuclear power. The uncertainties of the global energy system caused by the oil crises in the 1970s led to Canada's contentious National Energy Program that soured federal-provincial relationships during the 1980s. The federal government continued to support provincial programs to expand the oil and gas sector and increase hydroelectric generating capacity, but expanded its energy development activities during the 1970s. Federal renewable energy programs were designed to stabilise the markets for electricity, heating and cooling, and transportation energy amidst a number of political and economic pressures[4], and encouraged and supported research and development of solar, wind, wave, geothermal, hydrogen, and biomass energy technologies.[5]

Federal energy programs involve a host of departments, agencies and regulatory bodies. As the federal government relied increasingly upon the business community for leadership in energy development from the 1980s onward, more and more social groups have become involved in the process and more quasi- and non-governmental entities are required to facilitate oversight, compliance, and public awareness. The Department of Natural Resources Canada holds a central role in the coordination of federal policies and programs for the development of energy in Canada, and is one of the largest science-based ministries in the federal government with over 4,500 employees and a budget of

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[4] Natural Resources Canada, *Energy in Canada 2000* (Government of Canada, 2000 [cited August 30 2006]); available from http://www2.nrcan.gc.ca/es/ener2000/online/html/toc_e.cfm.

[5] Ibid.

$3.9 billion (fiscal year 2009-10).[6] In addition to its responsibility for Canada's energy, minerals, and forestry sectors and the advancement of earth sciences to survey Canada's natural resource reserves, it also holds jurisdiction over the development and regulation of energy resources and technologies at the federal level. It works with the provinces and other departments, including Environment, Industry, Agriculture and Agri-food, Transport and Finance to coordinate federal energy policies and initiatives.

Federal Biofuels Policy

Unlike traditional energy sources, biofuels production involves agricultural resources that are not directed by governments, but are instead operated by individual farmers, cooperative farming organisations, large industrial corporate agribusiness, and others that are subject to provincial land-use regulations. Moreover, "the primary purpose of agriculture is to provide an adequate, sustained food supply..."[7] Since the primary function of agriculture is to produce food, energy feedstock production is an auxiliary concern.

The progression of Canadian biofuels policy can be categorised in three stages. The first was the *voluntary* stage between 1970s and mid-1990s. This stage focused primarily on soft policy tools intended to encourage market activity, and included support for research and development, providing information, and offering tax incentives. The *program* stage occurred from the mid-1990s to mid-2000s. Beginning with a government

[6] Natural Resources Canada, *Departmental Performance Report* [website] (Government of Canada, 2009 [cited 2 November 2010]); available from http://www.tbs-sct.gc.ca/dpr-rmr/2008-2009/inst/rsn/rsn-eng.pdf.

[7] Michael J. Troughton, "Agriculture and Rural Resources: Addressing Conflict and Uncertainty," in *Resource Management and Development: Addressing Conflict and Uncertainty*, ed. Bruce Mitchell (Toronto: Oxford University Press, 2004), 233.

alternative vehicle fuel procurement program in 1995, this stage later included financial support programs directed at industry to encourage the expansion of national biofuels production. The *mandate* stage included both renewable content obligations and the coordination of a national strategy for the expansion of domestic biofuels production.

During the evolution of these three stages, the federal government used eight broad policy measures to advance the awareness, use and production of biofuels. Focused primarily on ethanol, stage one policy measures were *voluntary*, and targeted market actors by providing support in the form of: (1) research and development, (2) information and (3) tax incentives. Stage two policy measures were *programs* directed at relevant social groups, such as government administrators, agricultural and energy entrepreneurs, and multinational corporations and included: (4) legislation, (5) credit guarantees to investors, and (6) direct provision of repayable loans. The third stage integrated voluntary- and program-based policy measures while adding more stringent regulatory requirements. The *mandate* stage includes: (7) biofuel content obligations and (8) an overarching biofuels strategy. The introduction and use of these policy measures progressed from general programs to improve technical knowledge, production capacity, and awareness toward program-based initiatives to encourage specific outcomes, such as production goals and content ratios. Each measure is discussed in more detail below.

The *voluntary* stage began in the 1970s, when the federal government began to support *research and development* for first and second generation production techniques.[8]

[8] Early federal research and development programs included numerous renewable energy resources and technologies. In addition to biofuels, the federal government support research into solar, wind, wave, geothermal, and hydrogen. Natural Resources Canada, *Energy in Canada 2000.*

Canada has supported Iogen's pursuit of second generation ethanol from wheat straw, including a federal loan of $10 million in 1999 to build Iogen's $110 million cellulosic ethanol demonstration facility. After 25 years of research and development, the company is reportedly producing 2 million litres of second generation cellulosic ethanol annually.[9]

Providing *information* to energy users was the second broad policy measure undertaken to expand biofuels production in Canada. The Vehicle Fuels Initiative to Generate and Distribute Information to Energy Users (also called the *Vehicle Fuels Initiative*) first began as the *Alternative Transportation Fuels Initiative* in 1991 and evolved over a period of 15 years (1991-2006). Its initial objectives were to promote and increase alternative transportation fuels, especially methanol and ethanol, but also more environmentally-friendly fuels for automobiles, light duty vehicles, and heavy duty vehicles.[10] The initiative was renewed in 1997 as the *Alternative Transportation Fuels Market Development Initiative* to promote the use and development of alternative automotive transportation fuels and vehicles.[11] By 2000, the Office of Energy Efficiency relabelled this program again as the *Future Fuels Market Analysis Program* and refined the main objective to focus on promoting the use and development of alternative fuels in Canada. Policy analysis and joint projects were the main methods used to formulate niche development initiatives and reduce market barriers for new vehicle technologies and

[9] Canadian Renewable Fuels Association, *Plant Locations* (Canadian Renewable Fuels Association, 2010 [cited May 22 2012]); available from http://www.greenfuels.org/en/industry-information/plants.aspx, Iogen Corporation, *Cellulose Ethanol Is Ready to Go: Iogen Producing World's First Cellulose Ethanol Fuel.*

[10] Natural Resources Canada, *Evaluation of the Vehicle Fuels Initiative: 1997-2002* (Government of Canada, 2003 [cited 31 October 2006]); available from http://www.nrcan-rncan.gc.ca/evaluation/reprap/2003/fuels-carburants-eng.php.

[11] Ibid.

alternative fuel infrastructure.[12]

Throughout its evolution, the *Vehicle Fuels Initiative* provided analytical support for other transportation energy programs at Natural Resources Canada, as well as supporting the activities of other federal departments, industry associations, and fuel producers. In all its variations, the *Vehicle Fuels Initiative* intended to increase public awareness, to foster consumer confidence, and to attract producer interest and investment, but its success in achieving these goals is uncertain. The shift from the objectives related to fuel, vehicle and feedstock types as addressed in the 1991 *Alternative Transportation Fuels Initiative* to the broader analytical and information-sharing objectives of the 2002 *Future Fuels Market Analysis Program* makes it difficult to assess the effectiveness of the program. The 2003 program evaluation confirmed that, "…it is not possible to determine exactly what [the Vehicle Fuels Initiative] has achieved during the period 1997-2002"[13], due mainly to the lack of comparable program models and, in particular, models that examine environmental performance (e.g., greenhouse gas emissions) "over the entire fuel pathway from the [oil] well to the wheel from a Canadian perspective…"[14] While it is probable that the 15-year program contributed somewhat to the expansion of biofuels production in Canada, this claim cannot be verified.

The third policy measure was introduced in 1992 when Finance Canada removed the federal excise tax on refineries for the portion of ethanol in gasoline blends[15] to encourage market supply by increasing the volume of ethanol blends at the refinery.

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[12] Ibid..
[13] Ibid.
[14] Ibid.
[15] Finance Canada, *The Budget Plan 2003* (Government of Canada, 2003 [cited 31 October 2006]); available from http://www.fin.gc.ca/budget03/PDF/bp2003e.pdf.

However, insufficient ethanol production remained a significant barrier to the federal government's goal of increasing ethanol diffusion in Canada through voluntary measures. This prompted the federal government to develop a more coordinated approach of targeting governments and industry.

The first activity in the *program* stage of the evolving federal biofuels policy was legislation. In 1995, the *Alternative Fuels Act*[16] was the fourth policy measure employed by the federal government, and provided a legislative imperative to "accelerate the use of alternative fuels for motor vehicles".[17] The *Act* required that 75% of the fleet vehicles used by all federal bodies would operate on alternative fuels by April 1, 2004 and for every year thereafter. So long as it is "cost effective and operationally feasible"[18], this obligatory use would be achieved in a phased approach. By 1997, half of the fleet vehicles were to use alternative fuels. This requirement increased to 60% by 1998 and, by 1999 and each year thereafter, three quarters of the federal government vehicle pool was supposed to use alternative fuels.[19] However, the *Act* did not achieve what it had intended[20], largely due to a weak statute that lacked both definition and enforcement capacity. The federal government could not achieve the objectives as specified in the *Act* because, as Boyd identified, the definition of "alternative fuel" was too narrow and excluded other "fuels" such as electrical power in gas-electric hybrid engine and hydrogen fuel cells. Boyd identifies the large discrepancy between the 75% goal and the

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[16] *Alternative Fuels Act*, d, (22 June).
[17] Ibid.
[18] Ibid.
[19] Ibid.
[20] Natural Resources Canada, *Government of Canada Commits to Greenhouse Gas Reductions* (Government of Canada, 2001 [cited 31 October 2006]); available from http://www.nrcan-rncan.gc.ca/media/archives/newsreleases/2001/200140_e.htm.

achievement of only 6.8% of alternative vehicle fuels used in the government fleet as evidence that the *Act* had failed[21], but stops short of pointing out the lack of political will to ensure that government departments responsible for procurement processes facilitated the uptake of alternative fuels by the federal government.

It was clear by the failure of the *Alternative Fuels Act* that a more coordinated effort directed at industry was needed, which required a greater degree of government oversight. In 1998, the Office of Energy Efficiency was established under the Energy Sector in the Department of Natural Resources Canada. Its purpose was to manage Canadian ethanol and biodiesel programs and initiatives regarding energy efficiency and conservation in numerous areas, including: housing, buildings, equipment, industrial sectors, transportation and, of course, biofuels. In addition to seeking new measures to increase energy efficiency, the Office of Energy Efficiency also informed citizens and key decision-makers in government, industry and the environmental and international communities on "developments in technology that can conserve fossil fuels or support the shift to less carbon-intensive energy sources, including renewable energy".[22] Its original mandate was to "renew, strengthen and expand Canada's commitment to energy conservation and energy efficiency", which was a reflection of Canada's support for the Kyoto Protocol to reduce greenhouse gas emissions by an average of 6 percent below 1990 levels between 2008 and 2012.[23] By 2010, the mandate of the Office of Energy Efficiency was reframed to reflect Canada's rejection of its previous ratification of

[21] David R. Boyd, "Petition No. 167," in *Implementation and Potential Improvement of the Alternative Fuels Act* (Ottawa: Office of the Auditor General, 2006).

[22] Office of Energy Efficiency, *(Website)* [website] (Government of Canada, 2006 [cited 26 October 2006]); available from http://oee.nrcan.gc.ca.

[23] Ibid.

Kyoto, and the Office sought "to strengthen and expand Canada's commitment to energy efficiency in order to help address the Government of Canada's policy objectives".[24]

A sub-unit of the Office of Energy Efficiency, the Fuels Policy and Programs division is directly involved in developing and expanding Canada's biofuels industry. It initially focused on six alternative transportation fuels: battery-electric and hybrid vehicles, biodiesel, ethanol, fuel cells and hydrogen, natural gas, and propane. With the increased attention on ethanol and biodiesel, the division has shifted away from its analytical roots and toward program delivery. The higher profile of the biofuels portfolio and the reorientation of the division toward renewable transportation fuels came with an increase from about a dozen employees in 2006 to approximately thirty positions in 2010.

The fifth measure taken to expand Canada's biofuel sector was intended to increase investor confidence by guaranteeing bank loans to renewable fuel producers through the *Future Fuels Initiative* (1999-2004). Co-managed by Natural Resources Canada and Agriculture and Agri-food Canada, this program was initiated as part of the *Action Plan 2000 on Climate Change* with the objective to "increase Canada's fuel ethanol production and use in the transportation sector".[25] It had two goals: (1) encourage investment and (2) expand production. First, it renewed the 1994 *National Biomass Ethanol Program*[26] to encourage lender support for the construction of new and/or

[24] Natural Resources Canada, *Office of Energy Efficiency - Our Organization* [website] (Government of Canada, 2010-01-28 2010 [cited 2 November 2010]); available from http://oee.nrcan.gc.ca/corporate/about-us.cfm.

[25] Natural Resources Canada, "Improving Energy Performance in Canada – Report to Parliament under the Energy Efficiency Act - 2003-2004," (Ottawa: Government of Canada, 2005), 56.

[26] Agriculture and Agri-food Canada, *National Biomass Ethanol Program* (Government of Canada, 1994 [cited 1 November 2008]); available from http://www.iea.org/Textbase/pm/?mode=red&id=1234&action=detail.

expanded ethanol production facilities by helping to "overcome lender resistance to investing in ethanol plants because of uncertainty about excise tax policy"[27]. The 1999 renewal extended the *National Biomass Ethanol Program* with $140 million in contingent loan guarantees to offset capital investment risks in new plants for ethanol production from plant fibre, corn and other grains. However, the loan program only became active if all or part of the excise tax on the ethanol portion of gasoline was re-instated before December 31, 2010.[28] The second goal aimed to increase the total annual ethanol production in Canada by increasing the number of new biomass ethanol production plants.[29] To do so, the *Future Fuels Initiative* offered $3 million per year for five years to increase public awareness about ethanol as an alternative vehicle fuel. In addition, it conducted socio-economic and market analyses on ethanol production and consumption, coordinated federal-provincial biofuel policies, and consulted with private industries that were considering entering or expanding into the ethanol production industry. In all, the *Future Fuels Initiative* established a goal to increase Canada's annual biomass ethanol production and use from over 200,000 million litres to almost one billion litres per year.[30] However, the $15 million and 5-year timeline were insufficient to attain the program federal government's objectives, suggesting that the program may have been

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[27] The ethanol portion of blended gasoline has been exempted from the excise tax on fuel since 1992. The Government of Canada has indicated this to be one of the first demonstrations of its support for fuel ethanol, Office of Energy Efficiency, *Backgrounder - February 13, 2004* (2004 [cited 31 October 2006]); available from http://www.nrcan-rncan.gc.ca/media/newsreleases/2004/200402a_e.htm.

[28] Office of Energy Efficiency, *Future Fuels Initiative* (Government of Canada, 2004 [cited); available from http://oee.nrcan.gc.ca/transportation/fuels/ethanol/future-fuels-initiative.cfm?attr=8.

[29] Ibid..

[30] Ibid..

"too ambitious."[31]

The sixth policy measure provided repayable loans directly to successful applicants seeking assistance for the construction or expansion of ethanol facilities. The *Ethanol Expansion Program* was announced in August 2003, and reinforced the *Future Fuels Initiative* with an aim to "increase domestic production and use of ethanol…and reduce transportation-related greenhouse gas (GHG) emissions".[32] It provided seed money to help finance the construction of new or expanded ethanol fuel production facilities in Canada, and the $100 million initially approved for the program rose to $118 million by July 2005. The first round of funding began in 2003 with an announcement of $78 million contributed to seven expansion projects – one each in Quebec, Manitoba, and British Columbia and two each in Ontario and Saskatchewan – in order to increase total annual national production capacity by 750 million litres.[33] The results from Round Two were announced in 2005 with an expectation to invest $46 million for an additional 510 million litres of annual ethanol production – one facility each in Manitoba and Alberta, and three in Ontario. By the end of *Ethanol Expansion Program*, Round One provided $51.3 million and increased annual ethanol production capacity by 475 million litres.[34] Round Two provided over $60 million and increased annual ethanol production by another 559 million litres annually. In total, the program helped to increase annual

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[31] Claude Robert, interview, 31 October 2006 2006.

[32] Office of Energy Efficiency, *Ethanol Expansion Program* (Government of Canada, 2006 [cited 31 October 2006]); available from http://oee.nrcan.gc.ca/transportation/fuels/ethanol/eep.cfm?attr=8.

[33] Natural Resources Canada, "Government of Canada Launches Second Round of Ethanol Expansion Program," *The Newsroom - Natural Resource Canada's News Source (online)*, 6 December 2004 2004.

[34] Ethanol Market Staff Reporter, *Greenfield Ethanol Opens First Ethanol Plant in Quebec* (Ethanol Market, LLC, March 30, 2008 2008 [cited 1 November 2008]); available from http://www.ethanolmarket.com/PressReleaseGreenfieldEthanol033007, Robert.

ethanol production in Canada by 1034 million litres (Table 8-1).

Table 8-1: Successful Applicants to the Ethanol Expansion Program

Name	Location	Feedstock	Annual Capacity (million litres)
Round One (2003)			
Husky Energy, Inc.	Lloydminster, SK	Wheat	130
NorAmera Bioenergy Corp.	Weyburn, SK	Wheat	25
Suncor Energy Products Inc.	Sarnia, ON	Corn	200
GreenField Ethanol	Varennes, QC	Corn	120
Round Two (2005)			
Husky Energy, Inc.	Minnedosa, MB	Wheat	130
Permolex, Ltd.	Red Deer, AB	Wheat & corn	34
GreenField Ethanol	Johnstown, ON	Corn	200
Integrated Grain Processors Co-op.	Aylmer, ON	Corn	145
Amaizeingly Green Products LP	Collingwood, ON	Corn	50
Total			1034

(Source: Robert 2006)

The successful expansion of ethanol production capacity in Canada re-enforced the need to develop a coordinated national biofuels strategy. This *mandate* stage began with federal-provincial discussion to build on provincial biofuels content requirements and implement a national biofuels standard. The seventh policy measure was a biofuels content obligation. In 2006, the federal and provincial governments agreed to endorse a national renewable fuel mandate.[35] This federal-provincial collaboration was expected to regulate demand at 2.5 billion litres of biofuels annually (2 billion litres of ethanol and 500 million litres of biodiesel). Bill C-33 became law on July 1, 2008, requiring 5% renewable content in gasoline by 2010 and 2% renewable content in diesel fuel by 2012.[36] The targets required an estimated 20 additional biofuels production facilities[37], and both ethanol and biodiesel targets were based on an annual national consumption of gasoline and diesel of roughly 40 billion litres and 25 billion litres, respectively.

Building on the federal regulations on blend mandates outlined above, Canada's *Renewable Fuels Strategy* is the eighth and broadest biofuels policy measure, and involved four distinct programs and initiatives. The *ecoAgriculture Biofuels Capital Initiative* (ecoABC) and the *Biofuels Opportunities for Producers Initiative* (BOPI) are run by Agriculture and Agri-Food Canada to assist farmers to "seize new opportunities in biofuels production". The *ecoABC* initiative provided up to $200 million over five years (2007-2011) for repayable contributions for the construction or expansion of biofuels production facilities. Eligibility for this initiative was contingent on agricultural producer investment and required the use of agricultural feedstocks.[38] Ending on March 31, 2008, BOPI helped farmers and rural communities hire experts to assist with feasibility studies and business proposals. The *NextGen Biofuels Fund™* is coordinated by Sustainable

[35] Bruce Johnstone, "Ottawa's 5% Biofuel Program Backed," *Leader-Post*, 24 May 2006.
[36] *Canadian Environmental Protection Act*, S.C. 1999, (March 8, 2012).
[37] Jessica Sobolik, *Canada Passes Renewable Fuels Standard* (Biodiesel Magazine, July 1 2008 [cited November 3 2008]); available from http://www.biodieselmagazine.com/article.jsp?article_id=2497.
[38] Agriculture and Agri-food Canada, *Ecoagriculture Biofuels Capital Initiative (Ecoabc)* (Government of Canada, 2010-08-27 2010 [cited November 25 2010]); available from http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1195672401464&lang=eng.

Development Technology Canada and provides $500 million in repayable loans to support large-scale demonstration projects for advanced biofuels.[39] Finally, the *ecoENERGY for Biofuels* program is managed by the *Office of Energy Efficiency* under the Natural Resources Canada. It earmarked $1.5 billion for operating incentives between 2008 and 2017 to boost domestic biofuels production.[40] For the first three years, producers received a $0.10/litre incentive for renewable alternatives to gasoline and a $0.20/litre incentive for renewable alternatives to diesel. The remainder of the program (2011-2017) will see declining incentives as production volumes increase.[41]

The federal government pursued numerous policy tools in order to expand its national ethanol and biodiesel sectors. The *voluntary*, *program* and *mandate* stages represented shifting social functions and related policy concerns, all of which aimed to develop niches for ethanol and biodiesel within a changing transportation fuels regime. In contrast to the broader context of global biofuels pursued by the dominant biofuels regimes in Brazil, the United States, and the European Union, Canadian policy tools focused mainly on expanding feedstock supplies for domestic markets instead of increasing production for export (Table 8-2). Provincial and federal policies differed because provinces pursued niche development to increase biofuels production while Canada was more concerned with changing the national transportation fuels regime.

[39] Sustainable Development Technology Canada, *Funding* (Government of Canada, 2010 [cited November 25 2010]); available from http://www.sdtc.ca/index.php?page=about-our-funds&hl=en_CA.

[40] Office of Energy Efficiency, *Ecoenergy for Biofuels Program* (Government of Canada, 2010-11-03 2010 [cited November 25 2010]); available from http://oee.nrcan.gc.ca/transportation/alternative-fuels/programs/ecoenergy-biofuels/biofuels-intro.cfm?attr=16.

[41] Office of Energy Efficiency, *Incentive Rates* (Government of Canada, 2009-09-01 2010 [cited November 25 2010]); available from http://oee.nrcan.gc.ca/transportation/ecoenergy-biofuels/incentive-rates.cfm?attr=16.

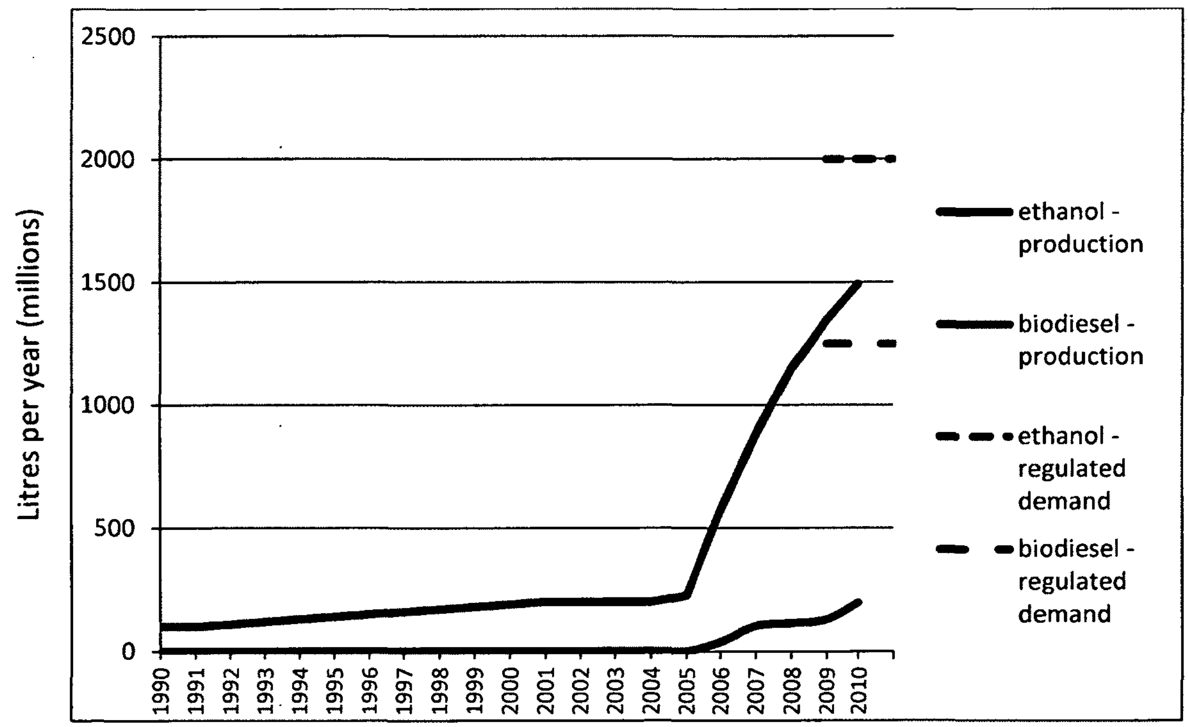
Table 8-2: Key Components of Transportation Fuels Regime Shift in Canada

Function	Policy concerns	Micro-level action	Meso-level action	Macro-level action
Energy security	National energy development			
Rural Development	Developing production & distribution	ecoAgriculture Biofuels Capital Initiative	National biomass ethanol program	
		Biofuels Opportunities for Producers Initiative		
	Expand feedstock supplies	NextGen^{tm} Biofuels Fund; ecoENERGY for Biofuels	Ethanol Expansion Program	
	Support Research & Development	Funding for third-party technical analysis	Inter-departmental cooperation	
	Stimulating technical diffusion	Favourable taxation	Alternative Fuels Act (1995); Content obligations	Information and public marketing
Trade	Enhancing Trade	Assisting market introduction		
	Supporting developing countries			
Environment	Capture benefits to environment		fuel quality standards	
Society	Capture benefits to society			

Source: Author's interpretation.

With the help of these federal efforts, total ethanol production capacity in Canada increased from 200 million in 1991 to over 1.7 billion litres in 2010. Total national biodiesel capacity was virtually non-existent in 1991 and has since exceeded 470 million litres. The Renewable Fuel Standard requires around 2 billion litres of ethanol and 1.25 billion litres of biodiesel each year. However, there is a shortfall between production capacity and actually output. As indicated in Figure 8-3, the dashed lines show Canada's current national biofuels production is still below the regulated demand as determined by the biofuels mandate for 2010.[42]

Figure 8-3: Canadian Biofuels Production (1991-2010)

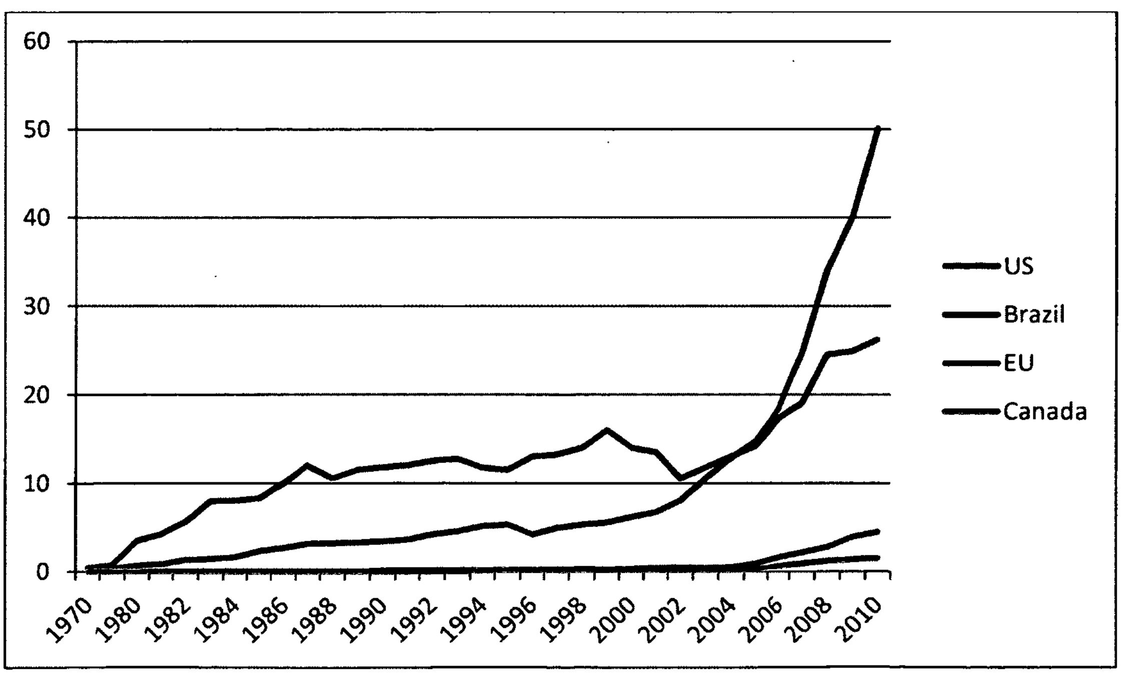


Source: Author's synthesis of industry data.

[42] Ayub. Note: actual production levels are lower than the total installed capacity.

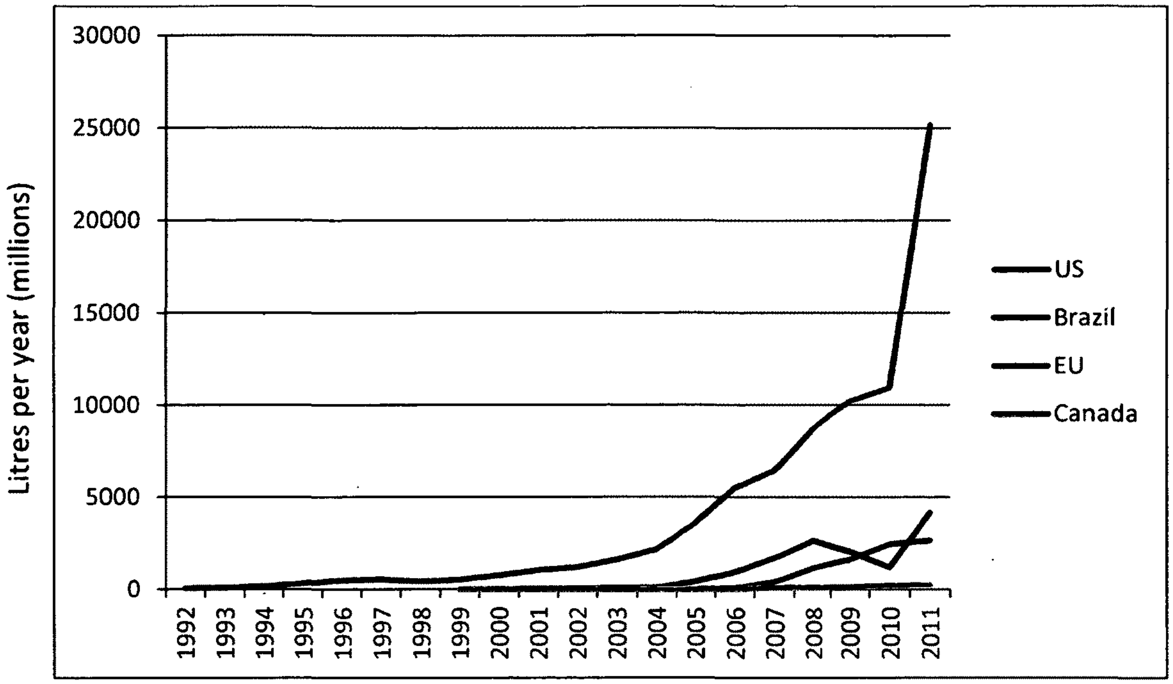
In 2010, actual biofuels production was less than nameplate capacity – ethanol production was about 1.5 billion litres while actual biodiesel production was 198 million litres. Increased production is needed to achieve government biofuels production targets. Canada will need to import the difference to meet the requirements of the Renewable Fuel Standard until domestic production increases. Yet aggressive production increases puts Canada at risk of following a technological trajectory that emulates the dominant biofuels regimes, which would likely result in a similar persistence of unsustainable first generation biofuels. In comparison to Brazil and the United States, Canadian ethanol production is comparatively low, but the rate of growth is more similar to the European Union (Figure 8-4). In terms of biodiesel, Canada is well behind all three dominant biofuels regimes (Figure 8-5).

Figure 8-4: Comparison of Ethanol Expansion, 1970-2010



Source: Author's synthesis of industry data.

Figure 8-5: Comparison of Biodiesel Expansion, 1992-2011



Source: Author's synthesis of industry data.

Niche Development in Canada

As defined in chapter three, *niches* are "...spaces in which radical novelties are tried out and developed further, while they are sheltered from mainstream competition".[43] They are those "protected spaces" that are subject to special rules, conditions, policies and processes. The configuration of these protective mechanisms can occur in very different ways depending on social, political, economic, environmental, or other contexts.[44] While niches can develop without government intervention, the strategic implementation of niche development programs is contingent on a number of factors,

[43] Schot and Geels, "Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda, and Policy."
[44] Rotmans, Kemp, and Asselt, "More Evolution Than Revolution," 17.

including: the scale and scope of government objectives; the evolution of those objectives over time; the saliency of the issue in the public realm; the organisational capacity of private actors; as well as the regime and landscape conditions that may or may not be apparent to stakeholders and decision-makers.[45]

The government of Canada encouraged the emergence of a national biofuels regime through investments, subsidies and other financial guarantees. It also exercised its federal spending power and sought provincial consensus on mandated biofuel content for petroleum fuels. The result of these federal efforts was that the Canadian government enabled a more favourable framework upon which to build a biofuels regime for the country. Although the federal government encouraged a significant expansion of the industry, the development of a national biofuels production system occurred within niche markets in select provinces.

The ensuing discussion explores the current state of biofuels in Manitoba, Saskatchewan and Ontario. This does not diminish the perceived and potential role of biofuels in other subnational jurisdictions, but they hold relatively few existing production facilities or facilities currently under construction (Table 8-6).

[45] Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective," 96.

Table 8-6: Ethanol and Biodiesel Production in Canada, December 2010

Province	Ethanol Production (capacity in million litres/year)					Biodiesel Production (capacity in million litres/year)					Total Biofuel Capacity
	Current	Planned	Current capacity	Planned capacity	Total Expected Capacity	Current	Planned	Current capacity	Planned capacity	Total Expected Capacity	
BC	0	0	-	-	-	1	0	10	-	10	10
AB	1	1	40	36	76	1	2	19	291	310	386
SK	5	0	342	-	342	1	0	1	-	1	343
MB	1	0	130	-	130	1	2	20	14	34	164
ON	8	1	858	190	1048	1	1	66	5	71	1119
QC	1	0	120	-	120	2	0	45	0	45	165
NB	-	-	-	-	-	-	-	-	-	-	-
NF	-	-	-	-	-	-	-	-	-	-	-
NS	-	-	-	-	-	-	-	-	-	-	-
PEI	-	-	-	-	-	-	-	-	-	-	-
YU	-	-	-	-	-	-	-	-	-	-	-
NWT	-	-	-	-	-	-	-	-	-	-	-
NV	-	-	-	-	-	-	-	-	-	-	-
Total	16	2	1490	226	1716	7	5	161	310	471	2187

(Source: Canadian Renewable Fuels Association 2010)

British Columbia[46] and Nova Scotia[47] have had limited experience with biofuels and, for different reasons, have not produced biofuels to any significant degree. Alberta may become a leading biodiesel producer in the country[48], but expansion plans have not yet translated into firm output. Quebec has redirected its biofuel strategy from ethanol to

[46] Ayub, Robert.

[47] Scott McCoombs, June 4 2009.

[48] Cheminfo Services Inc., "Ethanol Production in Alberta - Final Report," in *Intergovernmental Ethanol Committee* (Edmonton: Government of Alberta, 2000).

biodiesel production and has reduced overall production goals.[49] Newfoundland and Labrador and New Brunswick do not have biofuel producers, but Prince Edward Island has indicated an interest to expand its biofuels sector.[50] The Yukon experimented with government-sponsored pilot projects and determined that the barriers were too great.[51] No evidence of biofuels programs in the Northwest Territories was found, and although Nunavut relies entirely on diesel electricity generation[52], it has not investigated the potential for biofuels as a fuel substitute.

Subnational governments face their own challenges with biofuels expansion, and few have successfully leveraged federal programs. The efforts of these subnational governments can provide useful lessons for other regions on the challenges arising within the new global landscape for biofuels. The following explores biofuels programs in Manitoba, Saskatchewan and Ontario and reveals how foreign biofuels regimes and the emergence of global biofuels affected policies and programs in subnational governments.

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[49] Pierre Corbiel and Werner Schnappauf, "Déclaration D'intention Entre Le Ministère Des Ressources Naturelles Et De La Faune Du Québec Et Le Ministère De L'Environnement, De La Santé Et De La Protection De Consommateurs De La Bavière Portant Sur La Coopération Dans Les Domaines Du Biocarburant Et De La Protectoin Du Climat," (Government of Quebec (Canada) and Government of Bavaria (Germany), 2005), Ministère des Ressources Naturelles, *Ethanol: A Renewable Fuel for Sustainable Development* (Gouvernement du Quebec, no date [cited Jan. 21 2009]); available from http://www.mrnfp.gouv.qc.ca/english/publications/energy/ethanol.pdf.

[50] CBC Staff Reporter, *P.E.I. Looks to Ethanol* (Canadian Broadcasting Corporation, 3 August 2006 [cited 30 November 2006]), CBC Staff Reporter, *P.E.I. Sets New Target for Renewable Energy* (21 September) (Canadian Broadcasting Corporation, 21 September 2006 [cited 30 November 2006 2006]).

[51] Yukon Agriculture Branch, *Infarmation: Yukon Agriculture Branch Quarterly Bulletin* [Quarterly Bulletin] (Government of Yukon, 2006 [cited 1 December 2006]); available from http://www.emr.gov.yk.ca/pdf/InFARMation_Spring_2006.pdf, Yukon Energy Solutions Centre, *Biomass* (Government of Yukon, 20 October 2006 [cited 1 December 2006]); available from http://www.nrgsc.yk.ca/biomass.html.

[52] National Energy Board, "Energy Use in Canada's North: An Overview of Yukon, Northwest Territories, and Nunavut," in *Energy Facts* (Ottawa: National Energy Board, 2011).

Biofuels in Manitoba

The biofuels industry in Manitoba began in 1981 when Mohawk Oil opened Canada's first ethanol production plant in a former distillery in the town of Minnedosa. Mohawk joined Husky Oil Marketing Company (a subsidiary of Calgary-based Husky Energy Inc.) to operate the small-scale 10 million litre ethanol plant. In 2005, the federal *Ethanol Expansion Program* provided $10.4 million dollars toward the $145 million expansion project. By 2008, Husky expanded to 130 million litres, which matched the ethanol production capacity with the projected consumption of a 10% ethanol blend for the province.[53] Manitoba did not provide any subsidies for capital expansion or operating costs, but Husky was eligible for the province's 10% manufacturer's tax credit, which is open to any type of industry.[54]

In 2010, gasoline consumption in the province was almost 1.6 billion litres and diesel fuel consumption totalled 784.9 million litres.[55] At these rates of consumption, achieving a 10% ethanol blend (E10) would require about 150 million litres of ethanol per year to satisfy provincial demand. Since Manitoba imports all of its gasoline from out-of-province refineries, hundreds of millions of dollars in annual income transfers are paid to petroleum producers and refiners in Alberta and Saskatchewan. The province's ethanol blend mandate reduces these income transfers by 10%, and saves the provincial government tens of millions of dollars every year. Combined with annual savings from

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[53] Robert.

[54] Jeffrey Kraynyk, interview, 29 November 2006.

[55] Statistics Canada, *Sales of Fuel Used for Road Motor Vehicles, by Province and Territory* (Government of Canada, 2011-07-27 2010 [cited August 26 2011]); available from http://www40.statcan.ca/l01/cst01/trade37b-eng.htm.

federal excise taxes on gasoline, the province estimated between $50 and $70 million in savings per year for the provincial economy.[56] Moreover, the Provincial government anticipated that it could capitalise on its surplus wheat production and further expand its ethanol production by 300-400% in order to stimulate an ethanol export industry, thereby increasing Canada's gross domestic product and bring additional revenue to Manitoba. However, the surplus production capacity has not materialised.

In 2002, the Manitoba government created an Ethanol Advisory Council to explore the potential for a provincial ethanol industry and to identify policies and principles to inform the niche development strategy. The Council identified numerous policy instruments to encourage the province's ethanol sector, which included mandates, carbon taxes, financial assistance (for ethanol plant construction, ethanol production, and expanded distribution/retail outlets), other tax credit options, and public education programs.[57] These policy measures were designed to encourage ethanol production and consumption in the province, yet additional instruments were suggested to help facilitate the distribution and broader consumer acceptance necessary to fully integrate ethanol into Manitoba's vehicle fuel mix. Following the Ethanol Advisory Council's suggestions, the government suggested a number of principles to guide the development of the province's ethanol industry. These principles reflect the desire for consultation, administrative transparency, financial responsibility by public institutions, trade harmonisation and

[56] Manitoba Energy Advisory Panel, "Ethanol Made in Manitoba," in *Energy Advisory Panel Report* (Winnipeg: Government of Manitoba, 2002).

[57] Manitoba's Energy Development Initiative, *Homegrown Energy: Developing Manitoba's Ethanol Industry (Ethanol Backgrounder)* (Government of Manitoba, 2002 [cited 22 November 2006]); available from http://www.gov.mb.ca/est/energy/ethanol/introeth.html.

diversity in both scale and organisational structure of production facilities.[58]

The province created an Energy Advisory Panel to oversee and guide the Manitoba biofuels industry as it developed and adopted these principles when consulting with the Manitoba public to generate a number of recommendations, which modified the existing excise tax structure for retail fuel and government procurement. Provincial excise tax incentives for local ethanol production and use have been in place since the early 1980s. As of 2010, the provincial levy on gasoline remained at $0.115 per litre. An added incentive of $0.15 per litre for E100 reduces the provincial fuel excise tax for refiners of E10 fuel from $0.115 to $0.10 per litre.[59] Manitoba's subsidy is contingent on local production and consumption, and is among the highest such tax exemption in Canada. Through its vehicle procurement policy, over one fifth (22.1%) of the Province's light duty vehicle fleet (606 of 2737) were FlexFuel (E85) units as of March 2010.[60]

In addition, the Panel recommended a number of niche development activities such as developing higher yield wheat feedstocks and cellulosic ethanol, creating value-added co-products, and exploring other biofuels and blends. These also included efforts directed at the Canadian regime, which included provincial mandates for ethanol and biodiesel as a way to encourage the federal government to adopt a national mandate.[61]

The provincial government implemented many of these recommendations, and

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[58] Manitoba's Energy Development Initiative, "Developing Manitoba's Ethanol Industry: Consulting Manitobans - Maximising the Benefits," (Winnipeg: Government of Manitoba, 2002).

[59] *The Biofuels Act*, (December 4, 2003).. The rate of taxation as restructured in the 2008 *Biofuels Act* is subject to a declining rate of exemption over an eight year period. Beginning with a $0.20/l credit in 2008-09, this dropped to$ 0.15 for the period 2010-12, and further to $0.10 from 2013-15.

[60] Government of Manitoba, "Vema Annual Report, 2009-2010," ed. Manitoba Infrastructure and Transportation (Winnipeg: Vehicle and Equipment Management Agency, 2010).

[61] Manitoba Energy Advisory Panel, "Ethanol Made in Manitoba."

also leveraged federal programs to increase investor interest while urging the federal government to adopt a national mandate for biofuels content in gasoline and diesel fuel. However, only a handful of communities and companies have considered joining Husky Oil in Manitoba's ethanol sector.[62] In contrast, interest in biodiesel has been higher, which aligned nicely with Manitoba's plans to expand production of other forms of biomass energy.[63] After removing provincial taxes on biodiesel, the province chose and approved six community-based local biodiesel production projects, which were helped by federal support out of Natural Resources Canada's $1.5 million "Opportunities Envelope" funding program in 2006. There were a few other small-scale private industry projects slated for construction that did not apply for the federal funding, which suggests a high level of private sector confidence in this emerging industry that may have even greater potential than the province's ethanol industry.[64] Still, biodiesel in Manitoba has not lived up to its expectations. Speedway International of Winnipeg was the only facility to produce commercially-available biodiesel, while two others (in Arborg and Beausejour) have had difficulty producing sufficient quantity that meets the minimum fuel standards and specifications (Table 8-7).

On November 1, 2009, Manitoba was the first province in Canada to implement a biodiesel mandate requiring an annual average of 2% biodiesel content in petroleum diesel fuel sales. The implementation of this mandate was accompanied by the replacement of a fuel exemption of $0.115 per litre for diesel fuel with a $0.14 per litre,

[62] Kraynyk.
[63] Manitoba Energy Development Initiative, "Biodiesel Made in Manitoba," (Winnipeg: Government of Manitoba, 2003).
[64] Kraynyk.

five-year production grant for biodiesel produced in the province from 2010-2015. The Province announced that this would provide greater local support for biodiesel producers and would "keep Manitoba competitive with incentives offered in other North American jurisdictions".[65] According to local biofuel producer Royce Rostecki of Speedway International, the future for Manitoba biodiesel producers look favourable with these changes, and consumers may no longer have to rely solely on imported biofuels.[66]

Table 8-7: Biofuels Production Facilities in Manitoba

Name	Location	Feedstock	Co-located Operation	Annual Capacity (million litres)
Husky Energy, Inc	Minnedosa, MB	Wheat and corn	Former whiskey distillery	130
Bifrost Bio-Blends, Ltd.	Arborg, MB	Canola	Oil-seed processing	3
Eastman Bio-Fuels, Ltd.	Beausejour, MB	Canola	n/a	5
Speedway International, Inc.	Winnipeg, MB	Canola	Methanol racing fuel, windshield washer fluid	20
			Total	158

(Source: Canadian Renewable Fuels Association 2010)

Biofuels in Saskatchewan

The province's ethanol industry began in the town of Kerrobert with a pilot plant owned by Agchem Biosynthesis, Inc. of Saskatoon. Used mainly for research, its annual production capacity averaged between 1.5 and 2.0 million litres. However, the research facility operated intermittently, was not a commercial producer, stopped producing

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[65] Government of Manitoba, *Manitoba Leads the Way Wth Biodiesel Mandate: Rondeau* (Government of Manitoba, September 10, 2009 2009 [cited November 24 2010]); available from http://news.gov.mb.ca/news/index.html?archive=&item=6694.

[66] Ibid.

ethanol in 2002, and its on-site equipment was auctioned off in 2008. There are currently five ethanol production facilities in Saskatchewan (Table 8-8).

Table 8-8: Biofuels Production Facilities in Saskatchewan

Name	Location	Feedstock	Co-located Operation	Annual Capacity (million litres)
Pound-Maker Agventures	Lanigan, SK	Wheat	Cattle feedlot, distilled grain feed	12
NorAmera Bioenergy Corp.	Weyburn, SK	Wheat	Former whiskey distillery	25
Husky Oil Operations, Ltd.	Lloydminster, SK	Wheat	Heavy oil upgrader	130
Terra Grain Fuels, Inc.	Belle Plain, SK	Wheat	n/a	150
North West Bio-Energy, Ltd.	Unity, SK	Wheat	Grain terminal	25
Milligan Bio-Tech Inc.	Foam Lake, SK	Canola	n/a	1
			Total	343

(Source: Canadian Renewable Fuels Association 2010)

Saskatchewan consumed almost 1.7 billion litres of gasoline and over 1.2 million litres of diesel fuel in 2010.[67] Saskatchewan's annual ethanol production of 342 million litres provides more than double the 170 million litres of ethanol required to attain E10 across the province. The surplus 172 million litres are exported. With a benchmark

[67] Statistics Canada, *Sales of Fuel Used for Road Motor Vehicles, by Province and Territory*. This is the most recent data available

annual output of 400 million litres per year, early estimates were that the economic gain was expected to equal $346 million per year and increase provincial GDP by $139 million annually.[68]

Saskatchewan's ethanol policy began in 1991 with a set of production and consumption subsidies. This program was described as "hit and miss" in its early days due to "confusing" incentives that were "difficult to access".[69] Although this first attempt to develop a provincial ethanol industry was cancelled in 1995, policies were kept in place until the province created a Task Force to re-examine the potential for a Saskatchewan-based ethanol industry.[70] The Task Force offered recommendations aimed at both niche development activities and efforts to influence Canada's nascent biofuels regime. Niche-level recommendations included a twenty-year fuel ethanol rebate of $0.15 per litre (with an eight-year phase-out period) for all ethanol sold in the province that would be aimed at fuel retailers for a maximum of 30 million litres per year, per plant in order to "encourage the development of small-scale ethanol facilities, integrated with feedlots, which create greater regional economic activity".[71] Also, an ethanol tax abatement incentive to fuel retailers of $0.045 per litre for a 33-month period was recommended to assist industry implementation. In addition, the province established an ethanol advisory council to assist and to guide industry development, as well as the incremental implementation of increasing content obligations for ethanol-blended

[68] Saskatchewan Industry and Resources, "Greenprint for Ethanol Production in Saskatchewan," (Saskatoon: Government of Saskatchewan, 2002).
[69] Saskatchewan Agri-Vision Corporation Inc., "Saskatchewan's Hibernia (Ethanol) Project - Preliminary Report," in *Task Force* (Saskatoon: 2002).
[70] Ibid.
[71] Saskatchewan Agri-Vision Corporation Inc., "Hibernia (Ethanol) Strategy Report," (Saskatoon: Saskatchewan Energy and Mines, 2002), 6.

gasoline across the province in order to achieve domestic demand of approximately 150 million litres of ethanol per year.[72] On 1 November 2005, the Province became the first in Canada to legislate the use of 7.5% ethanol blended gasoline.[73]

More or less in alignment with Manitoba, Saskatchewan implemented the recommendation from Saskatchewan's Task Force. It restructured its existing incentive program and removed the fuel tax on the ethanol portion of gasoline to provide a $0.15 per litre benefit to distributors on the condition that the biofuel content is produced and consumed within the province. Alongside this niche-development measure, the government replaced the existing ethanol policy framework with its *GreenPrint for Ethanol Production in Saskatchewan* and a new ethanol program in 2002.[74] To communicate these changes the government unveiled its website "Ethanol – Fuelling the Province".[75] The Saskatchewan Ethanol Development Council was created in December 2004 in order to "promote and coordinate the efforts of all member stakeholders in the development of a strong, vibrant, profitable and sustainable ethanol industry in Saskatchewan".[76]

Distributors were able to voluntarily supply gasoline containing up to a 10% blend, which aligned nicely with the 2006 agreement to implement a national Renewable Fuels Standard. In addition, the province protected its ethanol niche through legislation

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[72] Ibid.
[73] *The Ethanol Fuel Act*, (15 July).
[74] Saskatchewan Industry and Resources, "Greenprint for Ethanol Production in Saskatchewan."
[75] Government of Saskatchewan, *Ethanol - Fuelling the Province* (Government of Saskatchewan, 2006 [cited 24 November 2006]).
[76] Saskatchewan Ethanol Development Council Inc., *About Us* (Saskatchewan Ethanol Development Council Inc., 2006 [cited 24 November 2006]); available from http://www.saskethanol.com/aboutus.html.

that reserved 30% of the provincial ethanol industry for small-scale production facilities with a yearly output of 25 million litres or less. Notable is the absence of any tax abatement incentives for industry implementation.

Saskatchewan implemented and successfully expanded its ethanol industry with the capacity to satisfy provincial demand. This success is further strengthened by the continuing interest of private investors to enter Saskatchewan's ethanol industry. The Guelph, Ontario-based International Debranning, Inc. was slated to build a 300 million litre per year facility near Rosthern.[77] The Rural Municipality of Rosthern has confirmed that the company still owns the property, but the project appears to have "stalled".[78] Following the implementation of its ethanol program, the Saskatchewan government expanded its biofuels sector into biodiesel production. In June 2006, the Saskatchewan Biodiesel Task Force submitted its report to the Province, recommending that the province set renewable fuel targets for biodiesel of 2% by 2010 and 5% by 2015.[79] There have been in excess of three dozen biofuel production proposals, which suggest a high degree of interest in Saskatchewan's ethanol and biodiesel industry. However, while the futures of these proposals are uncertain, the construction and operation of additional ethanol manufacturing plants has produced an ethanol surplus in the province. Encouraged by this success, the province diversified its ethanol industry, and has also expanded its biodiesel production capacity.

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[77] Bruce Johnstone, "Enthusiasm, Caution Urged on Ethanol Plans," *Leader-Post*, 8 June 2006.
[78] Wendy Penner, interview, May 20 2011.
[79] Saskatchewan Biodiesel Development Task Force, "Fueling the Future: Final Report on the Biodiesel Industry in Saskatchewan," (Saskatoon: Government of Saskatchewan, 2006).

Biofuels in Ontario

Ontario produces over 858 million litres of first generation ethanol annually, which is the highest production by any province in Canada (Table 8-9). It is also home to Iogen Corporation, which produces around 2 million litres of cellulosic ethanol annually at its pilot production facility in Ottawa.

Table 8-9: Biofuels Production Facilities in Ontario

Name	Location	Feedstock	Co-located Operation	Annual Capacity (million litres)
GreenField Ethanol	Chatham, ON	Corn	n/a	180
Suncor Energy Products Inc.	Sarnia, ON	Corn	Oil refinery	200
Integrated Grain Processors Co-operative	Aylmer, ON	Corn	Distilled grain feed	145
GreenField Ethanol	Johnstown, ON	Corn	n/a	200
GreenField Ethanol	Tiverton, ON	Corn	n/a	3.5
Amaizeingly Green Products LP	Collingwood, ON	Corn	Former cornstarch plant	50
Kawartha Ethanol	Havelock, ON	Corn	9.8 MW bio-gas plant	80
Great Lakes Biodiesel	Welland, ON	Multi-feedstock	n/a	170
BIOX Corporation	Hamilton, ON	Multi-feedstock	n/a	66
Methes Energies Canada, Inc.	Mississauga, ON	Yellow grease	n/a	5
Noroxel	Springfield, ON	Yellow grease	n/a	5
Iogen	Ottawa, ON	Cellulose	n/a	2
			Total	976.5
Planned				
GreenField Ethanol	Hensall, ON	Corn	n/a	190
BIOX Corporation	Hamilton, ON	Multi-feedstock	n/a	67
Methes Energies Canada, Inc.	Sombra, ON	Multi-feedstock	n/a	50

(Source: Canadian Renewable Fuels Association 2010)

Ontario consumed over 16.1 billion litres of gasoline and more than 4.9 billion litres of diesel fuel in 2010.[80] To supply an E10 blend for the provincial market, Ontario requires about 1580 million litres of ethanol annually. At this amount, Ontario needs about 730 million litres more in order to supply enough ethanol for the province in 2010. The anticipated expansion to 1048 million litres annually would still put Ontario at a half billion litres per year shortfall, which will continue the province's reliance on imported ethanol.

Fuel ethanol sold in Ontario has been exempted from the provincial gasoline tax since 1980. In 1994, the province announced that it would take part in ethanol manufacturers' agreements with private industry on a per contract basis. These project-specific agreements with ethanol producers using renewable feedstocks guaranteed that the current $0.147 per litre tax exemption would remain until 2010, regardless of shifts in provincial taxation policy. In June 2005, the province revealed its *Ontario Ethanol Growth Fund* that offered $520 million in government contributions over twelve years to encourage the province's bioethanol industry. This Fund offered capital grants (to subsidise the expansion or construction of manufacturing facilities) and operating grants (to mitigate the risks associated with the early stages of the ethanol industry and uncertain market conditions). It also created a fund to support independent retailers in meeting the blending requirements by 2007. An industry fund comprises another component of the *Ontario Ethanol Growth Fund* intended to foster research and development and to attract

[80] Statistics Canada, *Sales of Fuel Used for Road Motor Vehicles, by Province and Territory.*

investment that would further develop Ontario's ethanol industry.[81] To avoid "protracted and costly trade challenges", the *Ontario Ethanol Growth Fund* does not require ethanol feedstocks to be grown in Ontario.[82] Thus, the Ontario ethanol industry is open to other jurisdictions and producers. The province also announced its own renewable fuels standard in October 2005 with the finalisation of Ontario Regulation 535/05 - *Ethanol in Gasoline*. As of January 2007, the provincial mandate required that all gasoline sold in Ontario contain at least 5% ethanol.

Unlike Manitoba and Saskatchewan, the Ontario government did not publicise its research or provide documentation detailing its policy rationale or overall strategic guidelines or principles. There are no public documents or reports on this process, nor are there any available studies or policy plans on the implementation of the province's ethanol strategy.[83] However, its policy instruments are straightforward, consisting of the tax exemption on ethanol, Ethanol Manufacturers' Agreements, the *Ontario Ethanol Growth Fund*, and the mandate of 5% ethanol content by January 2007 (later replaced by the federal *Renewable Fuel Standard*). Except for the recent legislation requiring ethanol-blended gasoline, the province employed "supply-push" policy instruments. For example, the tax exemption created a favourable investment climate and the manufacturers' agreements guaranteed their continuance until 2017. The *Ontario Ethanol Growth Fund* subsidised both construction and operating costs in order to make industry investment

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[81] Ontario Ministry of Agriculture Food and Rural Affairs, *Ontario Ethanol Growth Fund: Program Overview* (Government of Ontario, 26 June 2005 [cited 25 November 2006]).

[82] Ontario Ministry of Agriculture Food and Rural Affairs, *Questions and Answers: Ontario Ethanol Growth Fund - Announcement of Funding Decisions* (Government of Ontario, 2006 [cited 25 November 2006]); available from http://www.omafra.gov.on.ca/english/policy/oegf/questions.htm.

[83] Tammy Tondevold, telephone interview, April 25 2010.

more favourable. The use of supply-push policy instruments to encourage ethanol expansion is indicative of Ontario's market-based approach. While it developed its fuel ethanol strategy later than Manitoba and Saskatchewan, Ontario has since expanded the province's fuel ethanol industry significantly. Ontario was the first jurisdiction in Canada to offer incentives for the production of biodiesel by exempting biofuel content from the $0.143 per litre road tax on diesel fuel in June 2002.[84] Nevertheless, only one biodiesel production facility was constructed in the province by 2010.

Niche Development and Subnational Variation

Since the start of their provincial niche markets, Manitoba, Saskatchewan and Ontario now produce enough biofuels to supply 10% of Canada's transport energy needs. Canadian provinces developed their ethanol and biodiesel niches in different ways. Though a combination of voluntary and mandatory policy instruments, Manitoba and Saskatchewan first developed provincial niches for ethanol, and later applied these experiences to niche development strategies for biodiesel. The prairie provinces pursued social, economic and environmental objectives, which included transparency and consultation, cooperative business models, minimising economic costs, protecting local production, using local agricultural produce, and reducing greenhouse gas emissions. In contrast, Ontario developed its ethanol and biodiesel niches much later, but its large population, substantial agricultural sector, presence of large industrial corporations, numerous research and academic institutions, and larger network of industry supporters

[84] Ontario Ministry of Finance, *Ontario Budget 2002* (Government of Ontario, 2002 [cited 27 November 2006]); available from http://www.fin.gov.on.ca/english/budget/bud02/english_complete.pdf.

prompted the Ontario government to embrace an aggressive biofuels development strategy as a contender for export to other provinces as well as to international markets. Ontario developed these niches to align with international and multilateral trade agreements. This global perspective focussed more on global, large-scale, economic competition rather than on local, small-scale, social or environmental objectives.

The objectives of these three subnational approaches to niche development differed, but they followed a similar pattern of implementation. Beginning with the success of policy measures to protect intra-provincial biofuels expansion programs, each province sought to capitalise on their positive local experiences to leverage federal support. The expansion of biofuels in Manitoba and Saskatchewan valued citizen participation in the niche development process, and sought to protect their local producers. Manitoba encouraged alternative ownership schemes to assist smaller enterprises while Saskatchewan took the more drastic step of reserving 30% of the market for small producers. In contrast, Ontario did not provide the level of government transparency that was offered by its western neighbours, but was nevertheless able to achieve a greater annual volume of production in a much shorter period. Also, Ontario's rejection of preferential treatment for local biofuels indicates its willingness to accept higher risk levels and a stronger desire for a smoother entrance into global markets.

While these provincial niches differed from each other, they simultaneously influenced and accommodated the national biofuels expansion program that was emerging during the 2000s. Provincial programs successfully expanded local production, but the diffusion of biofuels to the national level was aided by the alignment of provincial and national biofuels policies and programs, which included a broad harmonisation of legislation through biofuel content mandates, regulations specifying fuel quality and biofuels types.[85] This framework allowed sufficient flexibility for provinces to target specific objectives, such as types of feedstocks, tax incentives, types of biofuels, and implementation mechanisms. The private sector helped facilitate this harmonisation by developing voluntary product standards through the Canadian General Standards Board[86] and adjusting vehicle engine warranties to allow biofuel blends.[87]

A combination of voluntary and compulsory policy instruments within subnational regulatory frameworks provided the rules needed to enhance market certainties, improve consumer awareness, and to help facilitate the expansion of biofuels production. However, niche development efforts do not guarantee the achievement of subnational objectives, as landscape pressures and regime requirements can affect the trajectory of niche innovations in unexpected ways. This was the case in Manitoba, where the development of ethanol and biodiesel niches reveals how global biofuels interfered with a number of local objectives and concerns.

Situated about 200 kilometres northwest of Winnipeg, Manitoba on the Little Saskatchewan River, the town of Minnedosa (meaning "flowing water" in Sioux) was the site of Canada's first commercial transportation ethanol plant. This picturesque prairie valley town is home to around 3000 residents. Its agricultural economic base is supported by local farmers that rely on the fertile alluvial soil that covers the rolling hills and open

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[85] *Renewable Fuels Regulations*.
[86] Canadian General Standards Board, "Strategic Plan: 2010-2013," (Ottawa: Canadian General Standards Board, 2010).
[87] Engine Manufacturers Association, "Facts You Should Know About Renewable Fuels," (Chicago: Engine Manufacturers Association, 2009).

prairie around the town. The main crops include most cereal grains, oilseeds, as well as forage crops for livestock. Local businesses have successfully supported the needs of the local farming community by providing seed, chemicals, equipment sales and service, as well as agronomic advice and support. A small but stable retail and business district serves the surrounding area, and the declining number of small-scale farming operations (due to urban migration, retirement, and general decline experienced by many rural communities in most developed countries) has been somewhat offset by increased recreation and entertainment services.[88] Also, the town is the home of two large manufacturing plants that have recently expanded. One produces farm machinery and parts for markets around the world. The other, owned by Husky Energy, Inc., produces ethanol. While other towns in close proximity have suffered rapid out-migration and socio-economic deterioration, Minnedosa has clearly profited from global relationships and international trade while continuing to support local agriculture for domestic and foreign markets.

Manitoba produced over 3.2 million tonnes (119.8 million bushels) of wheat on about 3 million acres in 2010.[89] The 10% increase in demand for local wheat created by the expansion from 10 to 130 million litres per year in ethanol production was expected to address the Province's surplus wheat crop, reduce gasoline imports to Manitoba, and provide the foundation for further expansion of the local ethanol industry for export. This

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[88] Government of Manitoba, *Town of Minnedosa Community Profile* (Manitoba Agriculture, Food and Rural Initiatives, 2007 [cited July 9 2008]); available from http://www.communityprofiles.mb.ca/cgi-bin/csd/index.cgi?id=4615075.

[89] Statistics Canada, *November Estimates of Production of Principal Field Crops* (Ministry of Industry, December 2010 2010 [cited May 20 2011]); available from http://www.statcan.gc.ca/pub/22-002-x/22-002-x2010008-eng.pdf.

expansion was not expected to make much difference in the price or availability of wheat, but would open additional markets and increase sales for local farmers.

Provincial government endorsement, national program support, and the increased global popularity of ethanol have had short- and long-term effects for Minnedosa. The economic benefits to the town and surrounding area have been positive, and the Husky facility maintained the demand for local grain at a relatively stable level despite declining farming activity and an uncertain wheat market. Even when it was a small-scale facility, this niche development initiative created local jobs for this rural community while other towns suffered. However, the expansion to a large-scale 130 million litre/year operation has changed the scope and scale of local economic, social and ecological effects.

In April of 2008, Husky Energy officially opened the enlarged Minnedosa ethanol plant with an announcement that it expected to purchase all of the 350,000 tonnes of grain from local producers.[90] Due to rising demand for wheat from other sectors and related price effects, Husky Energy changed from an entirely wheat-based ethanol to include corn feedstocks (up to 75%). The company later pledged to purchase 80% of its feedstock from Manitoba farmers. It was expected that wheat would remain part of the feedstock mix, but within months of the increase in production capacity the president of the Manitoba Corn Growers Association estimated that 30-35% of the facilities total corn grain requirements had been contracted from Manitoba producers for 2009.[91]

Interestingly, corn was not grown in Manitoba in any significant way until 1978.

[90] Husky Energy Inc., *Husky Energy Officially Opens Minnedosa Plant* (Husky Energy, Inc., April 25 2008 [cited July 4 2008]); available from http://www.huskyenergy.ca/downloads/NewsReleases/2008/HSE_042508_Minnedosa_Opening.pdf.

[91] Larry Kusch, "Husky Turns to Corn at Minnedosa Ethanol Plant," *Winnipeg Free Press*, May 22 2008.

Due to Manitoba's comparatively short growing season, most corn growers now select hybrid corn in order to increase yield potential by improving stalk strength, disease resistance, grain density, and herbicide tolerance, while some choose the more expensive genetically modified varieties. Today, about 475,000 tonnes of corn is grown in Manitoba, which is about 3% of Canada's total production. If the total feedstocks for ethanol production at the Minnedosa plant was a 1:1 ratio of wheat to corn, the facility would require about 175,000 tonnes of corn, or almost 40% of corn grown in the province. A 100% shift to corn-based ethanol would require three quarters of Manitoba's total annual corn yield.[92]

Although it provides short-term benefits to Husky Energy and Manitoba corn growers, the switch from wheat to corn is not sustainable. First, the province's sizeable wheat surplus makes wheat-based ethanol a logical value-added product, while the relatively small corn market would likely experience soaring demand and impending supply shortages. Also the unsold surplus wheat would need to find other markets or remain unsold.

Second, corn is sensitive to Western Manitoba's semi-arid conditions, while the varieties of wheat grown in Western Manitoba are better suited to the short growing season and unpredictable weather systems ranging from very wet to very dry.[93] Farmers in this region who want to switch from wheat to corn must be willing to accept a greater risk of crop failure in years with low precipitation.

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[92] Ibid.

[93] Government of Manitoba, *Average Growing Season Precipitation for Corn* (Manitoba Agriculture, Food and Rural Initiatives, October 1999 1999 [cited July 9 2008]); available from http://www.gov.mb.ca/agriculture/climate/waa50s00fig42.html.

Third, the Province's goal of capitalising on surplus wheat by creating a value-added domestic product is no longer certain, while the potential for importing corn from other provinces or northern American states becomes much more probable. This does little to reflect the desires of citizens and stakeholders or achieve provincial government objectives to use local agriculture to provide energy feedstocks. Thus, from economic, agricultural and policy perspectives, corn-based ethanol does not make sense for Manitoba.

Fourth, the switch to corn does not make sense from the perspective of agricultural or environmental sustainability. Corn requires more inputs than wheat. Water consumption, fertilizer and pesticide applications are generally higher for corn due to its longer growing season, all of which contribute to increasing salinisation and declining soil fertility. An average Manitoba corn crop requires 21 inches of water while an average crop of spring wheat requires less than 12 inches. Average rainfall in Manitoba ranges from 9-11 inches annually with a 50% chance of lower-than-average precipitation.[94] Wheat is therefore a much more reliable crop as it more closely matches the growing conditions of local ecosystems.

In addition to high water requirements to grow corn compared to wheat, the manufacture of ethanol also requires large quantities of water, which present important implications in terms of the higher production capacity of the expanded ethanol plant. The Minnedosa facility uses about 9 litres of water for every litre of ethanol produced. At an annual production of 10 million litres, the original plant consumed at least 90 million

[94] Ibid.

litres of water for ethanol production *per annum.* This withdrawal from groundwater wells and the town reservoir seemed to be sustainable at this smaller scale, but the increased production to 130 million litres annually requires almost 1.2 billion litres of water. The Town of Minnedosa is supplying the ethanol plant with 2.5 times the groundwater that it supplies to homes, businesses and other industry connected to its water system by drawing stored water from the town's reservoir. While aquatic and terrestrial ecosystems were not expected to be adversely affected by this facility expansion, several engineers have projected that continued extraction at this level will cause water levels to drop by as much 4 feet every 25 years.[95] If this trend continues, private citizens and property owners will face reduced availability of water resources over the long-term while a private company will realize short-term benefits by extracting a common-use resource for shareholder profit.

Local farmers and industry, as well as municipal and provincial governments, all expect the larger ethanol plant to benefit the small town of Minnedosa. This niche response to the increased demand for biofuels has reinforced the use of first generation technology, changed the feedstock from local wheat to a mix of domestic and imported corn feedstock, put local farmers in a more uncertain position as they weigh the risks of shifting to corn production, and drastically increased the amount of water used by the small rural community.

These outcomes were freely chosen by a variety of actors in an attempt to achieve

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[95] Gaile Whelan Enns, *Town of Minnedosa Water Supply Upgrade Project (Husky Ethanol Plant) - Public Registry File #5205.00* (Manitoba Wildlands, 2006 [cited 13 November 2006]); available from http://manitobawildlands.org/water_projects.htm.

specific effects rather than encourage a long-term shift toward the satisfaction of social functions. The shift from small- to large-scale production was stimulated by the increased demand caused by the rapid growth of the national biofuels market and the promise of increased export sales from international trade. The expansion of this facility from a small-scale to large-scale first generation ethanol production facility has exacerbated local environmental pressures on its local water supply, and it appears that these effects will occur within this generation. This case shows how difficult it is for smaller producers to resist the influence of dominant biofuels regimes and the landscape contexts in which these regimes evolve. Societal rules to ensure a high priority was afforded to sustainability concerns might have obliged the ethanol producer to remain in accordance with the Manitoba government's niche development strategy. In this way, this subnational niche would have been better prepared to resist the global commoditisation of ethanol and biodiesel initiated and embraced by the dominant biofuels regimes.

Conclusion

These Canadian examples show that niche development of biofuels in subnational jurisdictions involved smaller scales of production and different policy approaches in comparison to the dominant biofuels regimes in Brazil, the United States, and the European Union. While confirming the importance of the local context of niche development of biofuels, the comparison of Manitoba, Saskatchewan and Ontario reflects how subnational jurisdictions within the same national regime can respond differently. The diffusion of global biofuels influenced niche development in small markets. Yet despite landscape pressures to harmonise the regulatory contexts according to the trajectories initiated by the dominant biofuels production regimes, subnational governments can still exercise discretion and choose to diverge from dominant trajectory when designing local production systems.

Considering that the dominant biofuels regimes described in chapter five have not gained complete influence over biofuels production in other jurisdictions, and that the "local" and "global" criticisms identified in chapter six suggests an undercurrent of dissatisfaction with the global expansion of ethanol and biodiesel, it would appear that the promise of biofuels must somehow address more social functions than those provided by first generation ethanol and biodiesel. The emerging critiques of global biofuels suggest a need also to address environmental integrity and social development in order to reconcile local goals and aspirations that may not coincide with the present trajectory of global biofuels.

The Canadian examples confirm some of the differences between local and global biofuels production. The similarities between local and global biofuels production are equally revealing, especially when the dominant biofuels regimes and the Canadian cases reveal strong symmetries in the progression of policy instruments. Like the dominant regimes, Canadian production systems also utilised production subsidies and tax incentives at both federal and provincial levels, followed by minimum biofuels content for transport fuels. However, the context of Canadian biofuels reveals some diverging trends in the subnational biofuels production strategies, such as the requirement for local feedstocks and job creation opportunities stemming from local production. Niche development was an important component in overcoming the challenges of innovation and diffusion. Provinces with established feedstock production adopted biofuels technologies to increase their competitive advantage in the context of a nascent global biofuels market. Both Saskatchewan and Manitoba grow an immense amount of wheat while Ontario has an abundance of corn. These three provinces developed successful biofuel strategies by actively encouraging the uptake of first generation biofuels technology in order to capitalise on an existing economic advantage of surplus agricultural production.

This chapter showed that while Canada was subject to harmonising pressures from the three dominant biofuels regimes, the development of Canada's national biofuels regime was also influenced by policy and program decisions of different orders of government. In Canada, the federal government can fund research and development, subsidise the construction of biofuel production facilities and related infrastructures, offer tax exemptions on federal portions of road taxes or motor fuel production taxes, and provide information to increase public awareness. These are all tied to the ability of the federal government to exercise its spending power. However, the provinces were responsible for the more difficult task of implementing biofuels policies and programs, such as regulating biofuel content, encouraging local production, and assessing the environmental impact over the course of the production chain. Knowing this, we can identify opportunities for government leaders and policy makers of small markets and subnational jurisdictions. In particular, we can find ways to direct niche development through sustainability criteria as a way to achieve sustainable biofuels.

NINE – Implementing Sustainable Biofuels

Transitions approaches are not always suited for making policy recommendations[1], but the multi-level perspective on transitions is useful when seeking to understand persistent disconnections between society and technology, undesirable technical effects, or other perverse policy outcomes. First generation biofuels have performed fairly well as a response to stated policy objectives related to rural development, energy security, and reducing greenhouse gas emissions. Yet criticisms discussed in chapter six reflect ongoing concerns with the wider system effects, suggesting that there are fundamental concerns with the use of liquid biomass fuels.

The multi-level perspective on transitions helps to identify these deeper issues by providing insight into three aspects of socio-technical systems. Not only does it provide a broader scope of analysis by examining the interactions between niche, regime and socio-technical landscape, but it explores technical variation and changes in selection environment in order to account for the evolution of structural and procedural elements of socio-technical systems.

The first half of this chapter explores the use of principles, guidelines and requirements that have characterised recent attempts to encourage sustainable biofuels. It also provides a conceptual definition of sustainable biofuels based on four broad areas for

[1] Niki Frantzeskaki and Hans de Hann, "Transitions: Two Steps from Theory to Policy," *Futures* 41 (2009), Genus and Coles, "Rethinking the Multi-Level Perspective on Technological Transitions.", Meadowcroft, "What About the Politics? Sustainable Development, Transition Management, and Long Term Energy Transitions.", Verbong and Geels, "Exploring Sustainability Transitions in the Electricity Sector with Socio-Technical Pathways."

consideration: sustainability, effects/functions, level of analysis, and level of policy activity. Using this conceptual definition, the chapter identifies twelve conditions of sustainable biofuels, which are then applied to three likely policy scenarios.

The second half of this chapter examines policy making in the multi-level perspective on transitions. In particular, it explores the potential to de-align and re-align the present trajectory of first generation biofuels in a more sustainable configuration. This chapter closes with a consideration of voluntary, industry-based, and compulsory approaches to regulatory development, and how small markets might use these approaches to include sustainability criteria and certification standards as part of the niche development strategies for sustainable biofuels.

Seeking Sustainable Biofuels

Given the unsustainability of the first generation biofuels supplied by the dominant regimes and the tendency of small markets to emulate the development trajectory of dominant jurisdictions, corrective measures are required to insert sustainability as a key consideration within decision-making processes and institutional structures. Such improvements could occur anywhere throughout the production-consumption chain, yet costly system upgrades are unlikely to be voluntarily incorporated by the private sector into production processes.[2] Likewise, consumers require confidence and familiarity with market goods, access to new products, and comparable price

[2] de Ron, "Sustainable Production: The Ultimate Result of Continuous Improvement.", Christopher O'Brien, "Sustainable Production - a New Paradigm for a New Millennium," *International Journal of Production Economics* 60-61 (1999).

structures in order to adopt new technologies.[3] In addition, the unsustainable trajectory initiated by dominant biofuels regimes has been reinforced by the momentum of expanding production levels of first generation ethanol and biodiesel. The present trajectory of these biofuels was made possible through the use of numerous policy tools, which enabled the expansion of production systems and creation of global markets. In a similar way, rules to encourage sustainability are necessary if biofuels are to become more sustainable.

Sustainability criteria and certification standards for biofuels provide an avenue to overcome the unsustainable growth of biofuels production and trade. Similar regulatory mechanisms are used extensively for other products and processes to ensure product consistency and consumer familiarity, and the biofuels industry might benefit from experiences in forestry, fisheries, agriculture, coffee and chocolate, to name a just a few sectors from the rapidly growing list of certified products.[4]

During the height of the global expansion of biofuels, a number of publications explored the potential of sustainability standards for the biofuels industry. Whether from a multilateral, national or independent source, early discussions on the sustainability of biofuels have taken the form of policy position papers, scoping documents to highlight areas for consideration, and international conferences. These discussions considered the process of regulatory development from different perspectives, and suggested how governments could improve sustainability in the sector. They did not prescribe specific

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[3] Buchholz, Luzadis, and Volk, "Sustainability Criteria for Bioenergy Systems: Results from an Expert Survey."

[4] Thomas V. Dietsch and Stacy M. Phillpott, "Linking Consumers to Sustainability: Incorporating Science into Eco-Friendly Certification," *Globalizations* 5, no. 2 (2008), Laura T. Raynolds, "Fair Trade: Social Regulation in Global Food Markets," *Journal of Rural Studies* 28 (2012).

regulations, but instead employed *principles*, *guidelines* or *requirements* as different approaches to developing regulations for sustainable biofuels.

Principles

The Energy Transition Task Force of the Dutch government explored the underlying principles of developing sustainability criteria for "...the production and conversion of biomass for energy, fuels and chemistry."[5] Based on consultations and stakeholder dialogue, the Dutch Energy Transition Task Force established a long-term vision for biomass as "an essential energy source in the transition to a sustainable energy supply".[6] The resulting principles for the development of sustainability criteria highlight the need to make the most of the opportunities that biomass can offer as an alternative to fossil fuels and as a means to mitigate carbon emissions. They also reflect basic premises that take into consideration both local and global factors. For instance, import of biomass feedstocks is necessary for the country to employ biomass as a sustainable energy source. In order to mitigate unsustainable extraction from biomass suppliers, the Netherlands based its sustainable biomass strategy on the application of a universal framework for all biomass production (i.e., the same criteria would apply for food, feed, and fuel) that was non-discriminatory (i.e., regulation would be harmonised as much as possible with international legislation, conventions, and certification methods). In addition, testing and verifiability, the development of appropriate indicators, and the manageability of data collection were identified as necessary measures to ensure that Dutch consumption would

[5] Project Group Sustainable Production of Biomass, "Criteria for Sustainable Biomass Production," ed. Jacqueline Cramer (Amsterdam: Energy Transition Task Force, 2006), ii.
[6] Ibid., 5.

be sustainable throughout the production-distribution-consumption-emission chain.[7]

The policy areas that sustainability criteria would address were identified as: greenhouse gas balance; competition with food, local energy, medicines, and building materials; biodiversity; economic prosperity; social well-being; and, environment. Identifying these criteria in relation to the principles endorsed by the Dutch government would help to prevent their omission from future policy decisions.[8] Further, the principles laid a foundation for sustainability criteria and also formed the basis for standards and certification. Thus, the principles-based approach pursued in the Netherlands recognized the importance of establishing in the very near term a frame of reference from which to discuss the long-term sustainability of biofuels.

The Dutch Task Force provided an example of how governments might employ a principles-based approach toward establishing sustainability regulations for biofuels. Non-government organisations can also employ principles to exhort governments to adopt more stringent regulations. For example, a diverse group from twelve different countries met in 2008 to explore the sustainable free global trade in biofuels. This Project Group on Sustainable Production of Biomass released their "Sustainable Biofuels Consensus" as a Declaration that

> ...calls upon governments, the private sector, and other relevant stakeholders to concerted, collaborative and coordinated action to ensure sustainable trade, use and production of biofuels, so that biofuels may play their key role in the transformation of the energy sector, climate stabilisation and resulting worldwide renaissance of rural areas, all of which are urgently needed.[9]

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[7] Ibid., 11.
[8] Ibid., 8-14.
[9] Gustavo Best et al., *A Sustainable Biofuels Consensus* (March 24-28 2008 [cited July 19 2008]).

This "Consensus" was one of a number of principles-based working groups that emerged to discuss, develop, and operationalise sustainable biofuels programs. In August of 2008, the "Global Principles and Criteria for Sustainable Biofuels Production", or "Version Zero", reflected the results of a year-long global stakeholder engagement process that involved 50 working groups and expert teleconferences, four in-person meetings (Brazil, China, South Africa, and India), on-line discussion boards, as well as emails and telephone conversations. The report identified twelve areas of broad policy concern:

1. ***Legality*** and accordance with national laws and international treaties;
2. ***Consultation, planning and monitoring*** of biofuels projects to avoid potential conflict;
3. ***Greenhouse gas emissions*** and the development of a standard method of assessing biofuels in comparison to fossil fuels for climate change mitigation;
4. ***Human and labour rights*** shall not be violated;
5. ***Rural and social development*** of local, rural and indigenous peoples;
6. ***Food security*** shall not be impaired due to biofuels projects;
7. ***Conservation*** to avoid negative impacts on biodiversity, ecosystems and areas of High Conservation Value;
8. ***Soil*** health should be promoted and degradation minimised;
9. ***Water*** is not to be contaminated or depleted due to biofuels projects, nor will such projects violate existing formal and customary water rights;
10. ***Air*** pollution shall be minimized along the biofuels supply chain;
11. ***Economic efficiency, technology, and continuous improvement*** stipulates that biofuels production should be cost-effective and technology must improve production efficiency and social and environmental performance in all stages of the biofuel value chain; and ,
12. ***Land rights*** shall not be violated by biofuel projects.[10]

These principles extended beyond the typical parameters of sector-specific regulations, and incorporated institutional, environmental, social, economic, technical, and ethical considerations.

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[10] Roundtable on Sustainable Biofuels, "Global Principles and Criteria for Sustainable Biofuels Production (Verson Zero)," (Lausanne: Ecole Polytechnique Fédérale de Lausanne - Energy Center, 2008).

These two examples showed how the Dutch government and a non-government organisation utilised principles-based approaches to pursue regulatory development. They provided over-arching principles for action by policy-makers, but do not specify for policy-makers and regulators how to determine an appropriate balance between economic, social, and environmental objectives.

Guidelines

Unlike the principles-based approaches discussed above, guidelines are intended to offer a policy decision framework that identifies opportunities and barriers regarding sustainable biofuels. The 2007 UN-Energy report "Sustainable Bioenergy: A Framework for Decision Makers" provides one example of guidelines for developing sustainability criteria and certification standards for biofuels. From the perspective of an international governance institution, the United Nations report outlined nine key policy areas related to sustainable biofuels: affordable access to energy services by the poor, development and job creation, health and gender, agricultural practices, food security, government budgets, trade and energy security, biodiversity and resource management, and climate change.[11] Although it recognised that establishing sustainability criteria for biofuels within national regulatory structures is complicated, the UN-Energy report emphasised that "this complexity should not restrain action. The movement towards more sustainable energy systems that draw from all potential renewable sources, including bioenergy, is a matter of urgency".[12]

[11] UN-Energy, "Sustainable Bioenergy: A Framework for Decision Makers."
[12] Ibid., 51.

The United Nations report identified the central role of national governments as the interlocutor between local and international activity. This is partly because of the structural context of United Nations membership, but also because this level is where the interaction of knowledge, policy, and action occur.[13] Knowledge of resources, technologies, and economic considerations are most often shared with a variety of stakeholders, and national policy-making offers unity and stability that provides direction for subnational governments. Agriculture, energy, industry, and the environment are examples of substantive policy areas in which national governments have unique capacities in procedural policy tools, such as fiscal (spending and taxation) and research and development policies. Moreover, national governments can regulate intersectoral programs by establishing legislation, determining and enforcing minimum standards, and developing and supporting guidelines or best practices.

The United Nations provided a set of guidelines for national policy-makers from the perspective of an international governance institution. The UK Royal Society's "Sustainable Biofuels: Prospects and Challenges" also provides guidelines on how regulations might encourage sustainable biofuels.

> The sustainability requirement needs to be approached at the international level, partly because it is a global problem and partly because international trade in these commodities is likely to expand in coming years. It is essential to establish a common and accepted set of sustainability criteria by which to assess not only the different biofuels, but also the different feedstocks, including food and non-food, and their production systems. This process is likely to involve extensive international collaboration to ensure comparability of results, and a high degree of transparency and stakeholder engagement to maximise public acceptability.[14]

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[13] Ibid., 51-6.

[14] The Royal Society, "Sustainable Biofuels: Prospects and Challenges," 2-3.

However, this differs from the UN-Energy report in that it locates the need to establish regulations for sustainability criteria at the international level. For the Royal Society, the "global problem" appears in line with the policy concerns of rural development, energy security, and climate change that motivated the dominant biofuels regimes to pursue international market diffusion. However, other important policy areas could be threatened by an accelerated international trade in unsustainable biofuels that would create other global problems, such as exacerbating poverty and hunger or, more generally, economic hardship, social decline, and environmental degradation.

Although the Royal Society focuses on the international community, it recognises the important role of national governments in the coordination of intersectoral policy areas like innovation, climate change, energy, and land use.[15] The Royal Society report observed that most national policy instruments tend to be short-term responses to long-term problems. For example, the report identifies a number of pathologies exhibited by national policies, such as: a tendency to avoid the shift toward new technologies that are at the outset more costly than proven products; the lack of carbon pricing (e.g., taxes or tradable permits); and the dearth of discussion on the environmental co-benefits of biofuels. These few examples suggest that national level policy processes are unable to foster a global shift to sustainable biofuels. Based on this, the Royal Society reports that "…it is clear that the transition to a low-carbon transport economy will require a much wider range of policies, and involve several more technologies and practices".[16]

The United Nations and the Royal Society offer two different perspectives on the

[15] Ibid., 49-56.
[16] Ibid., 53.

regulatory development of sustainability standards for biofuels. While both indicate policy areas and implementation issues that should be considered in the development of sustainable biofuels policy, neither provides instruction on how sustainability criteria and certification standards should be encouraged or enforced.

Requirements

More detailed and narrower in scope, requirements-based approaches to regulatory development also tend to be more instructive. In 2008, the European Commission initiated the development of environmental sustainability criteria for biofuels by proposing a Directive to Member States to expand their national biomass energy portfolios. The Commission suggested firm targets and identified specific activities that were deemed unsustainable, such as environmental sustainability criteria for biofuels to include a greenhouse gas emissions saving of at least 35%, and that this requirement not be obtained from land with a high biodiversity value or from land with high carbon stock.[17]

The European Commission later endorsed the European Environment Agency recommendation to suspend the 10% biofuel mandate pending a new comprehensive review of the associated environmental risks[18]. The European Parliament subsequently re-evaluated its biofuels policy, and also recommended in 2008 to reduce transport

[17] European Commission, "Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources."

[18] European Environment Agency, *Suspend 10 Percent Biofuels Target, Says Eea's Scientific Advisory Body* (European Environment Agency, 10 April 2008 [cited July 12 2008]); available from http://www.eea.europa.eu/highlights/suspend-10-percent-biofuels-target-says-eeas-scientific-advisory-body.

biofuels content targets from 10% to 6%.[19] This reduced commitment to biofuels was accompanied by calls for stricter sustainability criteria[20], and opened the possibility for other fuel alternatives to help achieve the 20% renewable energy goal without necessarily reaching the 10% biofuel content mandate by 2020.[21] Much of these reforms pointed to the need for environmental sustainability and related criteria in the areas of greenhouse gas emissions, biodiversity, and use of land with high carbon stock, as well as the "impact of increased demand for biofuels on sustainability in the [European] Community and in third countries", food supply and affordability, and "wider development issues".[22]

The 2007 *Roadmap for Bioenergy and Biobased Products in the United States* also provided detailed policy instruction. The *Roadmap* focussed on a narrow range of issues, and identifies key steps in the development and commercialisation of biomass technologies. In this document, sustainability is interpreted more strictly than other reports. For instance, the discussion on "sustainability" was primarily concerned with the availability, diversity, and development of biofuels feedstocks, and concentrated mainly on soil management, including soil fertility, impacts of biomass residue removal, tillage and cultivation methods, sustainable feedstock production, and increasing productivity.[23]

The "Roadmap" was requested by the federal Secretaries for Agriculture and

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[19] BBC Staff Reporter, *Eu in Crop Biofuels Goal Rethink* (on-line) (BBC, September 11 2008 [cited September 21 2008]); available from http://news.bbc.co.uk/2/hi/europe/7610396.stm.

[20] Taylor, "EU to Toughen Environment Criteria for Biofuels."

[21] European Parliament, *More Sustainable Energy in Road Transport Targets* (Europa, 9 September 2008 [cited 23 September 2008]); available from http://www.europarl.europa.eu/pdfs/news/expert/infopress/20080909IPR36658/20080909IPR36658_en.pdf.

[22] European Commission, "Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources."

[23] Biomass Research and Development Technical Advisory Committee, "Roadmap for Bioenergy and Biobased Products in the United States."

Energy and was intended as "a reference document for industry, academia, and policy makers to implement the steps" to achieve the 2002 *Vision for Bioenergy and Biobased Products in the United States*.[24] Rather than offer principles or guidelines, it instead "identifie[d] a concrete strategy of research and policy measures for decision-makers... to advance biomass technologies and enable an economically viable, sustainable and economically desirable biobased industry."[25]

Approaches to Regulatory Development

The six documents discussed above focus on different analytical levels and vary in the scope of policy activity (Table 9-1). Each approached the regulatory development of sustainable biofuels in different ways. Some viewed sustainability as both a local and global policy challenge, because of different feedstocks, production processes, geographic locations and time periods. These hold different implications for small economies and local communities and ecosystems in comparison to international political relations and global biospheric systems. Although some argue that the international community would be a more appropriate level from which to facilitate a sustainable global biofuels market, early multilateral collaborations on biofuels have thus far focussed on the lowest common denominator of technical compatibility for international trade.[26]

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[24] Biomass Research and Development Technical Advisory Committee, "Vision for Bioenergy and Biobased Products in the United States," (Washington, DC: Biomass Research and Development Initiative, 2002).

[25] Biomass Research and Development Technical Advisory Committee, "Roadmap for Bioenergy and Biobased Products in the United States."

[26] Tripartite Task Force, "White Paper on Internationally Compatible Biofuel Standards."

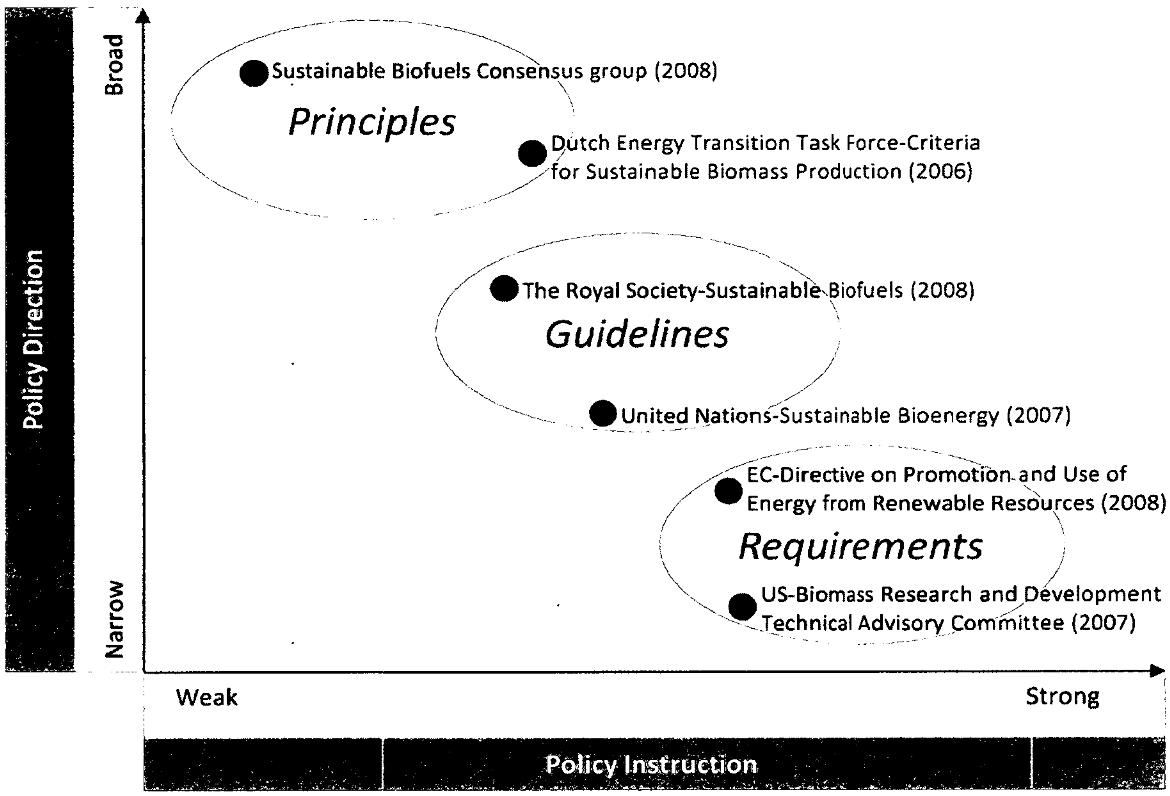
Table 9-1: Analytical Level and Scope of Sustainability Criteria: Key Reports

Organisation	Name of Report	Primary Level of Analysis	Scope of Policy Activity
Dutch Energy Transition Task Force	Criteria for Sustainable Biomass Production (2006)	National	Sustainable Consumption
Sustainable Biofuels Consensus group	A Sustainable Biofuels Consensus (2008)	Global	Sustainable Production
UN-Energy	Sustainable Bioenergy: A Framework for Decision-makers (2007)	National	Economy, Society, Environment
The Royal Society	Sustainable Biofuels: Prospects and Challenges (2008)	International	Economy, Society, Environment
European Commission	Proposal for a Directive of the European Parliament and of the Council on the Promotion and Use of Energy from Renewable Resources (2008)	Regional	Environment
US Biomass Research and Development Initiative	Roadmap for Bioenergy and Biobased Products in the United States (2007)	National	Soils and Feedstocks

Source: Author's interpretation.

The level of analysis and level of policy activity are important considerations, and these apply directly to the overarching policy direction and the degree of policy instruction. *Direction* and *instruction* are the variables that determine the rate and speed of regulatory development. In promoting requirements for sustainability criteria and certification standards for biofuels, the policy documents discussed above can be expected to have a different degree of resonance within government regulatory processes (Figure 9-2).

Figure 9-2: Approaches to Regulatory Development



Source: Author's interpretation.

For example, the policy directions provided in the Netherlands and by the Sustainable Biofuels Consensus group were based on overarching principles that sought broad outcomes. While supporting the overall argument for sustainable biofuels, they did not provide governments with an implementation strategy or related decision-making mechanisms. In contrast, the European Commission and the United States federal government provided a strong level of policy instruction by choosing narrow policy directions based on bounded system parameters. These provided implementation strategies and decision-making mechanisms, but did not include broader sustainability considerations. Balancing *direction* and *instruction* for regulatory development is necessary for policy design and program implementation in complicated policy areas. Achieve this balance requires and understanding of the underlying socio-technical context, in which often technical effects and social functions are often conflated.

Sustainability Criteria and Social Function

Attempts to specify sustainability criteria and certification standards have not yet resulted in concrete policy decisions or direction for biofuels producers due, in part, on the focus on their techno-economic effects at the expense of new and emerging social functions for biofuels. Recall from chapter three that *effects* are often used to define performance indicators and determine policy and program success. In contrast, *functions* are the socio-technical roles that contribute to the social order and how it might change to accommodate an innovation in technologies or techniques. Both are necessary components in the assessment and reinforcement of technological change, but the tendency is to focus intently on effects at the expense of their functions. Because most effects-based policy concerns and socio-technical functions were overshadowed by the economic priority of facilitating international trade, the alignment between economic growth, social development, and environmental protection created a biofuels trajectory in which effects and functions were not congruent.

In response to the persistent trajectory of first generation biofuels, new socio-technical functions are emerging that seek a future for biofuels that is more sustainable.

Some relevant social groups have perceived biofuels as a petroleum replacement.[27] Other groups have suggested that biofuels are best used as way to lessen the adverse effects of petroleum in the present transportation fuels regime.[28] Still other groups have considered biofuels to be vanguard artefacts that would challenge the dominance of petroleum in order to usher in a new sustainable energy regime.[29] Using the multi-level perspective on transitions helps to identify the social functions of ethanol and biodiesel can help to determine the socio-technical levels at which policy decisions can be directed with a greater likelihood of success. Social functions can also inspire the de-alignment and re-alignment of the socio-technical regime and shape the development of biofuels policies and regulations. By incorporating social functions as part of the objectives for niche innovation, the wider goal of sustainability might become part of the policy frameworks of both dominant and small biofuels regimes. In short, socio-technical functions are an integral component in defining sustainable biofuels, and need to be included in policy-making and regulatory development.

Defining Sustainable Biofuels

If first generation biofuels are to be sustainable, they need to meet the basic components of sustainable energy outlined in chapter three. The differences between effects/functions must also be reconciled. Also, the alignment *within* socio-technical levels and the interactions *between* socio-technical levels must be adequately

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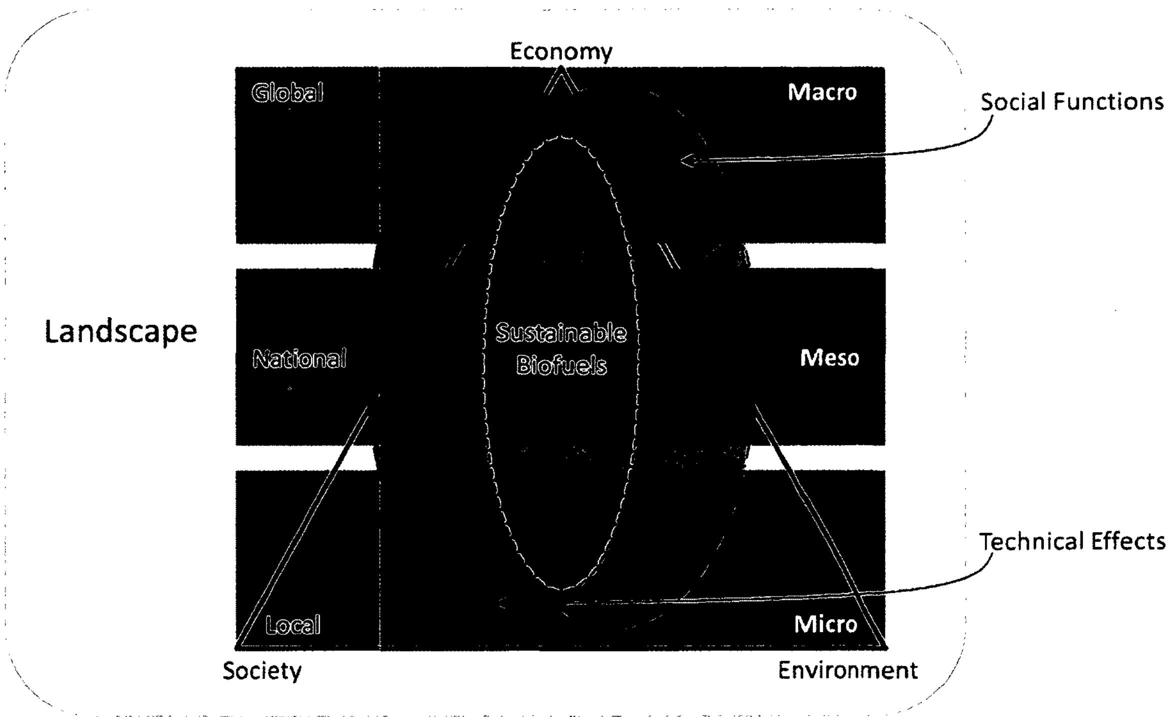
[27] Clovis Zapata and Paul Nieuwenhuis, "Driving on Liquid Sunshine - the Brazilian Biofuel Experience: A Policy Driven Analysis," *Business Strategy & the Environment (John Wiley & Sons, Inc)* 18, no. 8 (2009).

[28] Ayhan Demirbas, "Biofuels Sources, Biofuel Policy, Biofuel Economy and Global Biofuel Projections," *Energy Conversion and Management* 49 (2008).

[29] Lieuwen, Richards, and Weber, "Approaching Zero."

understandable. As a consequence, the definition of sustainable biofuels is subject to four broad areas of consideration (Figure 9-3).

Figure 9-3: Conceptual Depiction of Sustainable Biofuels



Source: Author's interpretation.

A regime in which sustainable biofuels might occur requires a "dynamic harmony"[30] between sustainability, effects/functions, level of analysis, and level of policy activity. These considerations provide structure for policy making and program implementation, both of which are important for the design of coherent and deliberative niche development strategies. However, landscape pressures are exogenous factors that can influence but not determine niche- and regime-level activities.

[30] Tester et al., *Sustainable Energy Policy: Choosing among Options*, 8.

The first area for consideration is represented by the triangle of society, economy and environment, and is included because it is the most influential heuristic in the sustainable development paradigm. This is the "triple bottom line" that is often referred to in the literature on sustainable development[31], and niche development for sustainable biofuels within the dominant regime must, at minimum, seek to development a policy direction that balances these three cornerstones of sustainability. The concept of sustainable development has been open to interpretation over the course of its history[32], and there have been many different ways that governments have sought to achieve desired effects and outcomes.[33] To define sustainable biofuels we must be able to ascertain that their technical effects are within the parameters of sustainability (i.e., they are sufficient, efficient, safe for human health, and environmentally benign).[34] Yet to achieve the fundamental goals of sustainable development, technical effects must reflect underlying social functions. We need to be confident that biofuels sufficiently fulfill the social functions expected by relevant social groups.

Technical effects can be identified and categorised according to local, national and/or global levels of analysis. Social functions can be similarly revealed by societal expectations and resulting micro-, meso- and macro-level policy activities. Represented by the overlapping ovals in the conceptual depiction of sustainable biofuels, effects and functions are conceptually distinct but are practically intertwined and mutually-

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[31] John Elkington, *Cannibals with Forks: The Triple Bottom Line of 21st Century Business* (Gabriola Island, BC: New Society Publishers, 1998).

[32] John Dryzek, *The Politics of the Earth: Environmental Discourses* (Oxford: Oxford University Press, 1997), Hajer, *The Politics of Environmental Discourse.*

[33] William M. Lafferty and Oluf Langhelle, eds., *Towards Sustainable Development: On the Goal of Development - and the Conditions of Sustainability* (London: Macmillan Press Ltd., 1999).

[34] WCED, *Our Common Future.*

reinforcing. The oval on the left reflects the scope of technical effects and their implications on all levels of analysis, represented on the left side of the horizontal bars. These local, national, and global levels suggest the scale with which to assess the implications and outcomes of a regime that contributes to the pursuit of sustainable biofuels. The local level of analysis includes the effects on individuals and relevant social groups, a particular geography or ecosystem, or a limited period of time. Local analyses tend to be narrow and parochial. National levels of analysis tend to focus on the needs of the state, and include economic growth, employment, taxation, comparative advantage, innovation and sector development. The national level often considers issues spanning into the foreseeable future, which can range from political cycles to historical eras. Finally, the global level of analysis includes international governance issues[35], such as geopolitical conflict, international markets, greenhouse gas emissions, biodiversity, as well as concerns with poverty, hunger, and health in developing nations. These three levels of analysis help categorise technical effects and their implications for societies, economies, and environments around the world.

In a similar manner, the oval on the right represents the social functions of biofuels. These functions seek to satisfy micro-, meso- and macro-level expectations. Micro-level functions, for example, might include local self-sufficiency or protecting the family farm, while meso-level functions might seek national energy security or innovation. Macro-level functions include climate change mitigation, and international

[35] International issues are often under the purview of international governance organisations. Among others, these include the United Nations, the North Atlantic Treaty Organisation, the World Trade Organisation, the International Monetary Fund, and the International Energy Agency of the Organisation for Economic Cooperation and Development.

development (e.g., poverty relief, food security). The scope and level of social functions change over time, and can best be gauged through stakeholder consultation and input into the decision-making process. By identifying social functions of biofuels, it is possible for policy-makers to be better informed as to the expectations of biofuels and the potential role they may have in society.

Each of the four components identified in the conceptual depiction of sustainable biofuels can be explored in order to determine whether or not a biofuel meets sustainability requirements. Achieving beneficial technical effects does not mean that fundamental social functions will be satisfied. Similarly, achieving local sustainability criteria does not mean that sustainability will be achieved at another level. As was demonstrated in chapter five, the evolution of the three dominant biofuels regimes involved a wide array of factors. The determination of a universal specification for "sustainable biofuels" is a difficult undertaking. As concluded in chapter seven, achieving sustainable biofuels requires a deliberate effort to understand how (1) biofuels interact with social values and government policies; (2) niche markets affect technical pathways; (3) biofuels co-evolve with existing transportation and bioenergy systems; and (4) the social framing of biofuels creates new socio-technical functions. Extrapolating these aspects in terms of niches, regime, and landscape of biofuels offers some basic premises from which to evaluate the sustainability of first generation biofuels. These are represented by the twelve questions laid out in the matrix below (Table 9-4).

Satisfying these conditions requires the evaluation of each of the four areas identified in the conceptual depiction of sustainable biofuels. Niche- and regime-level activities provide considerable scope for innovative policy activity, and are the levels at which the shift toward producing first generation biofuels in a more sustainable manner is most likely to succeed.

Table 9-4: Conditions of Sustainable Biofuels

Multi-level Perspective	Sustainable Development	Effects / Functions	Level of Analysis	Level of Policy Activity
Niche	Does biofuel ***balance*** economy, society, and environment?	Does technical performance ***reflect*** stakeholder expectations?	Does biofuel ***fulfill*** local, national, or global need?	Does biofuel ***provide*** micro-, meso-, macro-level policy solutions?
Regime	Does biofuel ***contribute*** to sustainable development paradigm?	Does technical performance ***accomplish*** societal expectations?	Does biofuel ***foster*** sustainability at local, national, global levels?	Does biofuel ***reinforce*** positive technological trajectory?
Landscape	Does biofuel ***coincide*** with international discussion on sustainable development?	Does technical performance ***respond*** to exogenous pressures?	Does biofuel ***correspond*** with socio-technical context?	Does biofuel ***satisfy*** international governance requirements?

(Source: Author's interpretation)

Niche development for technical innovation has long been employed as a policy option[36], yet niche development strategies differ according to the specific policy interventions within different socio-technical regimes. The benefits of past experiences provide insight into niche development in a conventional framework of economic

[36] Chris Freeman and Luc Soete, *The Economics of Industrial Innovation*, 3rd ed. (Cambridge, Massachusetts: MIT Press, 1997).

development, but niche innovations for sustainability involve a much wider array of policy areas, stakeholders and decision-makers in the development and implementation of innovation strategies. In order to respond to local, national, and global contexts, niche development programs must be robust and reflexive. If they are to encourage sustainability, the diffusion and adoption of niche innovations from protected spaces to open markets must also contribute to a de-alignment of the dominant socio-technical regime and a re-alignment toward sustainable biofuels.

There are numerous permutations on how these twelve considerations of sustainable biofuels might contribute to policy development and program implementation. The following three scenarios provide examples as to how different policy-makers might employ this definition of sustainable biofuels when designing corrective measures. This matrix will not be used in the same way for all scales and scopes of biofuels production. However, these considerations provide a framework for the de-alignment and re-alignment of biofuels trajectories so that they might become more sustainable. The assumptions of these scenarios are: (1) there is desire for sustainability; (2) there is capability for biofuels production; (3) there is willingness by politicians for change; and (4) there is capacity for policy-makers and program administrators. Given these assumptions, the following scenarios are provided as examples of how government leaders might engage with the conditions for sustainable biofuels as presented above.

Scenario 1: Rural municipal council seeks an ethanol facility

The potential benefits of a new ethanol production facility can be substantial. Regions rich in agricultural feedstocks, water resources, affordable and renewable electrical power, sufficiently skilled labour force, management capacity, and geographic proximity for distribution to end-markets could realise significant benefits from the new local investment. This economic growth requires infrastructure development and other ancillary services, all of which contributes to job creation over and above those required by the ethanol plant. With more employment, individual earnings increase and more wealth accumulates in the area, which can foster social cohesion in rural communities by stemming the out-migration of residents to large urban centres. Moreover, local governments receive more taxes, which could then be used to maintain local services, repair or expand infrastructure, invest into other rural development plans, etc.

This common scenario is fundamentally a niche-level consideration in the multi-level perspective on transitions as it pertains to biofuels. As such, the conditions of sustainable biofuels provided in the first row of the matrix above suggest additional considerations that extend beyond the socio-economic outcomes described in the preceding paragraph. The primary objective of constructing a new ethanol facility considers economic and, to a degree, social considerations but does not address ecological impact. By exploring the potential for sustainable development at the niche-level, we find an immediate need to ***balance*** the three domains of sustainable development. This initiates further assessment of the potential benefits and consequences of a new ethanol plant, which requires the council to examine the critiques identified in chapter six and how they relate to the local context.

The decision to construct an ethanol facility should also consider technical effects and social functions to ensure they ***reflect*** stakeholder expectations. Open and transparent public consultations can reveal whether or not the new facility is appropriate for the local context. For instance, a town that prides itself as a quaint idyllic rural community may take exception to the effluents, emissions, and overall footprint of an industrial site in the community. In a similar way, a rural community that values local development may oppose a factory owned by a foreign transnational corporation.

When assessing the potential for a new ethanol facility by these parameters, the level of analysis and level of policy activity become important considerations. The ethanol produced in this scenario is not intended to satisfy a local need for transportation fuel, but it might be useful for national or global markets. The local benefits stemming from this technological artefact but might indirectly ***fulfill*** local needs, while also fulfilling national objectives and the needs of global systems. As a result, the level of policy activity by the rural municipality needs to ***provide*** micro-level solutions in order be locally relevant *before* considering other levels of policy activity. This explains why rural development was the first policy driver for the expansion of biofuels. It also explains why energy security (national) and greenhouse gas emissions (global) reduction appeared in sequence. Overall, while niche-level consideration of these four conditions of sustainable biofuels are understandably directed at the local level, niche activities interact with regime-level considerations, particularly in terms of policy activity and sequence of implementation.

Scenario 2: Subnational government seeking to increase biofuel consumption

The recent implementation of biofuel content mandates for transportation fuels were met with a degree of hope and excitement. This type of policy measure consists of a regulatory requirement that establishes a consistent level of market demand. This provides certainty for market actors, which is intended to stimulate investment and contribute to niche development strategies. There were early promises that local production in subnational jurisdictions would offset economic "leakage" by reducing fuel imports and federal excise taxes, as well as create jobs and attract investment. Local biofuels were anticipated to have some effect on local ecosystems, but biofuels produced in any jurisdiction were expected to reduce carbon emissions, lower dependency on petroleum, and increase technological diversity in the transportation fuels sector.

Subnational governments may seek to increase biofuel consumption due to political promises made during the hype-cycles characteristic of earlier expectations or simply to follow the adage of "more is better". Utilising the matrix, we find that the subnational jurisdiction must contend with many of the same considerations as those identified by the rural municipal council in the first scenario (i.e., all four questions in the niche-level row of the matrix). The subnational government must also be more or less consistent with the national-level and its transportation fuels regime. In terms of sustainable development, the subnational government must move beyond the triple bottom line of economy, society, and environment, but should also evaluate whether or not the increase to biofuels content obligations ***contribute*** to the broader context of the sustainable development paradigm. In other words, does an increase to ethanol and biodiesel mandates balance the conditions of sustainability of the product, while also contributing to the socio-technical shift toward a sustainable society? The subnational government needs to consider the possibility, for instance, that it can stem economic "leakage" via means other than biofuels, such as other fuels, other vehicle power trains, efficiency/curtailment, or other modes of transportation.

The effects/functions of biofuels are again important considerations, as they must be perceived as a way to ***accomplish*** societal expectations. Some subnational jurisdictions can be expected to maintain a high degree of consistency through the expansion of its biofuels sector. These jurisdictions may be inclined to view an increase to biofuels content mandates as highly desirable. In contrast, some jurisdictions may be less committed to its earlier aspirations, and willing to explore other technological pathways. All subnational jurisdictions must be cognisant of the national policy framework, so the level of analysis becomes relevant to ensure that subnational initiatives ***foster*** sustainability in terms that agree with local and national levels. Similarly, subnational policy activities need to move beyond the solution-based approach characteristic of the rural municipality in the first scenario, and ***reinforce*** a positive technological trajectory at both subnational and national levels. In these terms, the subnational government needs to reconcile local objectives and evaluate the potential for biofuels across policy issues and between jurisdictional domains.

Scenario 3: National government seeking to reduce greenhouse gas emissions from transportation fuels

The increasing saliency of climate change mitigation continues to vex most national governments. Reducing greenhouse gas emissions in the transportation sector has proven to be more challenging than similar efforts in electricity and heat generation. While electric, hydrogen, gas-electric hybrid, and other transportation technologies are potential improvements to petroleum-power vehicles engines in terms of greenhouse gas emissions, none have materialised as a serious challenger to gasoline and diesel vehicles. Increasing ethanol and biodiesel content in petroleum transportation fuels is still the most feasible method to reduce greenhouse gas emissions in the short term.

Although it cannot fully control the development of a socio-technical regime, the national government can undertake policy and program initiatives to influence its speed and direction of change. Just as the subnational government must consider both niche- and regime-level considerations (i.e., all eight questions in the niche- and regime-level rows of the matrix), national governments must navigate through the demands and context of all three levels. Not only must the national government ensure that stricter greenhouse gas emissions limits balance the triple bottom line and contribute to the progression of the sustainable development paradigm, it must also ensure that its decisions ***coincide*** with international context. This means that national goals need to harmonise with international contexts even when the objectives may be contradictory.

The effects and functions of biofuels will be different as niches evolve and landscapes change. Just as with the niche- and regime-level considerations outlined in scenarios 1 and 2, a national government seeking to produce a sustainable biofuel in order to reduce greenhouse gas emissions will also need to be aware of how this new technology might ***respond*** to exogenous pressures, such as changes in international contexts (e.g., the UN Framework Convention on Climate Change), but also to crop failures, severe weather events, economic recession, war/revolt, etc. Changing contexts over longer time periods are to be expected, and national governments will need to adapt its level of analysis to ***correspond*** with the needs of the socio-technical system as its evolves over time. In addition, not only must national policy activity support (or at the very least, not inhibit) subnational government policy goals, but it must also ensure that the desired direction of the socio-technical regime will ***satisfy*** international governance requirements.

These three scenarios provide a brief example of how the twelve conditions for sustainable biofuels might provide greater insight to decision-makers. They reveal the contingency and malleability of the issues, but they also help to map policy areas and regulatory development processes to address these challenges in the future. The next section explores in more detail how these considerations might contribute to the de-alignment and re-alignment of the present trajectory of global biofuels.

Policy-making in the Multi-level Perspective

Transitions approaches focus policy recommendations on niche development and regime structure, largely because exogenous landscape pressures are outside of domain of policy influence. The multi-level perspective on transitions pays particular attention to the interactions between socio-technical levels in order to explore policy concerns and activities throughout the socio-technical system.[37] The process-based approach of the multi-level perspective on transitions is particularly useful for assessing policies and programs that require coordination between policy jurisdictions.

The policy concerns that stimulated the expansion of global biofuels reflect an inter-jurisdictional policy challenge for all three levels of the socio-technical system. Most analyses of this complex issue established narrow parameters and quantitative indicators, such as job creation, growing GDP, and greenhouse gas emissions reductions.[38] However, critics demonstrated that the technical effects of biofuels were inadequately addressed because they did not include other system properties. In particular, the effects on land use patterns, soil quality, water resources, biodiversity, air pollution, food security, and property rights identified in chapter six were among the most pressing issues of concern.[39]

This ongoing contention on the benefits and drawbacks of biofuels suggests that debates over their technical effects are subject to *positive feedback* and consequential *spill-over* to other technological forms. These "hype-cycles" (i.e., the rise and fall of technological expectations and their impact on niche trajectories)[40] are chaotic, but are nevertheless a necessary stage of emergent socio-technical functions. Social groups need

[37] Frantzeskaki and de Hann, "Transitions: Two Steps from Theory to Policy.", Genus and Coles, "Rethinking the Multi-Level Perspective on Technological Transitions.", Meadowcroft, "What About the Politics? Sustainable Development, Transition Management, and Long Term Energy Transitions.", Verbong and Geels, "Exploring Sustainability Transitions in the Electricity Sector with Socio-Technical Pathways."

[38] Bureau et al., "A Quantitative Assessment of the Determinants of the Net Energy Value of Biofuels."

[39] Harto, Meyers, and Williams, "Life Cycle Water Use of Low-Carbon Transport Fuels.", Venkatesh et al., "Uncertainty Analysis of Life Cycle Greenhouse Gas Emissions from Petroleum-Based Fuels and Impacts on Low Carbon Fuel Policies."

[40] Verbong, Geels, and Raven, "Multi-Niche Analysis of Dynamics and Policies in Dutch Renewable Energy Innovation Journeys (1970-2006): Hype-Cycles, Closed Networks and Technology-Focused Learning."

to develop their own interpretations of how such an artefact should work for them, and only trial and error will tell if new technologies can work for them at all. The succession of technical expectations can involve successful niches negatively affecting other niche trajectories. Conversely, technologies interpreted as a failure can inspire hope and confidence in other niche areas. For example, early commercial failures of ethanol stimulated interest in other liquid biomass fuels, including bio-butanol and methanol.[41] Similarly, the resilience and endurance of a vision for a sustainable future for biofuels is also uncertain.[42]

As discussed in chapter three, in order for emerging and/or established functions presented by new technologies, techniques, or social relations to contribute to the evolution of a socio-technical regime requires stability through laws, rules, and administrative structures. Without the stabilising presence of societal rules, social interactions would follow an aimless trajectory focussed on self-interested satisficing[43], and the achievement of solutions that might be acceptable in the short-term but undesirable in the long-term. Rules help to standardise the interoperability and accessibility of energy resources and technologies, while limiting their capture by economic and political interests. This helps to limit bandwagon enthusiasm and circus dynamics[44], which confuse the overarching vision and create a circumlocutive public

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[41] Heath, *Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels.*
[42] Plevin et al., "Greenhouse Gas Emissions from Biofuels' Indirect Land Use Change Are Uncertain but May Be Much Greater Than Previously Estimated."
[43] Herbert A. Simon, *The Sciences of the Artificial*, 3rd ed. (Cambridge, Massachusetts: The MIT Press, 1996).
[44] Verbong, Geels, and Raven, "Multi-Niche Analysis of Dynamics and Policies in Dutch Renewable Energy Innovation Journeys (1970-2006): Hype-Cycles, Closed Networks and Technology-Focused Learning," 571.

discourse that obscures technical effects and undermines social functions.

The stabilising influence of socio-technical regimes occur when niches, regimes and landscapes are in a state of alignment. Yet the necessary characteristics of what "alignment" might entail is open to interpretation. Transitions theorists, for example, have come to put a priority on innovations for sustainability, and many in this field argue that governments can play a strong facilitating role. Others are more ambitious and argue that sustainability should provide the conceptual focus for the vision of governance in the future as well as the ideals that guide public policy and administration.[45] While most acknowledge that laws, rules and administrative structures bring certainty to social systems by providing institutional stability, they can differ on the degree to which regulatory frameworks should aim to achieve positive technological effects or incorporate desirable socio-technical functions.

The ability to employ technical artefacts to achieve policy goals depends upon *technological variation* and the overarching *selection environment*. Technological variation involves experimentation with different technological features that respond to socio-technical contexts. Selection environment includes all the factors that can shape the technological artefact and its role in society. The interaction of technological variation with the selection environment occurs within the regime, and includes: technological synchronicity with existing system, policy frameworks, cultural and psychological perspectives, consumer demand, supply-side barriers, infrastructure, and the potential for

[45] Daniel J. Fiorino, "Sustainability as a Conceptual Focus for Public Administration," *Public Administration Review* 70, no. supp 1 D (2010).

adverse social/environmental outcomes.[46] Variation and selection help to define the context of a given technology and the prestructuration that enables and constrains the progression of socio-technical systems. The process of variation and selection contributes to the *alignment* with socio-technical levels, such as the correlation between technical features and consumer demand. The multi-level perspective on transitions suggest that socio-technical regimes can respond to "de-alignment and re-alignment" activities that occur when tensions internal to the regime or landscape pressures destabilise a regime and stabilise another configuration.[47]

Understanding the relationships between analytical levels is also necessary if we are to make sense of the *evolution* of socio-technical systems. Regimes evolve in response to niche-innovations and new landscape factors. Evolution is multi-dimensional and involves changes at all socio-technical levels. Consequently, evolution is the linkage process between alignment within and interactions between socio-technical levels.[48] Depending on the stability of the socio-technical system, this linkage can firmly connect the multiple levels to stabilise the system in a given configuration. In other configurations, the linkage can be more loose, which allows more variation and flexibility in how these levels progress and interact. The configuration of system elements can firmly establish biofuels regimes and their production infrastructure, governance institutions, rules and regulations, market actors and economic conditions, consumer demand and expectations, etc. In contrast, biofuels are less entrenched in small markets,

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[46] Kemp, Schot, and Hoogma, "Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management," 177-80.

[47] Geels, "The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860-1930)," 472.

[48] Geels and Schot, "The Dynamics of Transitions: A Socio-Technical Perspective," 96.

and are therefore more able to incorporate regulations to achieve broader societal goals. By requiring sustainable biofuels, small markets can act as "transition regions" that become "lighthouses" for eco-innovation from which other jurisdictions might find guidance.[49] They encourage policy development for sustainable innovation in governments and expand niche technologies to global markets, the result of which could be a new socio-technical regime.[50]

De-alignment/Re-alignment

As argued in chapter seven, the large producers did not pursue sustainability in their respective biofuels production regimes. Although small markets can be expected to follow the course of expansion set by dominant producers, they tend to have less biofuels production infrastructure investment than biofuels regimes in Brazil, the United States, and the European Union. As such, small markets may be in a better position to shift their own policy frameworks to achieve greater symmetry between technical effects and socio-technical functions. Small markets can be more responsive to emergent effects and functions, and therefore have the potential to be more adaptable to emerging socio-technical regimes[51], and can also reinforce positive socio-technical elements.[52] Regardless of whether policy changes are led by dominant regimes or small markets,

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[49] Philip Cooke, "Transition Regions: Regional-National Eco-Innovation Systems and Strategies," *Progress in Planning* 76 (2011).

[50] Jan Nill and René Kemp, "Evolutionary Approaches for Sustainable Innovation Policies: From Niche to Paradigm?," *Research Policy* 38 (2009), B. van Bree, G. P. J. Verbong, and G. J. Kramer, "A Multi-Level Perspective on the Introduction of Hydrogen and Battery-Electric Vehicles," *Technological Forecasting and Social Change* 77 (2010).

[51] Voss and Kemp, "Reflexive Governance for Sustainable Development – Incorporating Feedback in Social Problem Solving".

[52] Niki Frantzeskaki and Derk Loorbach, "Torwards Governing Infrasystem Transitions: Reinforcing Lock-in or Facilitating Change?," *Technological Forecasting and Social Change* 77 (2010).

alignment within socio-technical levels is a necessary consideration for policies and programs to achieve sustainable biofuels.

By developing niche innovations for sustainable biofuels, small markets can encourage a positive feedback on the transportation fuels regime, thereby making it possible to pursue sustainable alternatives to the persistent trajectory of first generation biofuels instituted by the dominant production regimes. To escape the *push* for biofuels production by dominant producers and global trade, small markets can foster a *pull* for biofuels production based on regulatory mechanisms that stimulate positive feedback loops within the dynamic harmony that characterises stable systems. Corrective regulatory mechanisms can help to overcome the tendency of decision-makers to be preoccupied by short-term effects by encouraging and supporting locally-relevant niche innovations for sustainable biofuels.

Niche innovations respond to system needs by providing technological complements or substitutes, which widens the transportation fuel market. Dominant and alternative technologies co-exist, which can stimulate innovations in advanced petroleum fuels (e.g., reformulated gasoline), while biofuels advocates seek to improve first generation ethanol and biodiesel. New power trains are simultaneously developed (e.g., gas-electric hybrid, hydrogen fuel cells, battery electric vehicles, etc.) as potential solutions to socially-defined problems with petroleum fuels. The re-alignment of the transportation fuel sector can take a number of forms, including: (1) the development of advanced petroleum fuels and their (re)assertion as the dominant technology (presumably alongside more efficient internal combustion engines)[53]; (2) inclusion of sustainable biofuels as (2.a) a transport fuel substitute[54] or (2b) a fuel extender[55]; (3) other power trains, supported by “clean” technologies to ensure low/no carbon emissions and minimal ecological effects (e.g., electricity complemented with carbon capture and storage)[56]; or (4) pursuit of energy efficiency and/or curtailment (e.g., walking, cycling)[57] or different modes of transportation (e.g., mass transit).[58]

The insertion of corrective regulatory measures like sustainability criteria and certification standards can direct niche development strategies toward a re-alignment of the transportation fuels industry in a more sustainable configuration. The process for implementing these sustainability regulations begins with the design of niche development strategies that include sustainability as a core objective (Figure 9-5).

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[53] Freedenthal, "Biofuels Have Questionable Path as New Fuels for Transportation.", Jaccard, *Sustainable Fossil Fuels: The Unusual Suspect in the Quest for Clean and Enduring Energy.*

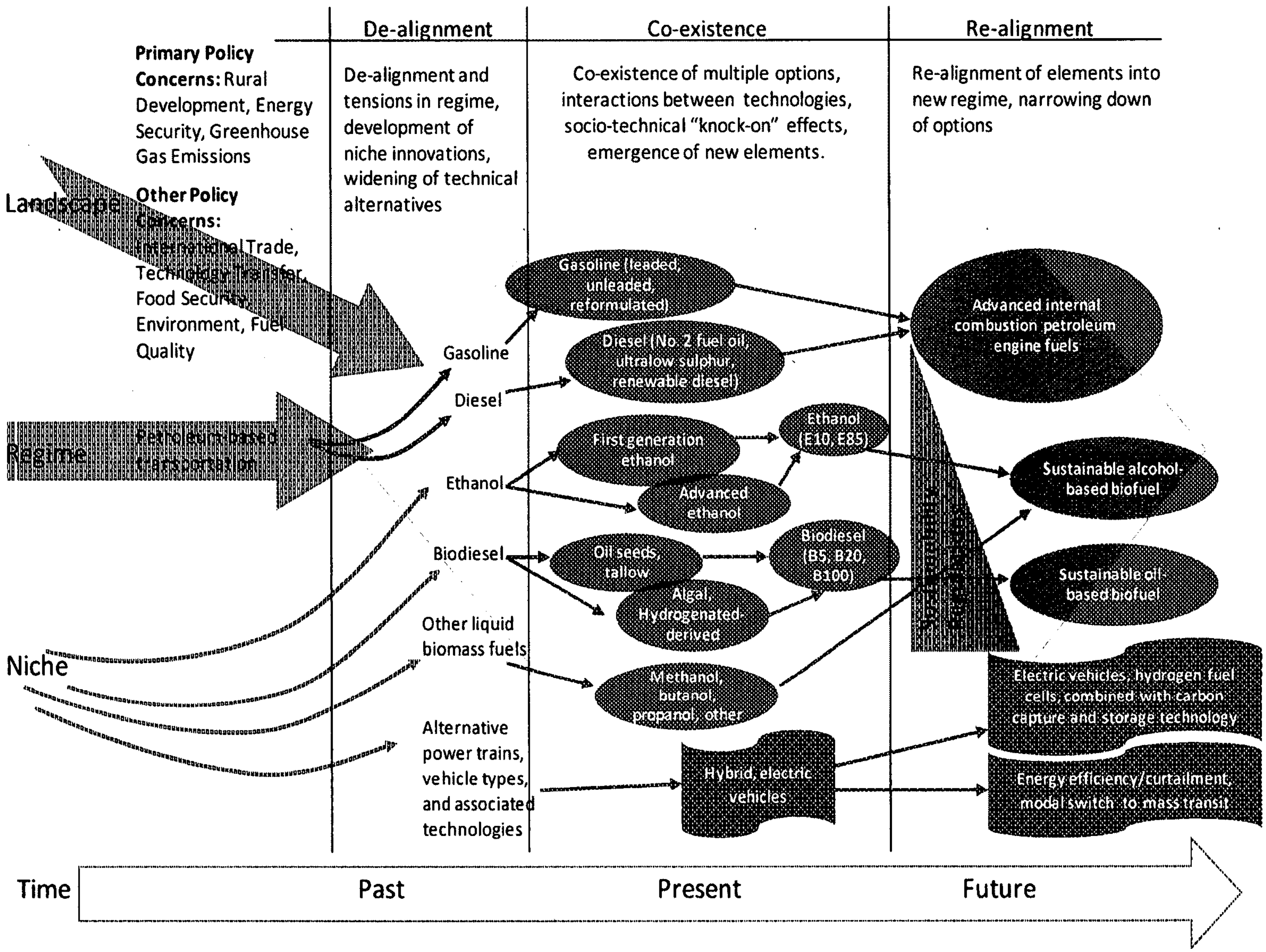
[54] Demirbas, "Biofuels Sources, Biofuel Policy, Biofuel Economy and Global Biofuel Projections.", Zapata and Nieuwenhuis, "Driving on Liquid Sunshine - the Brazilian Biofuel Experience: A Policy Driven Analysis."

[55] United States Environmental Protection Agency, *Regulation of Fuels and Fuel Additives: Renewable Fuel Standard Program - Notice of Proposed Rulemaking.*

[56] Azar, Lindgren, and Andersson, "Global Energy Scenarios Meeting Stringent Co2 Constraints - Cost-Effective Fuel Choices in the Transportation Sector.", Venkatesh et al., "Uncertainty Analysis of Life Cycle Greenhouse Gas Emissions from Petroleum-Based Fuels and Impacts on Low Carbon Fuel Policies."

[57] Geller, *Energy Revolution: Policies for a Sustainable Future,* Office of Energy Efficiency, *The State of Energy Efficiency in Canada* (Government of Canada, 2006 [cited 2 November 2006]); available from http://oee.nrcan.gc.ca/Publications/statistics/see06/pdf/see06.pdf, Schaffel and La Rovere, "The Quest for Eco-Social Efficiency in Biofuels Production in Brazil."

[58] Caulfield, Farrell, and McMahon, "Examining Individuals Preferences for Hybrid Electric and Alternatively Fuelled Vehicles.", Karplus, Paltsev, and Reilly, "Prospects for Plug-in Hybrid Electric Vehicles in the United States and Japan: A General Equilibrium Analysis.", Sanden and Hillman, "A Framework for Analysis of Multi-Mode Interaction among Technologies with Examples from the History of Alternative Transport Fuels in Sweden.", Zapata and Nieuwenhuis, "Exploring Innovation in the Automotive Industry: New Technologies for Cleaner Cars."



Source: Adapted from Geels (2005).

Figure 9-5: De-alignment and Re-alignment for Sustainable Biofuels

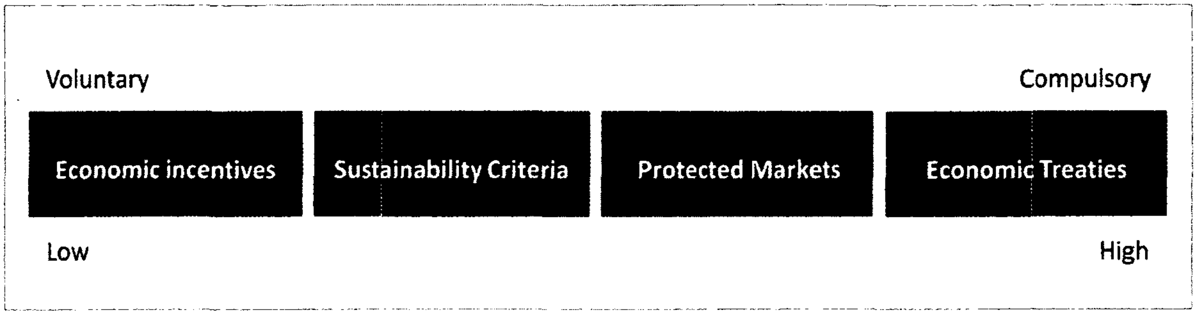
Implementing Sustainable Biofuels

Niche development programs can falter despite the best attempts of governments, the private sector, and other stakeholders to encourage their expansion into competitive markets. In most countries, the level of adoption and diffusion of biofuels are still in the early stages and the production infrastructure is comparatively small, and most will be influenced by the trajectory of the global expansion of first generation ethanol and biodiesel initiated by dominant regimes. Yet it is possible that they can adopt more robust and reflexive policy frameworks. The direction of niche development in small markets will be shaped by the alignment within and between the multiple levels and their configuration within the socio-technical system.

Depending on program objectives, technical capacity, economic activity, administrative structure, governance style, political culture, international trade, geopolitics, and other factors, policy implementation can embrace a framework situated anywhere along the spectrum of government intervention ranging from "voluntary" to "compulsory".[59] Niche strategies can contribute to the de-alignment and re-alignment of socio-technical trajectories by informing the type of policy implementation styles that governments might employ (Table 9-6).

[59] Michael Howlett and M. Ramesh, *Studying Public Policy: Policy Cycles and Policy Subsystems*, 3rd ed. (Don Mills, ON: Oxford University Press, 2009), 168-177.

Figure 9-6: Niche Development Measures and Level of Regulatory Intervention



Source: Author's interpretation (Adapted from Howlett and Ramesh, 2009).

Whenever the nature of a problem is somewhat intractable, the likelihood of governments to encourage voluntary measures is higher. Where the problem appears to be relatively simple, entails clear parameters, and is guided by clearly defined objectives, governments tend to respond with regulatory measures.[60] Uncertainty with early biofuels expansion programs in the United States and European Union correlated with the use of economic incentives to encourage diffusion of biofuels in their respective jurisdictions through voluntary adoption. In contrast, the uncertainties related to biofuels in Brazil were overshadowed by much larger policy problems (i.e., energy shortage, financial crisis) faced by an authoritarian government, which resulted in compulsory implementation of its national biofuels policy. In short, the policy design and level of intervention is relative to the uncertainty of the policy problem, as well as related policy and program areas.

In general, design of policy tools[61], particularly for niche development of

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[60] Ibid. R. E. Matland, "Synthesizing the Implementation Literature: The Ambiguity-Conflict Model of Policy Implementation," *Journal of Public Administration Research and Theory* 5, no. 2 (1995).
[61] Pearl Eliadis, Margaret M. Hill, and Michael Howlett, eds., *Designing Government: From Instruments to Governance* (Montreal and Kingston: McGill-Queen's Press, 2005), Robert Paehlke, "Policy

environmental technologies[62], can take numerous forms. Governments use milestone objectives to indicate desired outcomes, and often employ a mix of traditional policy instruments to encourage a particular direction for technological innovation. Regulations are effective tools for encouraging niche innovations for sustainability, and can take on numerous forms ranging from voluntary to compulsory. Voluntary measures are less interventionist, and seem to be preferred governance mechanisms for industrial development in the current era of international trade liberalisation.[63] Some policy concerns require significant government intervention, but compulsory regulations are "not the be-all and end-all of social innovation...Regulation is but one of many stimuli. It may, in fact, not be needed for environmental innovation."[64]

Voluntary Innovation

As protected spaces for experimentation and development of alternative technologies, niches are not limited to geography[65] and can also include intellectual

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Instruments and Sustainable Production: Toward Foresight without Foreclosure," in *Sustainable Production*, ed. Glen Toner (Vancouver: UBC Press, 2006).

[62] Caniels and Romijn, "Strategic Niche Management: Towards a Policy Tool for Sustainable Development.", Kemp, Loorbach, and Rotmans, "Transition Management as a Model for Managing Processes of Co-Evolution Towards Sustainable Development.", Johan Schot and Frank W. Geels, "Niches in Evolutionary Theories of Technical Change," *Journal of Evolutionary Economics* 17 (2007), Van der Laak, Raven, and Verbong, "Strategic Niche Management for Biofuels: Analysing Past Experiments for Developing New Biofuels Policies."

[63] James McCarthy, "Privatizing Conditions of Production: Trade Agreements as Neoliberal Environmental Governance," *Geoforum*, no. 35 (2004) (2004).

[64] Kemp, "Technology and Environmental Policy: Innovation Effects of Past Policies and Suggestions for Improvement," 36.

[65] Tittmann et al., "A Spatially Explicit Techno-Economic Model of Bioenergy and Biofuels Production in California.", Vuichard, Ciais, and Wolf, "Soil Carbon Sequestration or Biofuel Production: New Land-Use Opportunities for Mitigating Climate over Abandoned Soviet Farmlands."

niches[66] (e.g., innovation networks) or sectoral niches[67] (e.g., patents). Definitions of what constitutes a niche can vary according to local or national contexts, and depends on product characteristics, market conditions, and other socio-technical factors. Niches also provide a "wedge" that can be used to de-align and re-align a given technological trajectory in order to encourage more desirable system qualities for sustainable development.

Economic incentives and principled partnerships typically garner the most attention as policy options for niche development, but public industry is also a form of niche development that can be implemented as a monopoly or in competition with the private sector.[68] Brazil's ethanol program provides an example of monopoly while competitive niches are better reflected by public utilities or crown corporations. Protected spaces can include any of these niches and, as is more often the case, comprise multiple niches in combination.

Economic incentives typically include subsidies, tax expenditures, tax rebates, and payments for desired production practices and technologies. Less common are green auctions and tradable permits, although interest in these market-based alternatives has increased in a number of sectors responding to environmental challenges.[69] These market mechanisms are meant to support voluntary pursuit and/or uptake of innovative

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[66] Manfred M. Fischer, Luis Suarez-Villa, and Michael Steiner, eds., *Innovation, Networks and Localities* (Berlin: Springer, 1999), Lundvall, ed., *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*.

[67] Ulrich Dolata, "Technological Innovations and Sectoral Change. Transformative Capacity, Adaptability, Patterns of Change: An Analytical Framework," *Research Policy* 38, no. 6 (2009).

[68] Kemp, "Technology and Environmental Policy: Innovation Effects of Past Policies and Suggestions for Improvement."

[69] Organisation for Economic Co-operation and Development, "Economic Assessment of Biofuel Support Policies."

technologies. Subsidies and tax measures were used extensively to expand biofuels technologies in most countries, but some countries were not very effective at stimulating production and these subsidies became windfall profits to well-positioned market entities. In some cases, attempts to encourage international diffusion of biofuels through trade agreements have neither stabilised demand nor addressed the need for a sustainable energy product. For example, Di Lucia explored the influence of the European Union (a dominant regime) on Mozambique (a small market), and found that this type of technology transfer resulted in volatile biofuels prices and unstable demand, while sustainability indicators were narrowly focussed on issues of climate change and biodiversity.[70]

Innovation waivers, such as those used in the United States under the 1990 *Clean Air Act*, extend the deadline by which industry must meet a given standard (such as emissions reductions or energy consumption). They provide another example of an economic incentive used for niche development that allow industry to experiment with innovative pilot projects and to gain from production efficiencies that might result from the use of a superior technology. Kemp notes that the poor policy outcomes resulting from innovation waivers in the United States might have been avoided if there was greater institutional support (e.g., expert administration, capable oversight by a technology review panel, clear eligibility criteria, and/or allowances for longer time periods to allow for the commercialisation of technical innovation).[71] In short, innovation

[70] Lorenzo Di Lucia, "External Governance and the Eu Policy for Sustainable Biofuels, the Case of Mozambique," *Energy Policy* 38 (2010).

[71] Kemp, "Technology and Environmental Policy: Innovation Effects of Past Policies and Suggestions for Improvement."

waivers can play a supporting role in achieving sustainable biofuels by improving environmental performance of first generation technologies or by encouraging the wholesale shift toward advanced biofuels. However, innovation waivers seem to require more institutional support and assessment than is typically associated with market-based voluntary niche development strategies.

Principled partnerships are another type of policy option that can encourage a stronger commitment to niche development. Although broadly interpreted and often overlapping with other policy tools, principled partnerships are based on self-identification, information sharing and communication agreements, public-private research and development initiatives, matchmaking, technology compacts, among others. For niche development strategies that rely on government support, self-identification involves industry endorsement of a policy direction, but can also be more a formal negotiation of an agreement between industry and government. These agreements (sometimes called "covenants") parallel bilateral or international treaties,[72] in that they involve the recognition of mutual interests in which "industry promises to reduce the environmental burden of their products and activities"[73] while governments commit to employ minimal regulatory enforcement and only when absolutely necessary. These covenants effectively lower the regulatory burden for industry so long as they reduce adverse environmental effects resulting from their productive activity. This simultaneously reduces the administrative costs of oversight and enforcement by

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[72] Kemp, *Environmental Policy and Technical Change: A Comparison of the Technological Impact of Policy Instruments.*

[73] Kemp, "Technology and Environmental Policy: Innovation Effects of Past Policies and Suggestions for Improvement," 40.

governments[74], but can be subject to strategic exploitation or become prone to using "off the shelf" technologies rather than inspiring technical innovation for sustainable development. The problems associated with self-identification can be overcome by improving information-sharing and communication agreements between industry and government in order to enhance mutual knowledge of products, processes and desired outcomes. Linking these agreements to public-private research and development programmes can also encourage collaborative behaviour to achieve socio-technical innovations.[75] "Matchmaking" involves a designed "network of technology suppliers, users and research institutes"[76] that brings together synergistic relationships between industry and government actors. However, there is a general difficulty in finding government administrators that possess the "special competences" to encourage the development of such relationship in such a way as to create communities that are at once collegial and radically innovative.[77] Technology compacts might be useful to guide these relationships toward technological innovation, although these are subject to similar criticisms as self-regulation through negotiated agreements.[78]

As each case study of the dominant and nascent biofuels regime presented throughout this dissertation revealed, there is a strong degree of path dependency in the

[74] Kathryn Harrison, "Voluntarism and Environmental Governance," in *Governing the Environment*, ed. Edward A. Parson (Toronto: University of Toronto Press, 2001).

[75] Kemp and Volpi, "The Diffusion of Clean Technologies: A Review with Suggestions for Future Diffusion Analysis."

[76] Kemp, "Technology and Environmental Policy: Innovation Effects of Past Policies and Suggestions for Improvement," 45.

[77] David D. Kumar and James W. Altschuld, "Science, Technology, and Society," *American Behavioral Scientist* 47, no. 10 (2004). For a more critical assessment of collaborative public-private epistemic communities, see Michael Gough, ed., *Politicizing Science: The Alchemy of Policymaking* (Stanford, CA: Hoover Institution Press, 2003).

[78] Kemp, "Technology and Environmental Policy: Innovation Effects of Past Policies and Suggestions for Improvement," 45.

present technological trajectory of first generation biofuels that can overpower niche development strategies for sustainable biofuels. Voluntary regulations for niche development may not achieve the motivation or momentum needed for the diffusion of innovative technologies for socio-technical shifts toward sustainability. To strengthen niche development strategies of innovations for sustainability corrective regulatory measures aimed to integrate sustainability standards for global biofuels are necessary.

Industry Standards

Industry standards can include loosely-defined "best-practice rules" or mutually-defined criteria to delineate product specification. Best-practice rules, also known as "soft laws"[79] or "non-state market-driven" governance systems[80], typically refer to improving production efficiencies and encouraging continuous improvement of industrial processes. The use of product standards requires a greater degree of industry-wide cooperation to secure agreement on criteria for products and processes. These types of measures are best reflected by brand recognition/labelling programs such as eco-certification, certified organic, and fair trade product classifications. Other strategies for industrial standards have been investigated as part of the study on criteria and certification of sustainable biofuels.[81] Brazil's 2007 "Social Seal" is a biofuels labelling system to indicate the social sustainability of biodiesel feedstocks and production processes that include local and

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[79] Dieter Kerwer, "Rules That Many Use: Standards and Global Regulation," *Governance: An International Journal of Policy, Administration, and Institutions* 18, no. 4 (2005).

[80] Benjamin Cashore, "Legitimacy and the Privatization of Environmental Governance: How Non-State Market-Driven (Nsmd) Governance Systems Gain Rule-Making Authority," *Governance: An International Journal of Policy, Administration, and Institutions* 15, no. 4 (2002).

[81] These include conventions established by the International Labour Organisation (ILO), by Forest Stewardship Council (FSC) certification identifiers, and the criteria determined by the Sustainable Agriculture Network (SAN).

small-scale farmers in order to alleviate poverty and social dislocation. Other examples include sustainable biomass criteria in the Netherlands (2007), carbon and sustainability certification in the United Kingdom (2008), European Union Directives related to the Climate-Energy package (2009), and Germany's International Sustainability & Carbon Certification system (2010), to name a few.[82] In Europe, biofuels labelling initiatives to reflect sustainable ethanol (ethaSTAR) and biodiesel (fameSTAR) were created to increase the visibility and awareness of high quality sustainable biofuels.[83]

Private governance systems are based on various global systems that codify norms and rules, such as: reporting schemes, certification criteria, product quality requirements, and environmental management standards, to name a few. By definition, private governance systems exist outside of the public sphere, but they have enabled private actors to exercise a significant amount of influence in world politics and international markets.[84] The popularity of private governance systems has increased, but their success requires the negotiation of mutually-endorsed targets and the creation of compliance mechanisms that conform to pre-existing regulations. Proof of this compliance must be demonstrable and, in the case of international trade, must meet the regulations of participating nations and multilateral governance structures. While voluntary self-regulation through private governance systems can be highly effective,

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[82] Edgard Gnansounou, "Assessing the Sustainability of Biofuels: A Logic-Based Model," *Energy* 36 (2011). For a wider discussion of bioenergy certification efforts, see also van Dam, Junginger, and Faaij, "From the Global Efforts on Certification of Bioenergy Towards an Integrated Approach Based on Sustainable Land Use Planning."

[83] Gnansounou, "Assessing the Sustainability of Biofuels: A Logic-Based Model."

[84] Philipp Pattberg, "The Institutionalization of Private Governance: How Business and Nonprofit Organizations Agree on Transnational Rules," *Governance: An International Journal of Policy, Administration, and Institutions* 18, no. 4 (2005).

holding those standard-setting organisations accountable can be difficult.[85] This is due to the deliberate separation of government oversight from industry-led standard setting, and the increased authority of the private sector to determine product and process standards. While self-regulation by industry is attractive, there is a threat to social and environmental responsibility by "a focus on material-based profit-maximizing motivations".[86]

The current priority of profit-based decision-making over social and environmental metrics requires a fundamental shift to incorporate sustainable development as part of the business mandate. According to Auld et al., some of the difficulty associated with achieving regulatory compliance through private governance systems that apply to multiple jurisdictions might be overcome with improved tracking mechanisms and measuring technical performance.[87] Despite this possibility, however, there remains the problem of how private governance systems might overcome the potential for inherent political conflicts that are normally settled through the authority of public organisations. It is also difficult to determine the appropriate level of involvement of private governance systems to enforce compliance for international markets.

In response to the need to address global private governance systems, Pattberg examines the institutionalisation of private transnational governance systems, which are explicitly international in scope and distinct from national private governance systems, national administrative structures, and international governance organisations. These

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[85] Kerwer, "Rules That Many Use: Standards and Global Regulation."

[86] Cashore, "Legitimacy and the Privatization of Environmental Governance: How Non-State Market-Driven (Nsmd) Governance Systems Gain Rule-Making Authority," 522.

[87] Graeme Auld et al., "Can Technological Innovations Improve Private Regulations in the Global Economy?," *Business and Politics* 12, no. 3 (2010).

private governance systems correlated to the rise of transnational organisations, and have since "developed from being an intervening variable of the international system to establishing rules that exist mainly outside of it."[88] The construction of private transnational governance system involves numerous actors, institutions and ideas from multiple jurisdictions that can each be influenced by asymmetrical information and adversarial relationships among stakeholders.[89] Even though the establishment of national or transnational rival private governance systems (i.e., the creation of competing organisations undertaking the self-regulation of a common sector) may provide innovation benefits to both product performance and governance systems[90], there is always the potential for power-seeking actors to influence the political components of these systems in order to achieve strategic economic advantage.

Private governance systems provide one mechanism with which to de-align the persistence of unsustainable first generation biofuels for global markets. By encouraging guidelines for criteria and certification standards, private governance systems can re-align their socio-technical systems by exhibiting a greater emphasis on sustainability. However, these efforts are not without criticism, particularly in terms of whether certification and labelling programs can (1) be adequately accountable and trustworthy (so as not to be used for strategic gain via "greenwashing"), and (2) encourage a sufficient shift in the degree of innovation to contribute to substantial improvement to an industry, a product, and/or its processes.

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[88] Pattberg, "The Institutionalization of Private Governance: How Business and Nonprofit Organizations Agree on Transnational Rules."

[89] Ibid.

[90] Timothy M. Smith and Miriam Fischlein, "Rival Private Goverance Networks: Competing to Define the Rule of Sustainability Performance," *Global Environmental Change* 20 (2010).

Compulsory Regulations

There are always uncertainties associated with regulations, but their outcomes can be more certain if supported by stronger governance systems with greater public oversight and compulsory requirements. The aforementioned examples of product certification and labelling system suggest a growing appetite for stronger regulations, but the global application of sustainability criteria and certification standards have not yet gained traction.[91] Grafting sustainability criteria to the existing technical certification may become a useful part of the contracting process for future biofuels producers that could facilitate the uptake of sustainability as part of an existing trade instrument. The simplicity of this approach is attractive, but this quickly becomes complex in consideration of existing international agreements.[92] In particular, sustainability certification for biofuels would need to conform to the laws of the World Trade Organization, which would require clear evidence supporting the achievement of social and environmental sustainability and would be subject to the *General Agreement on Tariffs and Trade* (Article I - Most-Favoured Nation, and Article III - National Treatment) to ensure compliance with international trade laws. Sustainability certification standards would also be subject to the *Technical Barriers to Trade Agreement* to ensure the procedural fairness of certification schemes.[93]

In addition to the conventional approaches to niche development through

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[91] John A. Mathews, "Towards a Sustainably Certifiable Futures Contract for Biofuels," *Energy Policy* 36 (2008).
[92] Ibid.
[93] Marsha A. Echols, "Biofuels Certification and the Law of the World Trade Organization," in *Programme on Agricultural Trade and Sustainable Development* (Geneva: International Centre for Trade and Sustainable Development, 2009).

protected markets (e.g., tariffs, public industry, etc.), trade rules enforced by multilateral treaties provide a strong alternative for designing, implementing and enforcing certification standards by mandating specific protocols and product performance measures. The trade in “conflict diamonds”, for example, required much more than voluntary industry-led certification standards and labelling systems, and resulted in the implementation of the *Kimberley Process Certification Scheme* by the United Nations.[94]

Regulating global commodities and tracing the chain of ownership of biofuels and to determine their impacts on local ecosystems risks becoming an overcorrection to what might otherwise require less extreme measures. One must expect that weaving social and environmental criteria into existing economic instruments will face trade challenges, political resistance, technical arguments, as well as social and environmental critiques. But the opposition to regulatory change has been overcome before. Research and innovation, market protection, and economic treaties are often means to achieving comparative advantage of niche products or to avoid undesirable effects of “free market” trade and development. The inclusion of sustainability criteria and certification standards will extend the practice of creating rules to achieve market certainty into “non-economic” policy areas of social development and environmental protection. It is reasonable that regulatory measures begin with the least amount of intervention as needed to achieve desired outcomes. However, the trajectory of first generation biofuels has entered a stagnant state of development. The persistence of unsustainable production of ethanol and biodiesel requires a deliberate move from voluntary adoption for industry-based

[94] Jeffrey S. Morton, "The Legal Regulation of Conflict Diamonds," *Politics & Policy* 33, no. 3 (2005).

improvement and toward the use of compulsory regulations to facilitate the expansion of sustainable biofuels.

Conclusion

This chapter explored aspects of implanting sustainable biofuels. It assessed the use of principles, guidelines and requirements as way to insert sustainability criteria and certification standards into biofuels fuels regimes. Considering the likelihood that first generation biofuels supplied by dominant regimes will continue to supply unsustainable biofuels to global markets, corrective regulatory measures must be inserted into government programs to stimulate the de-alignment and re-alignment of biofuels production trajectories that include sustainability as part of the socio-technical regime.

The challenge is to determine a suitable way to design and construct corrective regulatory measures for niche development of sustainable biofuels. Throughout the history of biofuels expansion, most regulatory measures followed a voluntary approach to innovation. Policy tools used in this approach included economic incentives and principled partnerships. These are suitable in cases of high technological uncertainty, such as when effects of technical performance are unknown or before latent socio-technical functions appear in the public discourse. As discussed in chapter six, the increased attention given to ethanol and biodiesel has shed light on the technical, economic, social and environmental parameters of transport biofuels. The evidence suggests that regulations based on voluntary innovation have reached their limits.

The encouragement of "best practices" through private governance systems according to industry standards requires mutual endorsement by industry. Although they stimulate continuous technological improvement to increase production efficiencies, such approaches tend to respond to pre-existing regulations relevant to the industry rather than broader societal considerations. These types of regulatory measures are evolving, however, and these changes are exemplified by product labelling for eco-certification, fair-trade, or other attributes outside of the conventional industrial production system. Considering the persistence of global biofuels and difficulties identified in chapter eight for smaller markets to resist the trajectory established by the dominant biofuels regimes, industry standards are required if we are to achieve sustainable biofuels.

Given the shortfalls of voluntary innovation and industry standards, compulsory regulations seem to be needed in order to insert corrective regulatory measures into the present socio-technical configuration. How this will look will differ from country to country, and each jurisdiction must ensure they reconcile local regulations, national laws, and international agreements. There are, however, examples of how global principles have contributed to the design of compulsory regulations, and trade-based mechanisms aim for the least possible degree of government intervention and compliance mechanisms. Trade-based regulation can provide the basis for international standards, but these require further delineation by national or subnational governments in non-trade areas.

The most effective compulsory regulations are those that encourage voluntary innovation and industry standards that are in line with regulatory requirements, but reserve compliance and enforcement penalties as mechanisms of last resort. Here, the purpose of compulsory regulations is not to be overly ambitious or to zealously pursue those that are not in compliance. Instead, compulsory regulations can establish enforceable rules while allowing alternative compliance mechanisms in the other areas of voluntary innovation and industry standards.

If dominant biofuels production regimes are not achieving a sufficient level of sustainability, small markets need to stimulate niche innovations for sustainable biofuels through policy designs that include multiple policy tools working in concert. Similarly, these policy designs work best when situated within a policy framework that incorporates a mix of voluntary, industry and compulsory regulations. Small markets need to seek and exploit opportunities to exhort other markets to pursue high quality sustainable biofuels, so as to gain market share in relation to biofuels produced by dominant jurisdictions. This does not guarantee commercial success of sustainable biofuels, but the recent concerns with biofuels in the European Union suggest that there will emerge a more discriminating customer that favours a more sustainable biomass-based transportation fuel. A growing market for sustainable biofuels can provide the leverage required to influence the trajectory of unsustainable global biofuels.

Different national contexts have unique socio-technical landscapes, regimes, and niches, so there is no template that countries can follow to achieve sustainable biofuels. Tangible policy suggestions are nevertheless possible, such as compulsory requirements for biofuels production to exhibit a reduction in greenhouse gases over the product lifecycle. Rather than enforcing legal or financial penalties upon unsustainable facilities, requiring plant shutdown, or forced exclusion from the market, it is possible to allow producers to support sustainable development through industry standards (e.g., carbon offset mechanisms) to account for its greenhouse gas emissions, while exhorting voluntary innovation (e.g., by requiring a financial contribution to a sustainable biofuels fund earmarked for the research and development) to improve production technologies and processes.

Governments in small markets can provide policy shelters in which experimentation and refinement of different aspects of sustainable biofuels production might occur. Small markets can develop niche innovations to improve local production and consumption.[95] They can also seek bilateral agreements between subnational jurisdictions, such as the agreement between Quebec and Bavaria.[96] Collectively, these may help to improve the performance of biofuels in terms of common sustainability indicators that correspond with existing international standards and agreements focussed on technical performance and economic measures for tradability, while also corresponding with local contexts, national policies, and global governance

[95] Robinson, "Squaring the Circle? Some Thoughts on the Idea of Sustainable Development."

[96] Corbiel and Schnappauf, "Déclaration D'intention Entre Le Ministère Des Ressources Naturelles Et De La Faune Du Québec Et Le Ministère De L'Environnement, De La Santé Et De La Protection De Consommateurs De La Bavière Portant Sur La Coopération Dans Les Domaines Du Biocarburant Et De La Protectoin Du Climat."

TEN – Conclusion

This dissertation explored the diffusion and adoption of biofuels that occurred between 1998 and 2008. Despite the repeated commercial failure of biofuels in the 19th and 20th centuries, the evolution of the biofuels regimes in Brazil, the United States, and the European Union has resulted in the expansion of ethanol and biodiesel to global markets. The promise of biofuels was to provide a technological solution with which to address the policy concerns regarding rural development, energy security, and climate change. These have provided some benefit, but first generation ethanol and biodiesel are not "sustainable" energy options.

The multi-level perspective on transitions offered a unique approach from which to understand the expansion of first generation ethanol and biodiesel. It also helped to frame the evaluation of whether or not these biofuels can be considered sustainable. This final chapter summarises the main ideas of this thesis. It outlines the arguments presented throughout this dissertation, and identifies the contribution of this research to the fields of sustainable energy, transitions and public policy.

Dissertation Overview

This section summarises the main ideas presented in this dissertation. Chapter two identified the promise of biofuels as solutions to multiple policy problems, and discussed the key technical characteristics and effects of ethanol and biodiesel. This set the parameters for the examination of these first generation biofuels throughout this thesis.

Chapter three introduced the theoretical framework from which to understand the diffusion and adoption of ethanol and biodiesel. It suggested the current paradigm of sustainable development provides an initial framework for the re-evaluation of ethanol and biodiesel performance in terms of their potential as sustainable energy options. This chapter also introduced the transitions approach to understanding stability and change in socio-technological systems, and employed the concepts of "niche", "regime" and "landscape" as heuristic devices to identify the multiple levels of activity involved in technological change. The multi-level perspective on transitions provides a novel approach with which to understand the expansion of global biofuels. In particular, it conceptualises transitions as occurring from the interaction within and between these levels. It provides a process-based framework for analysis of complex subjects like sustainable development and sustainable energy that involve numerous policy areas.

The expansion of ethanol and biodiesel from local to global markets was addressed in chapters four through six. Chapter four explored the history of ethanol and biodiesel from the earliest applications up to the present, and showed how ethanol and biodiesel evolved into "mature" technological artefacts. Despite the efforts of different champions in different eras, these biofuels remained on the margins of the petroleum-based transportation fuels regime. For 150 years, these fringe fuels co-evolved with engine technology and other applications, but seemed destined to remain outside the mainstream. However, chapter five revealed how Brazil, the United States, and the European Union integrated biofuels into the wider transportation fuels regime. Further, it showed how these emergent biofuels regimes encouraged the rapid expansion of ethanol and biodiesel to international markets between 1998 and 2008.

Chapter six noted that the global expansion of biofuels slowed after 2008, which correlated with the stabilising technological trajectory of ethanol and biodiesel. The institutionalisation of global biofuels and the commoditisation of ethanol and biodiesel by the dominant biofuels regimes were two regime-level activities pursued by the dominant biofuels regimes that contributed to the global slowdown of biofuels expansion in 2008. At the same time, local environmental and social effects of global biofuels were criticised by relevant social groups on a number of issues. The broadening critique of ethanol and biodiesel suggests that the effects of first generation ethanol and biodiesel did not reflect emerging social functions and the need for transport biofuels to satisfy wider societal concerns.

Chapter seven investigated the resilience of ethanol and biodiesel as "two-world" technologies that were able to succeed despite commercial "failure". The institutionalisation of these first generation biofuels contributed to their persistence in the industry, but it was the robust characteristics of these biofuels that enabled them to remain technologically relevant. In the present socio-technical configuration of mass production and international trade, the robust attributes of first generation biofuels make them functionally relevant as petroleum substitutes, complements or, more ambitiously, as vanguard artefacts that could usher in a new socio-technical system based on sustainable energy. Even though they are not sustainable in the present socio-technical regime, biomass transportation fuels have important roles to play in the evolution of transportation fuels.

The contradiction between the stability of first generation biofuels and their potential as a sustainable energy option was discussed further in chapter eight. If dominant regimes contributed to the persistence of first generation biofuels, how might societies overcome this unsustainable trajectory? Chapter eight argued that small markets not yet reliant on mass production or integrated into international trade flows have a greater adaptability to pursue sustainable biofuels. By looking at Canada and the provinces of Manitoba, Saskatchewan and Ontario, this chapter revealed a degree of subnational variation between niche development strategies. These differences show that small markets can shape their respective biofuels industries, but that a future in which biofuels are globally sustainable necessitates the inclusion of other system levels. In short, small markets can inspire but not enforce sustainability of biofuels under global market conditions.

It does not appear that the dominant biofuels regimes will embrace the goal of sustainability any time soon. Chapter nine suggested ways to improve niche development strategies of governments in small markets so that they might inspire sustainability in the dominant regimes and emerging markets. It employed the multi-level perspective on transitions to identify policy areas that could foster a re-alignment of the current socio-technical system to place a priority on sustainability in the biofuels sector. Sustainability criteria and certification standards have been a popular response that many suggest could re-align the industry. However, sustainability standards based on voluntary innovation or industry self-regulation have not yet brought the desired results. Consequently, compulsory regulations are necessary in order to foster sustainability in the biofuels industry. Chapter nine concluded on a cautionary note that warned against overly ambitious regulations or zealous regulatory enforcement, both of which can be mitigated by offering flexibility mechanisms that encourage and support the less interventionist types of regulation that are typical of voluntary innovation and industry standards.

Main Arguments

There were four key arguments presented in this dissertation. First, the expansion of biofuels from local to global markets was due to the evolution of three dominant, yet distinct, biofuels regimes pursuing policy trajectories that converged toward the institutionalisation and persistence of first generation ethanol and biodiesel. Second, the expansion of ethanol and biodiesel to global markets followed a techno-economic trajectory along which their sustainability could not be achieved. Third, small markets were largely outside of global trade systems, and are therefore able to pursue niche development strategies that reflect local objectives, such as social development and environmental protection. Fourth, sustainability criteria and certification standards can help small markets to maintain their niche development strategies in the face of an unsustainable trajectory of global biofuels pursued by the dominant biofuels regimes.

As evidenced by the period between 1998 and 2008, the role of government support for the diffusion of biofuels continues to be of central importance, particularly as governments and citizens respond to the increasing expectations as to what biofuels can or should deliver. Despite the different motivations and implications of the large biofuels regimes, and in light of the different scales of production in both dominant regimes and small markets, biofuels production strategies have tended to converge toward similar if not common socio-technical trajectories. This helped to facilitate the diffusion and adoption of biofuels across global markets. While no longer a fringe fuel, most jurisdictions continued to conceive of ethanol and biodiesel as fuel extenders rather than as substitutes to petroleum transportation fuels. Only in Brazil can transport biofuels be considered as a potentially viable energy alternative, even though this regime remains firmly nested within the larger petroleum-based transportation fuels regime. The international diffusion of first generation biofuels shaped the trajectory of these socio-technical artefacts by focussing on economic development and narrow "effects-based" outcomes at the expense of the broader goals of sustainable development and new socio-technical functions of biofuels. Some governments were more open to the integration of new perspectives, and these more reflexive policy processes allowed the re-evaluation of global biofuels to occur as new critiques emerged. As a case in point, the growing critique on the adverse effects of biofuels outlined in chapter six provided additional motivation for the European Commission to review the sustainability of biofuels, which later informed the 2008 Proposed Directive on renewable energy that precipitated the review and re-calibration of the European Union biofuels policy. This response to the voice of critics and activities of small markets preceded the European Parliament's recommendations to reform to the European Union's biofuels policy direction so as to include environmental and social sustainability criteria.[1]

In other cases, adaptation to new information was limited. National mandates and federal spending power in the United States responded to the corn and soy lobbies, and to

[1] European Commission, "Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources."

transnational agribusiness whose interests were to increase national production and consumption of biomass energy feedstocks. In a similar way, strong federal policy coordination in Brazil exhibited a weak ability to adjust their national production paths to incorporate environmental and social sustainability. Yet both the United States and Brazil made some progress in these areas. For instance, there has been significant research and debate in the United States on the environmental effects of corn-based ethanol and the recognition that the 2005 Renewable Fuel Standard required more cellulosic ethanol in its national energy mix if it was to achieve its policy objectives.[2] Brazil has partially recaptured pollution created by ethanol distilleries by reducing effluent into water systems and producing electrical power from solid waste (bagasse). Also, Brazil has begun to address wider environmental and social sustainability issues by legislating that at least 10% of all new sugarcane fields must be dedicated to non-cane uses as an effort to maintain biodiversity and mitigate effects of monocultural industrial farming practices.[3] Further, Brazil has attempted to address social sustainability by way of a "Social Seal" for biodiesel feedstocks and production processes to include local and small-scale farmers in order to alleviate poverty and social dislocation in its distant northern regions.[4] Activities in the United States and Brazil have been somewhat responsive, with decisions to address local environmental impacts generally occurring only after reaching a critical level. This contrasts with the more precautionary approach

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[2] U.S. Environmental Protection Agency, *Epa Lays out a Plan for the Nation'S Increase in Renewable Fuels.*

[3] Rosillo-Callé and Walter, "Global Market for Bioethanol: Historical Trends and Future Prospects," 29.

[4] Biopact, *An in-Depth Look at Brazil's "Social Fuel Seal"*, Government of Brazil, *National Program of Biodiesel Production and Use (Pnpb)* (Government of Brazil, 2007 [cited June 28 2008]); available from http://www.biodiesel.gov.br/docs/Folder_biodiesel_ingles_paginado.

used in the European Union.

The global expansion of ethanol and biodiesel was supported and accelerated by Brazil, the United States, and the European Union, but each of these dominant biofuels regimes evolved to consider biofuels more as a tradable commodity than as a technological stage in the development of sustainable energy production. Consequently, the focus on trade rules and product standardisation was limited to securing national comparative advantage rather than encouraging a socio-technical transformation of the conventional energy regime toward one that is more sustainable. These dominant production systems informed and influenced the development of biofuels policy of national governments and subnational jurisdictions around the world.

Concurrent with the diffusion of biofuels, social rules and other institutions were created and elaborated in support of first generation biofuels and their expansion to global markets. These appear as a variety of policy tools, including laws, regulations, and international trade agreements. As well, new private and public sector organisations were created to encourage and govern the expansion of ethanol and biodiesel as global biofuels. Because these developed to accommodate first generation biofuels, we are provided an opportunity to see how the socio-technical content of technological artefacts (e.g., agricultural feedstocks, positive energy balance and lower greenhouse gas in comparison to gasoline, and simple production processes) can influence the direction of public administration in a variety of jurisdictions. In particular, the expansion of first generation biofuels required that incentives be directed primarily at agricultural producers. The need for energy crops coincided with rural and agricultural development objectives, and associated political support could not be accessed if similar incentives were provided to other social groups and economic actors, such as the industrial biochemicals industry in support of advanced biofuels production from non-agricultural resources. The institutional components of biofuels production systems in jurisdictions across the globe have been secured within their respective policy architectures. International policy frameworks have also helped to stabilise the technological trajectory of ethanol and biodiesel, which contributed to the persistence of unsustainable first generation biofuels.

Whereas the dominant regimes are heavily invested in first generation biofuels production facilities, small markets can play an important role to help stimulate the move toward a more sustainable global biofuels industry. This thesis investigated biofuels in Canada as a case study of small production systems and the diffusion and adoption of biofuels through national programs alongside the development of a global biofuels trade. It showed how biofuels expansion programs in Canada were supported by provincial governments that initiated niche development strategies and by federal programs that increased national harmonisation. These local and global influences on the national government helped to encourage a Canada-wide program based on different subnational production strategies. Despite the desire of some provinces to pursue ancillary objectives alongside their biofuels expansion strategies (e.g., transparency, environmental sustainability, and co-operative business models, to name a few), the prairie provinces were susceptible to the techno-economic trajectory created by the globally-focussed biofuels regimes.

Ethanol and biodiesel are likely to continue as the primary renewable transportation fuels alternatives to petroleum for as long as the existing production facilities continue to operate. This can be expected to contribute to the persistence of unsustainable first generation biofuels production on a global scale for the foreseeable future. This suggests that the current context of biofuels production will require greater regulatory intervention if sustainable biofuels are to be achieved. This dissertation suggested that national regulations can be harmonized with those of other countries, but that they must also meet the needs of local ecosystems, communities and economies. National (meso-level) initiatives could encourage niche development strategies based on internationally-endorsed sustainability criteria and certification standards as a way to de-align present production trajectories and re-align them in a more sustainable configuration. Niche development of sustainable biofuels can exert an upward pressure on regimes to produce better biofuels. Local sustainable energy transitions are more likely in small markets because they are not yet reliant on ethanol and biodiesel as global commodities.

Ultimately, if biofuels are to contribute to the socio-technical transition toward sustainable energy, the policy frameworks within the current socio-technological system must change to enable and encourage a different trajectory for biofuels to be produced more sustainably in terms of local, national and global scales. In short, small markets can stimulate the production of biofuels in a more sustainable way, but global uptake will require a coordinated regulatory framework across national boundaries in order to bring about a sufficient level of technical innovation for sustainable biofuels.

Contribution to the Field

This dissertation has contributed to the literature on sustainable energy, transitions and public policy. It explored the development of ethanol and biodiesel as a sustainable energy option, and confirmed the importance of the principles of sustainable development. However, these principles must be inserted into the policy framework in order to escape the problems associated with conventional development of our energy resources. This thesis argued that regulatory intervention was necessary in order to create market rules that place more value upon the three cornerstones of sustainable development, and that ethanol and biodiesel can contribute to the pursuit of "sustainable energy" on the basis of sufficiency and efficiency, while also ensuring human health/safety and environmental protection.[5] While the debate on sustainable energy can reflect numerous approaches, authors such as Musango, Rajagopal et al., Mullins, among others attempt to address the on-going debate on the sustainability of energy resources by increasing the sensitivity of technical assessments of quantifiable effects.[6] Similarly, others seek to delve further into the debate by addressing factors related to the broader qualitative societal effects of energy and sustainability, such as Najam's examination of the rising importance of energy in international organisation, the search for a broader understanding of sustainable energy undertaken by Tester et al., and Hertel's concern

[5] WCED, *Our Common Future.*

[6] Bureau et al., "A Quantitative Assessment of the Determinants of the Net Energy Value of Biofuels.", Melamu and von Blottnitz, "2nd Generation Biofuels a Sure Bet? A Life Cycle Assessment of How Things Could Go Wrong.", Mullins, Griffin, and Matthews, "Policy Implications of Uncertainty in Modeled Life-Cycle Greenhouse Gas Emissions of Biofuels.", Musango and Brent, "A Conceptual Framework for Energy Technology Sustainability Assessment.", Rajagopal, Hochman, and Zilberman, "Indirect Fuel Use Change (Ifuc) and the Lifecycle Environmental Impact of Biofuel Policies."

with the global impacts of regulating biofuels content in transport fuels.[7] This thesis contributed to, and expanded upon, these efforts to define sustainable energy by identifying four broad areas of consideration to help define sustainable biofuels: (1) the principles of sustainable development; (2) technical effects and social functions (3) level of governance; and, (4) level of policy activity. By including these four areas, this thesis moved beyond the effects-based approach typical in the literature on sustainable energy by including socio-technical functions, multiple levels of analysis and multiple levels of policy activity. Extending beyond the triple bottom line of society, economy and environment, this dissertation contributes to the on-going research conducted by Goldemburg, Sengers et al., Gnansounou, Kenessey and others that seek to explain the need for, and resistance to, sustainable biofuels.[8]

This dissertation also contributed to the literature on socio-technical transitions by applying existing theoretical approaches to new problem areas (i.e., ethanol and biodiesel niches, biofuels regimes, and the role of small markets to encourage socio-technical change). Martens and Rotmans, Voss and Kemp, Meijer and Hekkert, Loorbach et al., Geels, Schot, Grin, and Verbong represent only a handful of those working to refine the concept of socio-technical transitions, and to apply this theoretical and methodological

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[7] Hertel, Tyner, and Birur, "The Global Impacts of Biofuel Mandates.", Claude Mandil and Adnan Shihab-Eldin, "Assessment of Biofuels Potential and Limitations," (Riyadh, Saudi Arabia: International Energy Forum, 2010), Najam and Cleveland, "Energy and Sustainable Development at Global Environmental Summits: An Evolving Agenda.", Tester et al., *Sustainable Energy Policy: Choosing among Options*.

[8] Dias, Pedrozo, and da Silva, "Proposition of a Framework for Interpretation of Complex Problems and Initiatives Focused on Sustainability: The Food, Energy and Biofuel Crisis.", Gnansounou, "Assessing the Sustainability of Biofuels: A Logic-Based Model.", Goldemberg, "Ethanol for a Sustainable Energy Future.", Kenessey, "Transatlantic Cooperation for a Competitive and Sustainable Biofuel Industry.", F. Sengers, R.P.J.M. Raven, and A. Van Venrooij, "From Riches to Rags: Biofuels, Media Discourses, and Resistance to Sustainable Energy Technologies," *Energy Policy* 38, no. 9 (2010).

framework to social concerns and the shift toward a more sustainable society.[9] This thesis adds to these efforts by arguing that socio-technical functions can provide important insights into socio-technical transitions. Responding to the challenges posed by Geels and Berhees, Genus and Coles, and Smith et al.[10], the inclusion of social functions in the transition storyline responds to some methodological concerns with the multi-level perspective on transitions.[11] The focus on the global expansion of first generation of transportation biofuels provided an opportunity to utilise the multi-level perspective on transitions to understand a present and growing policy challenge.

Finally, this dissertation contributed to the field of public policy by identifying and applying a novel analytical framework to the policy challenges associated with first generation biofuels. The application of the multi-level perspective on transitions as a way to conceptualise public policy does not seek to replace current practices, but demonstrates how another layer of analysis can be useful for public policy-makers. For example,

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[9] Geels, "The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms.", Kemp, Loorbach, and Rotmans, "Transition Management as a Model for Managing Processes of Co-Evolution Towards Sustainable Development.", Jonathan Köhler et al., "A Transitions Model for Sustainable Mobility," *Ecological Economics* 68 (2009), Lee, Clark, and Devereaux, "Biofuels and Sustainable Development: Report of an Executive Session on the Grand Challenges of a Sustainability Transition.", Pim Martens and Jan Rotmans, "Transitions in a Globalising World," *Futures* 37 (2005), Meijer and Hekkert, "Managing Uncertainties in the Transition Towards Sustainability: The Cases of Emerging Energy Technologies in the Netherlands", Adrian Smith, Andy Stirling, and Frans Berkhout, "The Governance of Sustainable Socio-Technical Transitions," *Research Policy* 34 (2005), Verbong and Loorbach, eds., *Governing the Energy Transition: Reality, Illusion or Necessity,* Voss and Kemp, "Reflexive Governance for Sustainable Development – Incorporating Feedback in Social Problem Solving".

[10] Geels, "Ontologies, Socio-Technical Transitions (to Sustainability), and Multi-Level Perspective.", Geels and Berhees, "Cultural Legitimacy and Framing Struggles in Innovation Journeys: A Cultural-Performative Perspective and a Case Study of Dutch Nuclear Energy (1945-1986).", Genus and Coles, *A Critique of Geels' Multi-Level Perspective of Technological Transition* , Smith, Voss, and Grin, "Innovation Studies and Sustainability Transitions: The Allure of the Multi-Level Perspective and Its Challenges."

[11] Geels, "Ontologies, Socio-Technical Transitions (to Sustainability), and Multi-Level Perspective.", Geels and Kemp, "Dynamics in Socio-Technical Systems: Typology of Change Process and Contrasting Case Studies.", Geels, "The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms."

Doern, Hessing et al., Paehkle, and Fiorino have addressed the need to include sustainability as a conceptual lens for policy making.[12] These different perspectives provide an excellent step toward creating a founding vision for governments to explore potential pathways for regime change based on sustainable development. However, the application of transitions approaches by policy makers seeking a broader socio-technical transition for sustainability is an important development that has only recently been examined in the literature. Looking to Loorbach, Frantzeskaki, Kemp et al., Haan, and Alkemade reveals their attempts to bridge the gap between historical analysis and future-oriented policy-making for sustainability transitions.[13] This thesis developed twelve conditions of sustainable biofuels as an example of how to operationalise transitions theory within existing policy structures.

In addition to these contributions to the fields of sustainable energy, transitions, and public policy, this dissertation documented and analysed the biofuels industry in Canada. Despite previous reports on biofuels in Canada during the global expansion of the biofuels industry[14], and aside from the early work on transportation biofuels by

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[12] Doern, ed., *Canadian Energy Policy and the Struggle for Sustainable Development,* Fiorino, "Sustainability as a Conceptual Focus for Public Administration.", Melody Hessing, Michael Howlett, and Tracy Summerville, *Canadian Natural Resource and Environmental Policy: Political Economy and Public Policy*, 2nd ed. (Vancouver: University of British Columbia Press, 2005), Paehlke, "Policy Instruments and Sustainable Production: Toward Foresight without Foreclosure."

[13] Frantzeskaki and de Hann, "Transitions: Two Steps from Theory to Policy.", Frantzeskaki and Loorbach, "Torwards Governing Infrasystem Transitions: Reinforcing Lock-in or Facilitating Change?.", Kemp, Parto, and Gibson, "Governance for Sustainable Development: Moving from Theory to Practice."

[14] Coxworth, "The Role of Renewable Liquid Transportation Fuels in Canada's Climate Action Plan: Pros and Cons, and Stages of Development of Ethanol, Biodiesel and Thermal Depolymerization Oil..", Levelton Engineering Ltd., S&T Squared Consultants, and J.E. Associates, "Assessment of Net Emissions of Greenhouse Gases from Ethanol-Gasoline Blends in Southern Ontario.", Olar et al., "Ethanol Industry in Canada.", $(S\&T)^2$ Consultants Inc. and Meyers Norris Penny LLP,

Heath[15], the information provided on Canada and the provinces of Manitoba, Saskatchewan and Ontario is among the first of its kind that has been made available for public consumption. While there is an emerging interest in comparing dominant biofuels producers, Bomb et al, Cotula et al., Sorda et al, and others tend to explore the differences between jurisdictions.[16] In contrast, the comparison of the three dominant biofuels regimes of Brazil, the United States, and the European Union in this thesis explains the similarities and policy convergence between these distinct jurisdictions that pursued biofuels at different times, in different places, and within different socio-technical contexts. While Azar, Faaij, Cotti and Skidmore, Delshad et al., and others have offered explanations that the dramatic increase in ethanol and biodiesel production is linked to government support[17], this dissertation explained the underlying factors and overarching context as to why biofuels succeeded after 150 years on the margins of petroleum transportation fuels regime. It demonstrated how biofuels expanded and why this expansion is not sustainable. Moreover, it identified the role of small markets like

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"Economic, Financial, Social Analysis and Public Policies for Fuel Ethanol: Phase 1," (Ottawa: Natural Resources Canada, 2004).

[15] Heath, *Towards a Commercial Future: Ethanol & Methanol as Alternative Transportation Fuels.*

[16] Bomb et al., "Biofuels for Transport in Europe: Lessons from Germany and the Uk.", Carbon Positive, *Eu, Us Diverging on Biofuel Policy?* (Carbon Positive, 22 September 2008 [cited October 16 2008]); available from http://www.carbonpositive.net/viewarticle.aspx?articleID=1246, Cotula, Dyer, and Vermeulen, "Fuelling Exclusion? The Biofuels Boom and Poor People's Access to Land.", Kenessey, "Transatlantic Cooperation for a Competitive and Sustainable Biofuel Industry.", Antonio Domingos Padula et al., "The Emergence of the Biodiesel Industry in Brazil: Current Figures and Future Prospects," *Energy Policy* 44 (2012), Sorda, Banse, and Kemfert, "An Overview of Biofuel Policies across the World."

[17] Azar, Lindgren, and Andersson, "Global Energy Scenarios Meeting Stringent Co2 Constraints - Cost-Effective Fuel Choices in the Transportation Sector.", Chad Cotti and Mark Skidmore, "The Impact of State Government Subsidies and Tax Credits in an Emerging Industry: Ethanol Production 1980-2007," *Southern Economic Journal* 76, no. 4 (2010), Ashlie B. Delshad et al., "Public Attitudes toward Political and Technological Options for Biofuels," *Energy Policy* 38, no. 7 (2010), André P. C. Faaij, "Bio-Energy in Europe: Changing Technology Choices," *Energy Policy* 34 (2006).

Canada and the policy areas in which to encourage the shift toward sustainable biofuels.

Future Research

The evolution of biofuels followed a long and meandering innovation journey before taking hold in the 21st century. The expansion of ethanol and biodiesel that occurred over the past century and a half is not yet sustainable. The current stability of biofuels technology may yet re-ignite with the aim of achieving sustainable biofuels. If this occurs, the regulatory foundation for sustainable biofuels production needs to be well-established within the regime in order to provide the corrective policy measures to re-align the current trajectory of global biofuels in ways that can produce ethanol and biodiesel more sustainably. Yet even if biofuels become sustainable, ethanol and biodiesel face a long road in the race to replace petroleum.

The future research areas that this eventuality suggests are numerous. Petroleum transport fuels face socio-technical challenges from other technologies, such as advanced biofuels, electric vehicles, hydrogen fuel cells, curtailment of consumption, fuel efficiency, or some other future unknown socio-technical regime. The long-term prospects for biofuels will undoubtedly be influenced by unknown technologies following uncertain trajectories. In the present, however, first generation biofuels must be realigned if they are to contribute to the shift toward sustainable energy in the future. Understanding the socio-technical shift toward sustainable energy will provide ample subjects for further research and application of the multi-level perspective on transitions.

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