BSR

The Sustainability Impacts of Fuel

Understanding the Total Sustainability Impacts of Commercial Transportation Fuels

A Paper From the Future of Fuels Working Group

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About Future of Fuels

Energy is a cornerstone of global development, growth, and future prosperity, with fuel products serving innumerable direct and indirect societal benefits. At the same time, our reliance on current and emerging energy products implies trade-offs that are not always clearly visible or consciously determined. In order to shed more light on both the benefits and trade-offs of energy production and consumption, BSR has embarked on a member-requested Future of Fuels initiative that focuses initially on road transportation fuels in North America. Specifically, our members have requested a holistic review of the North American road transportation life cycle that steers clear of advocacy and focuses on developing an objective synthesis of available knowledge, benefits, and impacts.

Future of Fuels is a multistakeholder initiative aimed at promoting a total life-cycle framework for understanding the sustainability impacts of transportation fuels, and developing a shared perspective on how impacts, cost, and availability are likely to change over time. To do this, the initiative brings together critical players from the corporate, NGO, and public sectors in a series of facilitated dialogues supported by research.

Our intention is to advance a common road map for those industry players and partners who are interested in identifying continuous improvement opportunities across sustainability topics within the fuel sector for transportation fuels and related supply chains. Our work is intended to guide project participants in the development of policies and practices, while catalyzing industry and multisector partnerships to promote the creation and adoption of leading practices, better technology, infrastructure, and policy development for fuel production, distribution, and consumption.

Future of Fuels will publish research addressing the following issues:

1. **Framing the issues (this paper)**: What are the total sustainability impacts of North American road transportation fuels? We draw on existing studies and interviews with third-party experts to explore the state of knowledge about the sustainability impacts of transportation fuels.
2. **Understanding options**: How can we enhance the sustainability of existing and emerging sources for such fuels through more informed investments, operations, and procurement? Our next brief will look at how companies can use the information and frameworks described in this brief to elevate sustainability within their fuel supply chains.
3. **Highlighting opportunities for collaboration:** Our final brief will help companies see how they can best engage with stakeholders across the value chain.

About This Report

This first paper of the Future of Fuels working group frames the sustainability issues of transportation fuels in the context of their viability as large-scale solutions. We draw on a wide range of studies, interviews with experts, and BSR's own experience to create a holistic framework for understanding the total value-chain impacts of fuels, and identify related complexities and gaps in current knowledge. We address the following:

- What are the forecasts for fossil-based and alternative transportation fuels over 20-year, 30-year, and longer horizons?
- What are the major implications for reliable and affordable energy supplies given current and emerging energy sources?
- What are the full life-cycle environmental and social impacts associated with the current and emerging transportation fuel mix—including the broad areas of agreement/disagreement?
- What are the major policy issues at stake that have fundamental impacts on determining more sustainable fuel choices, both "better" fossil fuels and relevant alternatives?

In this paper, we address issues pertaining to the whole *value chain* or *life-cycle analysis* (LCA) of fuels—that is, the string of production activities that begins with the development of oil and gas wells, mines, and farms, and then carries all the way through to the purchase and use of final fuel products. This is a useful lens, but, as we shall see, even the best LCA tools are limited, in part because they do not effectively account for indirect effects linked to different levels of production, nor spatial (e.g. activities happening different at locations) and temporal (e.g. activities happening at different times) contexts. We hope this paper will develop into a frame of reference to allow better integration of these approaches.

It is worth noting that even with perfect information, key actors in the energy story—producers, refiners, buyers, investors, policymakers, and beyond—will continue to have different values and objectives. This presents its own challenges, but it is nevertheless true that improved transparency is a first step to building common ground.

In this paper we focus on road transportation in North America as the demand market, while the inputs to fuel and even refined fuel are part of an international commodity market in which it is currently impractical to trace fuels to their sources. Therefore, some examples will be used for production outside of North America when they are particularly important.

The three legs of the stool that will make a more sustainable transportation system can be thought of as fuel, vehicles, and infrastructure. This paper focuses on fuel specifically, though the distinctions among these legs are not always clear. For example, we often compare liquid fuels to alternatives found in electric vehicles, though the latter category is more a vehicle than a fuel.

This report was written by Eric Olson and Ryan Schuchard at BSR, and it is based on numerous sources, including scientific studies and other published analyses, input from expert contributors, and BSR's own experience. Organizational partners that have provided financial and/or significant in-kind resources are Coca-Cola, JPMorgan Chase, Nike, Shell, Suncor, the U.S. Department of Defense, UPS, and Walmart. Additionally, we thank the following for very helpful contributions:

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Request for Feedback

The Future of Fuels working group has published this report with the aim of bringing together a wide variety of issues and sources to describe the state of knowledge about the sustainability of road transportation fuels. It is a work in progress, and we welcome additional input. We are particularly interested in feedback related to the following:

1. What issues need to be better or more accurately depicted?
2. What additional tools and resources should be included?
3. What are the most important and innovative ways to alleviate the negative impacts identified in this paper, and enhance the positive ones?

If you have input on any of these items or feel there are nuances that should be better registered, we would like to hear from you. Feedback may be directed to futureoffuels@bsr.org.

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Executive Summary

Any treatment of fuel and sustainability requires consideration of climate change and the dangers it poses to global well-being. Because of these concerns, we have seen an increase in demands for substantial shifts in policy, business practices, and consumer behavior to change our energy mix. At the same time, there is intense pressure to restart economic progress and raise global standards of living—which will mean an increase in our global fuel use. Despite these pressures, there is a dearth of analysis on the total life-cycle impacts and trade-offs of both current and emerging fuel sources to facilitate:

- A systematic integration of longer-term, carbon-reduction objectives with other social, economic, and environmental variables that influence the nature, costs, timing, and impacts of substantial shifts in our energy portfolio
- Near-term improvements that will enhance the benefits and mitigate the adverse impacts of both existing and emerging fuel sources

This paper examines the sustainability impacts of fuels, synthesizing what is known and not known using a value chain (or life-cycle) perspective. It then considers the future market outlook for fuels, and explores some of the factors necessary for major changes and improvements to take place.

Summary of Findings

What We Know About Fuel Impacts	What We Expect About Fuel Markets	What Can Be Done to Advance Fuel Sustainability
1. Our knowledge of the total sustainability impacts of fuels has numerous gaps.	4. Advanced technologies are taking off but still require major investments and policy support to become commercially significant.	7. Scaling up efficiency and best practices in production and consumption is a top shared opportunity area.
2. It is critical that issues be addressed at a systemic level to avoid unintended consequences and/or promotion of solutions that will fail to have desired large-scale impact.	5. Oil will remain a driving force for the foreseeable future.	8. Value chain transparency and collaboration is an area of high innovation potential.
3. Addressing systemic issues requires a long-term perspective that is often at odds with the short-term requirements of business and politics.	6. The greatest certainty is enhanced diversification of fuels used in commercial transportation.	9. Business and government will need to work together more creatively to develop effective long-term energy policy.

The impetus for this paper is a desire by North American corporate purchasers of transportation fuels to improve understanding of fuel sustainability attributes and to identify ways to positively influence both “upstream” and “downstream” energy production and consumption practices.

Two premises underlie this paper. First, fuels have many sustainability impacts that are externalities and therefore are not valued in a commercial sense. Fuel purchasers will make better sustainability decisions only when there is more critical and fact-based analysis of the range of environmental, social, and economic sustainability impacts and benefits of various fuels. While direct climate impacts arguably represent the single most important impact of fuel, truly effective solutions must address sustainability concerns more holistically, from other environmental impacts to the social and economic factors that will help drive—or impede—adoption.

Second, commercial and public policy considerations directly affect the viability of sustainability-related decisions, as well as the deployment of sustainability practices within the transportation fuels sector. Our collective ability to address impacts in a meaningful way will depend on having well-informed policies that balance the numerous trade-offs inherent in any large-scale shift in the energy mix, and that encourage improved sustainability practices among existing and emerging fuel sources alike.

We begin this paper by surveying the current state of knowledge across the breadth of sustainability issues that apply to major transportation fuels (see Appendix 1). A few key themes emerge that deserve special attention:

1. **There are no silver bullets**: If we consider the full range of sustainability issues—social, environmental, and economic—all major fuel types are characterized by a wide array of both positive and negative impacts.
2. **There is significant room to improve our understanding of impacts**: There are numerous opportunities to develop a more robust understanding of the total life-cycle impacts of fuels. For example, while some important general conclusions can be drawn from “traditional” life-cycle analyses focused exclusively on carbon intensity, even these findings/assumptions are not free from controversy and debate. Existing analyses tackling social issues present even greater challenges for integration into a total life-cycle framework.
3. **Local conditions matter**: Many of the most significant impacts of different fuels (from water and land use to socioeconomic impacts) have different implications and consequences based on local conditions, suggesting that the best solutions will vary by region.

In the second section of this paper, we address the market outlook for fuels. Although energy forecasts can be unreliable (witness the unexpected pace of commercial North American shale developments and the changes to global markets these are spurring), a few details seem clear. First, most forecasts confirm that oil will remain a driving force for decades to come, though it will cede share to many other technologies. The extent of that diversification will depend on a number of political, economic, and technological factors that should be applied into any life-cycle analysis. Second, while alternative fuel technologies are taking off, they still require major investment and policy support to become commercially significant.

The expected continuing dominance of oil is an issue that must be tackled directly by those concerned with sustainability, for the following reasons:

1. **While the oil sector has made great strides in sustainability practices, global reliance on oil implies ongoing trade-offs and impacts** that affect the environment and society broadly. Because this resource maintains a dominant share in our energy portfolio, further sustainability-related improvements (ranging from efficiency to carbon sequestration to human rights management) will pay off significantly.

2. **Climate change is a crucial sustainability issue that most experts agree must be addressed more urgently than existing policies, markets, and business incentives currently encourage**. At the same time, shifts in policies and infrastructure intended to arrest climate change can have consequences (social, economic, and environmental) that need to be weighed in the context of their total sustainability impacts.
3. **Oil has many physical, market, policy, and infrastructure advantages that account for its large share of transportation energy supply.** As a result, evaluations of alternative fuel sources aimed at large-scale displacement need to incorporate these factors into sustainability cost/benefit analyses. The economic viability and possible geopolitical benefits of unconventional resources (including options such as natural gas that are promoted as “bridging” fuels based on lower carbon intensity) may slow the transition to non-fossil-fuel-based sources.
4. **Alternative fuels have their own sustainability impacts that must be managed.** The debate over biofuels, both in terms of total life-cycle carbon impacts as well as their impact on livelihoods and land use, offers one example. As the fuel incumbent, oil offers a useful baseline for measuring the merits of alternatives, with regard to the ranges of sustainability impacts and prospects for commercial viability.

This paper intentionally stops short of evaluating specific *solutions* for addressing the sustainability impacts of fuels, which we will cover in our next Future of Fuels paper. However, we do suggest some broad directions. First, a critical shared opportunity area for all players is to scale up efficiency and best practices throughout production and consumption. Second, an area of innovation potential lies in better collaboration among organizations throughout the value chain. And third, there is an urgent need for business and government to work together more creatively to encourage the development of sound long-term energy policies.

Introduction

By 2030, world energy consumption is set to rise by around 40 percent. During this time, the sources and structures of our transportation fuel systems will change radically.

These developments involve contradictions. On one hand, the production of renewable and hyper-efficient energy is rising fast, with wind, solar, and biofuels evolving from nascent technologies just a few years ago to mature and commercially competitive entrants today. On the other, the rapid growth in developing economies, fueled by energy-intensive industries and mobility needs, is driving a quest to uncover the cheapest energy wherever it is found, and often without a full consideration of sustainability impacts.

Energy is both the engine of the modern global economy and one of the biggest drivers of our sustainability challenges, including global climate change. Providing access to affordable sources of energy will be critical to alleviating poverty and ensuring peace and prosperity for the 9 billion people expected to inhabit Earth in 2050. However, if we don't find ways to address the negative sustainability impacts of our energy sources—including many of the newer technologies, from unconventional fossil fuels to fuels and technologies that reduce carbon—these benefits will be undermined.

Throughout the whole system of production, distribution, and use, energy and fuels create a substantial array of environmental, social, and economic impacts, from greenhouse gas (GHG) emissions to economic development.[1] These impacts have direct costs and benefits, which generally do not factor into the market-determined costs that producers bear or the market prices that buyers pay. (Some externalities, such those associated with regulation and "social license to operate," do result in direct costs for companies that seek to mitigate adverse impacts.) These externalities are typically considered to be a type of market failure that leads to costly societal inefficiencies.

As our fuel system expands, diversifies, and evolves, the issues and trade-offs are becoming more complex. A few examples of this complexity can be seen among the more prominent current and emerging fuels:

- While shale gas supplied only 2 percent of U.S. natural gas production in 2000, it accounts for more than 30 percent today. With natural gas offering a 20 to 30 percent reduction in climate impacts over oil, potential geopolitical advantages associated with security of supply, and the promise of economic revival, natural gas development has scaled up hydraulic fracturing activities. The growth has been so rapid that now more than 90 percent of new U.S. onshore oil and gas development uses fracturing in some form, stirring controversy over its possible environmental and social effects.

- The United States has huge reserves of shale oil, an unconventional oil resource that appears closer to rock than liquid in its natural state. Wyoming, Utah, and Colorado host an estimated 1.8 trillion recoverable barrels of shale oil. While these resources have not yet been exploited due to the cost of production, high oil and gas prices place increasing attention on developing them. Yet shale oil's full life-cycle GHG impacts may be about one-quarter to three-quarters greater than that of conventional crude oil, and production demands significant water in very dry environments. Exploitation of these resources will have substantial impacts.

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[1] Energy is the ability of one object to affect another or "to do work" (measured in joules or BTUs), power is the rate of energy over time (measured in watts), and fuel is material with energy stored. This paper typically discusses fuels for transportation, while referring to the wider uses and sources of energy, as well as the energy industry broadly. Also, some technical distinctions are made between energy and power in order to evaluate certain aspects of sustainability impacts and the future market outlook.

- Canada's oil sands help give that country its status as owner of the second-largest petroleum reserves in the world, make it the largest energy supplier to the United States, and support further claims to North American energy stability. These substantial resources, which are typically more difficult to extract than crude oil, require significantly greater energy inputs and land use and create more waste than their conventional crude oil cousins. While very little of the oil sands have been developed, virtually all land available in Canada with access to reserves has been leased (which has implications for future technology deployment as well as cumulative social/environmental impacts).

- The advent of advanced biofuels and electric vehicles represents significant potential for low-carbon, sustainable fuels. Yet in practice they have been associated with a range of potential impacts that can in some cases have even greater adverse impacts than crude oil—such as through deforestation or increased water stress from biofuels, or greater carbon emissions when electric vehicles are charged on grids powered with substantial amounts of coal.

Some impacts are relatively well-understood, such as the comparative life-cycle GHG emissions of different unconventional oil feedstocks (though ongoing technology improvements are mitigating many of the differences between conventional and unconventional resources). Other cases prove more difficult to generalize—for example, the evaluation of whether diesel derived from bio-based feedstocks is more water-intensive than that from petroleum. Still other impacts are not understood at all or are disputed, such as the relative socioeconomic impacts that might result from a large-scale energy project in two different underdeveloped and sensitive regions. Many sustainability impacts have temporal, geographic, and other characteristics, and so it is difficult to classify the significance of impacts without objectively defined criteria and qualifications.

An impact that is obvious to one observer may be invisible to another. Climate policy advocates may see energy through the eyes of GHG emissions but give little thought to the human rights impacts that can and do happen in the exploration and development activities, or to the water needed to irrigate some biofuel feedstocks (typically considered upstream). For people in underdeveloped regions that benefit from employment or other local investments associated with the development or operation of an oil/gas-production facility, climate change may feel like less of an immediate priority. For a family living near a large oil refinery, concerns about carbon may pale in comparison to other air-quality considerations or concerns about accidents near their home.

While direct climate impacts arguably represent the single most important global sustainability impact of a given fuel source, any truly effective set of solutions will need to address sustainability needs more holistically, from other environmental impacts to the social and economic impacts that will help drive—or impede—adoption. At the same time, a key ingredient in a discussion about low-carbon, sustainable fuel is commercialization. There is a growing gap between the world's increasing demand for energy and the known and potential sources of supply (putting pressure on the development of all sources of energy); we cannot expect to improve total life-cycle sustainability impacts without having technologies that provide viable large-scale solutions.

Despite the enormous value at stake, businesses and policymakers lack an underlying system of information to make good decisions about fuels. As a result, while solid science exists for certain aspects of fuel sustainability, there remains a notable lack of collective knowledge when considering the whole life cycle of fuel production. This serves as a barrier to more sustainable energy investments, and the resulting inability to accurately consider the impacts of a fuel's life cycle hinders the capacity of energy producers, buyers, and investors to incorporate sustainability needs when making practical decisions about fuel-related sustainability options or approaches.

THE CHALLENGE FOR BUSINESS

There is recognition that fuel use is particularly important, because both commercial and sustainability impacts associated with this use are growing, and the types of fuel-related decisions companies need to make are becoming more complicated. What follows are key considerations for some of the business groups most concerned about fuel sustainability.

Corporate users of fuel: Companies with large vehicle fleets and logistics networks are finding fuel to be an increasingly important—and complex—aspect of their strategic decision-making and financial performance. Prices are volatile and the landscape of fuel technologies is changing, with new sources of renewable and unconventional fuels, all of which dramatically increases the complexity transportation investment and purchasing decisions.

Meanwhile, these companies are fielding more and more calls from stakeholders to be more communicative and progressive on the sustainability impacts of their various fuel sources. The landscape of energy production is changing all around, and it will only continue to do so; with it, we expect investor and other stakeholder and public scrutiny to grow.

This situation presents a significant challenge. Companies typically have little visibility into the sustainability impacts of fuel prior to purchase. Also, companies cannot easily switch from the use of one fuel to another without also making changes to vehicles and infrastructure, which in turn need to be available and cost-effective. Corporate users of fuel, therefore, need to develop their knowledge and tools for managing the sustainability of fuels more creatively and collaboratively.

Fuel producers and providers: Companies in the business of providing fuel and other mobility energy technologies—including petroleum and biofuels producers, refiners, distributors, manufacturers, and service providers—all have stakes in fuel sustainability. As the energy landscape changes, this diverse group shares common interests. For one, as the system moves inevitably toward more diverse primary energy sources and production technologies, the sector as a whole will benefit from the greater public understanding and trust—and hence regulatory certainty—that can be gained through acknowledging the sustainability challenges that exist all around, and by addressing them with best-in-class practices.

Leading producers have therefore shown a desire to continually raise the bar of sustainability with the aim of preventing the industry from being defined by “lowest common denominator” producers. Corporate customers are beginning to demand better, and more standardized, information across fuel sources. These companies’ suppliers—energy mobility technology providers—are being asked to cooperate with and embrace the goal of sharing more information about impacts. In a similar vein, investors are increasingly interested in transparency, and helping meet their needs is important if companies hope to secure low-cost capital.

All companies in the sector have a stake in better investment conditions and higher profitability. They can promote this through public policy frameworks that both support the certainty needed for longer-term planning and investment, and reduce the frequency and intensity of boom-and-bust cycles.

While companies compete within and across the different mobility energy sectors, there is a case for helping promote frameworks that enable better understanding and accountability for fuel sustainability overall. This requires acknowledging current realities such as the fact that more unconventional energy will be used to meet growing demand, that renewable energy technologies also have sustainability impacts, and that petroleum will remain a sizable (though decreasing) part of our fuel backbone.

Fuel sector investors: Those making investments in fuel sectors need more information to make better decisions based on a comprehensive sense of the risks and opportunities posed by each fuel resource. This includes regulatory risks that might limit the continued use or expansion of fuel technologies as well as regulations that promote long-term certainty and stability.

There is also a reputational market risk that individual companies and entire sectors must face, including constraints that may be placed on an entire market due to the actions of individual companies or sectors. For better or worse, an operational failure in one area can bring reputational damage and strict regulation on an entire sector, and companies pursuing unconventional fuel sources through oil sands production, deep-water oil drilling, and hydraulic fracturing are increasingly in the spotlight.

Fuel sector investors also face country and community risks, including the challenges that may arise if development activity diminishes the socioeconomic viability or community health of an area.

The preceding categories of value chain actors are just a few of the key stakeholders that are interested in fuel sustainability, but certainly not the only ones. Others groups include information and communication technology (ICT) companies, researchers, and civil society, each of which also has an important stake in how this topic evolves.

As the sources of fuel production expand and diversify, all companies involved in energy production are increasingly exposed to activist campaigns, community mobilizations, and policy interventions that can influence their ability to do business. Some actions are relatively well-informed, and others are less so. All sides of the fuel industry have an interest in improving dialogue and developing a common understanding about priorities.

THE OPPORTUNITY

The impetus for this paper is a desire by North American corporate purchasers of transportation fuels to improve understanding of fuel sustainability attributes and to identify effective ways to positively influence both "upstream" and "downstream" energy production and consumption practices.

Transportation fuel is responsible for around a third of all energy consumption, and commercial transportation holds significant leverage to influence future fuel markets and sustainability investments. Additionally, North America is an important axis of unconventional energy, with production of oil sands and shale gas upending traditional pathways, simultaneous with the rapid growth of biofuels and electric vehicles (EVs).

We aim in this paper to strengthen knowledge about the sustainability impacts of commercial fuels and transportation, and to inform the creation of new systems, structures, and forums needed to allow for better information flow between organizations in order to support smarter procurement and production decisions.

This paper has two primary objectives: First, we aim to gather disparate information about sustainability impacts in one place, providing a working collection of information to discuss and debate. Second, we aim to survey sustainability impacts at a time when sustainability science is advancing and both renewable and unconventional energy markets—and campaigns for and against them—are taking off.

This paper will serve as the basis for our second and forthcoming paper, which will consider how companies can use the insights and frameworks contained here to promote greater consideration of sustainability impacts in fuel decisions and practices over time and throughout the life cycle. Among the tactics we will explore are assessing the value and prospects for supply chain traceability, the likely efficacy of voluntary procurement policies, and a variety of collaborative opportunities involving energy producers, governments, civil society, and others across the value chain for promoting better fuels.

This document—and the first phase of Future of Fuels—focuses on a key segment of transportation fuels, defined as follows: First, it encompasses the "end fuels" used for commercial road transportation in the United States and Canada (North America). Additional geographical markets and transport modes (such as air and marine) will be considered in future phases. Second, it addresses supply sources of these resources to the North American road transportation segment and to global markets.

The paper addresses the following fuels:

1. **Gasoline and diesel:** These fuels comprise 90-plus percent of the current road transportation fuels usage in North America. They are typically derived from conventional crude petroleum oil, as well as from unconventional sources such as oil sands, extra heavy oil, and, potentially, oil shale. Appendix 4 provides background on crude oil.
2. **Natural gas:** Natural gas comes as fuel in the form of compressed natural gas (CNG), liquid natural gas (LNG), and liquefied petroleum gas (LPG), and comprises around 4 percent of North American transportation fuel usage. It is derived from natural gas liquids (NGL) including shale gas and tight gas, where there is increasing public attention to the

production practices involved in high-volume and horizontal hydraulic fracturing (fracking). Vehicles that use natural gas can be considered natural gas vehicles (NGVs).

3. **Biofuel:** Biofuels comprise a similar share of usage as natural gas, and is a broad term that refers to several different actual fuels and dozens of plant and other feedstocks. It includes the liquid fuels of ethanol (and its cousins, methanol and butanol), which is derived from carbohydrates and biodiesel-derived lipids. It also includes emergent drop-in liquid fuels that can work in gasoline or diesel engines without major modifications, and which are derived from the same feedstocks above as well as others, including algae. It is worth noting that liquid biofuels may share the same feedstocks as biogas and solid biomass, and may offer alternative transportation fuels in the form of electric power generation for EVs. Appendix 5 provides background on biofuel feedstocks and generation classifications
4. **Electric power:** Electricity is not technically a fuel itself, but a carrier that powers EVs, and more specifically, battery electric vehicles (BEVs), which currently make up less than 1 percent of the market. Electricity is derived from the whole spectrum of feedstocks that fuel an electric power plant, including coal, natural gas, nuclear, and renewable energy sources such as solar and wind power.
5. **Hydrogen:** Also not technically a fuel, hydrogen vehicles make use of a fuel cell that takes in oxygen from the air and hydrogen from a tank and creates a controlled reaction to produce water vapor and electric power. Hydrogen vehicles make up less than 1 percent of the market. The feedstock for hydrogen is typically natural gas, but other fossil fuels can also be used.
6. **Efficiency:** Finally, the savings available in reducing energy use can provide an important source of additional energy. Energy efficiency is sometimes considered the “soft path,” a concept that came of age when it was presented by Amory Lovins in 1976. In this respect, we treat efficiency as a fuel for comparison alongside the others.

Throughout the paper, we use the term fossil fuels and hydrocarbons to refer to the full set of gasoline, diesel, and natural gas feedstocks. We also make the distinction that vehicles with internal combustion engines (ICEs) are those that use hydrocarbons or biofuels, and we therefore include hybrid-electric vehicles (HEVs) such as plug-in hybrids (PHEVs), which are technically high-efficiency ICEs.

In addressing these fuels and systems, we pay the most attention to those that currently play the greatest roles in our fuel transportation system, and which will likely continue to do so in the coming few decades. In particular, we explore hydrocarbon and biofuel technologies in greater depth than those for electric power and hydrogen, though we do conduct a broad survey of the latter.

This paper aims to draw widely from different sources to characterize the state of knowledge about fuel.[2] These sources include scientific and technical studies, of which most address environmental and economic topics; reports and examples based on documented case studies; and expert opinions and inferences drawn by comparing related facts and studies.[3]

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[2] Fuel is part of a bigger picture. We focus on the details of fuel because it has received less than adequate attention. However, a discussion about fuel impacts is inevitably linked to propulsion systems more broadly, as well as the options managers have for vehicle fleets and choices of modes. Because the utility for the fuel purchaser is ultimately expressed in measures such as cost and time efficiency of volumes/weights over distances, the choice of boundaries for anything narrower is problematic. For example, EVs don’t actually consume fuel. We ask the reader to keep this in mind as she or he considers the broader implications of fuel impacts.

[3] Most references are located in the last section of the paper.

Sustainability Impacts of Fuels

One of the primary objectives of this first paper in the Future of Fuels initiative is to develop a framework for understanding the *total value chain* sustainability impact of different fuels. As mentioned earlier, much of the current public discourse on energy is focused on specific issues and energy sources, often dominated by one-sided views from proponents of specific solutions, when what is needed is a clear and comprehensive view of all issues and how they are intertwined.

We believe there are two crucial dimensions to a total value chain understanding of fuels:

1. **Total: "**Total" refers to the need to consider all sustainability impacts—environmental, social, and economic—rather than just greenhouse gases (GHGs) or human rights.
2. **Value chain:** "Value chain" refers to the need to look at organizations and activities throughout the life cycle of fuel products—from exploration and production to distribution and consumption.

Much of the focus to date has been on climate impacts: Liquid fuels are responsible for around one-third of GHG emissions in North America, and there is concern that continued development of and reliance on unconventional resources such as Canadian oil sands and oil shale (currently in commercial production only in Estonia and northeastern China) will continue to drive higher GHG emissions. Similarly, much advocacy for the increased use of biofuels—which dates back to the 1970s—has been reinvigorated by the perceived potential climate benefits of combusting an organic, renewable resource.

Other environmental impacts include those on water, land, and biodiversity, and there have been few serious attempts to connect the dots between these impacts and those of climate change—or to consider potential trade-offs between different environmental issues and impacts across all available and emerging fuels.

Similarly, significant attention has been paid to cases of adverse social and economic impacts from large-scale exploitation of conventional oil and gas resources in developing countries, such as Nigeria. The causes of these impacts are complex, and in these cases companies often point to a lack of adequate governance and infrastructure to ensure positive outcomes for their populations (the so-called "resource curse") as the problem. In these cases, poor governance and institutionalized corruption represent two symptoms of what is understood to be the resource curse. External stakeholders, on the other hand, often emphasize company responsibility for the problem, and this raises public relations, social license, and legal challenges that companies will need to address. However, these cases and the issues they represent tend to be considered in isolation from climate change and other environmental impacts cited above.

This section attempts to organize, at a high level, the full range of known sustainability impacts of different fuels side by side, with the aim of enabling more holistic considerations and decision-making about the sustainability of fuels. As a starting point, Figure 1 provides a summary of the full menu of sustainability impacts that should be considered when evaluating current and emerging fuels.

Figure 1: Summary of Sustainability Impact of Fuels

Types of Sustainability Impacts		
Environment Impacts • GHG emissions • Water quantity • Water quality • Land use • Biodiversity • Ecotoxicity • Spills, blowouts, and explosions	**Societal Impacts** *Human Rights* • ILO Fundamental Human Rights Conventions • Other labor rights • Freedom of movement • Government relations • Indigenous peoples *Labor* • Occupational health and safety • PT/contractor issues • Well-being/livelihood • Training and education • Diversity and equal opportunities • Gender and vulnerable groups	*Society* • Community health and safety • Air quality and amenity • Boomtown effects • Resettlement • Interruption of livelihood • In-migration • Transparency/corruption • Local security • Land use and fair compensation
Economic Growth and Development Impacts • Jobs, revenues, and taxes • Local and rural development • Energy availability and affordability • Energy security • Food and other market impacts • Strategic national development		

Sources: Global Reporting Initiative, GREET, WBCSD, Equitable Origin, IPIECA, BSR, and others. Note that impact categories and types overlap, making this and any single other framework imperfect. Our categorization is based on BSR's experience about what is most understandable to companies given typical organizational divisions of responsibilities.

The types of sustainability impacts from fuels are diverse. They are also typically linked to one another and difficult to distinguish. For example, biofuels generated from soy or palm feedstocks may result in forest conversion, which is a land-use issue, but also generates GHG impacts. Human rights issues overlap with labor and society, and issues involving community livelihoods can arguably be characterized as being either “society” or “economic” issues. As with any analysis of complex issues, this organization is intended to distinguish common attributes among multiple concepts even though the labels inevitably overlap.

Typically, when a company considers sustainability impacts, it focuses on negative aspects (e.g. risks) that require mitigation—something they would do, for example, through defining objective metrics and then addressing the source of the problem. However, the reality with fuels is less clear-cut. What follows are additional dimensions that are especially important for fuels.

Positive impacts: While sustainability impacts are often framed as being negative, they can also be positive. Positive impacts are most clearly visible in the context of economic growth and development, with energy providing the foundation for a broad range of societal activity as well as direct/indirect jobs and business stimulus. Positive impacts can also be seen through the delivery of products (e.g. clean and renewable energy), restoration of habitats, and via the building of capacity, education/health infrastructure, and accountability of local governments. Much of the discussion about fuel impacts will necessarily cover negative impacts (risks), as they are often more concrete, but there should be significant opportunities for discussion of positive impacts as well.

Non-direct impacts: Many impacts result from actions that lead to direct effects. For example, a truck driver traveling 1,000 miles might produce around 1,000 pounds of carbon emissions from direct fuel combustion. However, important impacts also result from non-direct activities, such as from disruptions to communities resettled when making way for oil production, and the emissions of toxic chemicals that can occur when refining crude oil into gasoline. More generally, non-direct impacts include:

- *Indirect impacts:* Impacts from the production of goods in different parts of the value chain (sometimes called “co-product” effects) and economic impacts from goods and services that are essential to the construction of a project (“supplier impacts”).
- *Market-mediated impacts:* Market developments that create sustainability impacts elsewhere. For example, increased biofuel production can lead to expanded croplands that cause emissions from indirect land-use change (ILUC).
- *Induced impacts:* The economic impact of wages and salaries spent on items such as food, housing, transportation, and medical services.
- *Cumulative impacts:* While companies typically think about impacts in terms of their own operations, the cumulative effects of individual actions together can be overwhelming. There are concerns that the pace and scale of oil sands development, for example, will impinge wildlife corridors. In this case, no single company is solely responsible for the impact, yet the problem is real.

Situational impacts: When possible, we express impacts in terms of in an absolute measure. This works when the effect is universal. For example, every ton of land-based carbon dioxide (CO_2) has roughly the same effect on climate change, and worker deaths are human deaths, regardless of where they occur. However, the likelihood and consequences of many sustainability impacts depend on situational factors, including:

- *Location*: In many cases, the same action will have varying effects in different places. For example, water impact is based in part on the water stress of the region, biodiversity impacts depend in part on the sensitivity and value of the ecosystem, and the economic impacts of an investment are defined in some way by the applicability to the country’s industrial strategy. In these cases, it is insufficient to describe the impact without considering local context.
- *Time:* Demand for fuel and energy changes throughout different time periods and in noticeable patterns throughout daily, weekly, and annual cycles. Demand is typically highest during late afternoons and early evenings in the summer, and lowest during fall and spring nights. Throughout these different phases, different feedstocks are used to create power. Typically, this temporal lens is most relevant for power stations that fuel EVs.

Probabilistic impacts: Impacts are ideally described as being linked to specific or proximal sources. For example, burning a gallon of diesel leads to the direct emission of around 22 pounds of CO_2, and producing 100 megawatts of commercial solar energy may lead, for example, to 10 permanent jobs and 10 annual salaries. However, most studies on impacts explain them by showing ranges and averages based on numerous observations. These probabilistic evaluations are imperfect, as they provide limited detail, and, furthermore, technologies can change quickly. This means that even the most rigorous research can investigate activities that lag behind what is current practice. In all cases, it is useful to keep in mind the factors that bear on the likelihood of impacts, including:

- *Policy:* The type or quality of government with jurisdiction over an operation can be a predictor of the kinds of impacts that are likely to occur. For example, the Yale Environmental Performance

Index can provide a useful approximation of relative expected impacts: It shows that fugitive emissions are more likely to be prevalent in a refinery in Russia than a similar one in Norway. Notably, governments with greater safeguards also tend to be more transparent, which means that, in many cases, the greatest impacts and opportunities may be found precisely where information is lacking. However, it is not possible to conclude universally that if a company operates in a country where impacts are more probable (for example, where the government has a track record of human rights abuses) that this by itself leads to greater impacts than if the company decides *not* to operate there. In some cases, a local presence gives companies the opportunity to influence governments and provide higher standards of practice. Furthermore, exiting a country can have unintended negative impacts. Therefore, the impacts of "engagement versus disengagement" must be evaluated on a case-by-case basis.

- *Technology*: Another lens is the type of operating practice employed. For example, while the carbon emissions from oil derived from oil sands may be described by an average figure, we can be more precise if we consider the technology employed. Surface mining of oil sands produces a lower carbon footprint than in-situ extraction, which requires high-temperature steam injection. A challenge with this practice-based lens is that differences are often linked to proprietary technologies that give companies competitive advantages, which means that details are not necessarily publicly available. Additionally, production emission and environmental performance data is generally not available for crude oils produced outside of Organization for Economic Cooperation and Development (OECD) countries. Focusing scrutiny on sources for which data is available thus creates a risk of missing important issues in locations that lack visibility or transparency.

Over the past decade, we have gained a greater understanding of the supply chains of many industries. With transportation fuels, however, even the most progressive downstream companies remain unfamiliar with the mechanics and origins of their fuel supply chains, and end consumers know even less.
A broad range of refining capability exists in North America to process a wide variety of crudes. While processing will differ among refineries, the end products are virtually the same or indistinguishable and fungible. Therefore, with current systems, it is very difficult—nearly impossible—for an end user to know the origins of his or her fuel supply (and therefore what sustainability impacts might have occurred—both positive and negative—along the value chain).

At the heart of this challenge is a lack of good information. While there are a number of scientific studies on environment and health impacts, we do not yet have any rigorous reviews of the impacts of different fuels across all key sustainability issues. The following sections represent a summary of our current, imperfect state of knowledge across the issue categories set out above.[4]

ENVIRONMENTAL IMPACTS

The environmental impacts associated with fuels include those related to climate change, water, land use, and biodiversity. Some of these issues and impacts are global in nature (climate change and some land-use dimensions), while others are best understood and assessed in local contexts (water, biodiversity, and specific land-use impacts). Additionally, we can distinguish between impacts that are an inherent attribute of the fuel resource in question (e.g. oil sands won't flow without washing sand during the steaming of the subsurface), and others that are a function of specific production methods and locations (e.g. production emissions and water impacts). This is important because it shows that it is difficult to make hard and fast judgments about fuel types or feedstocks on their own.

Climate Impacts

The relative climate impacts of fuel, which take the form of greenhouse gas emissions, are among the best understood and quantified of all sustainability impacts of different fuel types. One reason that climate

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[4] Most references are located in the last section of the paper.

impacts are so well-understood is because “a ton is a ton” of emissions anywhere, more or less: Whether the carbon is emitted through tailpipes from gasoline or from the loss of forests in Brazil, the climate impact (taking just the carbon parameter) is the same. Yet impacts can vary greatly depending on feedstock, location, and production practice.

Emissions From Fuel Combustion

The climate impacts of fuels vary substantially between oil, gas, biofuels, and electric feedstocks, as well as within these categories.

For oil and gas, GHG impacts are generated primarily during combustion of the fuel. Because vehicle tailpipes account for 70 to 80 percent of life-cycle emissions and these vehicle emissions are the same regardless of the crude oil from which the gasoline is derived (see Figure 2 below), the consumption phase of liquid fossil fuels is the largest single area of impact. This explains why vehicle energy efficiency has been such a significant target of both government policy and environmental activism.

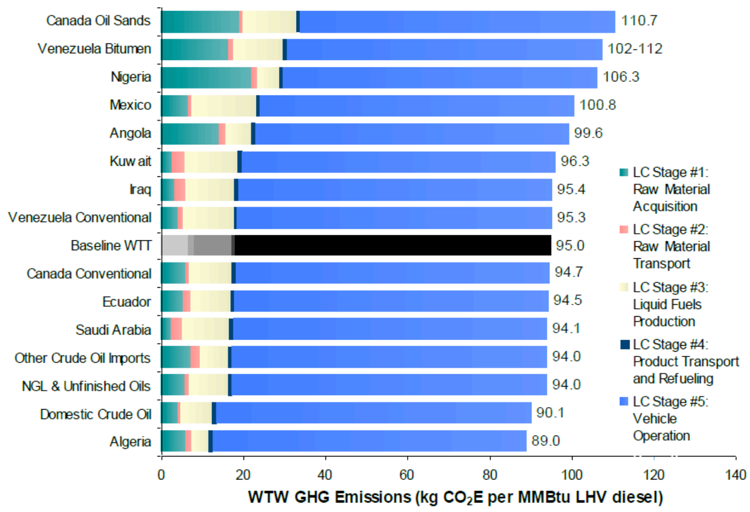
For biofuels, the fuel consumption phase is carbon-neutral because the carbon stored in the feedstock originated from the atmosphere only a short time before. EVs have the potential to produce zero emissions if powered by grids that burn renewable energy, but in practice, the climate impacts of different grids are very mixed. The potential climate benefits of EVs can be offset or potentially even reversed when powered by grids with large coal portfolios.

Arguably the best “fuel” of all for climate impacts is efficiency. Numerous studies have shown that energy efficiency in general presents the greatest carbon reduction per dollar spent. In particular, reduced demand from the point of use has the potential upside of reducing the negative impacts on the climate throughout the value chain system. A similar point holds true across all of the impacts, including economic and societal ones.

Life-Cycle and Market-Mediated Emissions

When considering the wider impacts of fuels, important differences emerge. Oil sands typically have 8 to 37 percent greater life-cycle GHG emissions than conventional oil), while oil shale is 23 to 73 percent greater, and coal-to-liquids (assuming no carbon capture) is around 128 percent greater. The differences among the sources are attributable to processing at the production stage; all have very similar profiles for actual combustion. The specific life-cycle analyses emphasized by civil society groups, as well as those from industry, both show a range of life-cycle GHG emissions performance for various conventional and unconventional sources.

Figure 2: Well-To-Wheels Full Life-Cycle GHG Emissions for Diesel



Source: National Energy Technology Laboratory

In general, fossil fuels derived from the unconventional oil resources of bitumen (from oil sands), extra-heavy oil, and oil shale generally have greater GHG impacts than average conventional sources on a full life-cycle basis, due to the additional energy needed to extract and process these resources.[5]

While oil companies point to continuous improvements in GHG impacts being made at the extraction and refining stages that could potentially narrow the gap between different sources of oil-based fuels (though the extent to which this is possible remains uncertain), technologies to capture emissions from tailpipes are not close to commercialization, though there are some in early stages of development.

Natural gas fuel is 20 to 30 percent less carbon-intensive than gasoline and diesel derived from average conventional oil, and 50 to 60 percent less carbon-intensive than coal in terms of direct climate impacts—meaning that there are relative climate benefits when using gas for transportation (instead of gasoline and diesel), and even more for using it for electric power generation (instead of coal). As a relatively low-carbon source available today, natural gas has been seen as an important bridging fuel to future low-carbon alternatives in power generation. However, there is concern about the need to manage potential methane leakage arising from the rapid development of unconventional (shale) gas in the United States, which could offset some or all of the climate benefits of a shift to natural gas.

Emissions from specific biofuel production processes are relatively low, such as around oil extraction and transesterification to biodiesel. The chief impacts from biofuels are inputs (machinery, fertilizers, and pesticides) and energy needed for other parts of production processes, and from potential land-use change. Compared to oil and gas, biofuels, which may include dozens of potential feedstocks and various production processes (see Appendix 5), have a higher range of potential adverse impacts, from relatively less to relatively more.

GHG impacts vary by feedstock: In the best cases, biofuels produce GHG savings greater than 100 percent over conventional oil, which occur during co-generation activities, such as biomethane derived from manure. More typically, feedstocks may be derived from waste products and result in impacts at 80 percent savings over fossil fuels.

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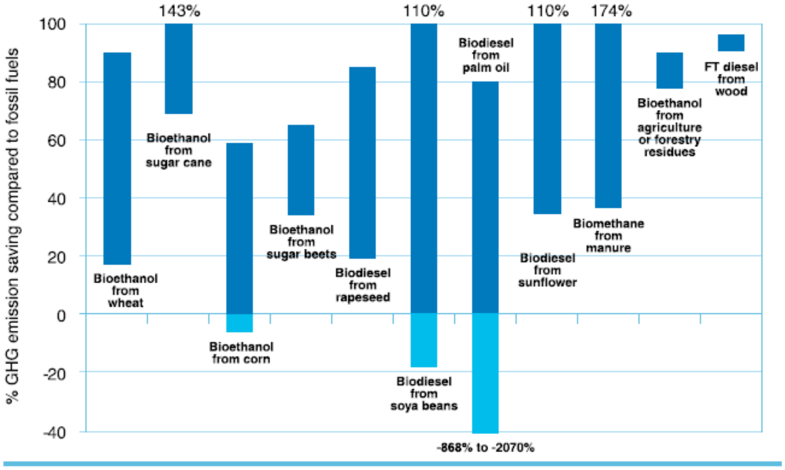
[5] Methodologies are not standardized and data may lag behind actual practices. However, there is general consensus that unconventional resources are more energy-intensive to develop and therefore constitute larger contributors to GHG emissions. This information came from the NRDC, which references underlying data from 2005.

Figure 3: Life-Cycle GHG Gas Savings of Biofuels Compared to Fossil Fuels



Sources: own compilation based on data from Menichetti/Otto 2008 for bioethanol and biodiesel, IFEU (2007) for sugar cane ethanol, and Liska et al. (2009) for corn ethanol; RFA 2008 for biomethane, bioethanol from residues and FT diesel

Source: UNEP

Ethanol from sugarcane can have one of the highest savings (70 to more than 100 percent) among dedicated crops, with rapeseed (canola) in the middle, and corn and soy offering potential savings as well as possible losses.

The greatest negative GHG impacts from biofuels result from methane and N_2O emissions during fermentation of residuals and methane escape from biogas. GHG emissions are far higher when coal, rather than natural gas, is used as the energy source to distill ethanol, and the lowest emissions result when plant residues are used as an energy source (e.g. bagasse from sugarcane).

When looking at biofuels more holistically, though, the greatest emissions result from the indirect effect of deforestation when land is converted into farmland. For example, expansion of sugarcane and crops for biofuels in Brazil will likely focus on the Cerrado region, which represents about 9 percent of the total area of tropical savannas in the world. Two-thirds of the current expansion of palm oil cultivation in Indonesia is based on the conversion of rainforests, in which one quarter of the land features peat soil with high carbon content.

Thus, when comparing fossil fuels to alternatives such as biofuels on a life-cycle basis, the results are mixed depending on choice of feedstock and related land-use impacts and cultivation practices. With current (or first-generation) biofuels production technology, many of the lowest-cost biofuels do not provide life-cycle benefits—some represent marginal improvements over petroleum, while others are actually worse than conventional petroleum fuels. (Furthermore, as we shall see, many feedstocks with attractive carbon-emissions profiles have other problematic impacts). Advanced biofuels currently in the early stages of development could lead to significant GHG benefits if breakthroughs are made, particularly in harnessing cellulose from waste and using algae to produce “drop-in” fuels. On the other hand, many of the concerns about biofuels are precisely about the potential effects that will happen if they reach a large scale.

Water Impacts

Water impacts from fuel are significant and growing, and they concern both water quantity (the contribution to declining freshwater availability) and water quality (the contamination of ground and surface water). The impacts vary across different fuels, and sometimes even more within a given fuel type based on location and production practices. Water impacts from fuel are expected to grow as fuel use itself increases. Also, despite increasing attention to water efficiency, most of the rapidly growing alternatives to conventional oil and gas use greater water per unit of energy produced.

Water Quantity Impacts

While the global population has tripled over the past 60 years, water withdrawals have increased six-fold during the same time period. Energy providers are among the largest industrial consumers of freshwater, with energy accounting for an estimated 40 percent of all freshwater withdrawal in the United States. Biomass fuels, which account for less than 10 percent of total primary energy production, account for almost 90 percent of freshwater used to produce energy.

Impacts on water quantity concern the depletion of water resources, which occur when water is consumed in areas where water availability is relatively low and local demands are high. Importantly, most water withdrawals are not actually consumed, but are returned to their source, such as when used for once-through cooling of power plants. Water consumption, contrasted with total withdrawals, accounts for only 3 percent of the total, and is evaporated or otherwise diverted.

Figure 4: Typical Water Consumption by Select Fuel Type (Gallons per GJ)

Feedstock	Production	Transformation	Fuel
Soy	13,209 – 71,325	4 (biodiesel refining)	Biofuel
Corn	2,377 – 26,417	25 – 65 (ethanol refining)	
Sugar	Minimal		
Conventional oil	13 – 23,775	7 – 17 (oil refining)	Gasoline and diesel
Enhanced oil recovery	18 – 4,755		
Oil sands	70–1,800		
Conventional gas	Minimal	2 (natural gas processing)	Natural gas
Shale gas	10 – 14		
Coal	1- 18	4 – 6 (coal to liquids)	Other liquids
		53 – 198 (thermoelectric power)	Electric
Uranium	45–150		
Oil	(See above)		
Gas			
Hydro	Minimal	1247 (hydro power)	
Solar	Minimal	205 – 257 (concentrated solar power)	
Geo	Minimal	389 (geothermal power)	
Wind	Minimal	Minimal (wind power)	
PV	Minimal	Minimal (solar PV power)	

Source: World Economic Forum

As depicted in Figure 4, the greatest consumption of water per unit of energy produced is with certain types of biofuels, which can use 70 to 400 times more water than other sources. Roughly 45 billion cubic meters of irrigation water were used for biofuels production in 2007, some six times more than all the drinking water used globally. Over 90 percent of biofuels' impacts are related to farming the crops, with most of the rest driven by processing and refining. Very high-yielding crops (e.g. miscanthus) may be water-efficient per unit of biomass, but if widely planted, they require an enormous amount of water. In the United States, irrigation of even a small amount of biofuel feedstock may substantially increase national water consumption for transportation fuels, with disproportionate impact in areas with insufficient rainfall.

Sitting in the middle of the water intensity spectrum is the production of unconventional oil (oil sands and oil shale) and unconventional gas (resources produced with fracking) as well as feedstocks for thermal electric generation and hydropower electric generation, which consumes water through evaporation. For natural gas production that uses fracking, water use typically runs from 2.7 to 3.9 million gallons of freshwater per well, with more water needed to drill and stimulate larger wells.

The lowest general water consumers per unit of energy generated are conventional oil and gas, biofuels that are not typically irrigated, electricity derived from nonthermal renewable sources, and hydrogen derived from methane or electrolysis via nonthermal renewable electricity.

However, volumetric consumption alone does not describe the full impact, as location and competition with other water needs is essential to consider. In particular, while shale gas is not among the highest water users, it is increasingly relevant in the dry U.S. West, where there is fierce competition for resources. More generally, highly consumptive fuel production in a water-plentiful area could be less impactful than less consumptive production in a location where water is scarcer.

Furthermore, while one project might not be a major problem, significant impact can accrue from the cumulative effects of many operations in a relatively small area. Information on water resource depletion for fracking is scant, but the issue is clearly growing in the public mind, with recent news stories about fracking operators competing with farmers at local water rights auctions in Colorado.

Looking ahead, projections show energy growth leading to increases of 85 percent to more than 165 percent of freshwater withdrawal by 2030, given the greater use of biofuels and other more water-intense energy production activities. Additionally, implementation of carbon capture and storage projects, although providing climate benefits, would increase water use to perhaps double that of current levels for electricity generation.

Water Quality Impacts

A second major water concern is impact on the quality of drinking water, freshwater, and other water sources. For example, thermoelectric facilities, which are responsible for 44 percent of water withdrawals in the United States (80-plus percent of U.S. electricity is generated this way), return most of their water to their source. This water can negatively impact local ecosystems when the temperature, chemical makeup, and/or pH is different from the receiving body—even if the water released meets regulatory requirements. Cooling is also required for concentrated solar power. In general, water withdrawals for thermoelectric power generation are poorly documented.

Oil and gas production rely on creating “produced water”—water brought to the surface through hydrocarbon extraction that may contain dissolved salts, metals, and radionuclides—which may create environmental and community impacts if not handled properly. Oil can also have negative impacts when it is spilled. Additionally, there is concern that natural gas produced with fracking has the potential to contaminate existing water sources, with more than 1,000 cases already raised alleging that fracking has resulted in contaminated groundwater supplies.

When mining takes place, such as for bitumen from oil sands, as well as coal and uranium, tailings are created that need to be stored in ponds. If not managed with appropriate safeguards, these tailings can contaminate ground water and aquifers.

Biofuels also have water quality impacts, especially around eutrophication (an excess of nutrients in water, often with negative impacts), nutrient loss, acidification, and groundwater contamination, depending on the feedstock and ecosystem. In the United States, increased production of ethanol is very likely to aggravate existing eutrophication and make it impossible to meet national targets to reduce the size of the Gulf “dead zone.” Organic waste from the sugar cane ethanol system (“vinasse”) can lead to polluted runoff to surface water and contamination of groundwater, with high organic content of the vinasse rapidly consuming oxygen and severely degrading water quality.

An important consideration with water is the likelihood of impact versus the degree. For example, certain biofuels can be generally expected to use certain levels of water when irrigated using certain practices. Oil production, on the other hand, does not lead to spills very often, but when it does, the impact is relatively severe.

Land-Use and Biodiversity Impacts

Land-use and biodiversity impacts are interdependent. For example, land use changes, such as the conversion of rainforests to agriculture, often cause loss of biodiversity. However, one can also occur without the other. In areas where biodiversity value is lower—such in large temperate forests—large-scale land-use change, though an impact in its own right, may not necessarily have a major effect on biodiversity. Similarly, in areas where species are threatened, fuel-production activities can significantly affect biodiversity even though they lead to little change in land use.

While climate impacts tend to be more universally quantifiable and water impacts tend to depend more on the local contexts, impacts on land use and biodiversity take on both constructs. We can usefully group these impacts into two types: (1) impacts that are intrinsic to a given fuel type (absolute impacts)—which include the tendency to displace acreage and create impacts elsewhere, something typically referred to as indirect land-use change (ILUC), and (2) impacts that depend fundamentally on location (we call them place-based impacts).

Absolute Impacts

Fuels create substantial impacts on land use and biodiversity, largely through the production of feedstocks. For some issues, the objective impacts are essentially consistent across the sector, regardless of where production activities take place. The impacts of fossil fuels in this area are driven in part by the large infrastructure requirements and facilities' physical footprints, as well as the risk of spills and/or explosions throughout the fossil fuel value chain—which of course result in harm to ecosystems and communities.

Within fossil fuels, land use and biodiversity impacts are likely to be greater for any resources that require surface mining, such oil sands and, in the case of electricity production, coal. Surface mining requires the removal of trees, peat, and other vegetation that otherwise act as carbon sinks, promote biodiversity, and provide other ecosystem services (in-situ mining, by contrast, requires greater energy and in turn tends to be more GHG-intense). In Canada, this is potentially partly mitigated by a regulatory obligation to reclaim the land to a comparable ecological state and to post a financial reclamation performance guarantee.

Increased biofuel production may have large impacts on biological diversity, as indicated by species richness and estimates of the number of species of plants and animals per unit area. Studies have shown that substantially increased biofuel production would result in habitat loss, increased invasive species, and nutrient pollution. Species and genotypes of grasses suggested as future feedstocks of biofuels may also achieve critical mass as invaders. Intensive fuel cropping, leading to nutrient emissions to water and air, will affect species composition in aquatic and terrestrial systems. The ultimate biodiversity balance mostly depends on the actual land that is converted into biofuels and on the number of years that a particular biofuel crop is grown. The burden depends on several factors, including feedstock used, practice employed, and location of production.

An important measure for evaluating comparative land-use impacts is power density, which explains the physical space needed to produce the different fuels. For fuel, power density shows the rate of energy released from a horizontal area of land or water surface (this is different than energy density, which expresses the amount of energy per unit weight or volume, rather than a rate—more on this in the next section). Figure 5 shows typical power densities of different fuel feedstocks.

Figure 5: Power Densities of Different Fuels (Watts per Square Meter (W/m2)

Fuel source	Typical power density (W/m2)
Natural gas – for electricity	200 – 2,000
Coal	100 – 1,000
Nuclear (South Texas Project)	56
Marginal natural gas well (60,000 cu feet / day)	28
Marginal oil well (10 barrels / day)	27
Solar electric power	4-10
Wind electric power	0.5 – 1.5
Biomass for electric power	0.5 – 0.6
Sugarcane for ethanol	0.29
Corn for ethanol	0.05

Source: Robert Bryce, Andrew Ferguson, Vaclav Smil

Fossil fuels naturally have higher power densities, and therefore fewer land area requirements, because they are based on concentrated stores of ancient photosynthetic production buried beneath the ground. As a result, making large-scale use of presently available biofuels or solar and wind renewable power generation would require much greater area—10 to a thousand times larger than today's infrastructure of fossil fuel extraction, combustion and electricity generation. This is essentially what has led some to assert that oil is in fact "greener" than alternatives that might replace it.

Land use is thus a limiting factor for biofuels, which, as Figure 5 shows, are characterized by relatively low power density compared to fossil fuels, especially when produced for liquid ethanol, methanol, butanol, and biodiesel. For such production, substantially greater land is required to create the same energy in a gallon of fuel, even in the best cases. This is problematic because it leads to land use change, causing biodiversity loss (and climate impacts, covered previously) as well as competition with food and possibly materials (covered in greater detail in the economic impacts section).

Because of the low power density of dedicated crops for biofuels, even those with potential GHG benefits such as sugarcane are caught in a catch-22—they risk encroaching on forests and other biodiverse areas, or alternatively, competing with food supplies. (One estimate shows that if cropland is used for biofuel production, the area required could account for 8 to 36 percent of the world's current arable land.)There have been proposals to use marginalized and abandoned land for such purposes, but available land needs to be evaluated against all of its potential uses, and there is little evidence that this is a large-scale panacea.

In some cases, second-generation biofuels (derived from waste, grass, wood, and algae) have much less negative impact than first-generation fuels derived from corn, sugarcane, waste oil, soy, palm, rape/canola, or jatropha. However, many dedicated energy crops, including those for cellulosic feedstocks, can displace food and cause substantial ILUC emissions.

Attaining the lightest land-use impact with current biofuels calls for using wastes, whether from food crops (e.g. distiller grains, sugarcane bagasse, wheat straw) or non-food feedstocks (wood chips and other agricultural, industrial, and municipal waste), where the biofuel is a co-product. Moreover, there are signs that using biomass for the production of electric power generation or biogas (which can be either compressed for direct transportation fuel or used for power generation) are more productive uses of the feedstock.

Some of the advanced biofuel technologies that are currently in the early stages of development may alleviate land impacts by creating drop-in fuels (e.g. they can be used in today's internal combustion engines with little or no modification), processing familiar waste feedstocks more efficiently, or are based on algae, fungi, and bacteria.

An additional intrinsic impact occurs in operations around marine and coastal ecosystems. Coasts can be particularly sensitive and both coastal and marina environments can be very remote, making remediation efforts difficult. Currently, offshore oil and gas operations exert the greatest impact in these environments through spills and waste treatment, though advanced biofuels (e.g. seaweed cultivation) and electric power generation (e.g. wind) are becoming more common.

Finally, biofuels may change the geographical distribution of the environmental burden of feedstock production within a country or a region, across borders, and also from developed countries to developing countries. The extent to which the co-products of biofuel production displace other products and their environmental impacts, rather than stimulate additional consumption, depends on the elasticity of demand in the relevant markets: The more inelastic the demand, the greater the substitution. Other factors include the way in which the co-products affect supply curves, and political and regulatory issues.

Location-Based Impacts

As discussed previously, many impacts do not affect all locations the same way. Fossil fuel-related spills and other accidents are especially problematic when they occur at sites that are heavily populated, or conversely at sites that are particularly remote or deep underwater (and thus difficult to respond to), in ecosystems that are considered pristine or otherwise highly fragile or valuable, and/or near border areas where political or cultural factors make cooperation on emergency response and cleanup efforts difficult. Starting with the countries of the greatest significance for fuel production (see Appendix 3), we can apply broadly accepted tools for evaluating impacts from energy production in the ecosystems of known importance and sensitivity.

One tool for understanding sensitivity is the World Wildlife Fund's (WWF) list of 238 global "eco-regions," which are terrestrial, marine, and freshwater ecosystems known for having the most important global biodiversity value.[6]

Of WWF's vital eco-regions, 127 are found in the countries of significance for fuel as defined by this report, and 33 have been identified as directly threatened by activities related to energy production (see Figure 6—and also Appendix 6 for more detail).[7] These eco-regions are threatened primarily by production of petroleum oil, while palm oil (as a potential biofuel feedstock) represents the major threat in Indonesia and Malaysia specifically.

Place-based assessments will be enhanced with greater research and technology to allow more granular comparisons by site and ecosystem over time. There are many such efforts under development.

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[6] Note that the International Union for Conservation of Nature (IUCN) is developing a framework for evaluating ecosystems more broadly (i.e. not just in terms of biodiversity).

[7] Although these are areas where energy production creates specific impacts, they are not the only region. For example, the Orinoco eco-region in South America and several in the Arctic are vulnerable to industrial production in general.

Figure 6: Biodiversity Impacts by Ecosystem

Region	Country	Eco-Regions	Eco-Regions With Energy Threats*	Energy Threat Type
North America	Canada, Mexico, United States,	45	9	O&G exploration, development, production
South America	Brazil, Colombia, Ecuador, Venezuela,	24	5	Land-use change for biofuels production; O&G exploration, development, production, and distribution infrastructure
Europe	Netherlands, Norway, Russia, United Kingdom	21	10	O&G exploration, development, production, and distribution infrastructure
Asia	Indonesia, Malaysia	22	6	Deforestation and land-use change for biofuels production (palm oil); O&G production and spillage
Africa	Algeria, Angola, Nigeria,	15	2	O&G exploration, development, production, and spillage
Middle East	Iran, Iraq, Kuwait, Qatar, Saudi Arabia, UAE	6	3	O&G exploration, development, production, and distribution infrastructure
Caspian**	Azerbaijan, Kazakhstan, Russia	3	-	-
Arctic**	Canada, Russia, United States, Norway, Sweden, Finland	11	1	O&G exploration, development, production

**Does not imply that these are the only regions affected by energy*
***Overlaps with other regions.*

One region not understood well is the Arctic (home to 11 eco-regions), where exploration is growing rapidly as melting sea ice makes coasts and waterways more accessible. In addition to the environmental and social vulnerability of the region, it is also remote—making mitigation and cleanup operations difficult—and there is concern about the heritage and symbolism of keeping this area pristine. Nonetheless, decisions to develop potential energy resources in the Arctic region in support of global demand will need to consider sustainability impacts, regulatory needs, and mitigation requirements.

Another region marked by uncertainty is the oil sands region in Alberta, with two issues of concern. The first concern is that while energy companies are taking part in environmental remediation efforts, the long-term effects on biodiversity and landscapes are not well-understood, making the effect of such activities unclear. Also, there are potentially significant impacts around ocean, coastal zone impact, air transition, and linear transmission if pipelines were to expand to seaport terminals.

The second oil-sands-related issue is represented by the system as a whole: This area can collectively be considered one of the largest construction projects in the world. While the impacts of individual companies' operations can be reasonably well-understood and potentially contained, the scale of physical development in the region as a whole is unprecedented. Of particular concern is the impact on caribou and the general ecological health of the region.

Only around 18 percent of Canadian oil sands land is available for mining activities. For the remaining 82 percent, the technology known as in-situ production, which is less intrusive than mining, applies. However, in-situ production can also subject extensive areas of land to lower levels of activities that can create cumulative effects, so that despite any one company's best efforts, the ecosystem may be overwhelmed by a network of companies.

Cumulative effects are not limited to oil sands. They concern other energy technologies where extensive physical networks are developed, such as with Pennsylvania's shale gas development and North Dakota's shale oil development. Large concentrations of wind farms may also create cumulative effects that need to be better understood.

SOCIETAL IMPACTS

Human rights, labor, and other societal impacts occur through all different stages of the value chains of the different transportation fuels. These issues are typically absent from life-cycle assessment studies, even though they are highly relevant as they cause noticeable costs and benefits. While these parameters are more site-specific and situational, it is not impossible to include them in robust analyses.

In the sections that follow, the majority of impacts discussed are negative. Positive impacts, particularly those associated with local economic growth and development, have been separated into the subsequent section.

Health Impacts

The impacts of fuel on human health are diverse and can be severe. Fuel has been linked to an assortment of ailments in workers and communities that include asthma, respiratory and cardiovascular illnesses, autoimmune diseases, liver failure, cancer, and other ailments for industry workers and communities living near major fuel facilities.

There are often greater health impacts in non-OECD regions, as OECD countries have comprehensive laws and regulations that control air pollutants, or criteria air contaminants (CACs), as well as construction codes and safety and health controls.

Hydrocarbon resources contain compounds that are carcinogenic, toxic, and irritating—in particular, the volatile organic compounds of benzene, toluene, ethyl benzene, and xylene (collectively known as "BTEX"), and the poisonous gasses of hydrogen sulfide and sulfur dioxide. Workers and nearby communities may be exposed to these compounds during general production operations and from venting, flaring, the creation of pits and ponds, blowouts, and fugitive emissions. Construction and maintenance of production sites typically involves vehicle traffic and motors that release pollutants such as ozone, carbon monoxide, dust, and particulate matter, which are harmful to the respiratory system. Notably, the World Health Organization has recently classified diesel exhaust as carcinogenic; workers can receive intense exposure to diesel exhaust from drilling, completion, and work-over trucks, rigs, and equipment such as pumps typically run off of diesel-powered or gasoline engines.

When oil sands are mined, production typically involves the creation of tailings ponds that store wastewater. Although strict safety measures are typically used, they may contain dangerous compounds including arsenic, ammonia, benzene, cyanide, phenols, toluene, polycyclic aromatic hydrocarbons, arsenic, copper, sulphate, and chloride. Stakeholders have expressed concerns that these compounds may be linked to abnormally high rates of cancer in neighboring communities, though studies are ongoing. There are also concerns that, whether or not there have been historical problems, the consequences of leaks or bursts in the future—even if the likelihood is small—could be catastrophic. A particular concern about tailing ponds is that security and safety are likely to become more lax when mines are shut down and no longer maintained.

There are also special concerns about the production of tight natural gas, which involves hydraulic fracturing that may lead to contamination of aquifers and air pollution, and possibly earthquakes. There are two potential sources of contamination. The first is the stimulation chemicals used for fracking, which include acids, corrosion inhibitors, surfactants, biocides, organo-metallic cross-linkers, and solvents. The second is seepage of carcinogenic or otherwise harmful contaminants such as methane that leaks from improperly completed wells into shallow groundwater aquifers. The actual health risks of fracking remain poorly understood, and the chemicals and processes used in North America are generally not regulated. The U.S. Environmental Protection Agency is undergoing a comprehensive study that is expected to shed light on the health impacts of fracking.

There are also health impacts linked to biofuel production. Ammonia associated with nitrogen fertilizers can be volatized in the air, attract fine dust particles, and form particles that cause respiratory impacts for workers and nearby communities.

One of the largest sources of air pollution from biofuel production comes from the practice of burning sugarcane before harvest. The resulting smoke, fine particles, and nitrogen gases in the atmosphere cause acid rain and contribute to a variety of human health impacts. Summer smog potential is particularly high for the tropical biofuels because cropland is often created with slash-and-burn techniques, or dry leaves are burnt before harvesting.

Additionally, the oil seed plant of jatropha is poisonous, containing a neurotoxin and causing adverse effects on humans and animals that come into contact with it. Accidental consumption of seeds by children is well-documented, and there is concern that increased cultivation of jatropha and utilization of its agro-industrial by-products may raise the frequency of dangerous contact.

Oil and gas refineries can be the source of substantial impacts around safety and health. As with production operations, refinery operations may expose workers and community members to various emissions and leaks through general operations as well as venting, flaring, explosions, and fugitive emissions. Toxic chemicals and gases that refineries produce include sulfur dioxide, sulfuric acid, nickel and cobalt compounds, ammonia, chlorine, chromium compounds, benzene, hydrochloric acid, lead, mercury, hydrogen fluoride, methanol, phenanthrene, and phenol.

Studies have found elevated levels of harmful pollutants and particulates in communities near refineries, and linked such communities to greater incidences of respiratory, cardiovascular problems, cancer, asthma, and premature death. Additionally, refineries have typically been associated with environmental justice concerns, where those affected tend to be from minority and poorer classes. Notably, however, health impacts vary significantly by jurisdiction, and emissions are highly regulated in OECD countries.

Oil sands production involves a pre-refining step called upgrading that converts heavy bitumen resources into petroleum derivatives and removes nitrogen, sulfur, and other elements to create a form of crude oil. The processing of these lower-grade, or more difficult-to-extract, resources can occur at the production site or refinery, and involves physical and chemical processes that produce significant byproducts, including the emissions of sulfur dioxide, sulfates, and metals. There are concerns that workers and communities near upgrading facilities are exposed to elevated levels of toxic metals, sulfur, nickel, nitrogen, lead, and other harmful chemicals as compared with conventional crude oil. However, a 2010 study found little or no pattern to the changes in concentrations of various air pollutants across the oil sands region over the past 10 years, showing that recent development has not necessarily had negative impacts in practice

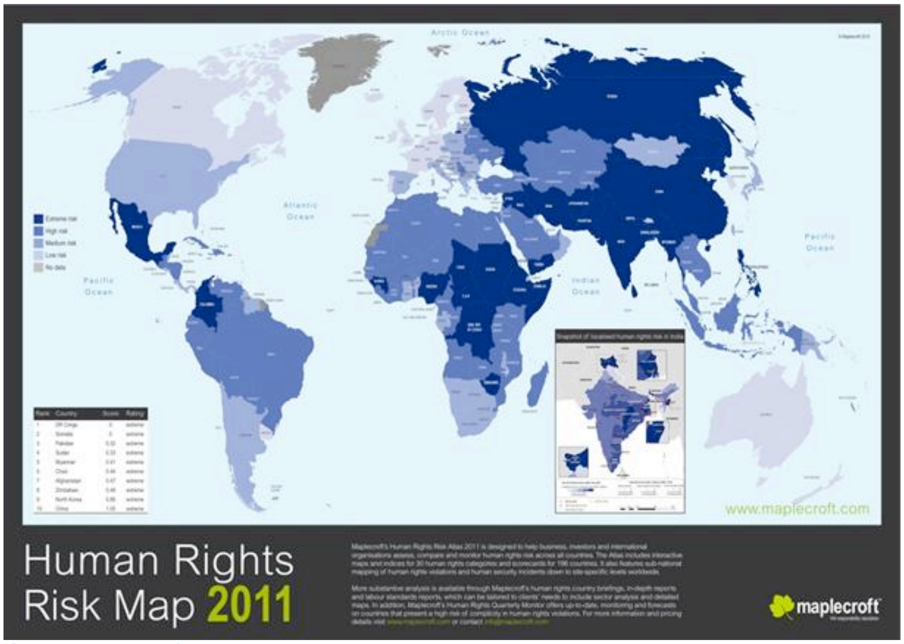
There is also concern that, even if the refinery is not upgrading oil sands, it is still more likely than other refineries to generate higher levels of sulfur dioxide air pollution when using bitumen blends as feedstock, as they have very high sulfur content.

Human Rights Impacts

For the purposes of this paper, human rights related to the production of fossil fuels include protections guaranteed under the International Labor Organization (ILO) conventions: prohibition of child labor and forced labor, antidiscrimination measures, freedom of association, just and favorable working conditions, adequate standards of living, freedom of movement, and indigenous people’s rights. These rights are generally much less secure in the countries of medium or high concern (as noted later in Figure 10) than they are in low-concern countries, including the United States and Canada. In addition to the ILO's Fundamental Human Rights Conventions, the UN Guiding Principles on Business and Human Rights (UN Guiding Principles) also provide guidance on key issues.

A heat map of human rights risk areas is shown in Figure 7 below, with high-risk countries extending throughout the Indian subcontinent, Southeast Asia, Eurasia, Mexico, South America, and a significant portion of Africa.

Figure 7: Sample Heat Map of Human Rights Risk Areas



Source: Maplecroft

One set of issues that transcends generally high-risk areas is that of indigenous peoples' rights, which has been cited as an area of significant concern across all producing regions. For example, even in Canada, which is low-risk from a human rights perspective, the Canadian oil sands are found within the historical homelands of a large number of First Nations communities. There are numerous government and corporate requirements for companies to engage with First Nations both prior to and during the construction and operation of an oil sands project, but some of these forums have been criticized as ineffective and not supporting true consultation.[8] Company efforts to engage and promote local benefits (discussed in next section) are also important activities in respecting and advancing human rights among individual communities.

Biofuels projects are vulnerable to the same human rights challenges faced by the food/agricultural sector broadly (e.g. treatment of labor and workers). The exploitation sometimes includes unlawful child labor and migrant workers. Additionally, land-use conflicts, rising food prices, and tension with traditional livelihoods are other important factors that have the potential to foment human rights challenges (for example with palm oil, which can be used for biodiesel production). As is the case with petroleum, the human rights impacts of biofuels production also differ according to the country in which resources are cultivated. Risk is generally greater in countries of higher concern due to questions about (1) land allocation and fair compensation for farmland, (2) use of arable farmland for fuel that could be used for food production, (3) labor issues on biofuels farms, (4) water access and excessive draw-down, and (5) cultural rights and sacred sites for indigenous populations.

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[8] Both Canada and the United States signed the UN Declaration on the Rights of Ingenious Peoples (DRIP), which includes a reference to "free, prior, informed consent" (FPIC) and which applies to all energy development adjacent to and on First Nation and Aboriginal lands.

Large-scale energy production projects often are vulnerable to two general areas of human rights impacts. The first is access to natural resource use and traditional livelihoods, which includes land, mobility, water (groundwater, river, and ocean), mineral resources (artisanal and small-scale mining), cultural heritage, forest resources, and post-project land use. The second is human rights and security, which includes abuses by security personnel (whether government, contractor, or company) in protecting assets, social disorder in camps, suppression of demonstrations, and targeting of activists.

Labor Impacts

The energy industry involves literally millions of businesses, many of them small contractors and services companies. The ILO estimates that nearly half of all workers in the energy industry are employed in small- and medium-sized enterprises, with contract workers often working in harsh working conditions.

The nature and quality of work goes far beyond simply providing income: Work is central to peoples' general well-being, providing a route to social and economic advancement and in turn strengthening individuals, their families, and communities. Such progress, however, requires that work is decent and creates potential for people to realize their aspirations.

Labor impacts are often related to human rights (as, for example, with the ILO Fundamental Human Rights Conventions), and also include the following focus areas:

- Health and safety at work
- Protection of part time/contract workers' issues
- Well-being, livelihood, and family-friendly policies or initiatives
- Vocational education and training (VET)
- Diversity and equal opportunity
- Gender and vulnerable groups

Large-scale energy-production projects can be major sources of concern when it comes to labor impacts. In such projects, there are two main impact areas. The first is general labor, which includes health and safety, working conditions, remuneration, right to assemble, representation in unions, and labor force participation for women. These conditions may be improved or worsened depending on the local situation and company practices. The second is gender and vulnerable groups, which includes risk of disproportionate impacts on and marginalization of vulnerable groups (e.g. women, disabled, aged, ethnic minorities, indigenous, and young), and equity in participation and employment.

Some limited generalizations can be made about comparative impacts. On the one hand, oil production and refining jobs will tend to pay better and create more training opportunities than similar jobs in biofuel production, even where there is lax regulation and oversight. On the other hand, biofuel jobs appear more plentiful and likely to filter down to the very poorest, per unit of fuel produced.

Certain direct labor impacts are more significant with large-scale fossil fuel projects than with biofuels and other renewables, as the construction phase generally stimulates a local supply chain, and employs a large contractor workforce as well as significant numbers of direct employees. While these can bring positive economic effects, the sudden influx of people and activities can overwhelm monitoring systems and local management capacity.

Other labor impacts, notably those connected with child labor, are more likely to occur with biofuels. As an agricultural feedstock, biofuel is unique among fuels in its potential for large-scale child-labor impacts. Globally, around 70 percent of the 132 million working children (there are 300,000 to 800,000 in the United States) are found in agricultural production. Agricultural work that includes biofuels can expose children to many threats, including working long hours in heat, hauling heavy loads, the risk of contamination from harmful pesticides, and the risk of injury from sharp knives and other dangerous tools and equipment. In agriculture generally, child workers have been forced to work without the most basic sanitation requirements, including access to toilet facilities, hand-washing facilities, and adequate drinking water, which increases the chances of pesticide poisoning, bacterial infections, dehydration, and heat illness.

Most of the relative impacts are a function of the policies and practices in the country of production, with countries of medium or high concern presenting far greater risk than in those of low concern.

While these generalizations offer clues, the labor impacts of fuels production vary tremendously across fuel types, individual companies or operators, and country or region, making it difficult to draw strong conclusions about the relative labor impacts of different fuel types.

Community and Other Societal Impacts

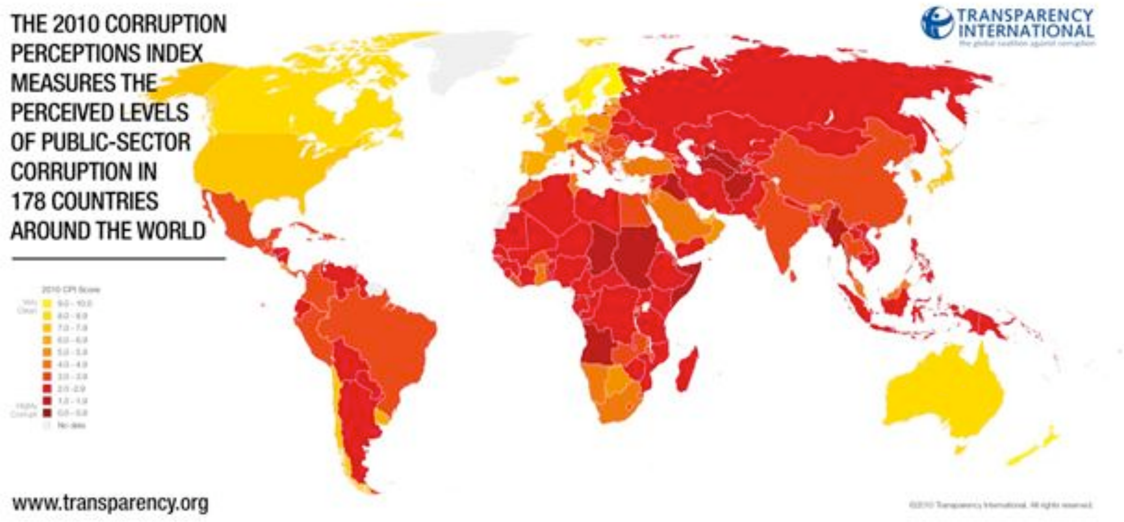
Community impacts, like labor impacts, tend to be most problematic in the pre-construction and construction phases of fossil fuel development. As mentioned earlier, the project cycle of fossil fuel development includes the sudden creation of sizable new infrastructure, leading to a large environmental and social footprint. Also, fossil fuel exploration and production is by nature high-stakes, which often leads to real and/or perceived problems with corruption related to the process of discovery, declaration, permitting, benefit sharing, revenue distribution, and planning. Specific social issues may include the following for both fossil fuels and biofuels:

- Boomtown effects: physical investment, services and raw materials required, spin-off effects on real estate, wages, etc.
- Resettlement: displacement due to project activities sanctioned by government
- Local environmental/health impacts (fossil fuels and biofuels): water, dust, air pollution, noise, scenic amenity, vibration, radiation, traffic
- Interruption of livelihood (fossil fuels and biofuels): traditional fishing, agriculture
- In-migration: populations, often with limited skills, seeking economic opportunity
- Transparency/corruption: at local, regional, and possibly national levels
- Land use (fossil fuels and biofuels) and fair compensation
- Impacts on food prices (biofuels)
- Government capacity to monitor and regulate

The above factors are generally the result of a significant and sudden influx of human activity (by expatriate employees, in-migrants seeking employment opportunities, and large-scale local or international contractors). Construction projects can result in boomtown effects—where short-term benefits in the form of jobs, housing, and infrastructure are not sustainable once the construction period ends and the project commences its much smaller-scale operations phase. The project life cycle, therefore, can place considerable strain on local social relationships and public services as well as company safety, employment, and procurement requirements.

The challenges noted above are obviously more acute in less developed countries, with weaker political institutions and narrower economic opportunities, than those enjoyed in countries such as Norway, Canada, and the United States. As with human rights above, Figure 8 provides Transparency International's assessment of risk areas associated with high degrees of corruption—there is a noticeable correlation with the human rights risk profile for many of the countries.

Figure 8: Corruption Perception Index



Source: Transparency International

In summary, it appears that fuels produced in countries of low concern such as Norway, Canada, the United States, and others represent better current human rights, labor, and social impacts than those produced in countries of higher concern.

However, there has also been recent upheaval in developed economies, notably the Alberta oil sands in Canada, the boom towns in the Bakken shale oil areas of the United States, and also with tight gas operations in Western Colorado.

Many contended that fossil fuels perpetuate a resource curse, where oil development booms, creating the illusion of prosperity and development while actually destabilizing regimes. Evidence is given by the examples of Venezuela, Iran, Nigeria, Algeria, and Indonesia, all of which chose a common development path that reinforces oil-based interests and weakens state capacity—with consistently disappointing outcomes. However, the causes and consequences are complex, and it is difficult to say that fossil fuel production leads to net negative impacts. Indeed, many others will argue that other countries have had different experiences and that further engagement and investment in these problematic countries is precisely what is needed.

Figure 9 summarizes impacts associated with large-scale oil, gas, and mining developments, with some aspects applicable to large-scale biofuels projects. Note that projects vary in terms of scope and impacts.

Figure 9: Summary of Community and Other Societal Impacts of Large-Scale Energy Projects

Community and Other Societal Impacts	
Population, demographics, and social order	In-migration, out-migration, workers' camps, social inclusion or exclusion, growth or decline of towns, pace of change for vulnerable communities, conflict and tensions between social groups. These factors may result in corruption, domestic violence, sexual violence, substance abuse and trafficking, prostitution, and change in social norms.
Social infrastructure and services	Less-developed areas may see project-related benefits and investment in housing, skills development (shortages and staff retention), childcare, health, education, and training. Alternatively, poor conditions may be perpetuated by absence of government, corruption, and/or substandard company practices.
Culture and customs	Change in traditional family roles, changing production and employment base, effect of cash economy, reduced and/or increased participation in civil society, community cohesion, sense of place, community leadership, cultural heritage.
Community health and safety	Disease, vehicle accidents, spills, alcohol and substance abuse, pollution, interruption to traditional food supply, awareness and treatment programs. Benefits may emerge from a company's focus and awareness-raising on health and safety as well as social investment programs.
Distribution of benefits, corruption	Family groups, cash economy, benefit-sharing agreements, corruption (or transparency improvements); substantial tax or royalty revenues.
Local market fundamentals	Housing (ownership and rents), wages, food, access to social services, food price impacts from biofuels.
Resettlement	Consent and consultation for resettlement, compensation, ties to land, adequacy of resettlement housing/facilities, equity, post-settlement conditions, livelihoods.
Disturbance	Disruption to economic and social activities (including by exploration), consultation for land access, frequency and timing, compensation.
Community engagement	Consultation, communication, participation, empowerment, access to decision makers, transparency, timing, inclusiveness—particularly for vulnerable and marginalized groups—respect of customs and authority structures, reporting.
Consent and participation	Indigenous sovereignty and title (free, prior, and informed consent), community consent, planning, development of programs, monitoring, selection of alternatives and technologies, operational aspects.
Remedy	Grievance and dispute resolution, acknowledgment of issues, compensation, mitigation.

Source: Franks

As is true in the case of some environmental issues, the production of fossil fuels generally involves a greater intensity of activity and therefore more concentrated social impacts in a given production area than biofuels (although biofuels may suffer from a broader range of specific types of issues such as child labor). Fossil fuel developments are also substantially more prevalent, rendering impacts much more obvious. Fossil fuels, and particularly oil, often have a strong material impact, in the form of tax revenues and economic benefits, on the local or even national economy in the producing country or region, with greater resulting impacts on political practices and social conditions.

On the other hand, in some developing country locations, the production of biofuels is accomplished by replacing subsistence agriculture—which keeps many people employed—with very large mechanized farming operations that require much less labor and thereby have a negative impact on the community.

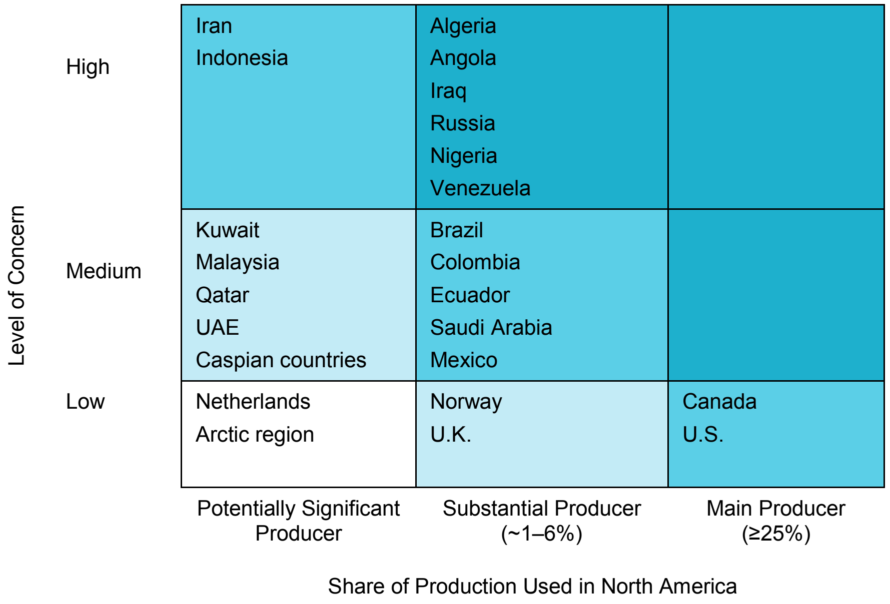
As in the case of environmental impacts, however, the relative human rights, labor, and social impacts of extraction and production often depend on the country/region in which they take place.. Just as environmental impacts are best understood in the context of local ecosystems, human rights, labor, and social impacts are best evaluated in the context of local political, social, and economic conditions—i.e. at the country level (and often at the asset or community level). This point is strengthened by the fact that a significant number of the "traditional" countries that are rich in conventional fossil fuels are located in conflict zones and/or are governed by authoritarian, repressive, or simply weak regimes in which rule of law is underdeveloped and mechanisms for promoting equitable social, political, and economic relations are weak or nonexistent.

One potentially negative impact is population displacement through the resettling of communities that may have occurred during the development of oil and gas projects (as well as other infrastructure projects). Displacement includes involuntary resettlement organized by governments to make way for a project, as well as displacement driven by conflict, worsening environmental conditions, and disasters. Nigeria, Sudan, Ecuador, Colombia, and Burma provide examples of displacement and resettlement. This issue starkly illustrates, as one recent report stated, the asymmetric power relationship between transnational capital and the populations of developing countries, in particular indigenous peoples.

Another negative impact is the effect of oil spills and potential oil spills on economic livelihoods. Oil spills occur when an oil rig is damaged (e.g. Deepwater Horizon in the Gulf of Mexico, 2010), tanker ships collide or ground (e.g. Exxon Valdez in Alaska, 1989), a pipeline breaks (e.g. Enbridge oil sands pipeline in Michigan, 2010), or storage tanks leak. There have been more than 1,000 large oil spills to date—38 involving supertankers. The impacts of spills are extensive: The Deepwater Horizon spill has accrued well over US$20 billion in direct cleanup expenses, and the impacts go much further, including lost direct sales and GDP (especially through tourism and fishing), reduced supply and spiking of prices for locally harvested food products, diminishment of labor forces, property values, habitats, coastal landscapes, reputation of travel destinations, and costs associated with death, injuries, and illnesses.

Figure 10 illustrates one framework for assessing the relative risks and impacts of production in different countries based on expert third-party opinion and BSR's extensive fieldwork with energy companies and their stakeholders.

Figure 10: Relative Risk of Human Rights, Labor, and Social Impacts by Country



Level of Concern	Potentially Significant Producer	Substantial Producer (~1–6%)	Main Producer (≥25%)
High	Iran Indonesia	Algeria Angola Iraq Russia Nigeria Venezuela	
Medium	Kuwait Malaysia Qatar UAE Caspian countries	Brazil Colombia Ecuador Saudi Arabia Mexico	
Low	Netherlands Arctic region	Norway U.K.	Canada U.S.

Share of Production Used in North America

Source: Percentage figures are based on composite BSR score using estimates. Scores themselves are based on BSR opinion. Additional sources to consider are Rents to Riches (World Bank), Failed States Index (The Fund For Peace), Corruption Perceptions Index (Transparency International), and EITI Compliant Countries (Extractive Industry Transparency Initiative).

However, as discussed in the introduction, just because a country is rated "high" in terms of relative concern, it does not necessarily mean that producers or purchasers should cease operations there. In some cases, developing or maintaining a presence in such countries can allow the company to influence policy, standards, and practices in that region for the better, while providing positive economic and other benefits for citizens.

ECONOMIC IMPACTS

The economic impacts of fuel production and consumption are often left out of discussions on sustainability. Yet economic factors are at the core: It is the pursuit of economic benefit that leads private companies to produce energy in the first place, and their economic actions produce benefits that can potentially lead societies to improve their environmental and social contexts.

The economic impacts of fuel have been explored extensively, though often from the standpoint of advocating a technology or project, rather than describing comparative impacts across fuels. It is difficult to find comprehensive, objective studies across different fuel types. Existing studies tend to address a narrow range of parameters, such as job creation, even as they note that these direct national or local impacts tend to be dwarfed by the broader indirect impacts of global affordable and reliable energy, regardless of fuel source. The politics of economic growth and development also create challenges to conducting objective analyses—whether reviewing the promise of green jobs in the industry or advocating for greater access to oil- and gas-drilling opportunities.

The economic growth and development impacts of fuels represent a complex topic with many constituent factors. Figure 11 provides an illustrative list along a spectrum of more versus less direct impacts. However, even with good data, it is difficult to compare the impacts of two fuel-production activities (e.g. corn production in Iowa versus crude oil production from the Caspian Sea) in economic terms. This is even more true than with the situational factors mentioned in previous sections, such as land use, because there are so many unique parameters to individual projects, and their economic impacts are further defined by local priorities and interactions with other unpredictable economic actors.

Types of Economic Impacts

Less Direct ↕ More Direct

- Job creation in the relevant energy sector, from development and construction to ongoing production
- Contribution to revenues in the producing country or region (GDP, taxes)
- Government tax and royalty revenues: receipts by governments at all levels for public services and infrastructure
- Infrastructure: Demands on, and investment in, roads, rail, ports, sewerage, telecommunications, power, and water supplies
- Direct economic benefits created through the provision of affordable and dependable energy
- Jobs and access for rural or poor populations
- Local SME and infrastructure development
- Indirect job creation provided or enabled by exploitation of a given resource
- Economic multiplier impacts: project-related hiring of local employees, skills-upgrading, training, and local procurement
- Spending of wages and salaries on items such as food, housing, transportation, and medical services
- National industrial development in the producing country or region, including desirable industry clusters

Source: *BSR*

Still, the following survey of the issues can provide some general guidance on the impacts to consider when comparing specific projects.

Jobs, Revenues, and Taxes

All fuel sources have the potential to create jobs, revenues, and taxes. Historically, fossil fuel and biofuels projects have tended to bring elevated levels of economic activity to regions, and oil and gas projects have substantially increased the GDPs of countries around the world, from Nigeria to Kazakhstan and Papua New Guinea, where a single LNG pipeline project is forecasted to double the country's GDP. Oil and gas projects also play a significant role in the U.S. and Canadian economies (both in terms of consuming affordable fuels that run the economy—see next section—and with respect to upstream production and direct economic benefits emerging from taxes, jobs, etc).

Large-scale natural resource projects provide jobs and economic multiplier benefits across the economy, and there is evidence that second-generation biofuels and other renewable energy sources tend to offer various economic advantages, including longer-term potential for jobs (though on a smaller scale than larger oil and gas projects).

Local and Rural Development

Local and rural development generally refers to economic-development issues that include a wide range of positive and negative effects. One positive impact relates to the development of local businesses through the provision of new procurement opportunities and the stimulation of the local economy. Another area is development of social infrastructure such as hospitals and schools through company-sponsored investments. Oil and gas companies often contribute significantly to these "local benefits" in communities adjacent to production operations.

There is also the potential for negative impacts. At the project level, impacts can be relatively abrupt, with severe economic jolts during construction ramp-up, ramp-down, and closure, as well as during sharp swings in oil-commodity prices that create uncertainty in social infrastructure planning and government spending. More generally, some countries have been vulnerable to resource curse challenges that can exacerbate these and other problems. The causes and issues are complex and are usually fueled by weak governance and corruption.

Energy Security

According to the International Energy Administration, energy security can be defined as "the uninterrupted physical availability at a price that is affordable, while respecting environment concerns." For transportation fuel, energy security is a function of the diversity, diffusion, and control of supplies. Supplies can refer to natural resources themselves, such as the sources of potential conventional oil and gas in the Middle East (or countries in OPEC more broadly), as well as all current and potential supplies of conventional and unconventional sources in North America and other non-OPEC production regions.

Security considerations also apply to distribution channels. Certain shipping corridors are vulnerable to blockages that, like lost production, can create substantial increases in total energy costs. The U.S. Energy Information Administration has labeled several locations "chokepoints": the Strait of Hormuz, Strait of Malacca, Suez Canal and SUMED pipeline, Bab el-Mandeb, Turkish Straits, Panama Canal, and Danish Straits.

For fuel users, energy security has systemic (macro) and specific (micro) components. In terms of macro components, supply disruptions in one region can produce price spikes that affect global market conditions. In terms of micro components, organizations can be vulnerable to local market, physical, and operational challenges that can cause disruptions that are more specific to their own procurement.

Drivers of energy security can be immediate and direct, such as the prevention of near-term threats from pirates and terrorist attacks. They can also be longer term, relating to economic and environmental conditions that avoid political unrest and community vulnerability over time.

As a result, the production of different energy types can have widely varying effects on energy security. In the near term, crude oil production may provide the resources to enhance community vitality and security around a production site. Over the long term, however, the carbon emissions from the use of that same fuel produced may contribute to climate change, which could destabilize that same community in the future. Given the known physical and geopolitical risks of climate change, a growing number of experts—from advocacy organizations such as Greenpeace to mainstream risk experts such as Lloyd's—are advocating for expanding the definition of energy security to consider GHG-emission-reduction objectives on an equal footing with security of supply.

In its 2010 *Sustainable Energy Security* report, Lloyd's concluded that the security of supply and emissions-reduction objectives should be addressed equally. They argued that prioritizing one over the other would increase the risk of stranded investments or requirements for expensive retrofitting.

In general, the following will tend to lead to enhanced energy-security impacts, all else being equal: (1) the production of energy resources that reduce dependence on dominant supply sources and restricted channels, (2) the production of energy resources domestically or close to home, which tends to direct investments more locally, and (3) the promotion of social, environmental, and economic stability around sites of energy production.

Energy security is often associated with more general national security issues, which highlights the important role played by governments. This is partly because energy is both a vital part of national products as well as the physical lifeblood of economies. It is also because globally, governments—in the form of stated-owned enterprises—control most energy themselves, including around three quarters of known oil and gas reserves.

Business decision-makers and stakeholders interested in energy security must develop a framework for sustainable transportation fuels that accounts for the current political realities, the issues related to energy security, and the changes that are likely to happen over time. As outlined in the Shell Energy Scenarios, we must focus both on policies and the approaches that “deliver affordable solutions now and technological advances for the future.”

Food and Other Market Impacts

Energy production—particularly for biofuels and the electric power for EVs—may affect other markets that are vital to our well-being. The most visible issue is when fuel competes with food for feedstocks in the production of biofuels. This is an important potential impact that has garnered significant attention recently: Droughts have depressed corn harvests and the harvests of other key commodities over the last two years, and food prices have climbed as a result. When energy-producing actors of any type acquire rights to land that would otherwise be farmed, local food security—defined by the World Health Organization as “access to sufficient, safe, nutritious food to maintain a healthy and active life”—can be negatively impacted.

Furthermore, the large-scale transition of farms from food crops to biofuel feedstocks can reduce supply and cause inflation of food prices internationally. In general, biofuels that compete with food for land are considered unsustainable, even for second-generation or other advanced varieties. To a lesser extent, as biofuel production includes greater use of cellulosic feedstock, there are rising concerns about competition with forestry, pulp, and paper materials. Germany, for instance, has already experienced this competition with its supply of sawdust, wood pellets, and wood chips for energy use, partly as a result of the financial support for bioenergy applications.

In a similar way, concerns have been raised that the large stock of new batteries needed to scale up EVs could lead to bottlenecks in rare earth and other materials. Also, the renewable technologies of wind and solar that make electricity carbon-free require investments in transmission and distribution that must be borne by someone, owing partly to the fact that there are essentially no commercial-scale electric storage systems, and switching energy sources between intermittent supplies and other sources is expensive.

Such effects are uncertain and may not amount to much. A recent study shows that a rise in agricultural commodity prices of 20 to 40 percent would increase the retail price of most processed grocery food products (breakfast cereal and bread) containing those commodities by only 1 to 2 percent. Given the different and complex global and local aspects of these markets, it is hard to make blanket statements about the effects of one fuel or feedstock over another. This area requires further study.

Energy Availability and Affordability

Fuel and energy are major inputs into economies and are necessary to stimulate economic development. Indeed, available and affordable energy is one of the key enablers of higher quality-of-living standards and is vital for improved human development. Therefore, a vital sustainability issue when evaluating fuels is the extent to which they make energy more accessible.

Alternative energy sources offer some promise in this area. However, because they tend to be expensive, they need to achieve greater per-unit cost-effectiveness to have meaningful positive benefits. Additionally, the new infrastructure and systems needed to support alternatives to gasoline and diesel require significant outlays and potential redistributions of costs that must be managed. For example, because commercial-scale battery power is not yet available, renewable energy sources—which are needed for EVs to achieve their potential—must be paired with natural gas or other production sources when they are not generating power. If the costs of new infrastructure and maintenance are shifted to ratepayers who are relatively poor, this could result in disproportionate negative impacts.

A related issue is that damages or requirements for additional maintenance need to be factored in. For example, ethanol fuels are corrosive and studies have shown that they lead to greater maintenance costs and shorter life spans of engine equipment.

Strategic National Development

A final area of economic impact is one that often garners less attention than it deserves: The impact that fuel production has on national development strategies, which are defined by political and market factors that bear on developing competitive energy supplies and sustaining and growing the economy. A recent major study for the World Economic Forum produced by IHS CERA summarizes this point as follows:

> *"Maximizing direct employment in the energy sector may not be the right goal if it increases energy prices and decreases the industry's overall productivity. Instead, focusing on how energy decisions contribute to the overall economy, not just the industry's direct economic contribution, is more likely to maximize welfare. The industry contributes to economic growth and job creation, in some countries to a very great extent. But in most countries, its position as the lifeblood of the modern economy dwarfs the direct effects."*
>
> *—Energy for Economic Growth, World Economic Forum, 2012*

The impacts of different energy and fuel sources on national strategic development depend significantly on the countries or regions of production. In this case the key factor is the ability of a given country to maximize the benefits to its overall economy by promoting a related industrial base and making wise use of the revenues from extraction.

In the context of relevant major transportation fuels, this logic would seem to give a boost to those sources—such as unconventional oil and gas as well as biofuels—that are produced in the United States and Canada, where existing political and economic regimes are more likely to lead to broader economic benefits as compared to countries characterized by weaker governance and greater susceptibility to corruption and other resource curse issues.

As mentioned earlier, however, few if any advocates for increased support to emerging economies would call for diverting investment away from these areas. Rather, they would emphasize the need for continued engagement and investment, with greater commitment to improving local governance and industry practices. On this latter point, current practices tend to vary more as a function of the commitment and capabilities of individual producers—both international oil companies (IOCs) and national oil companies (NOCs)—than the specific energy or fuel type in question. More study and dialogue on these critical issues is clearly required. In the meantime, we will consider their impact to be neutral in the identification and promotion of more sustainable fuel choices.

These developments may gradually contribute, over the long term, to moderating concerns about security of supply as well as those associated with peak oil. At the same time, the economic viability of unconventional resources may slow the transition to lower-carbon fuel sources due to both economic and security-of-supply objectives.

Arguably the best "fuel" of all from an economic standpoint is the reduction of energy demand through fuel efficiency. It applies throughout the different aspects of economic development, starting with jobs, revenues, and taxes. The only serious questions about negative impacts of efficiency is whether efficiency gains might not always lead to total fuel savings, because a reduction in energy costs could be offset by increased demand for fuel. This is known as the rebound effect and in its extreme form—i.e.

when incremental use is actually greater than the savings from efficiency—it is referred to as the Jevons Paradox.

Research has shown that there is indeed often a rebound effect with transportation fuel, though while savings may be moderated, they are not entirely negated. For private automobiles, the rebound effect is often 5 to 30 percent (meaning that 70 to 95 percent of improvements translate to saved fuel). For freight, studies show a rebound effect range of 30 to 80 percent (meaning 20 to 70 percent of improvements translate to saved fuel) a stronger impact because commercial savings go directly to production costs and structures, which allows a business to take not only longer trips but more frequent trips.

IMPACT HIGHLIGHTS

We have made some important distinctions about the impacts of different fuels, as follows:

Gasoline and Diesel

These incumbent sources of fuel (with their current relative affordability and scale of use) make an enormous contribution to economic growth and development, establishing the world's largest industry and enabling higher qualities of life and human development. One of the most important relative sustainability benefits of gasoline and diesel (and natural gas) compared to alternatives is often overlooked: its power density. While there are indeed site-specific and distribution-related land use impacts, its high power density keeps it from being implicated in wide-scale forest conversion and competition with food or other resources. This power density is a key trait that gives gasoline and diesel staying power, and something that alternatives must answer if they are to displace it.

However, these fuels derived from crude oil are responsible for several sustainability impacts. They are a top contributor to climate change, impose substantial health impacts on communities, bring about occasional deadly explosions and harmful spills/accidents, and are sometimes associated with negative economic impacts owing to the resource curse.

Generally speaking, unconventional fossil fuels involve even higher climate and health impacts due to their greater processing requirements. As for oil sands in particular, the practical question to consider is about the pace and scale of development, considering the potential cumulative effects and government oversight resources available. One potential advantage Canadian oil sands development offers to the United States, when compared with crude from other sources, is enhanced energy security.

Natural Gas

Natural gas has significant GHG benefits over gasoline and diesel and contributes to the potential for economic revival in North America. It also shares many of the same types of social and economic benefits and issues that oil does, including those involving safety. There remain unresolved concerns around groundwater pollution and more general environmental protections for communities hosting fracking operations, although technical remedies exist for most of the challenges of producing shale and tight gas in large quantities, even if they require increased regulatory oversight and significant community engagement.

Much of the promise of natural gas from a sustainability standpoint is that it can serve as a "bridge fuel"—i.e. it buys us time to "figure out the rest." However, what lies on the other side of that bridge is not yet clear, and it needs to be better defined.

Biofuels

There is a wide diversity of products and practices covered by the term biofuels, including several types of fuel, dozens of feedstocks, and many more production techniques, all of which are at various stages of maturity. In general, advanced biofuels derived from organic waste have among the lowest climate, biodiversity, and land-use impacts. Drop-in fuels created from algae and other biomass and biogas sources represent exciting potential, but their water and land-use impacts need to be better studied.

Biofuels that originate from dedicated crops, whether food or non-food varieties, look increasingly likely to create biodiversity impacts and/or competition with food or resource markets, owing in part to their having low power density, which offsets their climate benefits. Nevertheless, these biofuels are likely to persist in the short term, and when they do, there are ways to reduce impacts through sustainable management practices, for example by low-input cultivation of perennial plants, short-rotation forestry and grasslands.

Finally, there is increasing evidence that, when considering the range of pathways for biofuel feedstocks and transportation, electric power generation rather than liquid fuel production might ultimately be the most productive and least problematic use of biofuels.

Electric Vehicles

EVs show strong potential environmental benefits when used with grids that are powered with low-carbon electricity. However, if grids make any substantial use of coal, the climate and health benefits of EVs over gasoline or diesel are essentially reversed. Also, for renewables to have low impact when being used on a large scale, their power density needs to be substantially increased (as in the case of biofuels). Furthermore, wider scale use of renewables—which would be needed to fulfill the climate and health benefits of EVs—will require the development of costly transmission and storage infrastructure that could potentially impact individuals other than EV users.

Hydrogen and Efficiency

The two final “fuels” of hydrogen and efficiency do not feature heavily in the impact section, the former because it is still very emergent, the latter because the impacts are broadly understood to be overwhelmingly positive.

Further Discussion

There are multiple issues that cut across fuels, making it difficult to say that one fuel is categorically better or worse than another. One of these issues is water; although it is an impact area for every fuel, data is scarce and local context has an important bearing on the impacts of water use in a region. Another is human rights and labor: These issues are highly situational, making it difficult to draw conclusions based simply on the type of fuel.

There is also a theme of expansion and encroachment that runs through all the fuels. On one hand, energy production is drawing closer to peoples’ homes, with shale gas, wind, and solar literally moving into people’s backyards. On the other hand, petroleum production is reaching the furthest corners of the Earth, including remote and sensitive ecosystems such as the Arctic, in pursuit of more difficult-to-extract resources. The increasing amount of production and related activities in places that people find intrinsically valuable will drive a need for greater public discourse and community engagement.

Thus, crisp conclusions about the sustainability benefits of certain fuels over others are not easily drawn. Moreover, the knowledge gaps are significant. While we provided some highlights on what is known, what is not known is arguably just as significant. Key areas that require further development include:

- Further study on water, societal, and economic impacts across fuels
- Integration of life-cycle assessments with evaluations of social, market, spatial, and temporal impacts
- Development of methods that better address the complexity arising from fuel production burdens being different in one place than another
- Creation of frameworks to weigh and prioritize issues, something we have not attempted here. For example, is climate change the defining issue of our time that fuel frameworks need to focus on? Or are opportunities for improvement in North America relatively miniscule, and thus water and social impacts deserve greater attention?

- Establishment of better community and public knowledge. In many cases, data exist that may or may not be put to good use in engaging with communities.
- Monitoring all aspects of new solutions. This survey mostly addresses the impacts of today’s fuels, but technologies and their impacts are changing quickly.

In addition to the wide variety of impacts summarized above, each fuel type poses a distinct set of advantages and disadvantages, as well as limits and uncertainties. Many of these limits and uncertainties are connected to market viability, the subject of our next section.

Fuel Market Outlook

Future of Fuels aims to find collaborative pathways to enhance the sustainability of available and emerging transportation fuel choices. To ground our assessment of sustainability impacts for business planning, it is necessary to develop expectations about the evolution of energy demand and supply over the next 20 years and beyond, and to understand the dependencies that will enable a more rapid transition to low-carbon, sustainable fuels.

Anticipating future fuel markets is a vital part of understanding sustainability impacts, because many of the most acute impacts concern production and consumption that will happen at a later date. For example, many of the concerns raised about oil sands relate to the expected impacts from the cumulative effects of larger-scale production in the future.

Noted energy scholar Vaclav Smil has recently argued that we need to be wary of any strong, unqualified claims regarding the pace, timing, and extent of future adoption of new energy sources, diffusions, or performance. We endeavor to bear this in mind.

The issues and questions addressed in this brief are complex, often controversial, and topics of extensive analysis by corporations, industry associations, sustainability advocates, academics, economists, and politicians. This section contains some of the most important points of bearing for our focus topic of road freight transport in North America.

DEMAND PROJECTIONS

Over the next two decades, the world will see growing levels of energy demand, with total world energy consumption likely to increase by more than 50 percent between 2008 and 2035, according to the International Energy Agency (IEA)[9].

Global Energy Outlook

Several forecasts and scenarios provide medium- to long-term energy outlooks (see Appendix 2). Among them, those by the U.S. Energy Information Administration (EIA), Shell, and Greenpeace highlight key dependencies and assumptions that explain divergences among different outlooks. The four key—and related—assumptions driving different outlooks are:

1. The perceived likelihood of significant political action on climate change, in the form of new local and/or international policies
2. Current availability of and infrastructure for fossil fuels, as well as the potential of developed and undeveloped (conventional and unconventional) fossil fuel resources
3. The use of advanced alternative fuel technologies in a way that maximizes positive impacts and minimizes negative ones
4. The feasibility and likelihood of significant breakthroughs in terms of development and deployment of alternative, low-carbon energy solutions

With respect to the first assumption—concerning the prospects for significant political action on climate change—the most that can be said at the current time is that the future is profoundly uncertain. While earlier hopes for a comprehensive global “climate deal” have dimmed in the aftermath of the COP15 summit, significant action continues on a local and regional level in the form of cap-and-trade mechanisms, and various tax and subsidy regimes aimed at promoting greater energy efficiency and lower-carbon energy sources. It is unclear whether and how quickly these diverse initiatives can coalesce to produce globally significant impacts.

The second assumption—on the current and potential future supplies of fuel—underlies many considerations across all scenarios, including implicit or explicit assessments of the potential energy mix,

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[9] Most references are located in the last section of the paper.

the likelihood of government action to protect security of supply, and the basis for energy-efficiency activities.

The third set of assumptions—those related to the possible or likely rate of development and deployment of low-carbon energy solutions—are particularly important in evaluating the prospects of new transportation fuels and technologies, as the availability of fuels must be matched by the development of widely distributed infrastructure. This in turn creates a strong link back to our first set of assumptions about the outlook for new climate-related political action and policy, as the time and investment required for fuel and vehicle transitions tend to be substantial.

For example, although EVs and biofuels are beginning to enter the market (and hydrogen fuel-cell vehicles could enter by about 2015), it may take decades for any alternative fuel pathway to make a major difference in the global energy mix and related GHG emissions because of the time required for market penetration, vehicle stock turnover, and fuel supply development. Since development, transportation, distribution, marketing, and storage of current transportation fuels are heavily weighted toward oil products, the costs of shifting the transportation portfolio to other energy sources are substantial and would need to be borne by a combination of public- and private-sector incentives and policies over an extended time period.

Understanding Demand

As total energy use grows substantially, so too will that required for transportation, which is the largest category of final energy consumption, responsible for around one-third of global use—a share that is expected to remain stable over the next few decades. Within this category, commercial vehicle demand is significant and rising. Currently, about 43 percent of road transportation fuel is used for commercial purposes globally. This segment is expected to rise sharply through 2030, growing by about 30 percent in North America and Europe, and more than 100 percent in the Asia-Pacific region.

An understanding of the key segments of demand within commercial road transportation is important to identify where the greatest challenges, and hence opportunities, are likely to be. At the same time, different demand segments are supplied by different fuel sources, and understanding impacts requires links between the two. Of the four primary modes of commercial transport—water, air, rail, and road (consisting of light-duty and trucks)[10]—we have identified four key segments of demand: trucks, freight, medium- and heavy-duty vehicles, and fleets.[11]

Truck Demand

Around 76 percent of energy for transportation is consumed in the road transportation category (IEA), the second-largest energy user of transportation modes after light-duty vehicles and the fastest-growing segment of transportation modes. Trucks consume 20-plus percent of transportation fuel used in the United States today.

Medium- and Heavy-Duty Vehicle Demand

Road vehicles belong to one of eight classes, grouped by weight. Classes 1 and 2 are light-duty passenger vehicles (LDVs), and classes 3 through 8 represent medium-duty and heavy-duty vehicles (MHDVs). Fuel-use profiles are distinct among the different categories, with a mix of gasoline and diesel engines being used in Classes 3 through 7, and diesel engines used almost exclusively used in Class 8.

Demand from MHDVs is rising sharply. The share of fuel consumption by MHDVs among transportation modes is expected to climb from just over 20 percent to almost 30 percent by 2050, with heavy-duty vehicles having the largest percentage increase, up 21 percent by 2035. Class 8 vehicles—the heaviest

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[10] Our assessment excludes recreational boats, lubricants, pipeline, and military use.

[11] An additional distinction that is geography: Some places are growing faster than others, and have different transportation systems due to political-economic structures. We will embed this throughout the discussion and also address it in the supply section.

category of all, which includes all tractor-trailer trucks—consume around 80 percent of fuel from the MHDV class. Note that the “trucks” category above includes all MHDVs plus commercial light trucks.

Freight Demand

At least 28 percent of road transportation fuel is used for commercial freight in the United States. The demand for freight trucks is linked particularly to GDP and industrial shipments. As a result of macro trends, growth in freight trucks is expected to rise anywhere from around 75 percent to more than 150 percent through 2050, the largest growth level of all transportation modes.

Fleet Demand

Whether companies have in-house fleets or use outsourced logistics providers, corporate fleets are an important area of U.S. demand, accounting for more than 35 percent of the nation’s transportation-related fuel consumption, even though this group represents only about 7 percent of the U.S. vehicle stock.

In addition to these four primary categories of road fuel demand, a final consideration is the growing global level of demand. Aggregate demand for transportation energy has plateaued to some extent in North America, but is expected to rise globally nearly 45 percent by 2040, owing mostly to growing middle classes in emerging countries, especially China and India. This growth adds to the total demand drawing from the global pool of available resources.

VIABILITY REQUIREMENTS FOR MEETING FUEL DEMAND

The continued expansion of advanced and alternative energy sources has many requirements, including government policies, taxation, technology advancement and technology transfers enabling the industry to be profitable and feasible, patents restriction, research and development, and geopolitics.

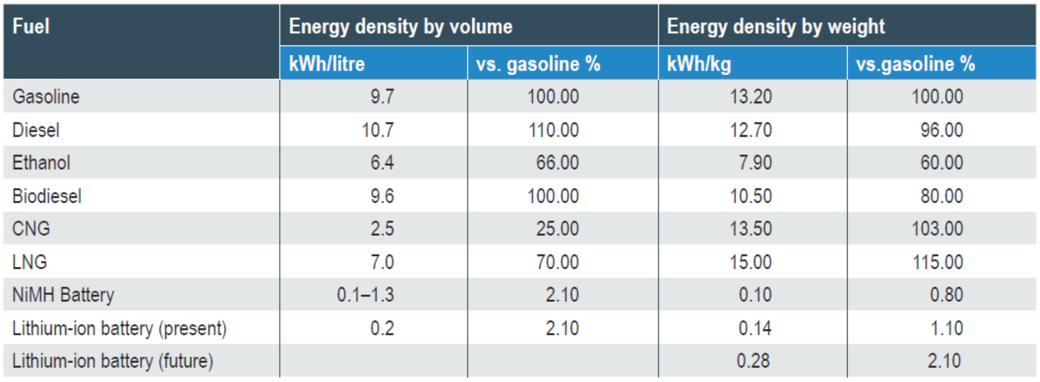
When considering the demand outlook as a whole, a picture emerges of the viability factors necessary for fuel development pathways to provide commercial-scale solutions. The following needs are particularly prominent for the commercial trucking sector.

1. **Resource availability:** For any fuel to achieve a large and durable share of the overall mix, it must possess resources in the form of technically and commercially viable feedstocks and the land required to produce and process them. Finite sources, in particular conventional oil, are decreasing. This will lead—at some point that may be very near—to the phenomenon called “peak oil,” in which supply becomes increasingly scarce in relation to demand. Some renewable resources, on the other hand, such as first-generation biofuels and wind, are constrained by space due to having low power density. Thus they require land resources not necessarily available.
2. **Infrastructure availability:** Fuels require physical and market systems that allow the extraction, production, processing, and delivery of final fuel products to end propulsion systems. For fuels besides gasoline and diesel, this includes systems such as LNG terminals, battery-charging stations, hydrogen pipelines, and/or solutions to renewable power intermittency.
3. **Vehicle technology availability:** Fuels other than gasoline and diesel require a vehicle to match them. Many advanced vehicles either are not widely available or prohibitively expensive, especially for larger-class vehicles.
4. **Vehicle range:** Sufficient distance between refueling is essential for commercial vehicles. Complications from reduced range may be neutralized by better fueling infrastructure, something that is more likely in high-traffic interstate corridors.
5. **Fuel energy density:** Fuel must be sufficiently energy-dense to be

transportable. Energy density is the amount of energy stored by weight (gravimetric) and volume (volumetric). There are typically tradeoffs between the two: For example, CNG has relatively high gravimetric density (meaning it is relatively light), but relatively low volumetric density (meaning it takes up more space). Fuel energy density is closely related to available vehicle ranges and vehicle technology. Energy density is different from power density, which typically refers to the rate of energy supplied by horizontal area required of the feedstock.

6. **Fuel cost at pump:** A central component of viability is the per-unit price of fuel borne by the purchaser. Of course, fuel has externalities, meaning that not all societal costs are reflected in the price of the fuel. Nevertheless, the relative attractiveness of price is a key motivator for the selection of fuels and even vehicles to match them—a fact that the advent of natural gas in North America is a testament to. Currently, natural gas and electricity options are less expensive than gasoline and diesel on a per-mile basis, while most biofuels command a 30 to 50 percent premium.
7. **Fuel performance:** Finally, fuels have different performance properties, and alternatives to gasoline and diesel will need to meet certain standards. This includes operating at very cold temperatures and not corroding or damaging equipment beyond acceptable levels, both areas where biofuels have faced challenges.

Figure 12: Comparative Energy Densities of Fuel



Fuel	Energy density by volume		Energy density by weight	
	kWh/litre	vs. gasoline %	kWh/kg	vs.gasoline %
Gasoline	9.7	100.00	13.20	100.00
Diesel	10.7	110.00	12.70	96.00
Ethanol	6.4	66.00	7.90	60.00
Biodiesel	9.6	100.00	10.50	80.00
CNG	2.5	25.00	13.50	103.00
LNG	7.0	70.00	15.00	115.00
NiMH Battery	0.1–1.3	2.10	0.10	0.80
Lithium-ion battery (present)	0.2	2.10	0.14	1.10
Lithium-ion battery (future)			0.28	2.10

Source: American Physical Society and U.S. Department of Energy (adapted from Canada Petroleum Products Institute)

Historically, energy sources do not change very quickly. However, quick penetration by electric vehicles is not that hard to imagine. The main challenge is the travel range provided by battery technology, which is currently limited. In the event of a breakthrough, there are no other major infrastructure challenges. Grids would need to be made somewhat more sophisticated, but the electric pathway is almost twice as efficient as the liquid fuel/internal combustion pathway, and fuel costs are already less than liquids.

The next section will survey most likely fuel supply scenarios. We will cover the most critical issues and assumptions that shape the current outlook for the different energy types at a high level, providing context for assessing life-cycle value chain impacts, though we leave it to future work to investigate the details of supply, infrastructure, demand, politics, and pricing.

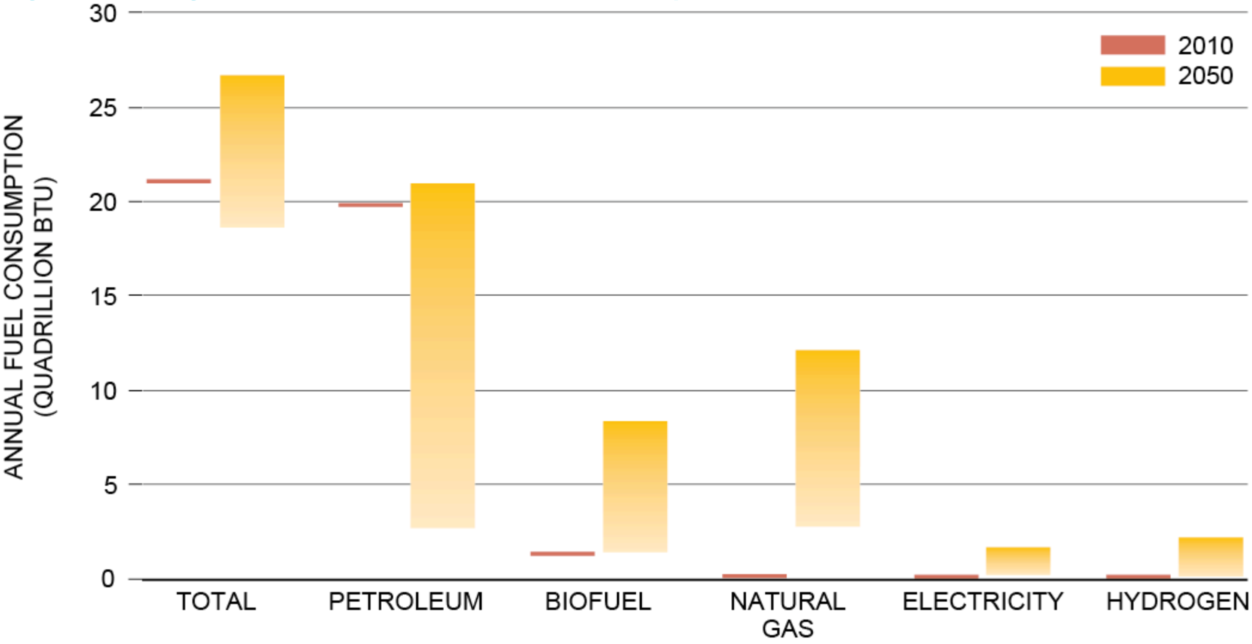
FUEL SUPPLY AVAILABILITY PROJECTIONS

The landscape of fuel supplies is changing for several reasons: reduced viability of conventional oils, innovation in renewable and unconventional energy and fuel production, innovation in vehicle propulsion systems, and opportunities to profit from an estimated US$38 trillion in needed investments over the next two decades.

What determines available fuel supplies? A major determinant is price, for two reasons. Not all of the sources discussed in this paper are simultaneously available. Rather, they only become available when energy producers believe that they are competitive with the real price of oil. For instance, in the 1980s when the price of oil appeared to be above US$30 per barrel, oil companies were active in offshore Arctic exploration. When the price fell to US$10 per barrel in the 1990s, they abandoned those investments. Now that the price may be above US$60 per barrel, they are back at it. Oil shale (kerogen from Colorado, Wyoming, and Utah) is not available at today's prices, and in this respect the revolution caused by horizontal drilling and hydraulic fracturing may push the arrival of oil shale out many more decades.

Second, as discussed in the previous section, prices help one decide whether a particular investment in sustainability makes any sense at all. Jatropha from sub-Saharan Africa may be a wonderful feedstock to reduce greenhouse gas emissions from the transportation sector, but if those reductions cost US$1,000 per ton of CO_2, no one would think it was a wise choice.

Figure 13: Range of 2050 On-Road U.S. Fuel Consumption



Note: At equivalent fuel consumption (by energy), alternatives such as hydrogen FCEVs and electric vehicles can support 2-3x the miles due to their higher fuel economy.

Source: National Petroleum Council

The International Energy Agency projects that through 2035, fossil fuels are expected to cede share of energy use from around 84 percent in 2010 to 80 percent—though clearly remaining the world's top transportation fuel (IEA). Renewables are the world's fastest-growing energy source, but will still represent only 15 percent of the total transportation fuel mix by 2035—up from about 3 percent in 2010.

Figure 13 provides a summary of likely fuel-consumption ranges through 2050. While these are the expected values given forecasted changes in underlying drivers, those forecasts carry uncertainty, and energy markets have a way of turning themselves upside down. For example, in little more than a year, the scaling up of natural gas has gone from being a dream for many environmentalists (replacing more carbon-intensive fossil fuels) to a nightmare come true (a headlong rush into uncharted waters of hydraulic fracturing). Four years ago, most expert agencies and companies had no idea the shale gas revolution was coming. Companies were proposing huge investments in LNG import capacity for the United States, advice that today seems misguided.

More generally, it is difficult to predict the future of emerging technologies. It is not inconceivable that the nearly vertical rise of mobile phone adoption in the 1990s could offer a model for future energy technologies. For example, a revolution in battery technology may be the foundation of the next big change in energy. We shouldn't ignore the possibility simply because it doesn't fit current forecasters' models. Still, establishing a set of working expectations about the future—even if tentative and subject to regular updating—is essential for making sound investments.

What follows are elements that could be game changers if they come to pass, as well as an outline of the most plausible scenarios for key fuel supplies.

Gasoline and Diesel

Petroleum, from which gasoline and diesel are made, is the raw material for 90-plus percent of transportation fuel, and transportation is responsible for around two-thirds of all oil use, in conventional liquid-fueled internal-combustion engine (ICE) vehicles.

Oil dominates current supplies and will continue to do so because of the maturity and scale of the technologies involved, with high-volume, low-cost supply chains and manufacturing capability and a liquid fuels supply chain that is also large-scale and well-developed. Manufacturers are currently introducing more efficient vehicles and have additional fuel economy improvements in the pipeline that will benefit consumers in the near term and beyond.

Most likely, diesel engines will remain the powertrain of choice for HD vehicles for decades to come because of their power and efficiency. There are, however, opportunities to improve the technology. Significant fuel economy improvements in diesel-powered trucks are possible.

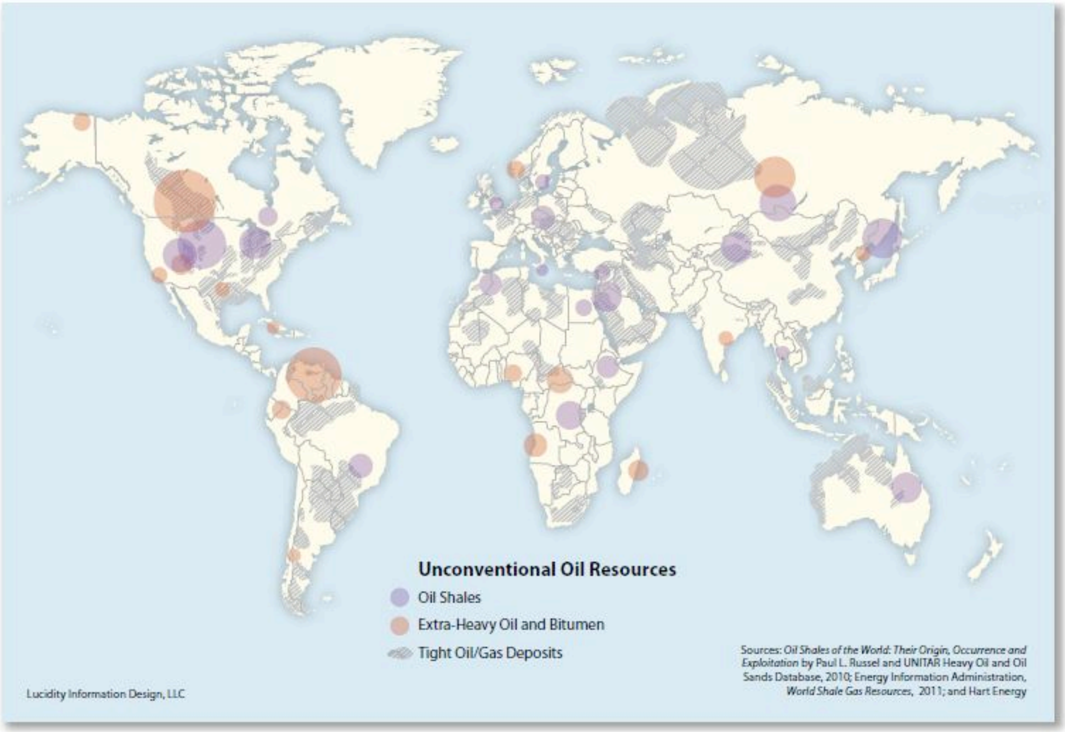
Despite petroleum's size and maturity, this large incumbent will cede share to emerging technologies, the only fuel type that is expected to significantly decrease as a portion of the total mix. It will do so in part because of the reduced potential for producing fuel from inexpensive, conventional supplies, and in part because of the increasing viability of alternative technologies.

There is a wide range of scenarios regarding how on-road fuel consumption will change through 2050. Assuming alternative vehicles are successfully commercialized (see Figure 13 on previous page), the average share for petroleum resources is expected to be around 50 percent, though with a huge range of uncertainty going from just under 15 percent to around 95 percent.

Within petroleum, unconventional sources are expected to grow substantially as a share of the total: The combination of oil sands, coal-to-liquids, extra-heavy oil, and gas-to-liquids is expected to grow from around 3.1 percent to 7.5 percent by 2010; oil sands increased by 8 percent to 1.7 million barrels per day in 2011 alone. Arctic exploration is another category that is on the rise, with potential for substantial expansion.

Figure 14 shows how the world's future oil supplies will no longer remain concentrated in the Middle East, Africa, and Russia, but increasingly will be found in the Western Hemisphere and over the long term they will be unearthed globally. Projections from the IEA indicate that North America is home to the world's largest stores of unconventional oils—extra-heavy oil, bitumen, and kerogen—with estimates of 50 percent more unconventional oil than total conventional reserves in the Middle East. Eastern Europe and Eurasia, followed by Latin America, have also been identified as part of the new geography of oil.

Figure 14: Unconventional Oil



Source: Carnegie Endowment for International Peace

It is highly plausible that the economic viability of unconventional resources will slow the transition to lower-carbon fuel sources due to both economic and security of supply objectives.

Natural Gas

The use of natural gas as a transportation fuel is well-established and growing worldwide. In North America, it is now in abundant supply and on an equivalent energy basis costs less than gasoline and diesel. It is therefore unsurprising that of all alternatives to petroleum, natural gas has achieved the greatest and fastest level of commercialization, and has some of the greatest prospects for near-term growth. Natural gas has already achieved successful penetration in three U.S. HD market segments: transit systems, school buses, and refuse trucks. Early adoption in heavier duty Class 7 and 8 freight trucks has also begun. There are currently 12,000 natural-gas-powered vehicles in Canada.

Natural gas is consumed mostly as compressed natural gas (CNG), with some consumption of liquefied natural gas (LNG) and liquefied petroleum gas (LPG). Companies across several industries have embraced CNG, with many CNG fleets currently traveling the roads. LNG is a fuel source with considerable potential, especially for long-haul distances, as it offers the greatest energy content of all natural gas fuels, comparable to traditional petroleum gas; but because of significant up-front investment and maintenance costs, LNG has yet to achieve substantial market share.

Historically, natural gas discoveries (and oil-based associated gas) were often deemed not commercial because of their location and lack of access to infrastructure. However, the advent of LNG as a transportation option for natural gas has helped to increase the resource's economic viability, typically on the basis of long-term contracts required to balance the risk and costs of large-scale natural gas developments, liquefaction, and regasification infrastructure. Although natural gas markets have previously been regionally based, due to transport costs, global prices will equilibrate (minus transportation costs) if LNG capacity expands sufficiently.

The increasing attractiveness of North American and other regional shale-based gas resources—from a pure economic standpoint—are also beginning to localize and decouple long-term natural gas price trends from that of global crude oil markets. This is an important development in the growth of natural gas as a potential transportation fuel, as well as in its increasing cost-competitiveness against alternative transportation (and coal-based power) fuels.

Natural gas has a versatility that can lead to greater-scale solutions overall—as it can be used for direct transportation fuel and power generation alike. It can provide an alternative to coal (which has much higher climate and health impacts), and usefully enable carbon-free sources such as wind and solar by providing power when their own power supplies are off.

If natural gas becomes broadly commercially adopted, its expected on-road fuel consumption scenario range through 2050 is around 34 percent, with a range of uncertainty extending from around 17 percent to just over 50 percent. However, it is not clear how quickly NGVs and an expanded natural gas refueling infrastructure can evolve. Currently, there are fewer than 400 public CNG fueling stations in the United States.
Refueling stations for natural gas vehicles are not likely to be built without some assurance that there will be sufficient numbers of NGVs to be refueled within a reasonable time period. Additionally, developers are weighing uncertainties related to capital and operating costs, taxes, and the potential for prices to be set on the basis of the prices of competing fuels.

The main challenges to market expansion are vehicle price premiums and infrastructure availability. Creating sufficient demand to quickly migrate to fully OEM-produced vehicles will result in substantial cost improvements from today's low-volume vehicle-modifier approach. The primary LD market technical and commercial challenges that need to be addressed and overcome are: limited make-model availability, limited refueling infrastructure, and minimal inclusion of CNG in the OEMs' current long-term product architecture plans regarding powertrain and chassis. Infrastructure to provide natural gas to LD or HD vehicle users is also a challenge, although to different degrees. HD natural gas demand for Class 7 and 8 trucks could be met more quickly and easily along heavily traveled freight corridors than MD trucks or LD vehicles, which require more widespread refueling infrastructure.

CNG and LNG have the greatest opportunity for accelerated adoption into the HD fleet, assuming that the current price spread between diesel and natural gas persists over time. Because of HD vehicles' high annual fuel use and fleet base, as well as the regional nature of a large element of the freight industry, they are well-positioned to take advantage of natural gas. There are challenges to overcome, however: The infrastructure transition to supply this fuel demand represents one of the largest obstacles to alternative fuels entering the HD market. The characteristics of initial customers for natural gas MD and HD trucks, such as inter-urban fleets, regional fleets, and freight corridors connecting regions, may provide pathways to expanding the vehicle market.

A key area of potential disruptive innovation for natural gas is advanced storage technologies that would allow gaseous fuel storage at higher densities and lower pressures, such as adsorbing onto the material surface, absorbing the material, or storing the fuel as a chemical compound.

Biofuels

There has been significant global growth in biofuels over the last 10 years, driven largely through blending mandates that define the proportion of biofuel that must be used in road-transport fuel—often combined with other measures such as tax incentives. More than 50 countries, including several non-OECD countries, have adopted blending targets or mandates and several more have announced biofuel quotas for future years.

Biofuel production capacity has increased from 437 million gallons in 2011 to more than 685 million gallons in 2012. According to a recent estimate, at least 27 new or retrofitted biofuel refineries are expected to come on line by 2015, and the industry will have the potential to produce 1.6 billion to 2.6 billion gallons of renewable fuel. In the near future, capacity companies will produce at US$0.60 to US$3.50 per gallon, depending on the feedstock and technology.

In practice, biofuels are typically blended with petroleum-based fuels, with ethanol mixed into gasoline, and biodiesel mixed into petroleum diesel. Most vehicles can use gasoline-biofuel blends containing up to 10 percent ethanol (E10) or up to 5 percent biodiesel (B5). Flexible fuel vehicles can use gasoline-ethanol blends containing up to 85 percent ethanol (E85). In the United States, there are currently about 700 fueling stations that offer this E85 fuel, most of which are in the corn- and soy-farming region of the upper Midwest.

Biofuels have become popular for a number of reasons, including energy security concerns, the desire to sustain the agricultural sector and revitalize the rural economy, and the reduction of CO_2 emissions in the transport sector, particularly within OECD countries.

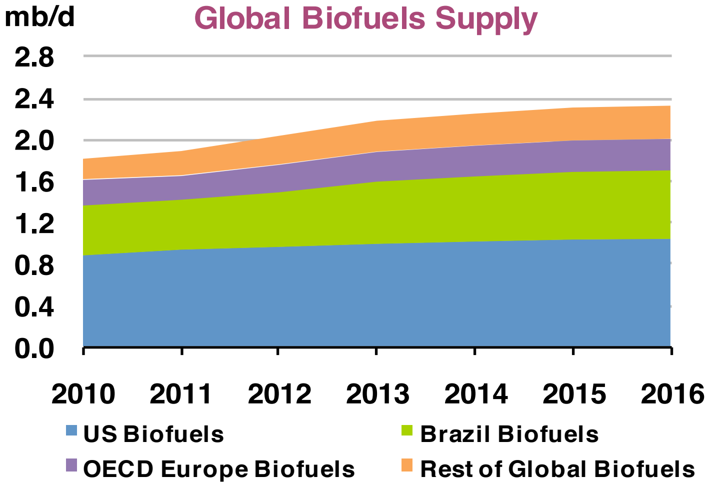
Yet, there are many practical challenges due to the low energy density of the fuel, in addition to the low power density of the feedstock that defines the first-generation biofuels that are currently in use. As a result, current forms of biofuels are unlikely to replace gasoline or diesel because of scalability problems.

The future potential of biofuels to contribute to energy supply is contingent on the ability to increase yields on existing farmlands, through adjusting crops and cultivation methods, through better utilization of organic wastes, and advances in drop-in fuel technology. Also, as many biofuel feedstocks can be used for electric power generation—and with signs showing that this may often be a more productive way to use the feedstock—there may be an additional pathway for biomass to power EVs.

Cellulosic biofuels that can be created from non-food crops and waste such as corn stover, corncobs, straw, wood, and wood byproducts will continue to advance. The great interest in and desire for non-food-sourced biofuels means that development of advanced biofuels is continuing to progress, but applications remain limited given technological and commercial constraints and lack of enabling policy incentives. A 2011 study by the National Academy of Sciences anticipates that cellulosic biofuels will not likely be widely available until 2022.

Figure 15 shows that biofuels are largely produced in the United States and Brazil, with substantial contributions from other OECD countries. For details on countries currently producing biofuels, see Appendix 5.

Figure 15: Biofuels Supply by Country



Source: IEA

There is likely to be further attention to the power density limitations—and in turn sustainability impacts—associated with any dedicated crops. As a result, there is likely to be growth in R&D for biomass that is derived from organic waste and materials that are no longer useful. The viability of drop-in fuels derived from algae and other sources, and likewise on-board biogas systems, are very uncertain.

From an economic standpoint, there are no major technological barriers preventing expansion of today's corn-based biofuels because feedstock logistics and fuel production technologies are well-established. Increasing production volume, however, will require the support of additional fuel and vehicle infrastructure. Continued expansion of biomass feedstock supply depends on crop yields, arable land availability, and co-product utilization. In order to gauge the sustainability of increased use of corn-based biofuels, soil, water, and other sustainability criteria must be taken into consideration.

Cellulosic biofuels do face material challenges to further development. Significant research efforts are underway to increase the yields of cellulosic energy crops such as switchgrass and miscanthus. Investments in infrastructure to collect, store, transport, and process biomass will be critical to aid wide-scale adoption. It should also be recognized that there will be additional demands on the biomass resource beyond liquid transportation fuels, including power generation, chemical feedstocks, and chemical products.

Biomass has been and will be part of the overall energy mix. However, transport biofuels will probably only make a small contribution to future energy supply. While their production efficiency could be improved by increasing the productivity of existing cropland and expanded by planting on degraded land, biomass may be more effectively used for stationary energy supply or material applications, or both.

If biofuels become commercially adopted, they could account for around 20 percent of overall road fuel use, ranging from around 10 percent to just over 30 percent. However, the low power density of most current biofuels mean that this will not happen without substantially increased sustainability impacts unless there are serious advances in biofuels technology and policy.

Key areas of disruptive innovation potential for biofuels include genetic engineering that enhance certain natural traits (e.g. frost, drought, and heat tolerances; water and nitrogen efficiency; and photosynthetic efficiency to the feedstock); microbial fuel cells that use bacteria to convert chemical energy of organic substrates into electrical energy; biosynthesis that use fatty acids to produce ethanol, butanol, and various other fuels; and improved production efficiency of seaweed (macro algae).

Electric Power

EVs have shown significant growth by percentage in recent years—and have the most potential to grow in terms of share. However, most of the growth is in the light-vehicle category, owing to the persistent challenges of applying these technologies to freight trucking, which requires long ranges and high energy density for heavy loads. A key challenge is battery life, mainly because of a combination of limited range, high cost of purchase, and uncertain durability.

In theory, EVs represent some of the strongest potential for growth, though there are serious sustainability and infrastructure issues that need to be addressed. Renewable energy capacity factors are very low, and currently commercial-scale electricity storage does not exist. Moreover, intermittency solutions are needed for wind and solar, which require expensive technical solutions. The generation of more reliable and still low-carbon electricity also faces a significant hurdle: Carbon capture and storage does not show signs of being a viable, widespread technology for coal generation in the coming decades due to the large volume requirements and infrastructure required. Together, these add up to a number of important contingencies standing in the way of large-scale EV adoption.

While some have compared the potential for adoption of EVs to the exponential rates of mobile phone adoption, the analogy should not be pushed too far: Unlike computer processing, EVs do not comply with Moore's law (e.g. that power doubles every 18 months), as battery power is already much closer to approaching real physical limits.

Nevertheless, a key area of disruptive innovation for EVs and hydrogen vehicles is the creation of advanced batteries, next-generation devices that will have higher energy densities than lithium ion, capacitor technology, and new chemistries such as magnesium ion, metal air, aluminum ion, and sodium ion.

Hydrogen

For hydrogen and fuel-cell vehicles, more extensive demonstration programs are underway that could evolve into full deployment efforts in key cities and countries; successful trials could help speed these technologies' development and increase the probability that they can play an important role in the future. This is especially important given ongoing uncertainties for electric vehicles and biofuels alike, the only other potentially zero-carbon energy carriers.

Hydrogen faces many challenges. First, hydrogen is typically derived from natural gas, but its source needs to be carbon-free in order to achieve climate benefits. Second, hydrogen must be distributed by pipelines and tankers to an extensive network of refueling stations. Third, a fuel cell that is sufficiently powerful, cheap, lightweight, and durable over time must be developed. Fourth, vehicles must have on-board storage systems that keep hydrogen cooled at -253°C in high-strength carbon-fiber compression tanks, with enough volume to travel hundreds of miles between refueling.

On all counts, hydrogen needs further development before it will achieve any significant scale. One area of promising potential is the development of non-precious metal catalysts for oxygen reduction in proton exchange membrane (PEM) fuel cells. The technology desired is catalysts that fully meet the requirements of electro-catalysts for oxygen reduction in PEM fuel cells but that do not require high-cost precious materials (e.g. platinum) like current catalysts.

Efficiency

Current transportation systems are very inefficient in transforming primary energy into moving goods—more than twice as much energy is wasted than is actually used. This waste is an important source of energy itself—and one that has some of the greatest stakeholder and political support, at least conceptually. In the near term, improved fuel economy offers the greatest CO_2 reduction potential, according to IEA.

However, the "soft path" of energy has been harder to tackle than originally thought, owing to the fragmented nature of sources and activities, misalignment of incentives, and lack of policies to drive fuel efficiency. As discussed previously, the rebound effect is also a mitigating factor with efficiency, having shown the potential to take back 30 to 80 percent of savings gained.

Studies indicate that efficiency is the top area of potential for MHDVs in particular. Up to 100 percent improvement in the fuel economy for new HD trucks is possible, primarily due to multiple incremental advances in engine and vehicle design. (Indeed, the fuel economy in miles per gallon for new Class 7 and 8 HD vehicles, which consume more than 70 percent of the fuel in the trucking fleet, could be doubled through efficiency improvements.

Feasible technological improvements in vehicle efficiency—coupled with "long combination vehicles," which raise productivity by connecting multiple trailers—can potentially raise the ton-mile efficiency of long-haul heavy tractor-trailers by a factor of about 2.5 with respect to a baseline of 130 ton-miles per gallon. Within existing technological and logistical constraints, these innovations (which don't include advanced opportunities such as hybrid-electric powertrains or auxiliary power units to displace fuel use while idling) could thus cut the average fuel used to move each ton of freight by about 64 percent. This would save the current U.S. Class 8 fleet about 4 billion gallons of diesel fuel and 45 million tons of CO_2 emissions each year.

Key areas of disruptive innovation for fuel efficiency are combustion optimization, ultra-lightweighting vehicles through eliminating components and using new materials, new processing and production methods, and "telematics:" ICT solutions that enable vehicles, road infrastructure, and traffic environment to communicate with one another and thereby reduce unnecessary energy use.

Findings and Implications

In the preceding pages, we have assessed what is known about the sustainability characteristics of different transportation fuels, as well as the ranges of expectations about their future market outlooks. What follows is a synthesis of our findings, grouped into three categories: what we know about the sustainability impacts of fuels, what we expect about the future of fuel markets, and what can therefore be done to advance fuel sustainability.

WHAT WE KNOW ABOUT FUEL IMPACTS

The first theme in our findings about the future of fuels is that **we must dramatically improve our understanding of the complex and interconnected sustainability impacts of fuels**. Fuel use is responsible for some of the greatest sustainability impacts that companies face, and yet there remains a significant lack of knowledge about what these impacts are.

Finding #1: Our knowledge of the total sustainability impacts of fuels has numerous gaps. When looking for comparisons of broad sustainability impacts across many fuel types, even the most data-driven, state-of-the-art information doesn't lend itself to simple conclusions, owing in part to the complexity of different inputs as well as inconsistent methodologies and numerous gaps in our current knowledge. Many of the diverse sustainability impacts of fuel have been studied, though usually on a stand-alone basis and without being synthesized into a framework for use by company decision-makers who wish to promote more sustainable fuel choices.

Appendix 1 provides a high-level representation of the current state of knowledge described in this paper. The color coding, explained in the legend, represents an initial judgment of the relative impacts of different fuel types based on our review of existing scientific studies as well as expert opinion derived from interviews and BSR's own field experience where relevant.

There are many reasons we continue to lack a holistic understanding of fuels, not the least of which is the simple fact that the issues are extraordinarily complex and varied across fuel sources. Additional reasons include:

- Different key players (companies, NGOs, governments) often work in isolation or in groups that do not work together.
- Discourse is therefore often dominated by one-sided views from proponents of specific solutions, when what is needed is a clear and balanced view of all problems and issues and how they are intertwined.
- Major producers and users possess critical know-how, but do not have the credibility to set the terms of discussion.
- There are imbalances in transparency and accessibility to data.

Life-cycle assessment is a powerful tool but remains limited in addressing the effects of different scales of production, as well as spatial and temporal effects. In particular, current knowledge of water use and quality impacts is especially crude and needs further development.

Even for issues studied carefully, such as the carbon impacts of different feedstocks, there is variation and uncertainty stemming not only from the differences among technologies but also from the assumptions and constraints of a given calculation methodology. For example, evaluating the effect of biodiesel from palm oil on natural forest area requires assigning a depreciation period, such as 100 years, that may or may not reflect reality.

Today's fuel production technologies are a mix of the old and emergent. Across some issues, such as water impacts, we have a vague understanding even of mature sources such as crude oil. Now, with new sources and technologies under development—such as crude oil produced from the Arctic and algae-based drop-in biofuels—we have very little understanding of what to expect at all.

Expanding the scope of assessment beyond carbon makes the picture substantially more complex, and even the GHG emissions of individual sources are dependent on specific production practices and location.

It is difficult to keep pace, as energy technologies are expanding rapidly, both in terms of the underlying practices being used as well as solutions for sustainability. Developments over the past five years in biofuels, oil sands, and shale gas are testimony to this.

When looking for comparisons of broad sustainability impacts across many fuel types, even the most data-driven, state-of-the-art-information is incomplete, owing in part to the complexity of different inputs as well as inconsistent methodologies.

As a result, knowledge about fuel sustainability is being advanced in certain corners of the fuel industry, but there is no guiding framework that reconciles the different approaches and bodies of information.

> *Implication*: Companies and wider society need to place a greater priority on filling in the knowledge gaps about fuel sustainability, and applying more measured analysis across all fuel sources. This means broader thinking—expanding beyond LCAs, which tend to be environment-focused—to help us understand the trade-offs between different fuel choices and thereby avoid potential unintended consequences of policies and practices that seek to encourage or discourage the use of a particular source. Diverse networks of business, civil society, and governments need to be a part of solutions that apply sustainable development principles.

Finding #2: It is critical that issues be addressed at a systemic level in order to avoid unintended consequences and/or promotion of solutions that will fail to have desired large-scale impact. All fuels have sustainability impacts, and all of today's existing and emerging large-scale fuel resources involve significant externalities in one or more of the issues areas we considered. In some issue areas, fuel is the number one source of impacts, such as for GHG emissions.

Unconventional oil and gas are currently more carbon-intensive, but could arguably promise better near-term social and economic impacts as a function of where they are produced (e.g. developed countries such as the United States, Norway, and Canada). Conventional oil and gas are somewhat less carbon-intensive but are associated with significant social issues (both adverse "resource curse" impacts and positive opportunities to support local economic growth and development in emerging economies) in many areas of production. Biofuels offer some promise but currently have significant negative water, land, and biodiversity impacts, and even their GHG benefits are highly dependent on feedstock and practices,

Moreover, the risks are increasing. As new fuel production technologies become available to meet growing demand—in particular for pursuing unconventional sources such as oil sands, natural gas derived from high-volume horizontal fracking, and petroleum supplies originating from the Arctic—the sustainability impacts are growing. Even fuel sources that seem to offer the greatest sustainability upsides, such as biofuels and EVs, bring the potential to create worse impacts if not carefully managed.

In addition to climate impacts, water and land-use issues are significant and their impacts could be exacerbated in the future if energy investments and activities are not better informed. This is vital both at the individual company level as well as for policymakers.

Electrification appears to be the most promising in terms of sustainability impacts over the long term, especially with wind development taking hold. However, infrastructure and vehicle systems will take some time to become widely viable even if a strong shift in energy policy takes place in key countries. Advanced biofuels also show significant promise in terms of sustainability impacts; however, these come with significant local dependencies, and much research and development is still needed. There are also currently major technical and economic limitations to scaling them up, which will require significant time and investment to address.

> *Implication*: Understanding and addressing the full range of fuel impacts should be a top priority for sustainability, especially focusing on what is happening at the margins. This is a basis for creating the interest and demand among the various stakeholders—customers, investors, and policymakers—needed to guide the development of more sustainable fuels

Finding #3: Addressing systemic issues requires a long-term perspective that is often at odds with the short-term requirements of business and politics. The greatest cause for concern about the sustainability impacts of fuels relates to their likely cumulative future impact. The warnings raised by scientists and stakeholders therefore are less about managing a company's marginal drop of fuel, and more about promoting investments that lead to "step-change" improvements as the landscape changes.

For example, some of the biggest concerns about oil sands are driven by the cumulative effects of large-scale development in the future: Currently, a very small amount of oil sand fields have been developed, but 99 percent of the more than 1,730 square miles of minable land (an area roughly the size of England) has been leased—meanwhile, governments do not have the resources to keep up with the pace and scale of development.

At the same time, the development cycles of fuel technologies are long, which presents a paradox. On one hand, the time is now for companies to act in order to prepare for the future. But on the other, they will need to have patient capital, with an eye to returns that need the better part of the coming decade or longer to arrive.

It is difficult to advance on all elements of sustainability simultaneously. Progress is driven by priorities, funding, technological advancements, timing, etc. Although a single stakeholder group might perceive little progress on its issue, advancements could be occurring elsewhere. This underscores the importance of establishing clear priorities with transparent rationales.

For North American fuel producers, the absence of clear GHG regulations and GHG pricing may delay capital investment in GHG-mitigation technologies. Therefore, policy has a role to play in enabling businesses to engage more productively in policy advocacy on energy issues through further guidance.

> *Implication*: Companies need to develop an approach to fuel sustainability that involves "planning for the long term urgently," which means finding ways to act now—due to long lead times for change—and creating the mechanisms needed to be patient about results.

WHAT WE EXPECT ABOUT FUEL MARKETS

Our second general theme relates to the market outlook for fuels and can be summarized as follows: **Oil will remain the backbone of an increasingly diversified fuel mix for at least the next 20 to 40 years**. There is great uncertainty about what will happen. This is inherent in all new technologies, and energy developments are no exception. However, there are certain physical and economic realities that we can use to establish expectations, and doing so is necessary for developing the confidence needed to make investments for sustainability.

Finding #4: Advanced technologies are taking off, but still require major investment and policy support to become commercially significant. Over the past decade, advanced renewable and clean technologies, such as biofuels, EVs, and hydrogen have taken off.

In Brazil, the most advanced biofuels market in the world, virtually all new cars can run on any mix of gasoline and ethanol. The United States is the second-largest grower of biofuels, and produces enough ethanol for 10 percent of its fuel. The U.S. EV industry is tripling in size annually (though still representing a very small percentage of the fleet), and here renewable energy, which would make EVs clean, is the fastest-growing segment of the energy sector.

Generating capacity for solar and wind has been expanding in the double and even triple digits annually, and today both technologies are commercially viable in Germany, Spain, and the states of North Dakota, South Dakota, and California in the United States. Solar prices also have dropped dramatically; at a solar power auction in California in the second half of 2012, developers sold projects to utilities at lower rates than were available from the existing power grid. As for wind, some studies have shown that it could power 20 percent or more of the entire U.S. electricity grid by 2030.

The feasibility and likelihood of significant breakthroughs in terms of development and large-scale deployment of alternative, low-carbon energy solutions is one of the key assumptions in optimistic timescales for shifting the transportation energy portfolio to new, low-carbon sources. This transition will involve substantial efforts and costs associated with infrastructure and scale-up that will likely be borne by a combination of public- and private-sector incentives and policies over an extended time period. Similarly, the time required for fuel and vehicle transitions—from market penetration to vehicle stock turnover and fuel supply development—is likely to be long, i.e. decades rather than years. By way of reference, new energy technologies have historically required decades of sustained support and growth to achieve even 1 to 2 percent share of the energy mix. The further buildup of these advanced fuels will not happen on its own, faces roadblocks, and is far from certain. In particular, technology and infrastructure challenges make these fuels expensive, and policies and investment to promote their scaling up will be needed.

> *Implication*: Companies should promote commercialization of advanced fuel technologies as part of their broader fuel sustainability portfolio, recognizing that significant time will be required for them to have major commercial impact.

Finding #5: Oil will remain a driving force. There are many open questions regarding the possible—and desirable—development rates of specific fuels and technologies. Actors such as the EIA, Shell, and Greenpeace provide expectations and prescriptions whose differences can be explained in part by varying assumptions and dependences. They center on expectations about the establishment of comprehensive climate polices, the availability of fuel sources and infrastructure, the level of development and widespread adoption of new technologies, and the extent to which unintended negative impacts of new technologies are minimized.

Yet even with these different viewpoints, it is reasonably clear that the world will continue to rely on fossil fuels for a large share of our energy needs for at least the next 20 to 40 years, and low-carbon renewables will remain a relatively small part of the energy mix, even as they continue to grow faster than any other source. Similarly, North America will continue to rely on petroleum for a large share of commercial transportation needs over this time period. Furthermore, economic viability of unconventional resources may slow the transition to lower-carbon fuel sources due to both economic and security-of-supply objectives.

This situation will be driven primarily by several large-scale trends. First, we will see a dramatic increase in global energy demand driven primarily by emerging economies, whose strong growth will more than offset the expected impact of efficiency measures in developed economies. Second, global supply will struggle to keep pace with this growth, leading to greater reliance on alternative sources of energy supply such as natural gas liquids, biofuels, and unconventional oil. And third, in the absence of a price on carbon, these alternatives will also benefit from economic and national security priorities and objectives, which may thereby slow the transition to other lower-carbon fuel sources.

The perceived likelihood of political action on climate change is an additional key assumption that explains much of the difference between the forecasts (and related prescriptions) produced by various organizations. Regional and local action on climate policy continues to gather momentum in many parts of the world— even in the United States where, for example, the state of California has cap-and-trade laws coming into effect. It is conceivable that these developments could be accelerated by other events that serve to put meaningful national and international climate policy back on the agenda, but this is likely to take more time than was hoped even a few years ago.

However, almost all experts and advocates are pessimistic about the prospects for any kind of a global climate deal within the next several years, as climate change has fallen down the list of priorities for the public and governments alike, and economic challenges in the developed economies continue to command most attention. Without global agreements, many countries and regions will be unwilling to take strong GHG emission reduction actions, given concerns over competitive disadvantages and losses of other economic benefits.

Without a substantial shift in policy directions, transportation fuel will be dominated by oil over the coming decades. Even in scenarios that foresee natural gas, biofuels, and EV systems achieving their greatest potential, oil is generally expected to play a major part.

> *Implication*: Companies must promote all relevant best practices related to continued use of oil as part of their broader fuels sustainability portfolio, as this will continue to represent a major element of their sustainability impacts.

Finding #6: The greatest certainty is enhanced diversification. While there is a wide range of outlooks about the roles of specific transportation fuels in the future, one thing seems certain: We face a long period of transition in which the global energy mix and North American transportation fuel system will become increasingly diverse, with natural gas, biofuels, EVs, and hydrogen taking market share from oil.

Along with the new technologies that diversification brings, new dimensions need to be managed. One of these is a spatial issue around physical expansion, encroachment, and cumulative scale of production, involving fuel sources as diverse as biofuels and oil sands. There will be an increasingly urgent need to address the pace and scale development in order to yield the greatest benefits without creating undue risk and cost.

Another dimension that will need more attention, especially as transportation becomes more electrified and grids become smarter, is the “temporal” one—that is, the impacts that are related to the time of use. As more fuel supplies are added to the mix, the sequencing and timing of the supplies used, in addition to the scheduling of routes, will have an effect on overall sustainability impacts.

As this happens, the fuel sector will become more defined by managing trade-offs among these different fuel types on many counts. Essentially every type of fuel—from different conventional and unconventional fossil fuels to biofuels and other renewables—will play a significant role, and we will need to become adept at managing the impacts created by their collective production and use.

> *Implication:* Companies that want to advance fuel sustainability should embrace a diversified portfolio approach, focused on increasing the benefits and reducing the negative impacts of all sources, rather than searching for a single “silver bullet” solution.

WHAT CAN BE DONE TO ADVANCE FUEL SUSTAINABILITY

The third and final general theme concerns the potential pathways to improve the sustainability of transportation fuels and can be summarized as follows: **A greater focus on broad collaborative solutions will be needed to support the transition to more sustainable fuels.**

In addition to more research on total sustainability impacts and market outlooks, there is also a need for insight about practices or approaches that either are or are not working to improve the sustainability of fuels. This section highlights some high-level guidelines that will be explored further in our next paper.

Finding #7: Scaling up efficiency and best practices in production and consumption is a top shared opportunity area. For all of the divergent views of fuel sustainability, there is a notable consensus around the idea that focusing on energy efficiency and best production practices is a win-win for all and offers some of the best investment potential. Efficiency is generally seen as the most cost-effective and least-damaging sources of future energy.

Efficiency is a broad category that applies throughout the life cycle of fuels. For fleet operators, vehicle and fuel efficiency holds one of the best opportunities for reduced impacts, and represents a source of fuel on its own. Looking upstream to petroleum production, energy efficiency is one of the key levers for reducing a whole set of negative sustainability impacts, because the greater the efficiency of the system, the fewer inputs and activities needed. Many technical studies have been conducted on efficiency to support this finding.

Best practices in fuel production need to be better understood and shared. While companies have typically kept these more closely guarded as competitive information, they increasingly can be found in voluntary disclosures and consent decrees.

> *Implication*: Companies and stakeholders should encourage best-practice production operations, and redouble the focus on efficiency. There is a large amount of work to be done through collaborative arrangements that promote the best technologies and techniques for fuel use and production.

Finding #8: Value chain transparency and collaboration is an area of high innovation potential. Currently, some of the most inspiring analogs for fuel sustainability can be found in the supply chain sustainability efforts of manufacturing industries, where companies develop transparency and capacity-building systems together.

Within the fuel industry, we need to find ways to improve discourse between producers, customers, and investors, and to make more information available to stakeholders broadly. The bulk of fuel sustainability information is maintained within large companies that treat such information as proprietary, provided on a need-to-know basis for compliance purposes. This in turn constrains the potential use of that information for better scientific understanding*.* This assessment has already highlighted the currently insufficient levels of information about fuel sustainability, but even if more information was made available, we do not have the systems in place that would be necessarily to use it. Therefore, it is imperative to find ways to encourage greater sharing of information that connects these data to real choices that customers, investors, and stakeholders have to make.

On the sustainability side, we need new analytical tools. Increasingly, fuel sources will have higher impacts in some areas than in others, making it difficult to make an intelligent decision if the inquiry is a typical binary approach. For example, it would be absurd to prefer fuel with higher GHG emissions just because it is associated with lower human rights impacts. Data aside, current modes of thinking are insufficient for addressing this in fuels.

Better data and greater transparency will also help address another barrier to the development of more sustainable solutions: limited public awareness and understanding. The public is generally unaware of the broad impacts of energy and what they mean. In order to enable innovators and governments to do more, this has to change.

Ultimately, engagement needs to extend not only to corporate users of fuel but larger segments of fuel end-users. They create the demand for fuel, are the direct targets that producers market to, and they are the ones who directly burn the fuels at the stage where they create some of the greatest environmental and societal impacts. As fuel systems and vehicle technology improve, customer behavior with respect to the types and levels of fuel usage must also be addressed. The advent of high-efficiency vehicles or lower-carbon energy sources should not give drivers the license to burn fuel without restraint.

> *Implication*: Companies need to find more advanced ways to process, share, reflect, and make decisions based on fair analysis of all relevant issues and on information about fuel sustainability throughout the value chain. At the same time, they need to help the public and other stakeholders to become more aware.

Finding #9: Business and government need to work together more creatively to develop effective long-term energy policy. As noted earlier, significant changes to current energy outlooks will require a combination of new public policies and major leadership efforts that go far beyond individual company decisions related to the production and procurement of individual transportation fuels.

Such initiatives will only come about through closer and more productive cooperation between business, government, and other key stakeholders. Their aims should include three things: They should seek to dramatically slow the expected increase in global energy demand; they should work to establish an effective floor price for carbon, so that reduced demand does not simply encourage more consumption of relatively cheap fossil fuels; and they should find ways to share significant wealth and assets from the developed to the developing world in order to achieve the above on a global basis.

Governments are also important as direct owners of energy assets. More than 75 percent of proven oil reserves are controlled by national oil companies, while the private "supermajors"—BP, Chevron, ExxonMobil, Shell, Total, ConocoPhillips—control less than 10 percent. Governments also provide direct support, with national governments heavily invested in fuel sources, particularly new unconventional ones. In the oil sands, the government of Canada is a major supporter, counting on major new tax revenues from production firms. In the United States, President Barack Obama is a champion of shale gas fracturing. Third, governments are already highly involved as regulators. Private oil companies are heavily regulated in many cases, especially for emissions and water use.

Companies need to work with broad new coalitions that include direct business actors as well as governments, researchers, and civil society. This could include working for the establishment and governance of an overall integrated North American energy strategy.

> *Implication*: Business and government must work together in more creative partnerships that engage not only direct actors but also coalitions from the fields of investing, research, advocacy, and the ICT sector.

Next Steps

It is easy to say that renewables simply must be scaled up, or that climate change doesn't matter, or that the whole state of affairs is too complicated to worry about. But while there are no simple answers and no silver bullets, the stakes warrant greater investment in understanding and managing the total sustainability of fuels.

This requires facing hard truths. Frameworks and actions aimed at enhancing the sustainability of fuels will necessarily need to address the issues associated with oil and gas, the most significant ongoing fuel resources. Also, companies need to think differently—looking at their entire portfolio of fuel investments.

With this survey, we hope to inspire further work to promote a comprehensive and detailed understanding of fuel impacts in order to improve our collective efforts to address them. Innovative corporate fuel purchasers, fuel producers and investors increasingly share this hope, and are working together in more creative collaborations.

We have heard that transparency in the fuel supply chain is so complex as to be impossible to achieve. But times have changed: We have far more technology available now, companies are evolving practices and priorities to act more quickly on sustainability information, and the stakes have become extremely high. It is time to move forward.

Our Next Phase of Research

The objective of this first Future of Fuels working paper is to assess what is known about the sustainability impacts of different transportation fuels in the context of their current and projected viability as large-scale solutions. The next stage of the effort will focus on understanding *how* companies can use the information and frameworks developed in this first paper to promote the development of better fuel choices. Key issues to address in this second brief will likely include:

- From the perspective of a buyer trying to make—and verify the impact of—better choices, what are the prospects for developing adequate traceability along the supply chain?
- What can both buyers and producers do, individually and collectively, to promote the development of more sustainable choices?
- What are the potential blind spots involved in focusing efforts on a single resource? For example, what might be the downsides to singling out oil or gas, or the Canadian oil sands, or conventional production in one of the more sensitive ecological zones? In other words, what are the real current and future impacts of one source compared to other sources in other regions?
- Based on the above, what is the most effective way to engage on specific present-day issues such as those currently presented by the Canadian oil sands (and other likely future issues along these lines)?
- What other stakeholders/organizations could we usefully work with to develop solutions that are both effective and credible?

This paper will go on to explore the market structure of fuels, and evaluate existing models of innovation.

After the current period of external review and revision of this draft paper, BSR will convene project participants and interested stakeholders for a facilitated discussion designed to test and refine some of the paper's key findings, including a revised framework for understanding the total life cycle impact of different fossil-based transportation fuels and a shared perspective on how these impacts, as well as cost and availability, are likely to change over time.

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Appendix 1: Materiality Summary

What follows is a graphical summary of material issues addressed in the report. Our intention is to provide a simple picture of the results, though it is understood that there are necessarily subjective judgments (e.g. distinctions between categories) and that they can change as more information becomes available.

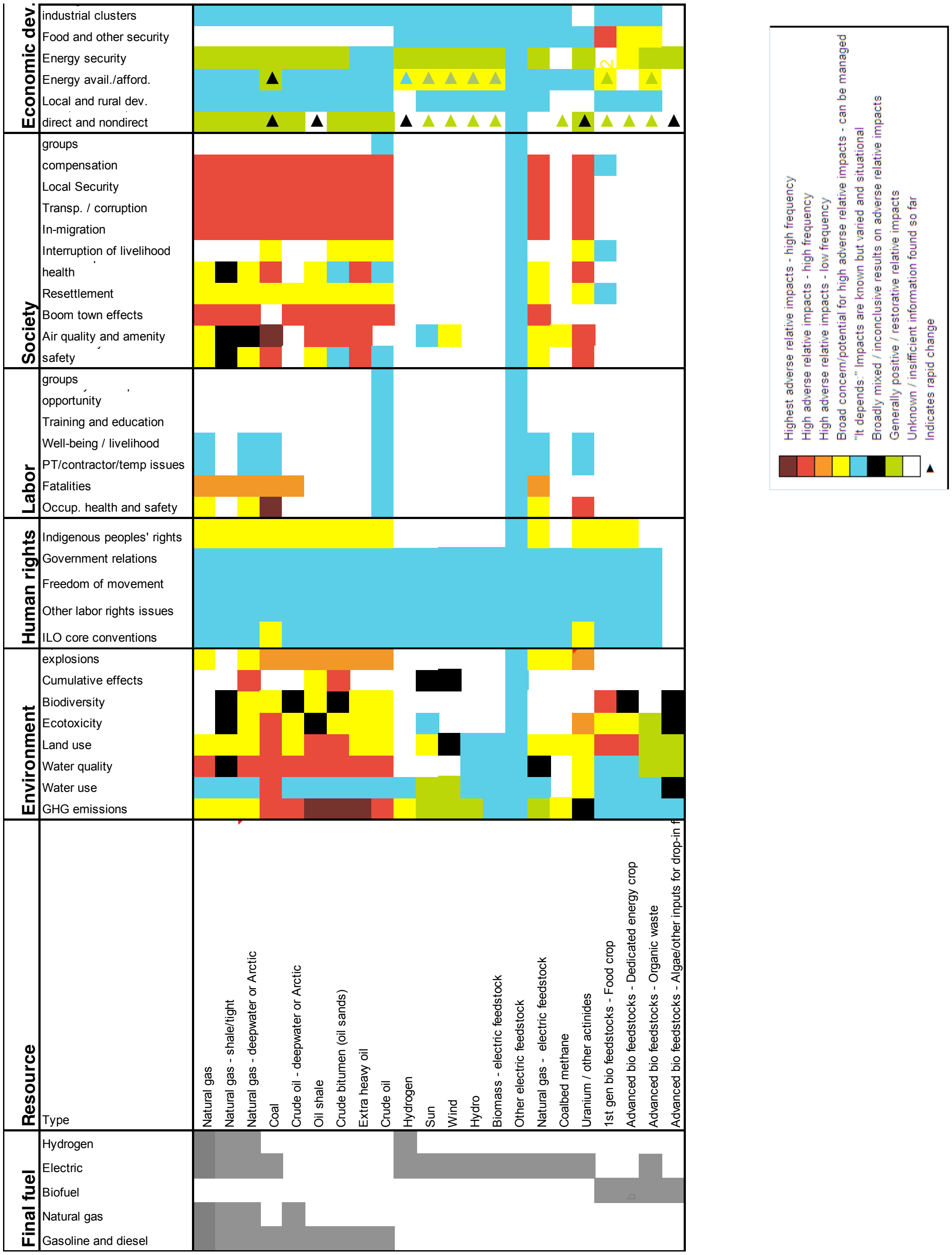


Figure 16: State of Knowledge About Fuel Sustainability

Notes:

We have placed different fuels into fairly broad categories of relative impact (highest/high/mixed etc.) as we are looking to identify major differences across a very wide range of different fuel types.

Overall conclusions about the relative sustainability impacts of different fuels cannot be directly read from this table as we have not attempted any kind of “weighting” based on the relative importance of the different sustainability impacts. Is a “red” on GHG impacts more/less important than a “red” in a specific social issue?

This is a work in progress, as evidenced by the significant amount of white space on the table representing areas where we have not (yet) encountered enough credible information to make an informed assessment. We hope and expect to fill some of these gaps, as well as correct our understanding of areas examined, based on comments from external reviewers and discussion partners.

The following sections summarize the thinking behind our ratings/designations in each issue area.

Environment

The key environmental impacts associated with fuels include those related to climate change, water, land, and biodiversity. Some of these issues and impacts are global in nature (climate change), while others are best understood and assessed in a local context (water, land, and biodiversity impacts). Additionally, we can distinguish between impacts that are an inherent attribute of the fuel in question (GHGs from combustion), and others that are a function of specific production methods and locations (production emissions and water impacts).

GHG Emissions

Unconventional oil from bitumen (oil sands), oil shale, heavy oil, and coal-to-liquids are the highest-emitting fuels on a life cycle basis. Oil sands are receiving a lot of attention for being more carbon-intensive than conventional fuels, but oil shale, which is enjoying a boom in the United States, as well as coal-to-liquids, are worse in this respect. In most of these cases, technology-driven improvements are expected to keep narrowing the gap between some unconventional and conventional fossil fuel sources, but the precise timing and scope of these likely improvements are hard to gauge.

Conventional oil, first-generation biofuels, and natural gas from deep water and Arctic sources, are placed in the next broad category of high-impact fuels.

Conventional natural gas produces lower emissions than those fuels in the above categories. There is some evidence that methane leakage may significantly impact the total GHG profile of gas when fracking is present, but the evidence is unclear.

Better still are the prospects for many second-generation biofuels, though they are generally at an early stage of development and GHG impacts can vary significantly based on local conditions and methods.

Water, Land Use, and Biodiversity

It is important to consider location in our evaluation of the water, land, and biodiversity impacts of different fuel types and production methods, making generalizations by fuel type difficult or even misleading. Water use and impacts, for example, are best understood in the context of local water availability and stress, which may vary dramatically by site.

Having said this, first-generation biofuels production is more water-intensive than that of conventional fossil fuels. The picture becomes more complicated, however, when one considers second-generation biofuels and unconventional fossil fuels.

With respect to broader water, land, and biodiversity impacts, the impacts of fossil fuels are driven in part by large infrastructure requirements and facilities’ footprints as well as by the risk of accidental spills and/or explosions. Although less susceptible to large-scale accidents, the production of biofuels can have very significant impacts on water, land, and biodiversity depending on the choice of feedstock and related agricultural practices and impacts.

As in the case of GHG emissions, second- and third-generation biofuels may have fewer negative impacts, but there is not yet enough experience with them at meaningful scale to confidently assess their impact relative to other fuels.

Social: Human Rights, Labor, and Society

The human rights, labor, and society impacts associated with different transportation fuels tend to be most prominent upstream; that is, during exploration, development, and production/extraction.

As is true in the case of some environmental issues, the production of fossil fuels generally involves greater scale of activity and therefore more significant social impacts in a given production area than biofuels. At the same time (and again, similar to some environmental issues) the location of extraction and production is just as important as the specific energy source and production methods used when considering relative human rights, labor, and social impacts.

Therefore, just as environmental impacts are best understood in the context of local *ecosystems*, human rights, labor, and social impacts are best evaluated in the context of *local political, social, and economic conditions*, (e.g. at *country-level)*. It appears that fuels produced in countries of low concern, such as Norway, Canada, the United States and others, represent better *current* human rights, labor, and social impacts than those produced in countries of higher concern.

Economic

Direct and Indirect Economic Impacts

As in the case of the human rights, labor, and society impacts, the overall economic impacts of different energy and fuel sources depend significantly on the countries or regions of production. In this case the key factor is the ability of a given country to maximize the benefits to their overall economy by promoting a related industrial base and otherwise making wise use of the revenues from extraction.

In the context of relevant major transportation fuels, this logic would give a boost to those sources—such as unconventional oil and gas, as well as biofuels—that are produced in the United States and Canada, where existing political and economic regimes are more likely to lead to broader economic benefits compared to countries characterized by weaker governance and greater susceptibility to corruption and other resource curse issues.

However, few if any advocates for support to emerging economies would regard diversion of investment from these areas as a positive step. Rather, they would emphasize the need for continued engagement and investment, with greater commitment to improving local governance and industry practices. More study and dialog on these critical issues is clearly required. In the meantime we will consider their impact to be neutral in the identification and promotion of more sustainable fuel choices.

National Security

The issue of energy security can be usefully divided between short-term and long-term considerations, noting that the dividing line between the two continues to shift as our understanding of the likely scope and timing of global climate change and other major impacts evolves.

Energy security has traditionally been understood in terms of near-term protection from supply disruption and price instability. Within this definition, any energy source that reduces dependence on dominant supply sources, such as conventional oil and gas from the Middle East (or OPEC countries more broadly), is a net positive, and this applies to any and all current and potential supplies of biofuels as well as conventional and unconventional fossil fuel sources in North America and other non-OPEC production regions.

At the same time, a growing number of experts are advocating an expanded definition of energy security that considers GHG emission-reduction objectives on an equal footing with security of supply, noting that a narrow focus on securing near-term supply will make us far less secure and competitive in the future.

For purposes of this analysis, we therefore assume that any energy source that is likely to reduce dependence on resources from the Middle East/OPEC can be regarded as contributing to national security unless that source involves significantly higher GHG emissions than those same resources.

Specifically, this means that biofuels and conventional oil and gas from non-OPEC countries can be seen as making a positive contribution, while unconventional gas produced by HV fracking and oil sands/bitumen remain questionable pending better understanding of the likely GHG profiles of these resources over the longer term.

The following figure summarizes many of the social issues discussed in the preceding pages as well as others that may be applicable to specific circumstances.

Appendix 2: Future Scenario Reference Data

Forecasts for the global energy portfolio are highly uncertain and encompass a broad range of complex interdependent variables. However, several outlooks are presented below in order to provide an overall frame regarding plausible future conditions and implications for North American road transportation fuels.

The Reference Case

The reference case for most future projections and scenarios is based on data and analysis supplied by the International Energy Agency (IEA) and the Energy Information Agency of the U.S. Department of Energy (EIA). The base case forecasts produced by these organizations are broadly similar, and so we use EIA data and forecasts, as they are relatively accessible. The most recent International Energy Outlook produced by the EIA, for 2011, paints a sobering picture of our potential energy future under their version of business-as-usual assumptions:

- World energy consumption increases by more than 50 percent between 2008 and 2035, with half of the increase attributed to China and India;
- Fossil fuels continue to supply almost 80 percent of world energy use in 2035—down from 84 percent in 2010;
- Renewables are the world's fastest-growing energy source, but still represent only 15 percent of the total mix by 2035—up from about 3 percent in 2010; and
- Based on the above, global energy-related CO_2 emissions rise 43 percent between 2008 and 2035, reaching 43.2 billion metric tons in 2035, taking planet Earth beyond the level of 450 ppm considered by most scientists to be the threshold for dangerous climate change, though there is increasing concern that changes we are already seeing at 400 ppm are unsafe.

Of more direct relevance to transportation are the projections for total growth and mix of liquid fuels, which include gasoline, diesel, and different compositions of natural gas. According to the EIA, production of liquid fuels increases from 84.1 million barrels per day in 2010 to 99 million barrels per day in 2035 (a 22 percent increase). Liquid fuels remain the largest energy source worldwide through 2035, but the share of conventional oil declines as sustained high oil prices encourage the increased development of unconventional fossil fuel sources and increased use of liquid biofuels. The projected change in the mix of liquid fuels is shown in Figure 17.

Figure 17: Share of World Liquid Fuels Production

	2010	2030
Conventional Liquids	94.7%	88.3%
Oil Sands/Bitumen	2.2%	4.3%
Biofuels	2.2%	4.2%
Coal-to-Liquids	0.2%	1.5%
Extra-Heavy Oil	0.6%	1.3%
Gas-to-Liquids	0.1%	0.3%
Shale Oil	0.0%	0.1%

Source: EIA World Energy Outlook 2011

It is important to note that the reference case produced by the EIA is based on macroeconomic and other models that do not attempt to account for potential new policies aimed at reducing GHG emissions. For a perspective on the possible alternative scenarios based on different assumptions about future policy and practices, we can turn to research provided by energy producers such as Shell and BP, as well a major 2010 report issued by Greenpeace.

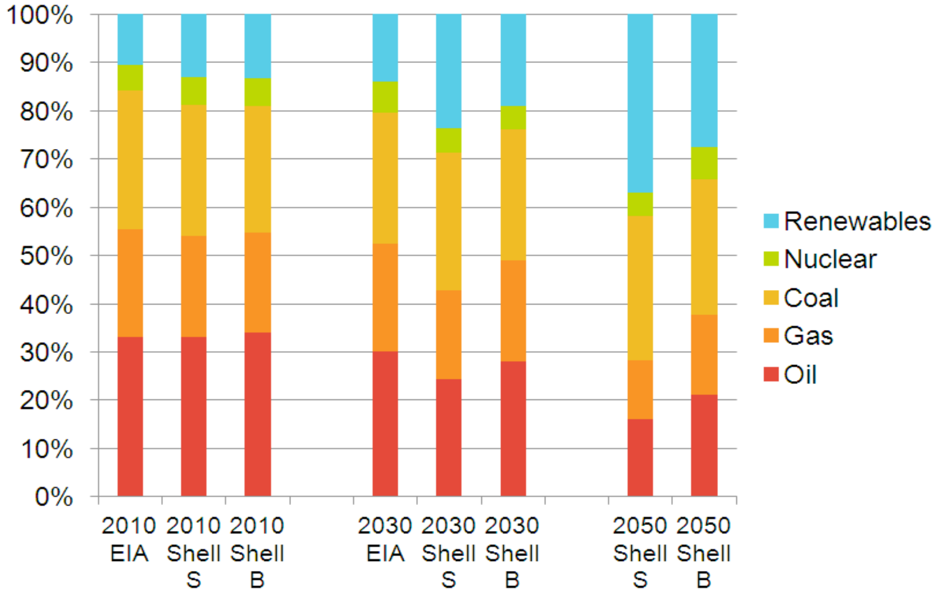
The Shell Energy Scenarios

Shell's most recent energy scenarios to 2050, published in 2008 and assessed again in 2011, are based on what they refer to as three hard truths about energy supply and demand:

1. We can expect a step-change increase in energy use driven by largely by emerging economies, whose strong growth will more than offset the expected impact of efficiency measures in developed economies;
2. Global supply will struggle to keep pace with this growth, leading to greater reliance on alternative sources of energy supply such as natural gas liquids, biofuels, and unconventional oil; and
3. Environmental stresses will continue to increase, making it difficult to remain within desirable levels of CO_2.

Against this backdrop, Shell offers two alternative scenarios—*Scramble* and *Blueprints*—each based on a different set of assumptions with respect to policy and related business investment decisions and behavior. Figure 18 below shows the expected changes in energy mix from 2010–2050 under each of these two scenarios, compared to the EIA reference case.

Figure 18: Development of Energy Mix Under EIA Reference Case and Shell Scenarios



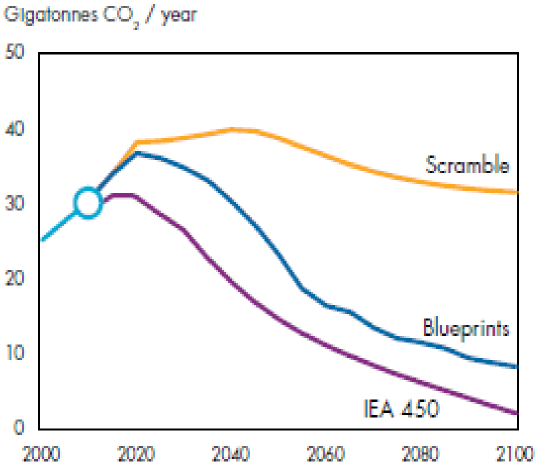
Source: Shell. Notes: Shell S = "Scramble" Scenario, Shell B = Shell "Blueprints" Scenario; in EIA reference case, "oil" includes a small amount of liquid biofuels

Scramble reflects a focus on near-term national energy security. National governments focus on supply-side levers, including bilateral agreements and incentives for local resource development, which lead to particularly strong growth in coal and biofuels. Efforts to improve efficiency and address climate change are deferred until late in the period, when more severe action results in price spikes and volatility. Although the growth rate of GHG emissions slows by 2050, the world is on a path to concentrations well above 550 ppm.

The *Blueprints* scenario foresees new coalitions of interests promoting action in both developed and developing nations on the basis of supply and environmental concerns, as well as entrepreneurial opportunities. In this scenario, individual cities or regions take the lead and their efforts become progressively linked as national governments are forced to harmonize the resulting patchworks of measures.

The United States, for example, takes significant steps to foster greater fuel efficiency, a gradual increase in corporate average fuel efficiency (CAFE) standards, and taxes on the sale of less fuel-efficient vehicles. As a result of these and other measures, effective market-driven efficiency measures emerge more quickly, and market-driven CO_2 management practices spread. The growth of GHG emissions is thereby constrained, leading to a more sustainable environmental pathway than that envisaged in Scramble, but still above the 400–450 ppm threshold most scientists believe is necessary to significantly reduce the risks of climate change (see Figure 19).

Figure 19: Shell Scenarios: Projected CO_2 Pathways



Source: Shell, 2011

When Shell presented these scenarios in 2008, they regarded the *Blueprints* scenario as feasible but requiring that we overcome very significant political and economic challenges. In its 2011 update, based on the failure to reach a global climate deal, the global recession, and other factors, the company concludes that the overall CO_2 future is likely to be closer to the *Scramble* scenario than to *Blueprints.*[12]

The Shell scenarios authors conclude that "with policy drift and increasing challenges to market-based solutions," we must focus on promoting policies that deliver on the parallel priorities of 1) delivering affordable solutions now and 2) enabling technological advances for the future. The main contributing factors to this more pessimistic assessment include the following:

- Climate change has fallen down the list of priorities for the public and governments, and below-average growth in developed economies will restrict their governments' freedom to maneuver as they inevitably tighten spending and raise taxes.
- The impact of political delay is amplified by the necessary timescales for change. The existing stock of vehicles can last 15 or more years; buildings, infrastructure, and power stations last many decades, and city structures and layouts can last for centuries. New energy technologies have historically required decades of sustained support and growth to achieve even 1–2 percent of the energy mix.

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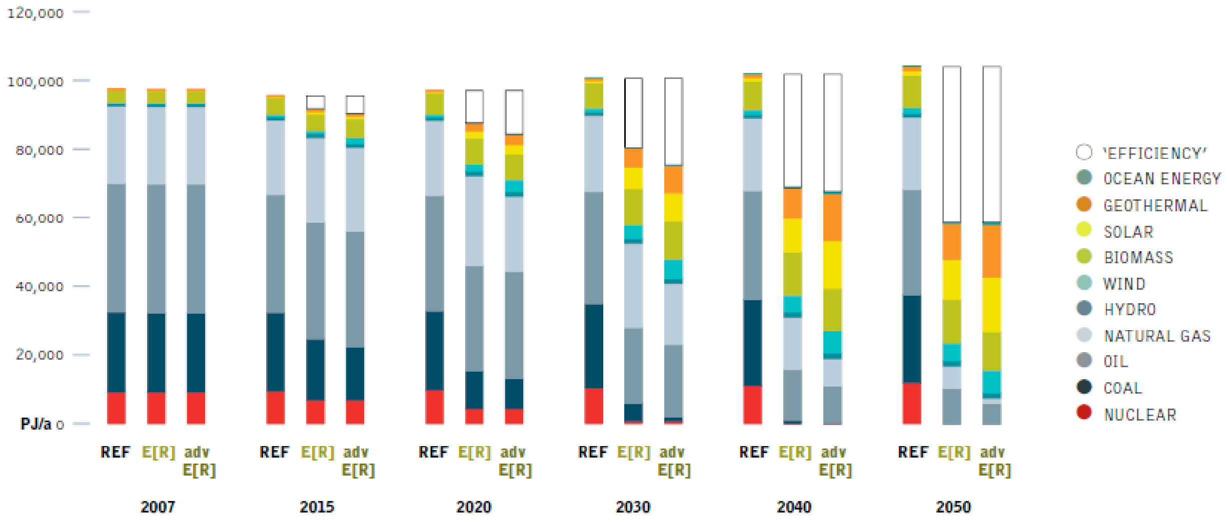
[12] The challenges of creating a global framework for carbon reduction are particularly pronounced between developing and developed countries—because in pressing for carbon reductions, the former aspire towards higher standards of living based on use of cheaper, more abundant fossil fuels). The tension between developing and developed countries is fueled by ongoing disagreements over how to interpret a fundamental underpinning of the UNFCCC and Kyoto framework—namely, the principle of common but differentiated responsibilities among industrialized (Annex I) and developing (non-Annex I) countries, particularly when it comes to establishing and achieving meaningful mitigation targets. Without global agreements, many countries and regions are unwilling to take strong GHG emission reduction actions given concerns over competitive disadvantages and losses of other economic benefits. At the same time, many regions are taking action more locally, perhaps most notably in California, which has cap-and-trade laws coming into effect. However, while carbon trading has significantly grown in recent year, the cost of carbon—and indeed, other impacts—is fully reflected in decisions associated with different transportation fuel choices without more widespread international mechanisms.

The importance of these key assumptions in shaping different pictures of the future are illustrated vividly by comparing the EIA reference case and Shell scenarios with the very different picture painted by organizations such as Greenpeace, as exemplified in their major 2010 report *Greenpeace Energy (R)evolution*.

Greenpeace Energy (R)evolution

The *Greenpeace Energy (R)evolution* scenarios are intended as a blueprint for an accelerated transition away from most fossil fuel use by 2050. The results of both an *Energy Revolution* and *Energy Revolution–Advanced* scenario are compared to a reference case based on EIA data in Figure 20.

Figure 20: Development of Energy Mix Under Three Greenpeace Scenarios



Source: Greenpeace 2010

There are two especially notable differences between the Greenpeace outlook and those produced by the EIA and Shell. The first is that *absolute* energy reduction is achieved with aggressive and large-scale efficiency efforts. The second is that nuclear and coal are replaced largely with renewables by 2040 and completely phased out before 2050.

The authors of the Greenpeace report are clear about the framing and the critical qualifying assumptions behind their scenarios, and they provide a useful perspective for assessing the likelihood of the very different future energy pathways described in their own work versus those considered earlier.

Greenpeace Energy (R)evolution starts from the premise that we must find a way to radically reduce GHG emissions to levels consistent with avoiding an average global temperature increase of 2 degrees Celsius or more. The alternatives are unthinkable, as the adverse externalities of climate change impacts outweigh the costs of investing in climate change mitigation. Working backwards from this necessary result they have created a blueprint that they believe achieves the necessary reductions in a way that is also beneficial in economic and other terms over the long term. Among the specific key assumptions underpinning this blueprint are the following:

- Dramatic reduction in overall energy demand, enabled by effective policies and incentives for more efficient buildings, vehicles, and manufacturing, is a “crucial prerequisite for achieving a significant share of renewable energy sources in the overall energy supply system, compensating for the phasing out of nuclear energy and reducing the consumption of fossil fuels.” Large-scale energy efficiency improvements do not lead to increased demand for energy that offsets the benefits.

- Investment costs must be shared fairly between developed and developing countries via some kind of a global climate regime, including mechanisms for large-scale transfer of financial and technology resources such as a Greenhouse Development Rights framework (GDR) and/or a global “Feed-in Tariff” Support Mechanism (FTSM).

By way of an initial action plan, the *Greenpeace Energy (R)evolution* report authors therefore demand that the following enabling policies be implemented for the energy sector:

- Phase out all subsidies for fossil fuels and nuclear energy.
- Internalize the external social and environmental costs of energy production through emissions trading and regulation.
- Mandate strict efficiency standards for all energy-consuming appliances, buildings, and vehicles.
- Establish legally binding targets for renewable energy and combined heat and power generation.
- Reform the electricity markets by guaranteeing priority access to the grid for renewable power generators.
- Provide defined and stable returns for investors, with programs like feed-in tariffs.
- Implement better labeling and disclosure mechanisms to provide more environmental product information.
- Increase research and development budgets for renewable energy and energy efficiency.

It is reasonable to assume that the authors of the EIA reference case and the Shell scenarios believe it is unlikely that such policies will be adopted any time soon, whether or not they agree that such moves are desirable.

WHICH FUTURE? KEY ASSUMPTIONS BEHIND THE SCENARIOS

The different forecasts and scenarios produced by the EIA, Shell, and Greenpeace usefully highlight the key assumptions that explain much of the variations between their own scenarios, and also the forecasts and prescriptions produced by other organizations. Four key—and related—assumptions driving the outlooks are:

1. The perceived likelihood of significant political action on climate change, in the form of new local and/or international policies
2. The current availability and infrastructure for fossil fuels as well as the potential resource base of developed and undeveloped (conventional and unconventional) fossil fuel resources
3. The use of advanced alternative-fuel technologies in a way that maximizes positive impacts and minimizes negative ones
4. The feasibility and likelihood of significant breakthroughs in terms of development and deployment of alternative, low-carbon energy solutions

With respect to the first assumption—concerning the prospects for significant political action on climate change—the most that can be said at the current time is that the future is profoundly uncertain. While earlier hopes for a comprehensive global climate deal have dimmed in the aftermath of the COP15 summit, significant action continues on a local and regional level in the form of cap-and-trade mechanisms, and various tax and subsidy regimes aimed at promoting greater energy efficiency and lower-carbon energy sources. It is unclear whether and how quickly these diverse initiatives can coalesce to produce globally significant impacts.

The second assumption underlies many considerations across all scenarios, including implicit or explicit assessments of the potential energy mix, government action to protect security of supply, and basis for energy efficiency activities.

The third set of assumptions regards using alternative fuel technologies in a way that maximizes positive impacts and minimizes negative ones. For example, if solar or wind energy are used to power electric vehicles, the energy they run on will be carbon-free. Conversely, if power plants that fuel EVs run on coal, then carbon emissions will be greater than with gasoline. A similar situation is true with biofuels: They hold the potential to have virtually zero life cycle emissions, but if not cultivated effectively they can lead to substantial land use impacts.

The fourth set of assumptions—those related to the possible or likely rate of development and deployment of low-carbon energy solutions—are particularly important in considering the prospects for new transportation fuels and technologies, as the availability of fuels must be matched by the development of widely distributed infrastructure. This in turn creates a strong link back to our first set of assumptions about the outlook for new climate-related political action and policy, as the time and investment required for fuel and vehicle transitions tends to be substantial.

For example, although electric vehicles and biofuels are beginning to enter the market (and hydrogen fuel-cell vehicles could enter by about 2015), it could take decades for any alternative fuel pathway to make a major difference in the global energy mix and related GHG emissions because of the time required for market penetration, vehicle stock turnover, and fuel supply development. Since development, transportation distribution, marketing, storage, etc. of current transportation fuels are overwhelmingly dominated by oil products, costs of shifting the transportation portfolio to other energy sources are very substantial and would need to be borne by a combination of public- and private-sector incentives and policies over an extended time period

IMPLICATIONS FOR ASSESSING THE SUSTAINABILITY IMPACTS OF MAJOR FUELS

The main implication of the findings in this section on the market outlook for different transportation fuels is that we are facing a long period of transition in which the world will continue to rely on fossil-based transportation fuel sources even as lower-carbon alternatives take hold in the market.

We must therefore cast a very wide net as we turn to the question of the relative sustainability impacts of different fuels, both in terms of the fuels considered—everything from different conventional and unconventional fossil fuels to biofuels and other renewables will play a significant role—and the impacts created by their production and use.

Appendix 3: Current Fuel Production by Country

Top 25 energy producers—based on approximate annual production of oil, natural gas, and biofuels in BTUs.

Figure 21: Current Fuel Production by Country

Country	Oil 61.3%	Natural gas 38.5%	Biofuel 0.1%	Sum total production
Russia*	21,742	21,200	0.00	**42,942**
United States*	20,509	21,996	147.03	**42,653**
Saudi Arabia*	22,271	3,022	0.00	**25,293**
Iran*	9,001	4,986	0.00	**13,987**
Canada*	7,374	5,483	5.78	**12,862**
China	8,623	3,690	8.12	**12,321**
Mexico	6,315	2,127	0.00	**8,442**
Norway*	4,518	3,827	0.00	**8,344**
United Arab Emirate	5,955	1,758	0.00	**7,713**
Algeria	4,399	3,065	0.00	**7,464**
Qatar	3,042	4,201	0.00	**7,243**
Nigeria	5,204	836	0.00	**6,039**
Venezuela*	5,028	824	0.00	**5,852**
Brazil*	4,871	867	90.32	**5,828**
Iraq*	5,593	47	0.00	**5,640**
Kuwait	5,187	414	0.00	**5,600**
Indonesia	2,181	2,981	0.00	**5,161**
United Kingdom	2,949	2,027	1.05	**4,977**
Libya	3,787	572	0.00	**4,360**
Angola	4,209	25	0.00	**4,233**
Kazakhstan*	3,404	727	0.00	**4,131**
India	2,020	1,901	0.88	**3,921**
Malaysia	1,516	2,394	0.56	**3,910**
Egypt	1,403	2,257	0.00	**3,660**
Netherlands	126	3,066	1.64	**3,194**
Argentina	1,617	1,444	9.78	**3,070**
Australia	1,163	1,624	1.43	**2,788**
Oman	1,837	891	0.00	**2,729**
Uzbekistan	184	2,128	0.00	**2,312**
Turkmenistan	457	1,526	0.00	**1,984**
Thailand	861	1,112	3.75	**1,977**
Trinidad and Tobago	307	1,526	0.00	**1,832**
Germany	312	455	17.00	**784**
Italy	321	302	3.89	**628**
Bolivia	95	530	0.00	**625**
Poland	60	219	1.96	**281**
France	180	26	13.41	**219**
Austria	63	62	2.22	**127**
South Korea	102	19	1.66	**124**
Spain	63	2	6.84	**72**
Belgium	24	0	2.64	**26**
Singapore	23	0	0.00	**23**
Portugal	10	0	1.60	**12**
Sweden	10	0	1.23	**11**
Jamaica	1	0	1.13	**2**

Source: CIA Factbook and BP.

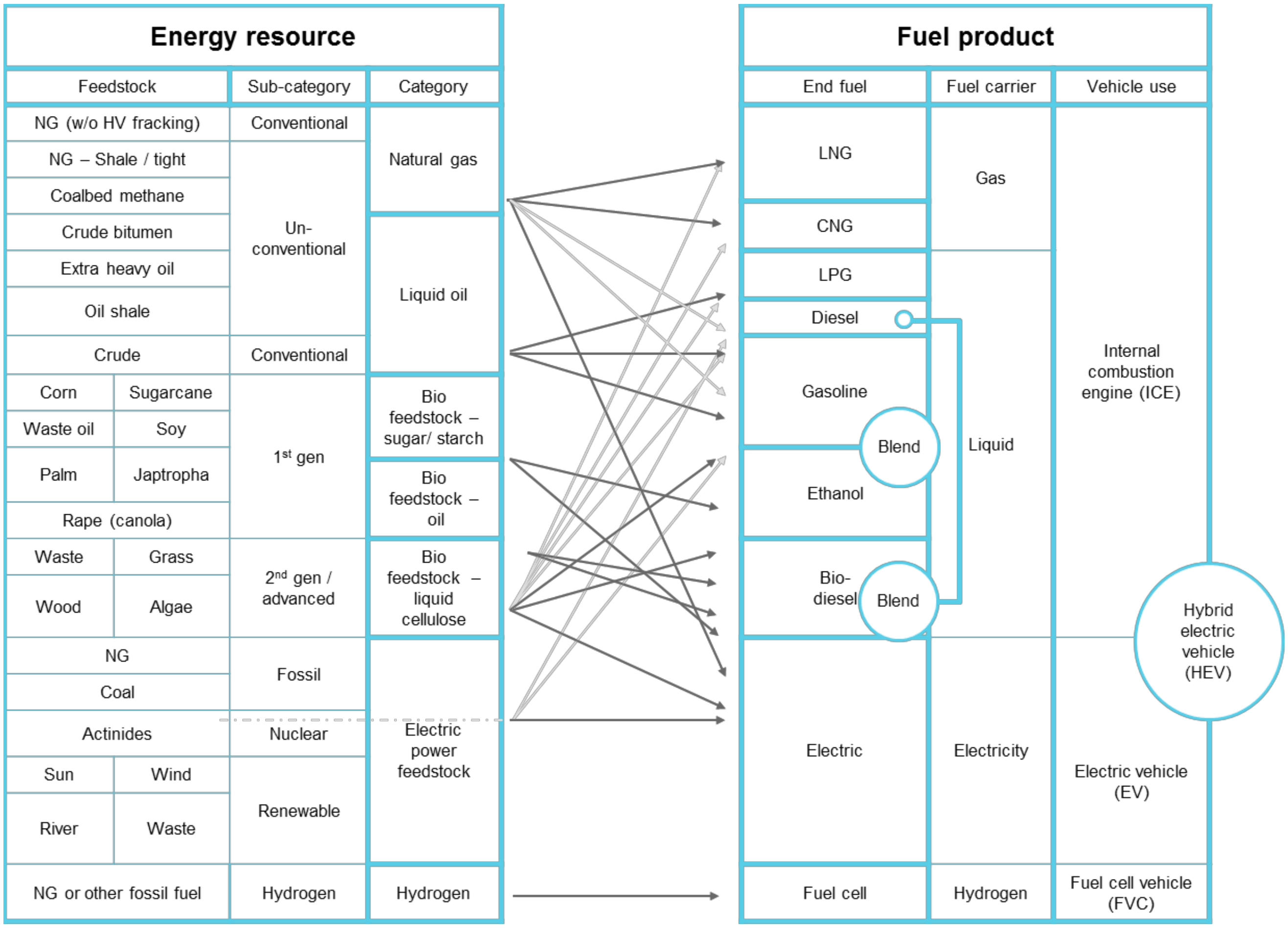
Notes: Asterisk denotes countries that have either substantial unconventional reserves or giant reserves of conventional oil. Biofuel includes ethanol and biodiesel.

Appendix 4: Background on Crude Oil

Given that oil provides the vast majority of transportation fuel feedstock, some clarifications are in order about the significance and structure of the industry. This section provides background.

These fuels are derived from a variety of sources and chemical and thermal conversions that take place in overlapping supply chains (see Figure 22). The resources of origin include conventional and unconventional oil and gas, a dozen or so bio-feedstocks, and all resources that might be used to drive an electric power plant, including coal, uranium, and renewable resources such as the sun, wind, hydro power, and hydrogen.

Figure 22: Fuel Value Chain Process Overview



Source: BSR

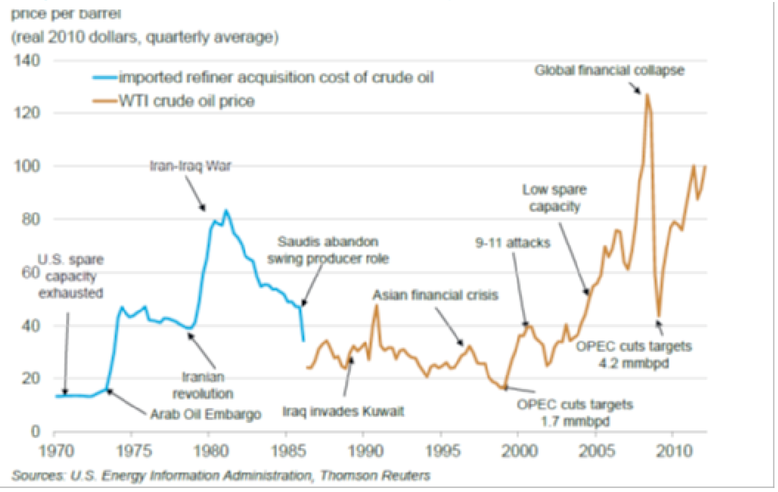
In practice, around 90 to 95 percent of transportation fuels in North America are currently petroleum-based, with gasoline taking up around 70 percent and diesel around 22 percent. Biofuels and natural gas comprise most of the remaining 5 to 10 percent somewhat evenly (2 to 4 percent each). Electric and hydrogen currently make up a small fraction (<0.1 percent each).

While biofuel, electric, hydrogen, and natural gas technologies are developing quickly, they are changing against very small baselines. Even with huge growth in all of these over the coming decades, the vast majority of fuel is still expected by even the most ambitious forecasts to come from petroleum-based sources.

The price of diesel and gasoline is based on the spot price of crude oil. In 2011, around two-thirds of the price for regular gasoline was from the crude oil itself, while the remainder was roughly evenly split between refinery costs and profits, distribution and marketing, and taxes.

The price of oil has a strong, albeit complex, impact on the competitiveness of alternative fuels. Sustained, high crude oil prices may make biofuels and other advanced alternative transportation fuels more competitive in the short term. In the long term, however, they incentivize development of additional crude oil production in the long term.

Figure 23: Crude Oil Price Volatility



Source: U.S. Energy Information Administration, Thomson Reuters

Economic volatility of oil is based on a range of political and economic factors that impacts and interacts with economic and sustainability factors (see Figure 23). For example, shifts in oil prices directly affect the global economy, national economies dependent on oil exports, and social well-being of communities receiving tax benefits from oil and gas operations.

Oil is primarily owned and controlled by OPEC governments, which manage oil as a strategic commodity and in some cases is a primary contributor to domestic GDP. Globally, state-owned companies control around 75 percent of proven energy reserves, while private Western companies control less than 10 percent.

In the United States and Canada, petroleum for transportation is consumed primarily as gasoline, the rest as diesel with the vast majority of these products from conventional crude oil, with a rising share from “unconventional” crude oil, such as from Canada’s oil sands. Oil can be classified as:

- Conventional oils: crude oil, natural gas liquids (NGLs), condensate
- Transitional oils: heavy oil, ultra-deep oil, tight shale oil
- Unconventional oils: extra-heavy oils, oil sands, oil shale
- Other unconventional hydrocarbons: Gas-to-liquids, coal-to-liquids, biofuels

Oil is extracted by drilling (except for shallow bitumen, which is surface-mined) and then processed in more than 130 domestic refineries.

Although we may think of oil as being uniform, the qualities and impacts of crude oil differ dramatically from its geological source, there are over 150 standard regional blends of oil (“benchmarks”), which can be themselves blended together before or at a refinery which creates the end fuel.

The end-use fuel can be derived from sources besides crude oil. For example, second-generation biofuels and—much less efficiently—coal can be used to create gasoline with the same technical specifications, some of which are considered proprietary inputs that companies differentiate themselves with.

This continuing blending of fuel’s supply chain distinguishes it from manufactured goods, where the origins of distinct components can be observed more readily. This means that even though there is attention to fuel sources such as oil sands, it is difficult or impossible to detect the origins of end-use fuels. Techniques do exist for detecting markers from specific locations, but we are not aware of any commercial-scale schemes that use them, due to high costs.

Notably, Canada holds around 70 percent of known oil sands reserves, and therefore the resource is often associated specifically with that country. However, oil sands also exist in Russia, Kazakhstan, and elsewhere; and Venezuela has similar reserves of bituminous heavy oil.

Appendix 5: Biofuel Feedstocks

What follows is a simple categorization of selected biofuel types and their feedstocks.

Figure 24: Biofuel Feedstocks

FEEDSTOCK								
			First-generation biofuels	Advanced (or "second-generation" and beyond) biofuels				
				Cellulose			Algae	Other
				Dedicated non-food energy crops	Organic wastes			
					Food crop wastes	Other residue, waste		
Fuel Type	Liquid transportation fuel*	Ethanol, methanol, and butanol	Corn Molasses Sugar beets Sugar cane Wheat Potatoes, fruits, and other sugars/starches that make alcohol	Cassava Corn stover, Elephant grass Guayule Miscanthus grass Poplar Switchgrass Willow	Distiller grains Sugarcane bagasse Wheat straw Other stems, leaves husk	Land-scape waste Wood chips Other ag, industrial, municipal waste	Algae (carbohydrates to bioethanol and biobutanol)	
		Biodiesel	Animal fats Castor seed Copra seed Cotton seed Field pennycress Groundnut kernel Flax Hemp Mahua Mustard Palm oil Pongamia pinnata Rapeseed (canola) Soy Sesame Sunflower Vegetable oils	Camelina Jatropha Elephant grass	Other fats, oils, and greases (FOG)	Biochemical Diesel	Algae (lipids to biodiesel)	
		Drop-in fuels		Jatropha		Biomass-to-liquids	Algae	Bacteria, fungi
	Biogas for transp. and electric power		Maize Millet Sudan grass White sweet clover			Municipal waste, green waste, plant material, and crops.		Biomass Manure, Sewage,
	Solid biomass for electric power						Wood Sawdust Grass Trimmings Domestic Refuse Charcoal Ag waste Non-food energy crops Dried manure	

*Additional liquid fuels include biochemical diesel, biohydrogen, DMF, and BioDME.

Appendix 6: Biodiversity Hotspots

What follows are eco-regions with biodiversity threatened by fuel production. Some items appear more than once so that they can be indexed by region.

North America

- **Aruba, Columbia, Netherlands Antilles, Panama, Trinidad and Tobago, Venezuela:** Southern Caribbean Sea (#237)
- **Bahamas, Cayman Islands (United Kingdom), Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico (United States), Turks and Caicos Islands (United Kingdom), United States:** Greater Antillean Marine (#236)
- **Brazil, Colombia, Venezuela:** Orinoco River and Flooded Forests (#148)
- **Canada:** Canadian Boreal Forests (#82), Canadian Low Arctic Tundra **(#114)**, Muskwa / Slave Lake Boreal Forests (#81)
- **Canada and United States:** Alaskan North Slope Coastal Tundra (#113), Gulf of Alaska Coastal Rivers and Streams (#177), and Northern Prairie (#94)
- **El Salvador, Guatemala, Honduras, Mexico, Nicaragua:** Mesoamerican Pine-Oak Forests (#63)
- **Mexico, United States:** California Chaparral and Woodlands (#121)

South America

- **Aruba, Colombia, Netherlands Antilles, Panama, Trinidad and Tobago, Venezuela:** Southern Caribbean Sea (#237)
- **Brazil, Colombia, Venezuela:** Orinoco River and Flooded Forests (#148)
- **Colombia, Ecuador, Panama, Peru:** Panama Bight Mangroves (#142)
- **Colombia, Ecuador, Peru:** Napo Moist Forests (#43) and Tumbesian-Andean Valleys Dry Forests (#57)

Europe

- **Aruba, Colombia, Netherlands Antilles, Panama, Trinidad and Tobago, Venezuela:** Southern Caribbean Sea (#237)
- **Armenia, Azerbaijan, Bulgaria, Georgia, Iran, Russia, Turkey, Turkmenistan:** Caucasus-Anatolian-Hyrcanian Temperate Forests (#78)
- **Finland, Norway, Russia, Sweden:** Fenno-Scandia Alpine Tundra and Taiga (#115)
- **Japan, Russia:** Okhotsk Sea (#204)
- **Norway, Russia:** Barents-Kara Sea (#85)
- **Russia:** Russian Far East Temperate Forests (#71), Eastern Siberian Taiga (#84), Kamchatka Taiga and Grasslands (#198)

Asia

- **Indonesia:** Sumatran Islands Lowland and Montane Forests (#26), Central Sulawesi Lakes (#188), Banda-Flores Sea (#220)
- **Brunei, Indonesia, Malaysia**: Borneo Lowland and Montane Forests (#31)
- **China, Mongolia, Russia:** Daurian Steppe (#96)
- **Indonesia, Papua New Guinea**: New Guinea Mangroves (#138), Lakes Kutubu and Sentani (#187)

Africa

- **Angola, Cameroon, Democratic Republic of Congo, Equatorial Guinea, Gabon, Ghana, Nigeria:** Gulf of Guinea Mangroves (#135)
- **Nigeria:** Niger River Delta (#155)

Middle East

- **Armenia, Azerbaijan, Bulgaria, Georgia, Iran, Russia, Turkey, Turkmenistan:** Caucasus-Anatolian-Hyrcanian Temperate Forests (#78)
- **Iran, Iraq, Kuwait:** Mesopotamian Delta and Marshes (#158)
- **Djibouti, Egypt, Eritrea, Israel, Jordan, Saudi Arabia, Sudan, Yemen:** Red Sea (#231)

Arctic

- **Finland, Norway, Russia, Sweden:** Fenno-Scandia Alpine Tundra and Taiga (#115)

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