The Sustainability Impacts of Fuel

Understanding the Impacts of Transportation Fuel for Trucking in North America

A BSR Future of Fuels Initiative Publication

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About BSR's Future of Fuels

BSR's Future of Fuels is a multistakeholder initiative that aims to promote a more comprehensive understanding of 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.

We intend 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 multi-sector 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 is informed by BSR's Business in a Climate-Constrained World initiative, which shows that we must pursue strategies to enhance resilience with urgency and ambition. We must both reduce our emissions to keep them consistent with a 2°C pathway and enhance adaptive capacity in the face of inevitable climate impacts.[1]

About This Report

This report is written by Eric Olson, Ryan Schuchard, Nate Springer, and Sekita Grant at BSR, and it is based on numerous sources, including a wide range of scientific studies, input from experts, and BSR's own experience.

We welcome feedback to futureoffuels@bsr.org.

[1] Intergovernmental Panel on Climate Change (2007). "Climate Change 2007: Synthesis Report." At the Fifteenth Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC) meeting in Copenhagen, Denmark, in December 2009, countries agreed to hold the increase in the global mean temperature below 2°C above preindustrial levels in accordance with the findings of the "IPCC Fourth Assessment Report."

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Preface

This study explores the total sustainability impacts of North American road transportation fuels. The intended audience is corporate fuel users and their value chain partners who seek to understand the sustainability impacts of fuel and broad sets of risks and opportunities associated with addressing them. The paper was first published in 2012 and is updated for 2014.

The catalyst is a stated desire by North American corporate purchasers of transportation fuels and decision-makers with supply chains that use them to improve knowledge about fuel sustainability attributes and to identify ways to positively influence both energy production and consumption practices using a system and life cycle perspective.

In order to maintain focus, this paper has a limited scope: It addresses fuels for road (and not air, ocean, or rail) and specifically freight (and not passenger transport). It focuses on the characteristics of fuel supply, rather than fuel-demand issues such as efficiency, mode choice, and logistics optimization (although we will point out that these are critically important theaters of action). Finally, it focuses on fuel that is consumed in North America. Wider elements are left for future research. An effect is that it has a strong emphasis on heavy-duty and long-distance trucking applications, where oil comprises more than 90 percent of the fuel currently used.

In organizing this updated study, BSR brings several key assumptions:

Climate Change Is an Urgent Priority. BSR is greatly concerned about climate change and believes we must stabilize global warming at 2°C. Business leaders need to take climate science seriously, aggressively reduce emissions, and call on governments to take bold climate action. We already know that transportation is a major source of energy-related GHG emissions, and the impacts of climate change could damage transportation infrastructure from more intense floods, droughts, and heat waves.

Solutions Must Be Broadly Sustainable. We must take care to promote climate solutions that are broadly sustainable, both to ensure that they have a durable “license to operate” and that they do not undermine other important development objectives. Therefore, this report considers climate change as a first order of business, while providing a framework to evaluate a wider set of issues as companies reduce climate impacts from fuel.

Externalities Persist and They Need to Be Internalized. Fuels have many sustainability impacts that are externalities and therefore are not included in the prices paid by fuel consumers. Fuel purchasers may be able to make the best decisions only when the most critical environmental, social, and economic sustainability impacts are internalized.

To Meet the Challenge, Policies that Incentivize Long-Term Investment Are Required. 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 while incentivizing long-term investment, and that encourage improved sustainability practices among existing and emerging fuel sources with attention to the need for sustained transition to more-sustainable fuels.

Corporate Fuel Users Can Play a Critical Role in Driving Change. We believe that fleet operators and other corporate users of fuel can play a key role in unlocking and enabling increased fuel sustainability through creative purchasing and partnerships in the industry. As a corollary, we believe that policymakers should view corporate fuel users as potential allies in the drive to make fuel more sustainable. This report therefore focuses on fleet users as key potential decision-makers and influencers.

Impartial Synthesis Is In Short Supply. The field of study on fuel sustainability is vast, and key analysts—which include scientific institutions, government agencies, fuel producers, fuel users, vehicle manufacturers, investors, and issue activists—have diverse values and objectives. There are many experts and studies associated with individual sustainability issues, technologies, and geographies related to fuel. As a result, a complete picture that companies can use to make investments in fuel sustainability broadly has not yet been developed, and companies face dueling studies and single-subject advocacy. Therefore, much work remains to be done to inventory the issues present across the whole current—and likely future—portfolios of fuels that include incumbent, "transitioning," and emerging fuels. This brief will leave judgments about a desired proper mix of fuel types in the system to other forums, and simply consider attributes and issues within fuel types across a portfolio.

Decision-Makers Need to Be Visionary Yet Grounded. From the standpoint of corporate fuel users, research and advocacy on fuel sustainability tend to be either too abstract to support investment decisions or simply unambitious. We need to be much more inventive with fuel sustainability, and, at the same time, to develop a clear picture of economic and operational issues associated with fuels. This report therefore discusses both fuel sustainability and fuel markets together.

SUMMARY OF UPDATES

This report is an update of a working draft published in 2012, and is guided by two main objectives. First, it aims to reflect new understanding about the science of fuel sustainability, and incorporates new findings throughout. These include numerous new studies cited as well as feedback from experts during various forums led by BSR's Future of Fuels over the last two years. It also reflects the recent report by Future of Fuels, "Transitioning to Low-Carbon Fuel: A Business Guide for Sustainable Trucking" (BSR, 2014), which outlines an approach for companies to transition to low-carbon transportation fuel.[2]

Second, this update more strongly emphasizes the need to take bold steps today to address climate change and keep global warming below 2°C. This is a reflection of IPCC reporting in 2014 that the world is on track for more serious climate change than previously thought, and BSR's belief that resolving this problem is urgent and a top priority, because failing to do so will undermine progress in virtually all other aspects of business and sustainability. This premise is supported in the review of literature and dialogue outlined above. For more information, please see "Business in a Climate-Constrained World: Catalyzing a Climate-Resilient Future through the Power of the Private Sector" (BSR, 2014).

We have also aimed to make the report more accessible by simplifying and re-ordering some sections and making the overall flow easier to follow.

This paper has a companion publication, "Transitioning to Low-Carbon Fuel: A Business Guide for Sustainable Trucking in North America" (BSR, 2014), which explores how to enhance the sustainability of existing and emerging sources for such fuels through more-informed investments, operations, and procurement. In particular, it considers how companies can use the information and frameworks described in this paper to elevate sustainability within their fuel supply chains.[3]

BSR's Future of Fuels has also produced a series of briefings for fuels (petroleum, natural gas, biofuels, electric vehicles, and hydrogen) which summarize some of the information presented here by fuel type.

Additional research and resources are available at www.bsr.org/futureoffuels.

[2] Olson, E.; Schuchard, R. (2014). "Transitioning to Low-Carbon Fuel: A Business Guide for Sustainable Trucking in North America." BSR.

[3] Ibid

Executive Summary

This paper examines the sustainability impacts of transportation fuels, synthesizing what is known and not yet known, with a focus on fuels used in medium-duty vehicles (MDV) and heavy-duty vehicles (HDV) for road freight in North America. The paper considers diesel and gasoline derived from petroleum (90 percent of current supply), natural gas (4 percent of current supply) and biofuels (3 percent of current supply), and to a lesser extent electric vehicles and hydrogen (under 1 percent of current supply).

The paper begins by characterizing the current market for fuels and reviewing forecasts for the future. We show that, assuming no major policy changes, oil is likely to remain a major component for decades, though it will cede share to other diverse sources. However, while alternative fuel technologies are taking off, they currently require major investment and policy support to become commercially significant and economically viable. Therefore, the extent of diversification beyond oil will be a function of political action, technological breakthroughs, relatively attractive fuel prices, and the success of new business models whose emergence are difficult to predict.

We then evaluate climate and other sustainability impacts associated with those fuels, considering the whole value chain that starts with the development of wells, mines, and farms, and carries all the way through to the distribution, use, and disposal associated with final fuel products. We find that there is a wide range of impact types, and there remain gaps in collective understanding of the impacts in part because of the many different dimensions involved (Appendix 1).

Key findings are as follow:

1. Fuel Markets: What we know about fuel markets	» Oil is the dominant fuel, though it is now ceding share to alternatives. » While the future mix of fuel is impossible to predict, we do expect it to become more diversified and a “poly-fuel” economy to emerge. » Advanced technologies such as biofuels and electric vehicles are taking off, but will require major investments and policy support in order to scale up.
2. Fuel Impacts: What we know about fuel sustainability	» Fuels create many critical sustainability impacts and addressing them should be a high priority for companies and policymakers. » Our knowledge of the total sustainability impacts of fuels has numerous gaps, and we should strive for better science and understanding. » Systematic remedies require taking a long-term perspective that is often at odds with the short-term requirements of business and politics.
3. Accelerating Fuel Sustainability: Priorities for Investment	» 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. » Despite some uncertainties and tradeoffs, the case for bold action is clear. » Practical solutions exist to accelerate low-carbon fuels and avoid or reduce their sustainability impacts.

The paper does not make judgments about a desired overall mix of fuel types. It also does not evaluate specific solutions for addressing the sustainability impacts of fuels, which is covered in the companion brief, “Transitioning to Low-Carbon Fuel: A Business Guide for Sustainable Trucking in North America.”

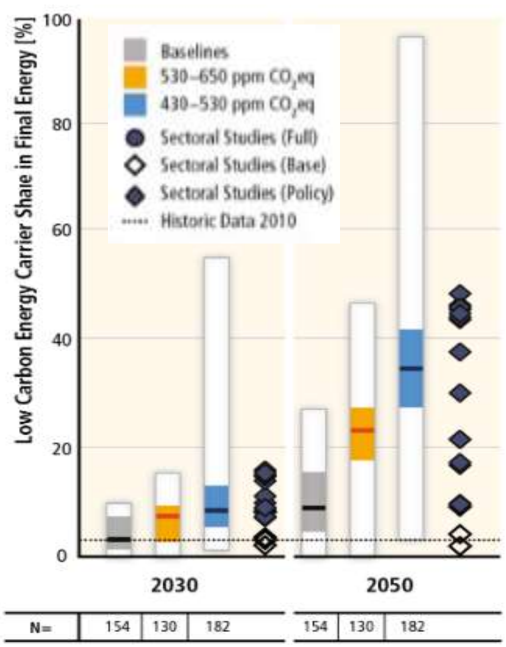
Introduction

Earth is on a path to global warming of 3.7°C to 4.8°C by the end of the century, which is creating major risks including increased intensity and frequency of extreme weather events, threats to biodiversity and ecosystem services, and changes in water distribution.[4]

To avoid the worst climate impacts, we must keep the rise to 2°C by reducing global greenhouse gas emissions (GHG) by 40 to 70 percent between 2010 and 2050.[5] Achieving these reductions will depend on bold and comprehensive action with transportation fuel and surrounding vehicles and infrastructure.[6]

Transportation is one of the main drivers of direct climate impacts, with fuel combustion causing 14 percent of global GHG emissions and 23 percent of CO_2 emissions from energy in 2010.[7] These emissions are rising faster than in any other energy end-use sector, and without aggressive and sustained policy intervention, could double from 6.7 gigatonnes of CO_2-equivalent ($GtCO_2eq$) in 2010 to 12 $GtCO_2eq$ by 2050.[8]

Figure 1: Low-Carbon Transportation Fuel: Market Share Increase Required to Limit Warming to 2°C



Source: IPCC AR5 (2014)

Additionally, transportation creates significant wider impacts through the production, refining, and distribution of fuels (the so-called "well-to-tank" phase), and the life cycles of vehicles and road infrastructure. Impacts from this phase are difficult to estimate, but add to emissions.[9] Emissions from fuel production are a growing source of impacts within transportation as alternatives to conventional petroleum, such as unconventional oil sources and natural gas, are associated with higher potential for emissions that occur "upstream."

A key method for reducing transportation emissions is to reduce demand for fuel by avoiding journeys, shifting modes, improving efficiency, and enhancing infrastructure and logistics.[10] Much-needed research and investment is taking place here. This paper is intended to complement this good work by looking at the other side of transportation emissions: fuel supply—the GHG intensity and nature of other impacts and issues that are associated with the actual fuel that is produced and used.

Reducing the intensity of emissions from fuel sources is a priority as recommended by the world's most authoritative global climate science body, the Intergovernmental Panel on Climate Change (IPCC). The IPCC shows that that we need to increase the share of low-carbon transportation

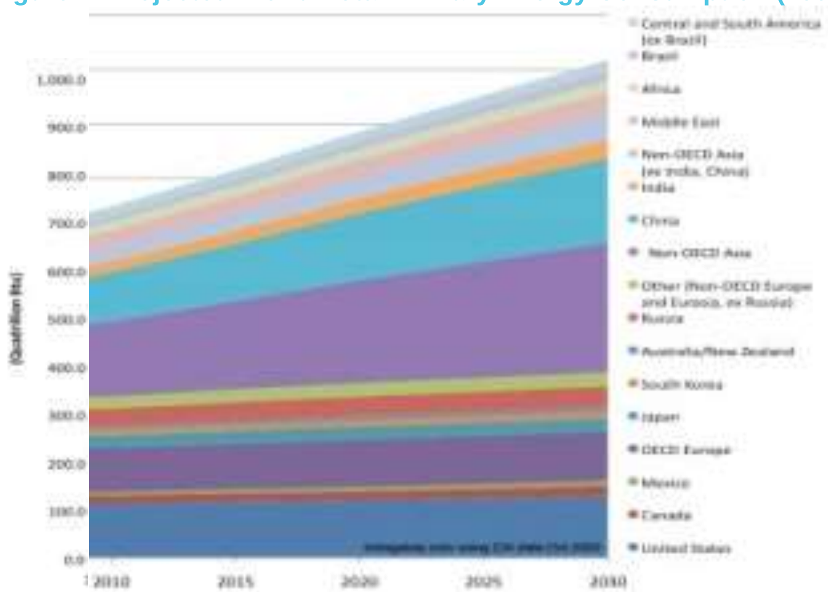
[4] Intergovernmental Panel on Climate Change (2014). "Climate Change 2014: Mitigation of Climate Change."
[5] We Mean Business (2014). "The Climate Has Changed."
[6] Ibid.
[7] Ibid.
[8] BSR and University of Cambridge (2014). "Climate Change: Implications for Transport." Based on the IPCC 5th Assessment.
[9] William Cowart, Veronika Pesinova, and Sharon Saile, "An Assessment of GHG Emissions from the Transportation Sector," US Environmental Protection Agency, 2003, www.epa.gov/ttnchie1/conference/ei12/green/pesinova.pdf See also Ryan Schuchard, "Transportation Fuel and Climate: Five Key Issues for Business Leaders and Policymakers," BSR, 2014, http://www.bsr.org/en/our-insights/blog-view/transportation-fuel-and-climate-five-key-issues
[10] Ibid.

fuels (e.g. biofuels, electricity, hydrogen) from around 3 percent today to nearly 10 percent by 2030, and around 35 percent by 2050 (See Figure 1).[11] It is also increasingly important to policymakers. The historic U.S.-China climate accord commits the U.S. to reduce GHG emissions 26-28 percent from 2005 levels by 2025 and China to peak its carbon dioxide emissions by around 2030. The U.S. intends to achieve its reductions through several measures, including standards for heavy-duty engines and vehicles and methane reduction in oil and gas systems.

This represents a significant challenge. On our current trajectory, the share of low-carbon fuel supply will remain virtually unchanged by 2030, and will not exceed 10 percent by 2050. This is the result of several factors: Fuel is part of a global energy market where consumption is set to rise by around 40 percent by 2030 (see Figure 2), there is a lack of a price on carbon, and operational needs mean that fuel for transportation must meet much stricter specifications than for stationary power.

Meanwhile, the makeup of transportation fuel supply is changing fundamentally for economic reasons, most recently with the rapid introduction of cheap natural gas. Over the last few years, the supply of natural gas has risen dramatically, and now sells for roughly US$2 per diesel gallon equivalent less than diesel (Figure 3).[12] Natural gas is a key potential lower-carbon fuel solution, representing up to one-third fewer GHG emissions than diesel.[13]

Figure 2: Projected World Total Primary Energy Consumption (1990-2030)—Reference Case



Source: International Energy Agency

However, the degree to which natural gas can serve as an attractive climate alternative depends on whether the sector can minimize methane leakage.[14] It also depends on the sector's ability to promote a swift transition to low or zero GHG emissions—to act as a true bridge—without introducing delays or barriers to doing so.[15] Additionally, being a sustainable alternative will require addressing legitimate concerns about community and water impacts at the wellhead that are not well-regulated.[16] In either case, an important effect of expanded natural gas deployment has been a greater awareness by major energy users and vehicle original equipment manufacturers (OEMs) about alternative fuel and openness for investing in vehicles that use fuels other than oil.[17]

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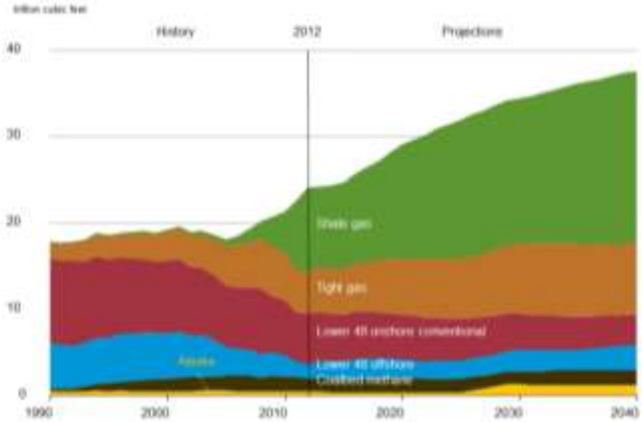
[11] This paper uses "low-carbon" as shorthand for "low GHG emissions" generally.
[12] America's Natural Gas Alliance (2013). "US and Canadian Natural Gas Vehicle Market Analysis: Heavy-Duty Vehicle Ownership and Production." Final Report.
[13] California Air Resources Board (2013). "Table 6: Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline." Renewables Portfolio Standard.
[14] Brandt, A.R., et al. (2014). "Methane Leaks from North American Natural Gas Systems." Science. Vol. 343: 733-735
[15] Davis, S.J. and Socolow, R.H. (2014). "Commitment Accounting of CO_2 Emissions." Environmental Research and Letters. Vol. 9.
[16] Jackson, R. B., et al (2014). "The Environmental Costs and Benefits of Fracking. Annual Review of Environment and Resources."
[17] Fleet Central (2013). "Top 50 Green Fleets," Automotive Fleet 500.

Climate impacts (and more specifically, GHG emissions) can sensibly be considered a primary focus for sustainability improvement with transportation fuel. However, fuel also involves many other health-related, environmental, and other issues that must be considered alongside climate change.

Figure 3: Projected U.S. Natural Gas Production by Source (1990-2040)—Reference Case



Source: EIA http://www.eia.gov/forecasts/aeo/images/fig_mt-44.png

This report explores the sustainability impacts of fuel with a focus on road freight or trucking, which has a disproportionately large impact for its size. While constituting only 4.3 percent of highway vehicles and 10 percent of highway miles traveled in the United States, GHG emissions from trucking are around 17 percent of the total from transportation.[18]

These emissions are forecasted to grow in the United States and globally as regional trade agreements liberalize, consumption escalates, and more shopping moves online.[19] Growth in freight will be sharpest in non-OECD countries; for example, in China, freight is rising twice as fast as passenger travel.[20] As a result, by 2030, freight emissions are expected to exceed 20 percent of total emissions in the United States and increase to a similar share worldwide.[21]

THE CHALLENGE FOR BUSINESS

Fuel use is a particularly important issue for companies because the business and sustainability risks and opportunities are growing at the same time that global demand is increasing dramatically and technology is changing rapidly. What follow 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 to include new sources of renewable and unconventional fuels. These factors all dramatically increase the complexity of transportation investment and purchasing decisions.

Meanwhile, these companies are fielding more and more calls from stakeholders to be more transparent 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 increasing scrutiny from stakeholders ranging from investors and regulators to the general public.

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

[18] Federal Highway Administration (2011). “Freight Facts and Figures 2011.” Federal Highway Administration.
[19] Jiyong Eom (2012). “‘We Keep on Truckin’: Trends in Freight Energy Use and Carbon Emissions in 11 IEA Countries.” Energy Policy.
[20] Intergovernmental Panel on Climate Change (2007). “Climate Change 2007: Synthesis Report.”
[21] Ibid.

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 greater public understanding and acknowledgement of the sustainability challenges that exist all around, which can lead in turn to greater regulatory certainty and best-in-class practices.

Leading producers have therefore shown a desire to continually raise the bar in 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. All sides of the fuel industry have an interest in improving dialogue and developing a common understanding about priorities.

THE OPPORTUNITY

The issues and trends outlined in this report present both complex challenges and significant opportunities. Trucking fleet operators and their partners need to find ways to more rapidly and effectively transition to low-carbon fuels and improve the sustainability of all fuels even as they meet rapidly growing and changing global demand.

For more on the opportunities for action, we encourage readers of this report to refer to our companion paper, "Transitioning to Low-Carbon Fuel: A Business Guide for Sustainable Trucking in North America." In that paper we present a practical, systematic approach for trucking fleet operators to work together with business partners and stakeholders to promote a low-carbon, sustainable fuel transportation system. That approach is summarized below.

Figure 4: Guide for Fuel Sustainability

Source: BSR: Transitioning to Low-Carbon Fuel (2014)

While the approach in "Transitioning to Low-Carbon Fuel" is aimed primarily at trucking operators, it also addresses their key value chain partners: shippers, fuel providers, manufacturers of vehicles or components, and investors.

The remainder of this report provides key information for exploring the opportunities outlined in "Transitioning to Low-carbon Fuels." As such it aims to draw widely from different sources to characterize the state of knowledge and the most important stakeholder concerns about fuel.[22] 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, stakeholder views, and inferences drawn by comparing related facts and studies.[23]

[22] 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.

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

The Transportation Fuel Market

Consideration of the sustainability impacts of fuel begins with an evaluation of which fuels make up the market today and consideration of the future outlook. This allows a basis for determining which fuels are relevant for focus, what barriers stand in the way of scaling up more-sustainable solutions, and emerging risks and impacts.

COMPOSITION OF FUEL SUPPLY

The current transportation fuel market is dominated by oil, which contributes to more than 90 percent of overall supply. Natural gas and biofuels, and to a lesser extent electrification and hydrogen, have begun to contribute to minor but rapidly expanding shares.[24]

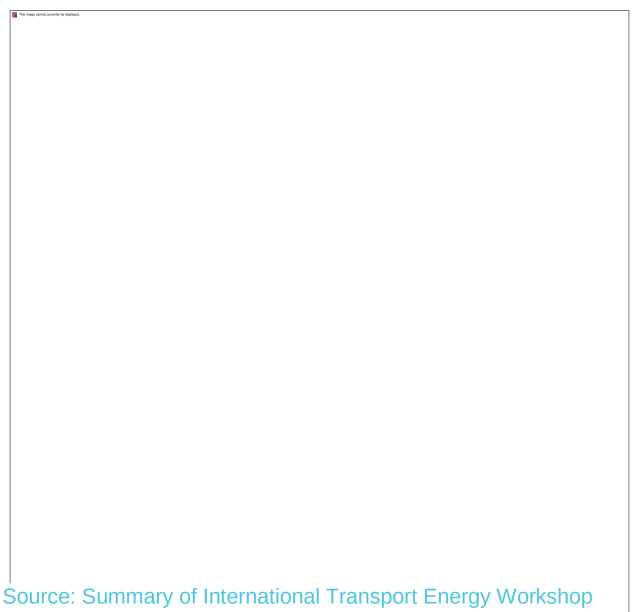
Looking to the future, there are a number of perspectives, including the International Energy Agency (IEA), U.S. Energy Information Administration (EIA), World Energy Council, large energy companies (including Shell, ExxonMobil, and BP), civil society groups such as Greenpeace, and consultants. There is agreement about a few broad shapes of the “reference case” (otherwise known as “business as usual”):

» Renewables are the world’s fastest-growing energy source, but they are building from a very small baseline. The IEA expects renewables to represent only 15 percent of the total transportation fuel mix by 2035—up from about 3 percent in 2010.

» Fossil fuels are expected to cede share of supply for energy uses (transportation, electric, and thermal power) though remaining the world’s top transportation fuel.

» Unconventional energy, which includes the production of oil sands and heavy oil, the production of gas and oil using high-volume and horizontal fracturing (“fracking”), and drilling in ultra-deep water and in the far North, is expanding and presents environmental and social issues that deserve attention. [25]

Figure 5: Estimates of Global Fuel Consumption in 2040



Source: Summary of International Transport Energy Workshop (UC Davis ITS, October 2014)

Beyond these contours, the future composition of supply is impossible to predict, as it is driven by many unknowable factors such as whether comprehensive climate polices will be established, the nature of available fuel sources and infrastructure, the level of development and adoption of new technologies, and the extent to which unintended negative impacts of new technologies are avoided. Still, developing a working sense of what is plausible is needed to construct a framework for considering sustainability.

With that in mind, Figures 5 and 6 provide high-level summaries of plausible fuel-consumption ranges in 2040 and 2050. These sources represent different approaches from different sources but provide generally similar overall pictures. Appendix 2 provides detail on outlooks from three different analysts, the U.S. Energy Information Administration, Shell, and Greenpeace.

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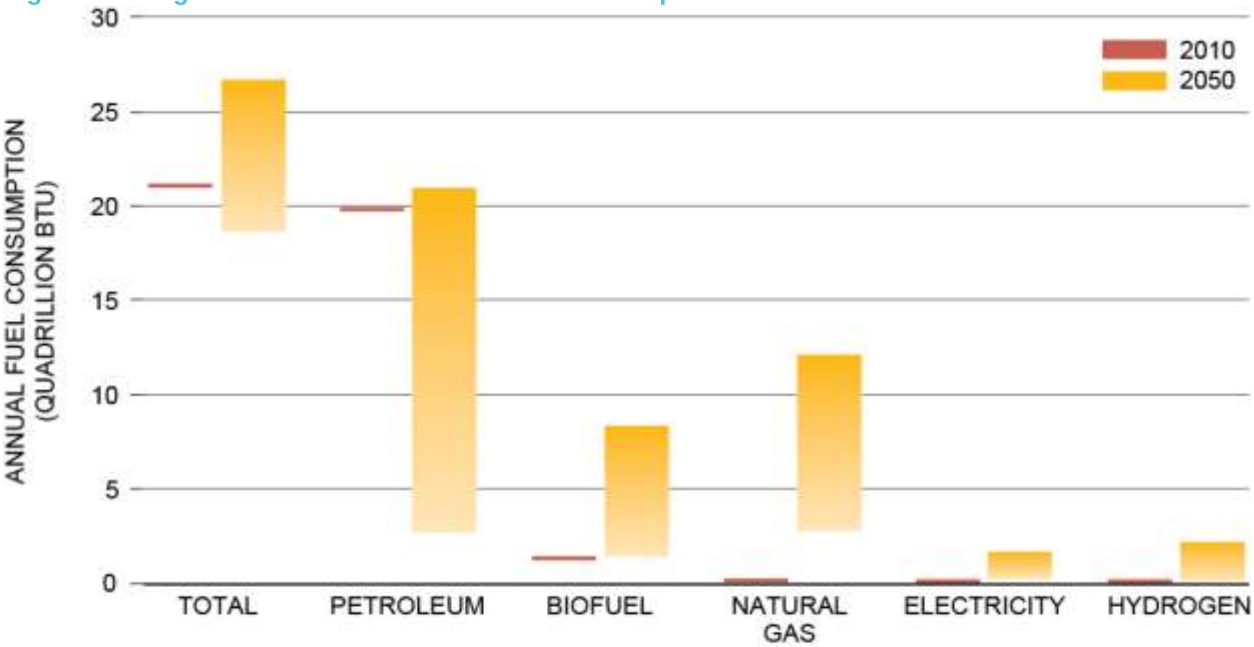
[24] Additional fuels exist, such as dimethyl ether (DME), but are not considered here in detail either because of their relatively small share of the North American market or limited information about sustainability factors.

[25] International Energy Agency (2014). “Frequently Asked Questions: Oil.” [“Conventional oil is a category of oil that includes crude oil and natural gas liquids and condensate liquids, which are extracted from natural gas production…Unconventional oil consists of a wider variety of liquid sources including oil sands, extra heavy oil, gas to liquids and other liquids. In general conventional oil is easier and cheaper to produce than unconventional oil. However, the categories “conventional” and “unconventional” do not remain fixed, and over time, as economic and technological conditions evolve, resources hitherto considered unconventional can migrate into the conventional category.”]

We advise caution when considering outlooks because their determinants are subject to change. For example, as late as 2011, companies were proposing huge investments in liquid natural gas import capacity for the United States. Today, cheap and available domestic sources of natural gas are growing by millions of barrels annually. Furthermore, outlooks are highly dependent on assumptions about the future and confidence in drivers such as policy, technology, and behavior to create change.

Figure 6: 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 (2012)

With this mind, the following subsections provide an overview of the key fuel supplies, outlooks for the future, and an outline of potential "game changers" that could change that picture.

Gasoline and Diesel

Gasoline and diesel together comprise more than 90 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 3 provides details on the sources of crude oil production and Appendix 4 provides background on production processes. Transportation is responsible for around two-thirds of all oil use, in conventional liquid-fueled internal-combustion engine (ICE) vehicles.

Oil is a fungible global commodity and is produced by a mix of international oil companies (10 percent) and national oil companies (75 percent) with smaller producers making up the rest. The U.S. produces about 14 percent of global supply and consumes about 21 percent of global demand.[26] The main sources of U.S. oil imports are Canada (31.9 percent), Saudi Arabia (13.5 percent), Mexico (9.3 percent), Russia (4.7 percent), Colombia (4.0 percent), and Iraq (3.5 percent).[27]

[26] U.S. Energy Information Administration (2014). "Short-Term Energy and Winter Fuels Outlook: Table 3a: International Petroleum and Other Liquids Production, Consumption, and Inventories."

[27] U.S. Energy Information Administration (2014). "Petroleum and Other Liquids: U.S. Imports by Country of Origin." Data: Total Crude Oil and Other Products, Annual Thousands of Barrels.

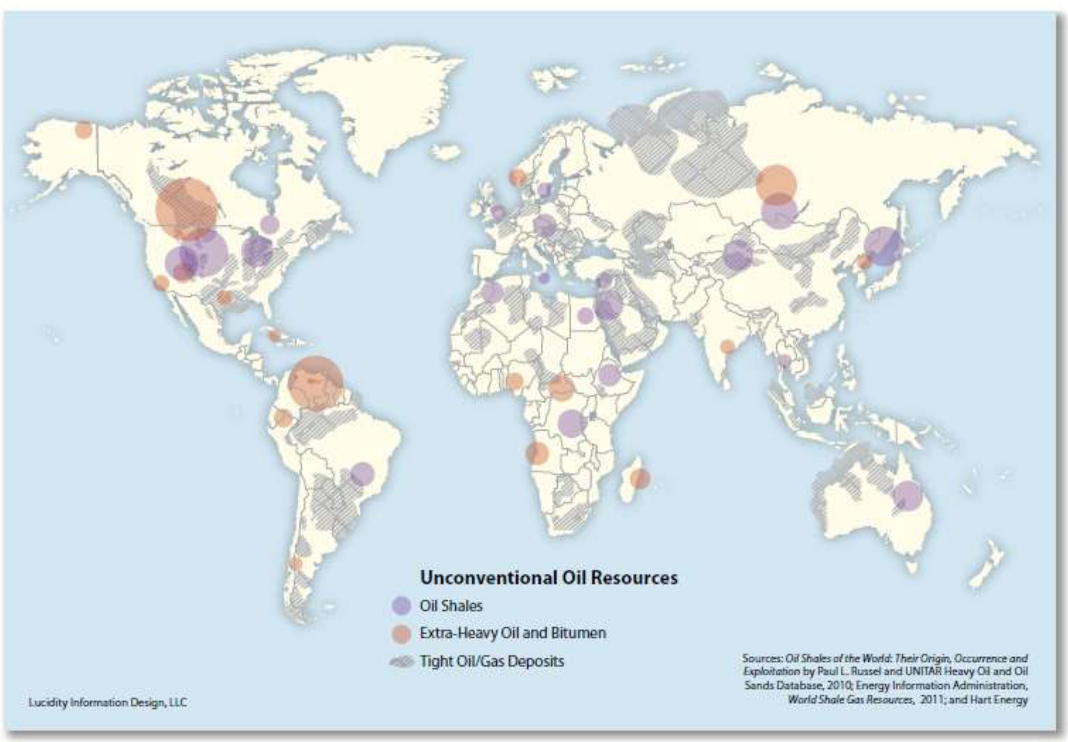
Oil dominates current supplies and is expected to continue to do so because of the maturity and scale of the technologies involved, with high-volume, low-cost supply chains and manufacturing capability and a liquid fuels supply chain that is also large-scale and well-developed.

However, despite petroleum’s size and maturity, this large incumbent will cede share to emerging technologies, making this 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, in part because of the increasing viability of alternative technologies, and in part due to rising public concern and regulation of high-carbon energy sources.

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 6 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.

Figure 7 shows how the world’s future oil supplies with shift, notably away from the Middle East, Africa, and Russia, and 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 7: Sources of Unconventional Oil Reserves



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

Natural gas works as transportation fuel in the form of compressed natural gas (CNG), liquid natural gas (LNG), and liquefied petroleum gas (LPG from “wet” natural gas), 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).

The use of natural gas as a transportation fuel is growing worldwide. In North America, it is now in abundant supply and, on an equivalent energy basis, costs less than gasoline and diesel in current prices. 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. HDV market segments: transit systems, school buses, and refuse trucks. Early adoption in heavier-duty Class 7 and 8 freight trucks has also begun. Today, there are 112,000 NGVs in the United States and roughly 14.8 million vehicles worldwide.[28]

Natural gas is used as a fuel mostly as CNG, with some consumption of LNG and LPG. Companies across several industries have embraced CNG, with many CNG fleets currently traveling the roads especially in transit, refuse, and regional trucking fleets. LNG is a fuel source with considerable potential for long-haul distances, as it offers the greatest energy content of all natural gas fuels, comparable to traditional petroleum gas. Due to significant up-front investment and new tasks and intervals required for fleet management, LNG has yet to achieve substantial market share. Even so, many large commercial fleets have begun deploying hundreds of LNG HDVs and the associated in-yard fueling stations.

Contrasted with oil, natural gas behaves less as a fungible global commodity because storage and distribution costs are higher. Indeed, 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. Currently, low natural gas prices in North America are creating strong incentives to export and distribute, which may lead to the leveling of prices and the globalization of the commodity.

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. In the absence of comprehensive state or national data, one estimate puts the number of active oil gas wells that have been hydraulically fractured in the United States at 1.1 million.[29]

Renewable natural gas (RNG), also called biomethane or "biogas," is produced from anaerobic digestion of organic materials, such as waste from plants, landfills, livestock, and wastewater, and can be used to replace CNG or LNG derived from fossil fuels. There are thousands of waste facilities that could produce significant amounts of biogas, although most of this biogas is currently being used for electricity generation.[30] According to the U.S. government, there is enough biogas potential in the United States to produce the equivalent of 2.5 billion gallons of gasoline for vehicles.[31]

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 greater climate and health impacts), and complements carbon-free but intermittent energy sources such as wind and solar when those power supplies are not generating electricity.

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

[28] U.S. Department of Transportation (2013). "Natural Gas Vehicles." Alternative Fuels Data Center.
[29] FracTracker Alliance (2014). "Over 1.1 Million Active Oil and Gas Wells in the U.S."
[30] U.S. Department of Energy. "Renewable Natural Gas (Biomethane)." Alternative Fuels Data Center.
[31] U.S. Department of Agriculture, U.S. Environmental Protection Agency, U.S. Department of Energy (2014). "Biogas Opportunities Roadmap."

to just over 50 percent. The rate of deployment for natural gas is highly dependent on a range of OEM product choice for different segments of the trucking market and an expanded natural gas fueling infrastructure.

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. Natural gas vehicles offer comparable maintenance costs to diesel but the intervals and tasks performed are different and primarily related to fuel storage. While light-duty and heavy-duty NGVs are available from OEMs and qualified system retrofitters can also economically, safely, and reliably convert many vehicles for natural gas operation, market and technical barriers still exist. The primary market technical and commercial challenges that need to be addressed and overcome are: Limited make-model availability, limited refueling infrastructure, and minimal inclusion of NG in the OEMs' current long-term product architecture plans for powertrain and chassis. Infrastructure to provide natural gas to LDV or HDV 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 MDVs or LDVs, which require more widespread refueling infrastructure.

CNG and LNG have the greatest opportunity for accelerated adoption into the HDV fleet, assuming that the current price spread between diesel and natural gas persists over time. Because of HDVs' 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.

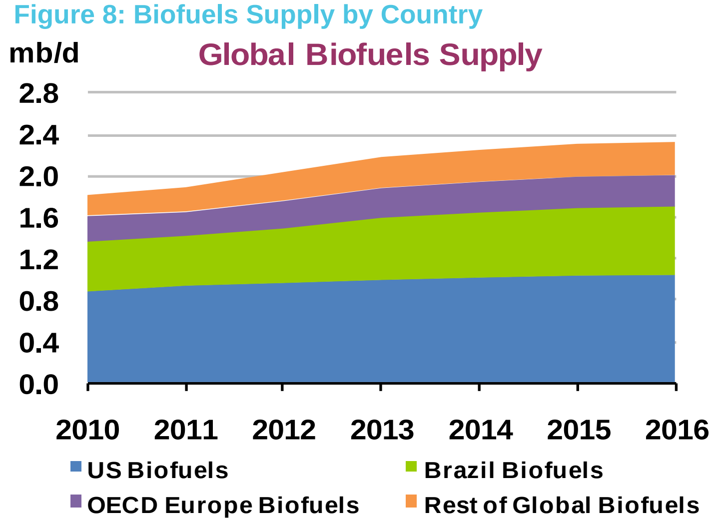
The infrastructure transition to supply this fuel demand represents one of the largest obstacles to alternative fuels entering the HDV market. The characteristics of initial customers for natural gas MDV and HDV trucks, such as inter-urban fleets, regional fleets, and freight corridors connecting regions, may provide pathways to expanding the vehicle market. In addition, the requirement to use a spark-ignited engine (less power, torque) or pilot with diesel reduces the power of an NG engine and can be a major holdback for fleets.[32] Finally, IEA and others have noted that the full life cycle GHG reduction benefits of using natural gas are complex and depend on a range of inputs.[33]

A key area of potentially 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 as well as aerodynamic and other enhancements learned from improving efficiency of diesel vehicles.

Biofuels

Biofuels include ethanol (and its cousins, methanol and butanol), derived from carbohydrates; biodiesel, derived from lipids; and renewable diesel, which is derived from a number of compounds and produces a fuel that is chemically similar to conventional diesel. Biofuels are liquid fuels produced from dozens of plant and other feedstocks and are mostly produced in the United States and Brazil, with contributions from a handful of other OECD countries (See Figure 8 and Appendix 5). In the United States, biomass

Figure 8: Biofuels Supply by Country



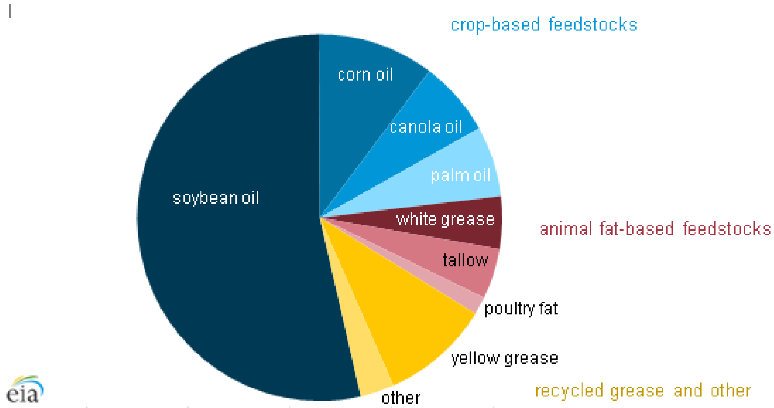
Source: International Energy Agency

[32] Fleet Owner (2014). "Alt Fuels: Beyond Natural Gas."
[33] International Energy Agency—Advanced Motor Vehicles (2014). "Enhanced Emissions Performance and Fuel Efficiency for HD Methane Engines." Report prepared for IEA by AVL-MTC AB.

energy provides around 5 percent of all energy consumed, and biodiesel contributed less than 5 percent of an estimated 4,500 trillion Btus of biomass energy consumed in 2013.[34]

Biofuels accounted for roughly 7.1 percent of total transport fuel consumption in 2012, or 13.8 billion gallons.[35] Total annual U.S. production of biodiesel was 1,339 million gallons and consumption was 1,368 in 2013.[36] Globally, production of biodiesel is projected to be 24.33 billion liters (bnl) from vegetable sources (soy, palm), 4.07 bnl from non-agricultural tallows and fats, and 0.69 bnl from jatropha in 2015.[37] In the United States, soy made up 65 percent, corn was 7.5 percent, and poultry and tallow less than 8 percent of production of 8,478 million pounds of feedstock inputs in 2013 (Figure 9).[38]

Figure 9: Major Biodiesel Feedstocks (2013)



Source: IEA

Currently, ethanol is cheaper than gasoline on a volume basis, but more expensive on an energy-content basis.[39] Ethanol in Brazil is the only cost-competitive biofuel used in transportation, with biodiesel costs averaging US$0.64/liter from soy in the United States compared to US$0.38/liter for diesel.[40]

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.

In the United States, a major contributor to biofuels development is the Renewable Fuel Standard (RFS), a U.S. federal law that specifies a mandatory minimum volume of biofuels must be used in the national transportation fuel supply. The RFS was established by Congress in the Energy Policy Act of 2005 (RFS1) and updated and expanded in the Energy Independence and Security Act of 2007 (RFS2).

The RFS2 specifies that the total supply of qualified biofuels (which are defined as biofuels that reduce emissions 20 percent compared to conventional oil) must expand to 36 billion gallons by 2022. Furthermore, within that framework, supplies must grow as follows:

1. Advanced biofuels: 21 billion gallons
2. Cellulosic and agricultural waste-based biofuel: 16 billion gallons
3. Biomass-based biodiesel: 1 billion gallons

The RFS is implemented by the U.S. EPA, which administers detailed compliance standards for fuel suppliers, a tracking system based on Renewable Identification Numbers (RINs) with credit verification and trading, special treatment of small refineries, and general waiver provisions.[41]

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[34] U.S. Energy Information Administration (2014). "Biofuels production drives growth in overall biomass energy use over past decade."
[35] U.S. Department of Agriculture (2014). "U.S. Bioenergy Statistics: Overview." Economic Research Service.
[36] U.S. Energy Information Administration (2014). "FAQ: How much biodiesel is produced, imported, exported, and consumed in the United States?"
[37] OECD and FAO (2011). "OECD-FAO Agricultural Outlook 2011-2020." Biofuels.
[38] U.S. Energy Information Administration (2014). "Table 3. U.S. Inputs to biodiesel production."
[39] Gruenspecht, H. (2013). "Biofuels in the United States: Context and Outlook." Biofuels Workshop. U.S. Energy Information Administration. January 24, 2013. Washington, DC.
[40] OECD and FAO (2011). "OECD-FAO Agricultural Outlook 2011-2020." Biofuels.
[41] Olson, E.; Schuchard, R. (2014). "Transitioning to Low-Carbon Fuel: A Business Guide for Sustainable Trucking in North America." BSR.

In practice, biofuels are typically blended with petroleum-based fuels, with ethanol mixed into gasoline, and biodiesel mixed into petroleum diesel. Most LDVs can use gasoline-biofuel blends containing up to 10 percent ethanol (E10) and many HDV trucks use up to 20 percent biodiesel (B20). Flexible fuel vehicles can use gasoline-ethanol blends containing up to 85 percent ethanol (E85). In the United States, there are currently about 2,383 fueling stations that offer this E85 fuel and 300 that offer B20 (excluding private stations), most of which are in the corn- and soy-farming region of the upper Midwest,[42] yet there remain cost and infrastructure-development constraints to large-scale biofuels deployment.

Biofuels have become attractive for a number of reasons, particularly in OECD countries, because of the potential to reduce GHG emissions in the transport sector and many other sustainability benefits, including their renewability compared to the finite nature of fossil fuels. Biofuels are seen as enhancing energy security and providing a means to sustain the agricultural sector and revitalize the rural economy. Biofuels also represent a liquid fuel that could work in internal combustion engines with no major changes needed and which have relatively high energy density—something that is especially important for long-distance and heavy-duty applications and aviation.

According to the International Energy Agency, by 2050, biofuels could provide 27 percent of total transport fuel and contribute in particular to the replacement of diesel, kerosene, and jet fuel.[43] However, a number of challenges stand in the way of this expansion. While there are no major technological barriers preventing expansion of today's corn- and soy-based biofuels, challenges include the following:

- » Cost: Currently, policy and regulatory incentives drive the market for biofuels. If biofuels are to become a reliable transportation fuel supply, production costs at scale must decline significantly to near or complete parity with diesel and natural gas for the investment and adoption required for biofuels to become a viable low-carbon transport fuel. As mentioned earlier, this has only occurred in the LDV market in Brazil, where a decade or more of favorable policies has reduced costs and created the market.
- » Infrastructure: Expanded production volumes will require the support of additional vehicle infrastructure and larger-scale infrastructure to collect, store, transport, and process biomass. Also, vehicle manufacturers need to create engines that run on higher concentrations of biofuels under warranty, and U.S. policymakers may need to adjust the so-called "blend wall," a federal law that allows for no more than 10 percent of ethanol blended into gasoline. For more on the blend wall and biofuels policies in the United States see "Transitioning to Low-Carbon Fuel" (BSR, 2014).[44]
- » Land Requirements: Biofuel crops may require substantial physical space that encroaches on forests or other arable land. Space requirements per BTU vary greatly and the future potential of biofuels to contribute to expanded supply will depend on the ability to increase yields and use production processes that generate more energy from each hectare.
- » Commodity Interactions: The production of bioenergy crops may in some cases increase food prices, as well as prices those for fibers, chemical feedstocks, chemical products, and biomass for electric power where it can be used more efficiently.
- » Sustainability. There are a number of sustainability issues that need to be resolved in certain cases, such as water and other environmental impacts, which are outlined in the next section.

None of these issues alone are "deal-breakers" for biofuel; indeed, the sector promises many sustainability benefits over oil and gas that make addressing these issues worthwhile. Nevertheless, they do show that the continued expansion of biomass feedstock supply depends on using crops that create the most power per area of land and that maximize crop yields.

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[42] U.S. Department of Energy (2014). "Ethanol Fueling Station Locations" and "Biodiesel Fueling Station Locations." Alternative Fuels Data Center.
[43] International Energy Agency (2011). "Technology Roadmap: Biofuels for Transport."
[44] Olson, E.; Schuchard, R. (2014). "Transitioning to Low-Carbon Fuel: A Business Guide for Sustainable Trucking in North America." BSR.

Second generation, or “advanced biofuels,” offer the potential to address many of these commercial and sustainability limitations. Cellulosic biofuels can be created from non-food crops such as switchgrass and jatropha, and from waste such as corn stover, corncobs, straw, and wood waste. BioDME (dimethyl ether) can be produced via catalytic dehydration of methanol or directly from syngas (gasification of a carbon-based fuel to produce heat). Renewable natural gas (RNG) or “biogas” can be produced from landfills, agriculture, and other methods that capture methane that would otherwise escape into the atmosphere as GHG emissions.[45] Advanced biofuels from lignocellulosic biomass, waste material, and other non-feedstocks are expected to represent 10 percent of global production by 2020. Jatropha alone is expected to provide 7 percent of biodiesel production in 2020.[46]

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).

Some biomass fuels suffer from lower energy density, higher costs of production, and smaller GHG reduction benefits compared to biofuels. As a result, it is possible that biomass is more wisely, and beneficially, used to generate electricity instead of fuel, especially when that electricity would otherwise be generated by coal-fired power plants.

Electric Power

Electric vehicles, and more specifically, battery electric vehicles (BEVs), are fueled by electricity and currently make up less than 1 percent of the vehicle 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.

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 (see Figure 10). Key challenges include battery size, particularly with HDV trucks, and battery life, mainly because of a combination of limited range, high cost of purchase, and uncertain durability.

Figure 10: 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)

In theory, EVs represent some of the strongest potential for growth, though there are sustainability and infrastructure concerns that need to be addressed. To exist as a low-carbon vehicle option, it is important that the electricity grid charging EVs is clean and not heavily reliant on fossil fuels.[47] Electricity grids using

[45] Renewable natural gas outlook described in more detail in the “Natural Gas” section above.
[46] OECD and FAO (2011). “OECD-FAO Agricultural Outlook 2011-2020.” Biofuels.
[47] Hawkins, et al. (2012). “Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles.” Journal of Industrial Ecology, vol. 17:1.

high percentages of renewable energy such as wind, hydroelectric, and solar provide a lower-carbon option for EV charging.[48] Bringing more renewable energy onto the grid, however, comes with challenges such as low capacity factors and resource intermittency (i.e., solar and wind energy are only available when the sun is shining and the wind is blowing). Intermittency solutions such as increased demand response, increased use of smart grid technologies, and affordable energy storage options are needed for wind and solar grid integration.[49]

EVs can also operate as part of the solution. Increasingly, EVs are being used to help with renewable integration by providing battery storage for homes and business relying on solar photovoltaic (PV) power for energy generation.[50] For example, the National Renewable Energy Lab (NREL) is working with the U.S. Department of Defense and the U.S. Army Corps of Engineers to develop a system that integrates solar energy and EVs into a microgrid system at a large Army facility in Colorado.[51] The microgrid will use EVs to integrate renewable generation and will support an increase in energy security, cost savings, and reliability benefits.[52]

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

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 a fraction of a percent of the market. The feedstock for hydrogen is largely natural gas, but other fossil fuels and renewable resources can also be used.

As an option that generates zero emissions during vehicle operation, hydrogen vehicles, particularly if derived from renewable resources, can have major sustainability benefits. In addition, hydrogen vehicle drivetrains are more efficient than diesel-driven powertrains because they avoid combustion, thermal, and friction energy losses.[53]

Hydrogen also faces big hurdles. First, 95 percent of current hydrogen production uses natural gas to power the fuel cell, although hydrogen production can come from renewable electricity or biomass.[54] Using fossil fuels to power the fuel cell emits roughly half as much as a gasoline vehicle on a well-to-wheels basis.[55] In order to maximize climate benefits and qualify as a carbon-free fuel, it is important for hydrogen to shift to a renewable feedstock instead of relying on natural gas. Second, hydrogen generally requires an extensive network of refueling stations, pipelines, and tankers for distribution. 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.

In response to these challenges, several factors have emerged in the last few years, including continued hydrogen vehicle production that is leading to lower vehicle costs and better performance, more investment and advancement in hydrogen fueling stations, low-cost natural gas, more public-private investments, new carbon policies, and interest in using hydrogen fuel cells for storing renewably generated electricity.[56] Although this shows progress, heavy-duty hydrogen vehicles still face challenges,

48 Ibid.
49 California Independent Systems Operator (2013). "Demand Response and Energy Efficiency Roadmap: Maximizing Preferred Resources."
50 California Independent Systems Operator (2014). "California Vehicle-Grid Integration Roadmap: Enabling vehicle-based grid services."
51 National Renewable Energy Laboratory. "Electric Vehicle Grid Integration Projects."
52 Ibid.
53 den Boer, et al. (2013). "Zero Emissions Trucks: An Overview of State-of-the-Art Technologies and Their Potential." CE Delft.
54 Ogden, J., et al. (2014). "The Hydrogen Transition." UC Davis Sustainable Transportation Energy Pathways; Howes, L. (2013). "Artificial Leaf in the Shade but Still Growing."
55 Ogden, J., et al. (2014). "The Hydrogen Transition." UC Davis Sustainable Transportation Energy Pathways.
56 Ibid.

at least for the next couple of decades. Specifically, there are cost and technological challenges associated with moving toward a lower-cost and zero-carbon (i.e., renewable) energy pathway. Furthermore, major investments in infrastructure are required.[57] Technical issues include poor battery durability as well as high volume capacity and weight requirements of vehicles. [58] However, some experts see hydrogen as a viable option for heavy-duty vehicles in the long term.[59]

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 fuels.

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. Catalysts that fully meet the requirements of electro-catalysts for oxygen reduction in PEM fuel cells without high-cost precious materials such as platinum are the ideal process.

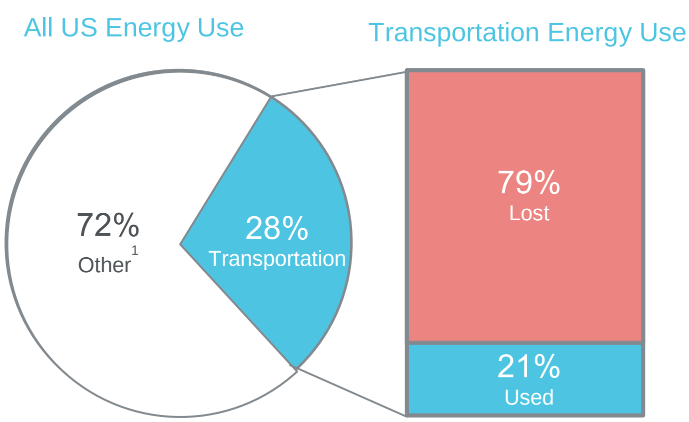
Although additional development needs to occur before hydrogen vehicles reach significant scale, hydrogen vehicles do have advantages and present the only technology currently available that provides a zero-emission operation option for long-range, heavy-duty vehicles.

Efficiency

The savings available in reducing energy use can provide an important source of additional energy. Therefore 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, efficiency can be treated as fuel for comparison alongside the others.

Efficiency is widely considered to be the best "first fuel" because so much energy is wasted—approximately 80 percent used in transportation is lost (see Figure 11)—and it provides an effective alternative to new fuel supplies with virtually no net negative impacts.[60] For that reason, this activity, which is the first to focus on action, is to maximize the fuel efficiency of existing fleets.

Figure 11: Energy Lost in US Transportation



Note: This figure includes thermodynamic limits but excludes miles not traveled. "Other" is defined as "residential, commercial, and industrial."
Source: Lawrence Livermore National Laboratory, "Estimated Energy Use in 2012: 95.1 Quads," 2013.

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[57] den Boer, et al. (2013). "Zero Emissions Trucks: An Overview of State-of-the-Art Technologies and Their Potential." CE Delft.
[58] Ibid.
[59] Ibid.
[60] Lawrence Livermore National Laboratory (2013). "Estimated Energy Use in 2012: 95.1 Quads."

When thought of as a source of fuel itself, efficiency has some of the greatest sustainability benefits of all fuels. There are essentially zero negative impacts, and it enjoys strong political support—at least conceptually. And in the near term, improved fuel economy offers the greatest CO_2 reduction potential, according to IEA.[61] It also may be one of the most cost-effective, with predictable and good returns on investments by fleet owners.[62]

However, the soft path of energy efficiency has been harder to tackle than originally thought, owing to the fragmented nature of sources and activities, misalignment of incentives, and some, but arguably insufficient policies to drive fuel efficiency in heavy-duty-vehicles. The rebound effect – where demand and total use can increase following efficiency gains – is also a mitigating factor of 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 MDVs and HDVs in particular. Significant improvements in the fuel economy for new HD trucks are 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 GHG emissions each year. Furthermore, some estimates suggest that the addition of a sixth axle, which would enable increasing weight limits up to 97,000 pounds, would save 2 billion gallons of diesel fuel annually, resulting in a 19 percent decrease in fuel consumption and emissions per ton-mile.[63]

Key areas of disruptive innovation across most truck technologies 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). The U.S. Department of Energy's SuperTruck Program aims to increase overall tractor-trailer freight efficiency by 50 percent and increase engine efficiency by 20 percent over a 2010 baseline by accelerating development of advanced efficiency technologies that are not currently on the market.[64]

Even with technological improvements in vehicle efficiency, including light-weighting and hybridization, some experts are finding that a switch to zero-emission vehicles is still necessary in order to get necessary GHG emission reductions.

FUEL DEMAND ISSUES AND TRENDS

Oil costs—long term—are on average rising as oil is increasingly coming from inaccessible sources. New renewable energy, unconventional energy, and vehicle propulsion technologies are continually being invented. And an estimated US$38 trillion investment needs to be made in renewable fuels over the next two decades.[65]

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[61] International Energy Agency (2012). "Technology Roadmap: Fuel Economy of Road Vehicles." [Compared with 2005 levels, the potential for improving the fuel economy of all vehicle types within the 2030 time frame ranges from 30 percent to 50 percent. This represents a very important opportunity for saving oil and cutting carbon dioxide (CO_2) over the coming two decades and beyond. Fuel efficiency accounts for a 4.5 $GtCO_2$ reduction in the 2DS compared to 6DS in 2050, representing 50 percent of total emissions reductions in the transport sector.]

[62] BSR and University of Cambridge (2014). "Climate Change: Implications for Transport." Based on the IPCC 5th Assessment.

[63] Coalition for Transportation Productivity (2014). "The Facts: Supporting Studies and Research."

[64] Delgado, O., Lutsey, N. (2014). "The U.S. Supertruck Program: Expediting the Development of Advanced Heavy-Duty Vehicle Efficiency Technologies." The International Council on Clean Transportation.

[65] International Energy Agency (2011). "World Energy Outlook—Quotes."

Changes to oil prices have diverse effects on alternative fuels. In the near term, lower oil prices reduce the relative attractiveness of alternative fuels, but they also increase the workability of policies that place a price on carbon. With higher oil prices, and all else being equal, alternative fuels and high-efficiency vehicles look more attractive, but so does investment in heavier oils that tend to have higher GHG intensity (assuming no carbon regulation). An additional factor is volatility: In general, companies most affected by oil price volatility favor a diversified fuel system through increased use of alternative fuels to mitigate cost risks.

These examples show that in addition to the current and expected composition of supply, a number of demand issues and trends are shaping the marketplace for transportation fuel that will be key determinants of the sustainability, or lack thereof, of fuel. What follow are key trends that will critically shape transportation fuel sustainability over the coming decades:

Aggregate global demand is growing, causing pressure for the cheapest fuel available to be used. Over the next two decades, total world energy consumption is likely to increase by more than 30 percent, owing mostly to growing middle classes in emerging countries, especially China and India.[66] Transportation is the third largest category of final energy consumption, currently responsible for around 20 percent of global energy use.[67] The overall share of energy from transportation is likely to remain stable, which means that the aggregate demand is expected to rise globally nearly 45 percent by 2040.

Not all of the sources discussed in this paper are simultaneously available, but instead are developed based on their market price, and alternatives to oil become available when energy producers believe that they are competitive with the real price of oil. 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 is above US$80 per barrel, production has restarted.[68] 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.

For this reason, prices help to determine 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, there would most likely be other more cost-effective opportunities available.

Therefore, North America is part of a global pool of available resources that are affected by demand everywhere. This means that prices and availability of fuel in the United States are related to developments in other countries, and addressing sustainability requires being concerned with impacts and practices related to the global system of production.

Transportation fuel users have practical needs that fuels must address in order to be successful. 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. Fuels for transportation, additionally, need to meet specific operational requirements, and those for trucking are narrower still. Following are key viability requirements for most trucking operators:[69]

[66] International Energy Agency (2012). "World Energy Outlook, Executive Summary."
[67] U.S. Energy Information Administration. "Frequently Asked Questions: How much energy is consumed in the world by each sector?" available at http://www.eia.gov/tools/faqs/faq.cfm?id=447&t=1
[68] Bloomberg Energy and Oil Prices.
[69] Trucks are generally considered Medium- and Heavy-Duty Vehicles. 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 today being used in Classes 3 through 7, and diesel engines used almost exclusively used in Class 8.

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 cheap and easily accessible conventional oil, are decreasing. Some renewable resources, on the other hand, such as first-generation biofuels and wind, require land resources that may limit scale.
2. **Infrastructure availability:** Fuels require physical and market systems that allow the extraction, production, processing, and delivery of final fuel products to 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:** Many advanced vehicles either are not widely available or are prohibitively expensive, especially for larger-class vehicles. Technologies that are beginning to enter the light-duty vehicle market, such as EVs and even hydrogen vehicles, may be further to commercial viability (or may never be viable) in heavy-duty vehicles.
4. **Vehicle range / fuel energy density:** Fuel must be sufficiently energy-dense to be transportable between fueling over useful ranges. 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. Reduced range may be neutralized by better fueling infrastructure, something that is more likely in high-traffic interstate corridors.
5. **Total cost of fuel and vehicles:** 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. Additionally, lifetime cost for maintenance, repair, and residual value factor into the purchasing decisions of fleet owners.
6. **Fuel performance and quality:** 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.
7. **Safety and usability:** Another important consideration for vehicle operators and fleet owners is the ease of use and safety of new vehicles. In the United States, 333,000 large trucks were involved in traffic crashes during 2012—an estimated 6.5 percent of all highway-related accidents.[70] Truck technical safety requirements are part of the standards, training, and practices used by the industry to maintain safety.

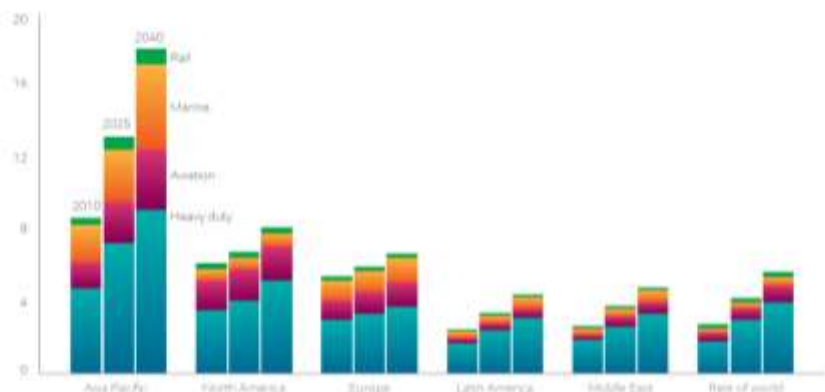
[70] U.S. Department of Transportation (2014). “Traffic Safety Facts: 2012 Data;” National Highway Traffic Safety Administration and U.S. Department of Transportation (2012). “Freight Facts and Figures 2011: Table 5-3. Accidents by Freight Transportation Mode: 1980-2010.” Federal Highway Administration.

The demand for key transportation sub-sectors is growing, creating greater impacts from and attention to the sector. Following are demand trends of key subsectors:

- **Commercial Demand.** Within transportation, 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 70 percent from 2010 to 2040. Nearly every country is expected to see an increase, but the highest increases are anticipated in developing countries, especially China.[71]

- **Medium- and Heavy-Duty Vehicle Demand**. Currently, MHDVs use over 25 percent of on-road transportation fuel, but only represent 7 percent of vehicles on the road.[72] 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.[73] Class 8 vehicles—the heaviest category of all, which includes all tractor-trailer trucks—consume around 75 percent of fuel from the MHDV class.[74] Demand from MHDV's is rising sharply, in particular for heavy duties, which will be the largest driver of commercial transportation energy demand over the next few decades. From 2010 to 2040, demand for fuel for heavy-duty vehicles is projected to rise by about 70 percent, and account for about 60 percent of the total increase of transportation fuel demand (see figure 12TK).

Figure 12: Commercial Transportation Demand by Region
Millions of oil-equivalent barrels per day



Source: ExxonMobil (2014). The Outlook for Energy: A View to 2040

- **Freight Demand.** More than 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. Trucking's share of freight (by tonnage) was 69.1 percent in 2013 and is expected to grow to 71.4 percent by 2025.[75] 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 United States' vehicle stock.[76]

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[71] ExxonMobil (2014). The Outlook for Energy: A View to 2040

[72] Union of Concerned Scientists (2013). "Heavy-Duty Vehicle Global Warming Emissions and Fuel Economy Standards."

[73] National Petroleum Institute (2012). "NPC Future Transportation Fuels Study: Advancing Technology for America's Transportation Future—Chapter 3: Heavy Duty Vehicles."

[74] Ibid.

[75] American Trucking Association and IHS Global Insight (2014). "Forecast: U.S. Freight Transportation Forecast to 2025."

[76] Sierra Club. "Future Fleet—How Companies Can Clean Up Their Acts."

Sustainability Impacts of Fuels

Transportation fuel creates significant sustainability impacts that include greenhouse gas (GHG) and other emissions that result from combustion. Fuels also create an array of wider environmental, social, and economic impacts associated with the production, distribution, and disposal of fuels throughout the whole value chain. Figure 13 provides an overview of typical issues raised by stakeholders.

In the following section, we examine what is known about the sustainability impacts of fuel, focusing on gasoline/diesel, natural gas and biofuels, and to a lesser extent electric vehicles and hydrogen. We will consider the issues listed in Figure 13 and focus on characterizing where there is reasonable scientific understanding and credible stakeholder opinion.[77]

The aim is to build an understanding of the total comparative value chain sustainability impact of different fuels in order to enable more holistic considerations and decision-making about the sustainability of fuels in considering total impacts, we examine the breadth of sustainability issues, which include greenhouse gas emissions as well as wider environmental, social, and economic impacts.

We also consider impacts that occur throughout the value chain, or the set of organizations and activities that comprise the entire life cycle of fuel products, from exploration, farming and production to distribution, consumption and in some cases disposal. These collective activities are known as "well-to-wheels" (WTW), which is often divided into the "well-to-tank" (WTT) and "tank-to-wheels" (TTW) components.

Sustainability impacts have multiple dimensions: They can be negative or positive, probable or actual, objective or relative, direct or wide, frequent or infrequent, and scientifically validated or reflective of credible stakeholder concern. Appendix 1, "Dimensions of Sustainability Impacts," outlines these different dimensions, and the section following discusses the most important impacts in a mix of those dimensions.

All impacts create costs—and in some cases benefits—for society that often do not factor into the costs that producers bear or the market prices that buyers will pay. However some externalities, such those associated with regulation, health and safety, and "social license to operate," do result in direct costs for companies that seek to mitigate adverse impacts.

Figure 13: Summary of Sustainability Impact of Fuels

ENVIRONMENTAL IMPACTS
- Life cycle GHG emissions
- Toxic and criteria pollution
- Water quantity
- Water quality
- Soil quality
- Land use
- Biodiversity
- Ecotoxicity
- Waste
- Spills and blowouts

SOCIETAL IMPACTS

Human Rights
- Fundamental Human Rights
- Other labor rights
- Freedom of movement
- Government relations
- Indigenous peoples
- Land tenure/property rights

Labor
- Occupational health and safety
- PT/contractor issues
- Well-being/livelihood
- Fair wage
- Training and education
- Diversity / equal opportunities
- Gender and vulnerable groups

Society
- Community health and safety
- Air/water quality and amenity
- Boomtown effects
- Resettlement
- Interruption of livelihood
- In- and out-migration
- Transparency/corruption
- Local security
- Land use and fair compensation
- Food security
- War and despotism
- Loss of recreational areas

ECONOMIC IMPACTS
- Jobs, revenues, and taxes
- Local and rural development
- Energy availability and affordability
- Energy access and security
- Food stability and security and other market impacts
- Strategic national development

Sources (Figure 13): 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.

[77] For organization of issues by fuel type, please see BSR's series of briefs at www.bsr.org.

ENVIRONMENTAL IMPACTS

The environmental impacts associated with fuels include those related to climate change, water, land use, and biodiversity.

Figure 14: Life Cycle GHG Emissions of Various Fuel Types

Fuel	Carbon Intensity (gCO_2e/MJ)
Biodiesel – waste oil	11-16
CNG/LNG – bio*	12-27
Electricity*	12-40
Cellulosic ethanol	16-21
Renewable diesel	20-82
DME – bio	30
Hydrogen – bio*	36
Hydrogen – NG*	44-68
Sugarcane ethanol	58-73
CNG/LNG – fossil*	65-90
Corn Ethanol	73-121
Propane*	78
Biodiesel – soy	83
Diesel	92-95
Gasoline	92-99
Unconventional oil	101-123

*Adjusted for Energy Economy Ratio; see footnote.

Italics: Has Indirect land-use component that range from 13.2-42.3 depending on feedstock, according to California Air Resources Board.

Source: Various. See endnote.[a]

Climate Impacts

Transportation fuel creates nearly 25 percent of direct global CO_2 emissions and could be associated with 40 percent or more when considering the full life cycle of fuels and related vehicles and infrastructure.[78] Globally, the combustion of transportation fuel is projected to be fastest-growing GHG emissions source through 2050.[79]

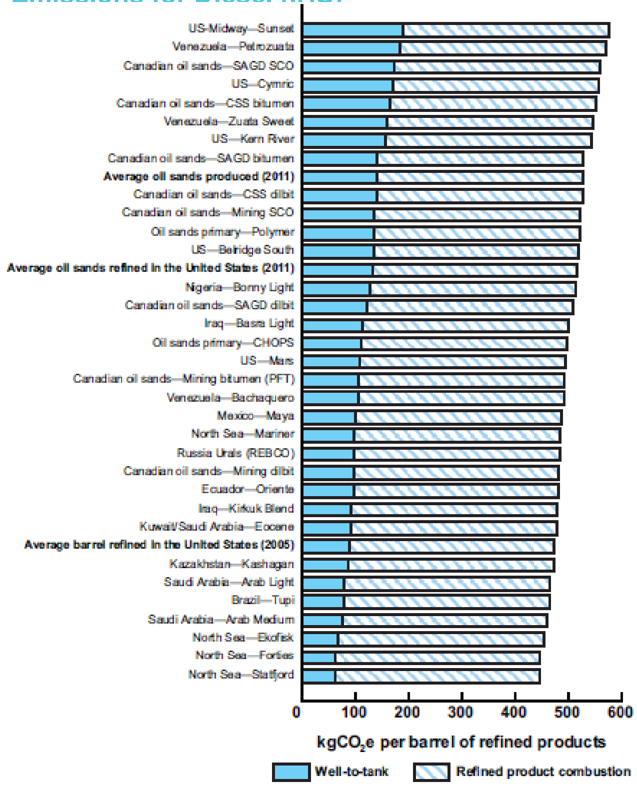
GHG emissions from fuel are relatively well-understood and quantified as compared to other sustainability impacts from fuel. A key reason is that GHG emissions are objectively measured: One ton of CO_2 emissions has the same effect no matter where it occurs. However, characterizing emissions of fuels is by no means simple, because in addition to variances between oil, gas, biofuels, and electricity, the impacts can vary depending on feedstock, location, and production practice within those categories.

Average diesel in the United States has about 99 gCO_2e/MJ of carbon intensity (CI) when considering the whole life cycle (see Figure 14). This figure (or an approximate nearby range) serves as a benchmark that low-carbon fuels are measured against. The value for diesel ranges from a high of at least 123 gCO_2e/MJ for some unconventional sources down to 20-82 gCO_2e/MJ for renewable diesel. Some sources have very wide ranges depending on their production practices, notably renewable diesel and corn ethanol.

GHG emissions impacts from the transportation sector are principally from gasoline, diesel fuel, and jet fuel. Around 80-90 percent of GHG impacts from oil are generated during combustion of the fuel, with the remainder generated in the well-to-tank phase of production and distribution. These impacts can be significant and also vary greatly. For example, oil sands typically have 1 to 19 percent greater life cycle GHG emissions than conventional oil).[80]

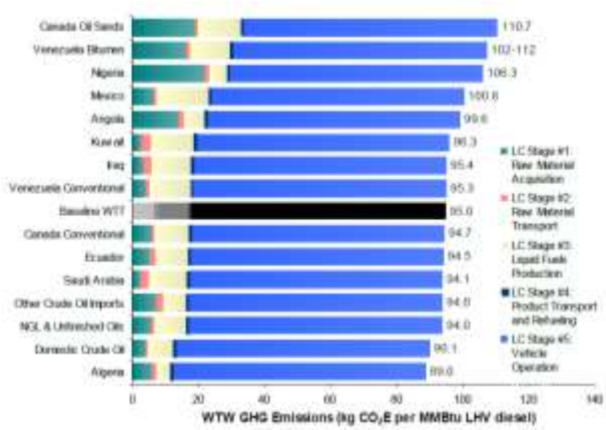
[78] For the direct figure (23 percent), see Intergovernmental Panel on Climate Change (2014). “Climate Change 2014: Mitigation of Climate Change.” The wider life cycle figure is difficult to estimate, for reasons explained in Appendix 1. The “40 percent or more” figure refers to life cycle emissions from fuel as well as vehicles and infrastructure. See Cowart, W.; Pesinova, V.; Saile, S. (2003). “An Assessment of GHG Emissions from the Transportation Sector.” U.S. Environmental Protection Agency; See also Schuchard, R. (2014). “Transportation Fuel and Climate: Five Key Issues for Business Leaders and Policymakers.” BSR.
[79] Intergovernmental Panel on Climate Change Fifth Assessment Report (2014).
[80] IHS Energy (2014). “Comparing GHG Intensity of the Oil Sands and the Average U.S. Crude Oil.” Canadian Oil Sands Energy Dialogue.

Figure 15: Well-To-Wheels Full Life Cycle GHG Emissions for Diesel (IHS)



Source: IHS Energy (2012). "Oil Sands, Greenhouse Gases, and U.S. Oil Supply Getting the Numbers Right—2012 Update." Canadian Oil Sands Energy Dialogue.

Figure 16: Well-To-Wheels Full Life Cycle GHG Emissions for Diesel (NETL)



Source: National Energy Technology Laboratory

Emissions estimates for production of a single type of crude can vary by as much as 30 percent, and some findings, especially for oil shale, are still in early stages of research.[81] In general, fossil fuels derived from the unconventional oil resources of bitumen (from oil sands), extra-heavy oil, and oil shale 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.[82] Research on GHG emissions impacts of unconventional oil is still an area of uncertainty. Figures 15 and 16 demonstrate the variation in total GHG emissions from various types of diesel.

Switching from diesel to natural gas has the potential to reduce GHG emissions by 10-33 percent, with RNG allowing for significantly higher reductions.[83] Based on a life cycle analysis, RNG from landfill gas can reduce GHG emissions up to 88 percent below diesel.[84] If derived from high solids, biomethane can have a negative carbon intensity roughly 115 percent below diesel.[85] RNG sources are renewable and have significant environmental benefits by redirecting waste that might otherwise contaminate soils and waterways.[86] Biogas from landfills can help reduce the 9 percent of U.S. GHG emissions that methane accounts for.

Investments that focus on and maximize RNG can have substantial benefits, providing a relatively efficient fuel with low impacts and low upfront investment requirements. Biogas uses landfills, agriculture, and other opportunities to capture methane that would otherwise escape into the atmosphere as GHG emissions. These sources are renewable and have significant environmental benefits by redirecting waste that might otherwise contaminate soils and waterways.[87]

Whether natural gas has an attractive climate profile compared to diesel depends on two unresolved issues. The first is that recent research shows that potentially significant amounts of "fugitive" emissions or "methane leakage" are occurring during production, distribution, and storage.[88] Leakage was once thought to be from less than 0.2 percent to 1.5

[81] Ibid.
[82] Ibid.
[83] California Energy Commission (2014). "2014-2015 Investment Plan Update for the Alternative and Renewable Fuel and Vehicle Technology Program."
[84] Ibid.
[85] Ibid. [Dry high solids are anaerobic digestion feedstocks such as food and green wastes with higher than 15 percent total solids. Due to co-products such as compost and lower energy inputs than feedstocks with higher liquid content, GHG reduction benefits from diesel can exceed 115 percent.]
[86] U.S. Department of Agriculture, U.S. Environmental Protection Agency, U.S. Department of Energy (2014) "Biogas Opportunities Roadmap." Available at http://www.epa.gov/climatechange/Downloads/Biogas-Roadmap.pdf
[87] Ibid.
[88] Brandt, A.R., et al., Science Magazine (2014). "Methane Leaks from North American Natural Gas Systems."; Miller, S., et al. Proceedings of the National Academy of Sciences (2013). "Anthropogenic emissions of methane in the United States."

percent based on EPA data estimates over the last decade. However, recent studies suggest actual emissions may be between 1.25 and 1.75 times higher than the EPA estimates.[89] Current research suggests that keeping methane leakage from natural gas below 1.0 percent would ensure that GHG impacts from the natural gas system are less than diesel or coal.[90]

A second issue is whether or not the natural gas industry can play a role to promote a swift transition to low- or zero-GHG emissions and not create delays or barriers to doing so. As a relatively low-carbon source available today, natural gas has been seen as a "bridge" fuel that will stand in as a preferable alternative to oil. However, if investments in infrastructure create a "lock-in" that prevents or delays transitions to even lower-carbon fuels, then moving to natural gas could undermine attempts to move to those fuels. This problem is understood but there is not yet a clear roadmap that expresses what role the sector should play.[91]

Biofuels offer the potential to reduce life cycle GHG emissions by 10-120 percent when used as an alternative to diesel.[92] Recent research shows that achieving carbon-neutrality requires meeting relatively strict criteria in terms of feedstock type, the technology used, and the time frame examined.[93] Key factors include feedstocks, production processes, land management, and distribution (See Appendix 5).[94] First-generation diesel replacements from rapeseed, palm oil, and waste offer approximately 18-83 percent reductions. Biogas for natural gas offers a similar reduction of an estimated 20-80 percent. Advanced biodiesel from hydrotreated vegetable oil provides a potential reduction of approximately 10-80 percent, and biomass-to-liquids could reduce emissions 55-120 percent from diesel.[95]

One variable that affects the GHG reduction benefits of biofuels is land use. The science for characterizing impacts of emissions from land use is emergent, although recent advances in modeling and new standards and regulations have increased clarity on the issue for fleet owners. Both the U.S. federal Renewable Fuel Standard (RFS) and the California Low-Carbon Fuel Standard (LCFS) require biofuels on existing land to avoid direct land-use impacts for certification, and both consider indirect land use in their certification schemes. Advances in modeling have also enabled a likely range for impacts of indirect land use of 13.2-38.7 g/MJ CO_2 emissions for corn ethanol, 10.1-41.1 for sugarcane, and 13.4-42.3 for soy biodiesel in a recent California Air Resources Board (CARB) analysis.[96] The Roundtable on Sustainable Biomaterials (RSB) uses a comprehensive set of criteria to evaluate any potential for direct land use for its certification, and offers a "low indirect-impact biofuel" claim for producers who use the Low Indirect Impact Biofuels approach created by WWF International, Ecofys, and EPFL.[97]

The U.S. Environmental Protection Agency has characterized a number of biofuel pathways that create a more than 20 percent reduction (and in many cases much greater) from biofuels compared to conventional gas and diesel. Those include biodiesel and renewable diesel from soy oil, waste oils, fats, greases, and algae; ethanol from corn starch, sugarcane, and cellulose; and several other sources including crop and forest residue, secondary annual crops planted on existing crop land such as winter cover crops, separated food and yard waste including biogenic waste from food processing, and perennial grasses including switchgrass and miscanthus.[98]

The majority of biofuels current commercially available—corn in the United States, sugarcane in Brazil, sugar beets and agricultural residues in Europe—are all lower-emission fuels than oil. Corn ethanol is

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[89] Ibid.

[90] Bradbury, J., Obeiter, M., (2013). "Clearing the Air: Reducing Upstream Greenhouse Gas Emissions from U.S. Natural Gas Systems." World Resources Institute.

[91] Davis, S.J. and Socolow, R.H. (2014). "Commitment Accounting of CO_2 Emissions." Environmental Research and Letters. Vol. 9. See also Unruh G (2000). "Understanding Carbon Lock-In. Energy Policy. Vol. 28, 817-830.

[92] International Energy Agency (2011). "Technology Roadmap: Biofuels for Transport." IEA.

[93] Bracmort, Kelsi (2013). "Is Biopower Carbon Neutral?" Congressional Research Service.

[94] Strogen, B.; Horvath, A. (2013). "Greenhouse Gas Emissions from the Construction, Manufacturing, Operation, and Maintenance of U.S. Distribution Infrastructure for Petroleum and Biofuels." Journal of Infrastructure Systems, 19(4), 371-383.

[95] When co-products are used to produce heat and power, replacing fossil fuels, such as by burning sugarcane bagasse or cellulosic residue, theoretical benefits exceed 100 percent reduction in GHG emissions.

[96] California Air Resources Board (2014). "ILUC Analysis for the Low-Carbon Fuel Standard (Update)." California Environmental Protection Agency.

[97] Ecofys (2014). "Low Indirect Impact Biofuel Certification Module." LIIB Methodology.

[98] United States Environmental Protection Agency (2010). "EPA Life Cycle Analysis of Greenhouse Gas Emissions from Renewable Fuels."

considered by the U.S. EPA to be a “conventional renewable fuel” with a minimum GHG emissions reduction of 20 percent relative to average 2005 petroleum fuel. Furthermore, the next generation of biofuels and biodiesel from cellulosic, agricultural residues, and biomethane from landfills promise even greater carbon emissions reductions. Ethanol from Brazilian sugarcane, biodiesel, and cellulosic ethanol are all considered “advanced biofuels” by the U.S. EPA because of GHG reductions of a minimum of 50 percent compared to average 2005 petroleum fuel. More detail about recent regulatory clarity on biofuel sustainability can be found in Appendix 6.

The most significant direct GHG emissions from biofuel production (other than from land use) are methane and NOx emissions produced during fermentation of agricultural residues 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 renewable energy or plant residues are used as an energy source (e.g., bagasse from sugarcane).

EVs have the potential to produce zero emissions if powered by electricity from renewable energy. In practice, the climate impacts of different utility grids are mixed. The potential climate benefits of EVs can be offset or potentially even reversed when powered by utilities with large coal portfolios. As the United States continues to lower the carbon intensity of the electricity grid, however, EVs become a more-sustainable option.[99] Furthermore, electrification is regarded as a key strategy for overall emissions reduction from transportation and is moving forward rapidly in LDVs.

This section has explored GHG emissions from mainstream commercial fuels, but there are additional sources. For example, emissions from oil shale could be 23 to 73 percent greater than diesel, and coal-to-liquids (assuming no carbon capture) has been estimated around 128 percent greater. On the low end, emissions from advanced biofuels, renewable natural gas, hydrogen, and electrification could be very close to zero.

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 more 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. Electricity generation is one of the largest industrial users of freshwater, with energy accounting for an estimated 40 percent of all freshwater withdrawal in the United States.

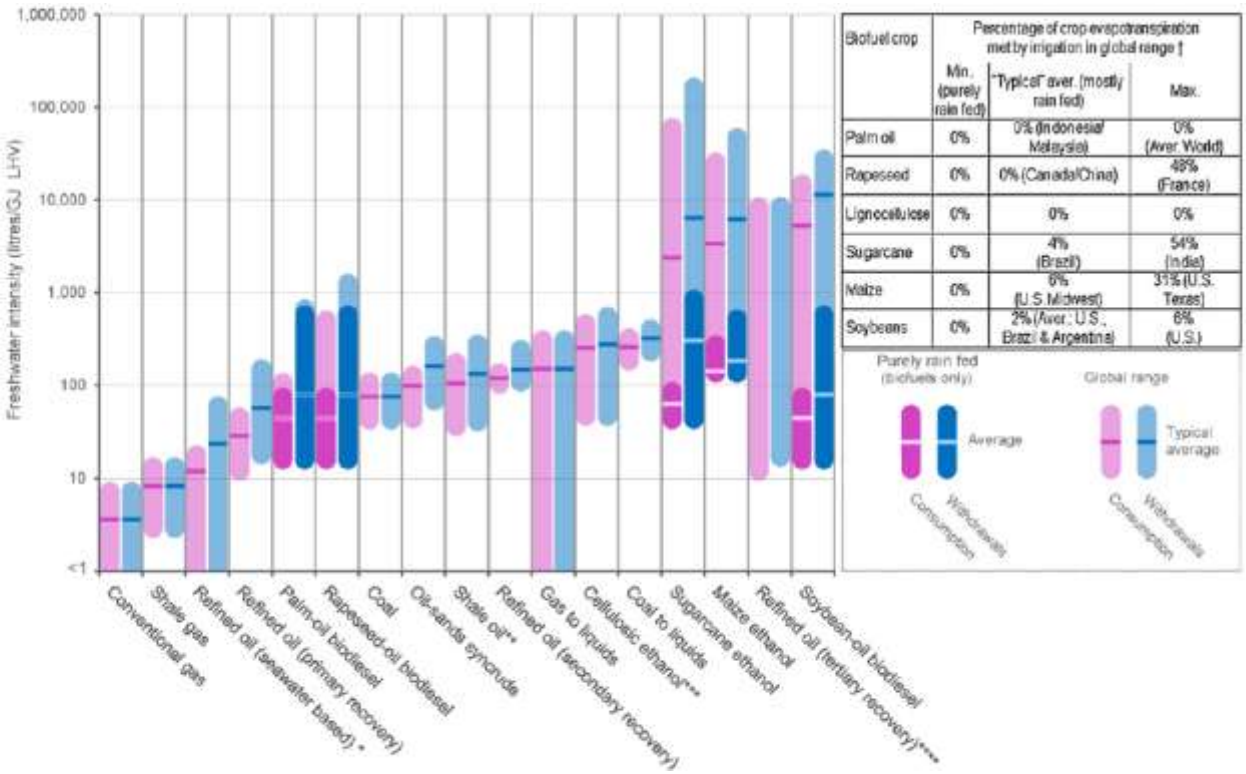
Impacts on water quantity concern the depletion of water resources, which occur when water is consumed in areas where water availability is relatively low and local demands are high. Importantly, most water withdrawals are not actually consumed, but are returned to their source, such as when used for 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.

Certain biofuels consume the most water of any type of energy, though there are notable variations by feedstock type, fuel pathway, and crop watering. The freshwater intensity of biofuels from soy, sugarcane, and corn can be two orders of magnitude larger than average freshwater consumption for the oil-to-liquid fuels supply chain (primary recovery).[100,101] Over 90 percent of biofuels’ impacts are related to farming the

[99] U.S. Energy Information Administration (2014). “U.S. Energy-Related Carbon Dioxide Emissions, 2013.”
[100] Primary recovery is oil pumped through pressure from the oil formation without the use of introduced pressure when well pressure falls.
[101] Schornagel, et al. (2012). “Water accounting for (agro)industrial operations and its application to energy pathways.” Resources, Conservation and Recycling. 61 (2012) 1-15.

crops, with most of the rest driven by processing and refining. Water use is most relevant in regions where crops are irrigated, given competition with other local water uses. Soy, sugarcane, and corn that are irrigated have freshwater intensities 18 to 350 times higher than the same crops that are rain-fed.[102] The regions and crops that matter most to North American fuel users in the near term—corn and soy from the Midwest and sugarcane from Brazil—are mostly low- or no-irrigation crops.[103,104,105]

Figure 17: Typical Water Consumption by Select Fuel Type (Gallons per GJ)[106]



Source: Schornagel et al., 2012

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. In North America, water use for natural gas production from fracking typically runs from 2.3 to 5.6 million gallons of freshwater per well (based on one-time use), with more water needed for refracking or for drilling and stimulating larger wells.[107]

The lowest general water consumers per unit of energy generated are conventional oil and gas, biofuels that are not 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. Fracking for natural gas and concentrated solar power are two technologies that consume

[102] Ibid.
[103] U.S. Department of Agriculture (2008). "2008 Farm and Ranch Irrigation Survey." Census of Agriculture.
[104] International Water Management Institute (2007). "Water for Food, Water for Life: A comprehensive assessment of water management in agriculture." London: Earthscan, and Colombo: International Water Management Institute.
[105] IPIECA (2012). "The biofuels and water nexus: Guidance document for the oil and gas industry." Biofuels Task Force, Operations, Fuels and Product Issues Committee.
[106] Everything is normalized to gigajoules (GJ), different fuels have different uses and use efficiency, i.e., a GJ of liquid fuel gets fewer vehicle miles traveled (VMT) than a GJ of electricity.
[107] Jackson, R., et al. (2014). "The Environmental Costs and Benefits of Fracking: Annual Review of Environment and Resources."

significant quantities of water and may increasingly compete for limited water resources in arid and agricultural regions. 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.

Looking ahead, projections show energy growth leading to increases of 85 percent to more than 165 percent of freshwater withdrawals by 2025, given the greater use of water-intensive energy production activities.[108] Additionally, implementation of carbon capture and storage projects, though providing climate benefits, could 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. 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 has 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 contamination discovered in California as recently as October 2014.[109]

There are also special concerns about the production of tight natural gas, which involves hydraulic fracturing that may lead to contamination of aquifers. 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, silica, and solvents.[110] The second is carcinogenic or otherwise harmful contaminants such as methane that leaks from improper wellbore construction into shallow groundwater aquifers.[111] Water quality in the United States is regulated under the Clean Water Act, but exemptions have been made for fracking.[112] States and provinces in Canada each regulate differently.

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 groundwater and aquifers.

Biofuels also may have water quality impacts, especially from eutrophication (an excess of nutrients in water, often with negative impacts), nutrient loss, pesticide runoff, 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 of Mexico's "dead zone." Organic waste from the sugarcane ethanol system ("vinasse") can result in polluted runoff to surface water and contamination of groundwater, with the high organic content of the vinasse rapidly consuming oxygen and severely degrading water quality.

The production of electricity causes water impacts. For example, thermoelectric facilities, which are responsible for 44 percent of water withdrawals in the United States (more than 80 percent of U.S. electricity is generated this way), return most of their water to their source, though water withdrawals for thermoelectric power generation is poorly documented. Altering the water quality and quantity in this way 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. Water is also required for cooling in concentrated solar power facilities.

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[108] Asian Development Bank (2013). "Thinking About Water Differently: Managing the Water-Food-Energy Nexus."; World Economic Forum Water Initiative (2011)."Water Security: The Water-Food-Energy-Climate Nexus."

[109] Center for Biological Diversity (2014). "Documents Reveal Billions of Gallons of Oil Industry Wastewater Illegally Injected Into Central California Aquifers." *Press release.* Available at: http://www.biologicaldiversity.org/news/press_releases/2014/fracking-10-06-2014.html

[110] U.S. Environmental Protection Agency (2011). "Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources." Office of Research and Development.

[111] NPR (2014). "Tap Water Torches: How Faulty Gas Drilling Can Lead To Methane Migration." State Impact: A reporting project of NPR member stations (Pennsylvania). http://stateimpact.npr.org/pennsylvania/tag/methane-migration/

[112] U.S. EPA (2014). "Regulation of Hydraulic Fracturing Under the Safe Drinking Water Act." Accessed Oct 3, 2014. http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_hydroreg.cfm

There are also water impacts involved with the production of electric vehicles; for example, some studies suggest that EV production may result in increases in production of chemicals toxic to human health and aquatic ecosystems, largely from mining materials for and manufacture of batteries.[113] However, this is not well-understood and a complete analysis would require evaluating the wider impacts of vehicle manufacturing that include non EV powertrains.

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. On the other hand, although relatively rare, a severe spill from oil production has catastrophic consequences. In addition, minor spills from oil production are fairly common,[114] and can impede the survival and reproductive rates of marine birds and mammals.[115]

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.

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. These impacts can be usefully grouped 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 (called here 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 as 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-intensive). 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.

One consideration for evaluating comparative land-use impacts is space requirements from surface area used to produce the fuel or feedstock. Land use is a tradeoff with first-generation biofuels, which require

[113] Hawkins, et al. (2012). "Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles." Journal of Industrial Ecology, vol. 17:1.
[114] Lepore, M.J. (2014). "Risk-Based Inspections: Strategies to Address Environmental Risk Associated with Oil and Gas Operations." Colorado Department of Natural Resources Oil and Gas Conservation Commission.
[115] National Research Council (2003). "Oil in the Sea III: Inputs, Fates, and Effects, National Academies of Science."

greater land area to create the same energy in a gallon of fuel. When primary forest or other ecosystems are converted to agricultural (or other energy) production, biodiversity and ecosystem services are lost. While it may continue to be a point of some uncertainty, standards by the U.S. Federal Government and State of California, as well as certifications by RSB and others, are designed to avoid and minimize this impact.

Attaining the lowest 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 (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 or converted for direct transportation fuel or used for power generation) are more-productive uses of the feedstock.

Fossil fuel sites tend to have fewer direct physical area requirements than biofuels or solar arrays and wind farms, since they make use of concentrated stores of ancient photosynthetic production buried beneath.[116] However, oil and gas sites may have wider indirect physical effects associated with emissions, effluent, and noise. Also, in general, fossil fuels are becoming harder to extract, while biofuels and electric power production from renewable sources are becoming more productive.

An additional impact occurs from producing and transporting fuel in and through marine and coastal ecosystems. Depending on timing and location, a spill can cause significant harm to individual organisms and entire populations, as in the Exxon Valdez spill of 1989 and the 2010 Deepwater Horizon spill.[117] The frequency and volume of oil spills have declined most of the years since 1973, due especially to reduction in spills from barges and tankers.[118]

Renewable energy production from solar and wind also use more land for equivalent energy production than fossil fuels.

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 representative examples of all of the world's terrestrial, marine, and freshwater ecosystems, in addition to ecosystems that contain exceptionally high levels of biodiversity.[119]

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[120] by activities related to energy production (see Figure 7 and also Appendix 7 for more detail).[121] These eco-regions are impacted primarily by production of petroleum oil, while palm oil (as a potential biofuel feedstock) represents the major impact in Indonesia and Malaysia specifically.

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[116] Bryce, R. (2010). "The Real Problem with Renewables." Forbes.
[117] Ramseur, J. L. (2012). "Oil Spills in U.S. Coastal Waters: Background and Governance." Congressional Research Service.
[118] Ibid.
[119] 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).
[120] U.S. Environmental Protection Agency (2014). "Learn more about Threatened and Endangered Species." Pesticides: Endangered Species Protection Program; WWF (2014). "About Global Ecoregions." [According to U.S. Environmental Protection Agency, endangered species are those plants and animals that have become so rare they are in danger of becoming extinct, and threatened species are plants and animals that are likely to become endangered within the foreseeable future throughout all or a significant portion of its range. WWF has extended this concept to the ecosystems that support the biological diversity and ecosystem services necessary to support endangered and threatened species.]
[121] 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.

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.

Figure 18: 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. While energy companies are taking part in environmental remediation efforts, the long-term effects on biodiversity and landscapes from mining and support infrastructure are not well-understood, making the effect of such activities unclear.

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 across regions.

Cumulative effects are not limited to oil sands. The production and distribution of all fuels, including electricity generation, can lead to cumulative effects. Other energy technologies, such as with Pennsylvania's shale gas development, North Dakota's shale oil development, and even development of utility-scale solar in U.S. deserts can contribute to cumulative effects anywhere that extensive physical footprints and distribution networks are developed.

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 despite being 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 across the fuel value chain 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 production, refining, and distribution facilities. These health impacts are often greater in non-OECD regions, where policy and regulations that control air pollutants as well as construction codes and safety and health controls can be weaker.

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 gases of hydrogen sulfide and sulfur dioxide. Workers at and communities near fuel extraction and processing facilities 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, NOx, SOx, and particulate matter, which are the most damaging product of fuel combustion and harmful to the respiratory system.[122] Workers can receive prolonged exposure, resulting in chronic effects, from diesel exhaust from drilling, completion, and work-over trucks, rigs, and equipment such as pumps typically run off of diesel-powered or gasoline engines.

Combustion of fuels and energy generation is associated with a number of health risks. Notably, the World Health Organization has recently classified diesel exhaust as carcinogenic.[123] The EPA concludes that there is "considerable evidence that diesel exhaust is a likely carcinogen," with greatest risks in occupational settings.[124] The combustion of other fuels including natural gas, biofuels, and the generation of electricity from fossil fuels likewise produces emissions of criteria pollutants with known health risks.[125,126,127] Some research indicates that biodiesel may produce higher hydrocarbon, acetaldehyde,

[122] Attfield, M. D.; Schleiff, P. L.; Lubin, J. H.; Blair, A.; Stewart, P. A.; Vermeulen, R.; Coble, J. B.; Silverman, D. T. (2012). "The Diesel Exhaust in Miners Study: A Cohort Mortality Study with Emphasis on Lung Cancer." JNCI Journal of the National Cancer Institute.
[123] World Health Organization (2012). "IARC: Diesel Engine Exhaust Carcinogenic." International Agency for Research on Cancer.
[124] U.S. Environmental Protection Agency (2014). "Diesel Particulate Matter."
[125] Wang, M. (1999). "The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model, Version 1.5." Center for Transportation Research, Argonne National Laboratory.

and ethanol emissions and lower carbon NOx, carbon monoxide, and benzene emissions compared to diesel from fossil fuels, but this is an area of further study.[128,129]

When oil sands are mined, production typically involves the creation of tailings ponds that store wastewater. They may contain dangerous compounds including arsenic, ammonia, benzene, cyanide, phenols, toluene, polycyclic aromatic hydrocarbons, arsenic, copper, sulfate, and chloride for which safety measures are required. According to the Government of Alberta, tailings ponds in Alberta cover a surface area of about 30 square miles.[130] Mining companies are required by law in North America to prevent leakage and remediate sites after mine closure. At the same time, credible stakeholders such as Environmental Defense Canada and the Natural Resources Defense Council have expressed concerns about water contamination and potential links to high rates of cancer in neighboring communities.[131]

There is also increased data and concern that fracking and energy extraction cause earthquakes, also referred to as induced seismicity.[132] Felt seismicity has only been documented in a handful of cases and the earthquakes recorded are of a relatively low magnitude, however, seismic activity due to fracking is increasing and significant damage has occurred in some instances.[133] More research is needed to better understand this impact.

The actual health risks of fracking remain poorly understood, and the chemicals and processes used in North America are not yet regulated comprehensively. The U.S. Environmental Protection Agency is undertaking a comprehensive study that is expected to shed light on the health impacts of fracking.[134] One study found higher rates of respiratory illness and skin problems by people living close to natural gas wells in Pennsylvania[135], but there is a big gap in peer-reviewed research on health impacts to communities from fracking that needs to be filled.

There are also health impacts linked to biofuel production. One of the largest sources of air pollution from biofuel production comes from the practice of burning feedstocks (e.g., sugarcane and palm trees) before harvest. The resulting smoke, fine particles, and nitrogen gases in the atmosphere cause acid rain and have known direct acute and chronic cardio-respiratory as well as other health impacts.[136] Summer smog potential is particularly high for tropical biofuels because cropland is often created with slash-and-burn techniques, or dry leaves are burnt before harvesting. Technological advancement is helping to address these issues. For example, burning sugarcane is rapidly phasing out to mechanized harvesting.[137] Additionally, ammonia associated with nitrogen fertilizers can be volatilized in the air, attract fine dust particles, and form particles that cause respiratory impacts for workers and nearby communities.[138]

One health effect is specific to a single feedstock: Jatropha. The oilseed 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 documented, and there is concern that increased

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[126] U.S. Energy Information Administration. "What are the greenhouse gas and air pollutant emissions factors for fuels and electricity?" Accessed Sep 18, 2014. http://www.eia.gov/tools/faqs/faq.cfm?id=76&t=11
[127] U.S. Environmental Protection Agency (2012). "National Ambient Air Quality Standards (NAAQS)." Accessed Sep. 18, 2014. http://www.epa.gov/air/criteria.html
[128] U.S. Environmental Protection Agency (2010). "EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond." Office of Transportation and Air Quality. EPA-420-F-10-007.
[129] Hubbard, C. et al. (2013). "Ethanol and Air Quality: Influence of Fuel Ethanol Content on Emissions and Fuel Economy of Flexible Fuel Vehicles." Environmental Science and Technology. 48, 861−867.
[130] Alberta Government (2013). "Oil Sands Tailing." http://oilsands.alberta.ca/FactSheets/Tailings_FSht_Sep_2013_Online.pdf
[131] Secretariat of the Commission for Environmental Cooperation (2013). "Determination in accordance with Article 14(1) and (2) of the North American Agreement for Environmental Cooperation." Determination Articles 14(1)(2)
[132] Jackson, R.B., et al. (2014). "The Environmental Costs and Benefits of Fracking: Annual Review of Environment and Resources."
[133] Ibid.
[134] Description and latest results of the study to be posted at: http://www2.epa.gov/hfstudy
[135] Rabinowitz, P. M., et al. (2014). "Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania." Environmental Health Perspectives. DOI:10.1289.
[136] U.S. Environmental Protection Agency (2012). "Agricultural Burning." National Agriculture Center. Available at: http://www.epa.gov/agriculture/tburn.html Accessed Sep. 23, 2014.
[137] Silva Capaz, R. (2013). "Impact of mechanization and previous burning reduction on GHG emissions of sugarcane harvesting operations in Brazil." Applied Energy Volume 102, February 2013, p. 220–228.
[138] UNESCO (2009). "Biofuels and Environmental Impacts." UNESCO; SCOPE; UNEP Policy Brief June no. 9.

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 health and safety risks to workers and communities. 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.[139] Additionally, refineries have typically been associated with environmental justice concerns, where those affected tend to be from minority and poorer classes.[140] 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 by-products, 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 a refinery does not upgrade oil sands, there is a higher risk than at other refineries to generate higher levels of sulfur dioxide air pollution when using bitumen blends as a feedstock, given that they have very high sulfur content. This can lead to increased exposure to SO2, which is a concern for asthmatics. It also can lead to increased downwind particulate matter (PM) production, through the atmospheric photochemical conversion of SO_2 to SO_4 PM.[141]

Additional health concerns include noise pollution or increased traffic affecting quality-of-life as well as direct safety.[142] There is also a growing evidence base for other organ and system effects, including neurodevelopmental, metabolic, and stress.[143]

Human Rights Impacts

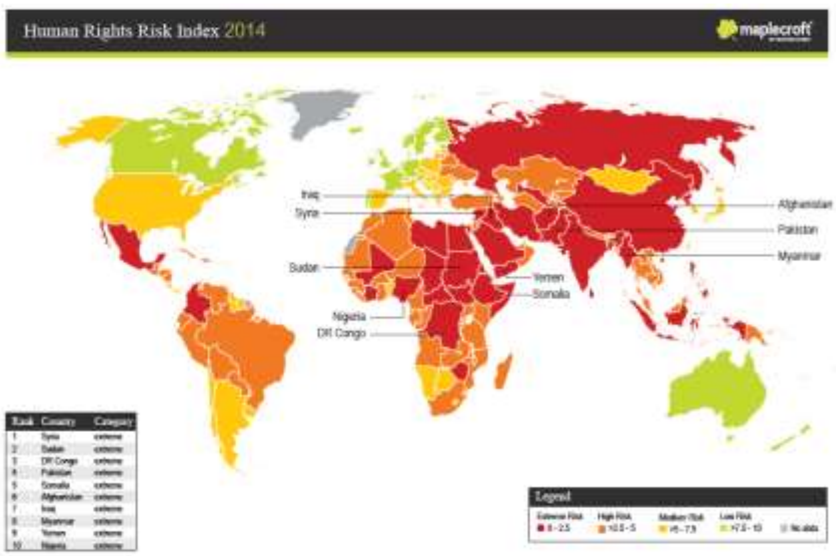
For the purposes of this paper, human rights related to the production of fossil fuels include protections guaranteed under the International Labor Organization (ILO) conventions: Prohibition of child labor and forced labor, antidiscrimination measures, freedom of association, just and favorable working 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 in Figure 19) that make up much of the fuel supply chain than they are in low-concern countries, including the United States and

[139] Brody, Julia Green, et al. (2010). “Linking Exposure Assessment Science with Policy Objectives for Environmental Justice and Breast Cancer Advocacy: The Northern California Household Exposure Study.” American Journal of Public Health. 100(3): 393.
[140] U.S. Environmental Protection Agency (2011). “Addressing Air Emissions from the Petroleum Refinery Sector: Risk and Technology Review and New Source Performance Standard Rulemaking.” Tribal Consultation Presentation.
[141] U.S. Environmental Protection Agency (2008). “Integrated Science Assessment (ISA) for Sulfur Oxides—Health Criteria (Final Report).”
[142] Lercher, P., et al., (2011). “Cardiovascular effects of environmental noise: research in Austria.” Noise Health; Van Kempen et al. (2012) “Neurobehavioral effects of exposure to traffic-related air pollution and transportation noise in primary schoolchildren.” Environ Res, 115:18-25.
[143] U.S. Environmental Protection Agency (2007-2009). “Particulate Matter (PM) Standards—Documents from Current Review—Integrated Science Assessments.”

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 19 below, with high-risk countries extending throughout the Indian subcontinent, Southeast Asia, Eurasia, Mexico, South America, and a significant portion of Africa. Three of the top 10 countries of highest risk for human rights abuses are oil-producing countries (Iraq, Nigeria, Yemen), and numerous others such as Saudi Arabia, Iran, Mexico, and Venezuela are in the "High Risk" to "Extreme Risk" category.[144]

Figure 19: Sample Heat Map of Human Rights Risk Areas



Source: Maplecroft 2013

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.

Even in Canada, which is low-risk from a human rights perspective, oil sands are found within the historical homelands of a large number of First Nations communities. The potential human rights risk to and opposition by indigenous peoples extends to most types of fuel production and distribution: Solar development in Arizona, pipelines in the Midwest and Mountain states, coal shipments through the Pacific Northwest.

First Nations are particularly at risk to human rights abuses and as such, frameworks for the protection of human rights such as the IFC's Performance Standards outline specific steps for consultation with and informed consent from indigenous peoples. However, some of these forums have been criticized as ineffective and not supporting true consultation.[145] Company efforts to engage and promote local benefits (discussed in the next section) are also important activities in respecting and advancing human rights among individual communities.

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[144] Maplecroft (2013). "Human Rights Risk Index 2014." http://reliefweb.int/sites/reliefweb.int/files/resources/2014_Human_Rights_Risk_Index_Map.pdf

[145] 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.

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.

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 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
- Displacement of populations

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 risks, notably those connected with child and forced labor, are more likely to occur with biofuels. 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.[146] 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

[146] Food and Agriculture Organization of the UN (2013). "Biofuels and the sustainability challenge: A global assessment of sustainability issues, trends and policies for biofuels and related feedstocks." Rome.

illness. There have also been cases of forced labor in biofuel production, as in Brazil, where 1,000 laborers were freed by the country's anti-slavery program in 2007.[147]

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
(For Economic Impacts such as job creation and economic development, see "Economic Impacts" section below.)

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:

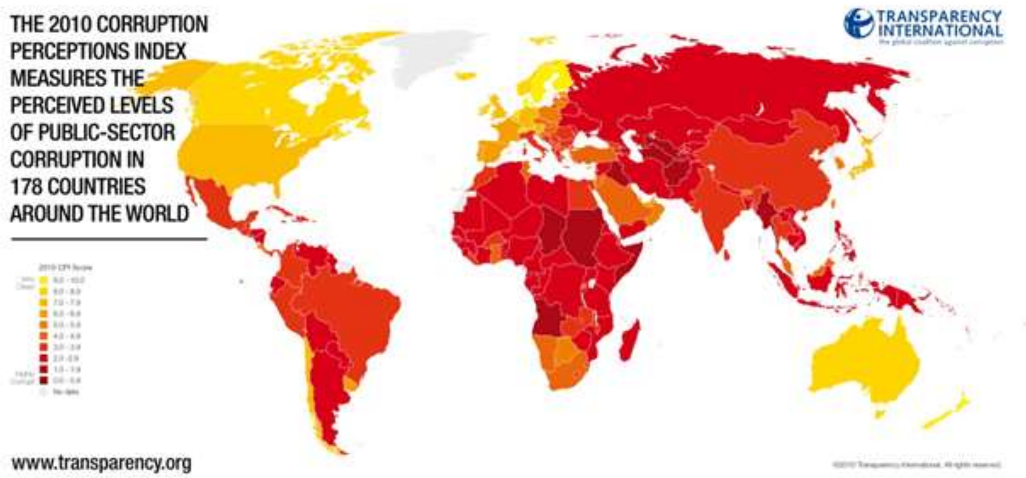
- » Boomtown effects: physical investment, services and raw materials required, spin-off effects on real estate, wages, etc.
- » Resettlement: displacement due to project activities sanctioned by government
- » Local environmental/health impacts (fossil fuels and biofuels): water, dust, air pollution, 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
- » Loss of recreational areas

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.

As with human rights above, Figure 20 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.

[147] BBC (2007). "'Slave' labourers freed in Brazil."

Figure 20: Corruption Perception Index



Source: Transparency International

The challenges noted above are obviously more acute in less-developed countries, with one of the most extreme examples coming from oil development in Nigeria that has contributed to conflict, migration, and other community impacts. However, rapid energy development has resulted in community impacts even in developed economies, notably the Alberta oil sands in Canada and the boom towns in the Bakken shale oil areas of the United States, where inflation has made mining counties in North Dakota some of the most expensive in the country.

Some stakeholders claim that fossil fuels perpetuate a resource curse where oil development booms, creating the illusion of prosperity and development while actually destabilizing regimes. Evidence for this claim is offered 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 21 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.

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, and losses, 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 may require less labor and possibly have a negative impact on the community.

Figure 21: 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 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 22 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 22: 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—both positive and negative—are often left out of discussions on sustainability, in part because of their difficulty to quantitatively compare to other sustainability issues. 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. Furthermore, energy and energy access are increasingly recognized for the important role they play in human development and progress.

The economic impacts of fuel have been explored extensively on an individual project basis, but 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. They also tend to be produced by an industry or stakeholder organization with a specific agenda to promote. 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.

Energy is the engine of the modern global economy and driver of human development. Over the past generation, 663 million people—nearly 10 percent of the population— have moved from poverty to at least basic levels of comfort and dignity. Access to modern energy services plays a fundamental role in this development by fulfilling basic social needs, driving economic growth, raising productivity, and promoting health and education. Furthermore, energy generation, distribution, and consumption affects the local, regional, and global environment with serious implications for the livelihood and prospects of poor people. Providing access to affordable sources of energy and reducing the worst negative social and environmental effects will be critical to alleviating poverty and ensuring peace and prosperity for the 9 billion people expected to inhabit Earth in 2050.

The economic growth and development impacts of fuels represent a benefit, but also a complex one to measure. 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.

Figure 23: Types of Economic Impacts—More to Less Direct

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 and Revenues

All fuel sources have the potential to create jobs and generate revenues. Historically, fossil fuel and biofuels projects have tended to bring elevated levels of economic activity to regions. Oil and gas projects also play a significant role in the United States 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). Scaling up electric vehicles also has the same effect of creating more jobs and revenue for local economies.

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 Agency, 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—including advocacy organizations such as Greenpeace, mainstream risk experts such as Lloyd's, and the U.S. Department of Defense —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. 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 the United States, commodity competition for biofuel feedstocks can be a concern. For example, cleaning product manufacturers have criticized policies that support renewable fuel industries because they divert inedible beef tallow to fuel production and away from use for production of cleaning products.[148]

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. Recent research suggests, however, that this might not be the case.[149] 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 in the United States.[150] Another study showed that biofuel was an important contributor to the recent food-price inflation of 2001-2008 but its effect on food-commodity prices declined after the recession of 2008-2009.[151] This is an area of uncertainty that would benefit from additional research.

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[148] American Cleaning Institute (2014). "Comments to the Environmental Protection Agency: Air and Radiation Docket and Information Center—Regulation of Fuels and Fuel Additives: Renewable Fuel Standards: Docket ID No. EPA-HQ-OAR-2013-0479."; Pine Chemicals Association, Inc. "Bioeconomy Controversy: The Facts."

[149] Wallington, T., et al. (2012). "Sustainable Mobility: Lithium, Rare Earth Elements, and Electric Vehicles." Proceedings of the FISITA 2012 World Automotive Congress Lecture Notes in Electrical Engineering Volume 191, 2013, pp. 155-166.

[150] National Research Council (2011). "Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy." Committee on Economic and Environmental Impacts of Increasing Biofuels Production. The National Academies Press.

[151] Hochman, G. (2012). "Biofuel and Food-Commodity Prices." *Agriculture.* 2, 272-281.

In developing countries, the price effect could be greater, as the cost of labor is generally lower and the raw agricultural commodity price is a greater influence on retail prices.[152] 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

[152] Seale Jr., J. (2003). "International Evidence on Food Consumption Patterns." Technical Bulletin no. 1904. Economic Research Service, U.S. Department of Agriculture.

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 diminishing supply of cheap conventional sources of 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 question 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—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 fuel savings). 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.

Findings and Implications

We have discussed key fuels for transportation, outlined their current market positions and outlooks over the next few decades, and inventoried what is known about their sustainability impacts. What follows is a synthesis of findings, grouped into three categories: What we know about fuel markets, what we know about the sustainability impacts of fuels, and what can therefore be done to advance fuel sustainability.

1. WHAT WE KNOW ABOUT FUEL MARKETS

At the current trajectory, **oil is poised to remain the backbone of an increasingly diversified fuel mix for at least the next 20 to 40 years**. However, there is great uncertainty about the pace with which oil will give way to alternatives, and to what extent various alternatives will expand. This uncertainty is inherent in all new technologies, and energy developments are no exception.

Finding #1: Oil is the dominant fuel, though it is now ceding share to alternatives. There are many open questions regarding the possible and desirable development rates of different fuels. Analysts such as the U.S. Energy Information Administration, Shell, and Greenpeace provide projections and prescriptions that are quite different (Appendix 2) , and whose differences can be explained by varying beliefs about what issues are most important, expectations about what will drive change in the marketplace, and confidence in which changes are most likely. Therefore views about the future vary based on authors' views on whether or not comprehensive climate polices will be established, 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 avoided.

Yet even with these different viewpoints, it is reasonably clear that the commercial transportation system in North America and worldwide will continue to rely on petroleum for a large share of energy needs for at least the next 20 to 40 years. During this time, low-carbon and renewable fuels will remain a relatively small part of the energy mix, even as they continue to grow faster than any other source. The economic viability of unconventional resources may slow the transition to lower-carbon fuel sources as governments prioritize what they perceive as economic and security objectives, even if these views ignore the economic and security risks of climate change that are brought on by GHG-intense fuels.

This situation will be driven primarily by several large-scale trends. First, we expect to see a dramatic increase in global energy demand led primarily by emerging economies, whose strong growth will more than offset the expected impact of efficiency measures in developed economies.[153] Second, global supply will struggle to keep pace with this growth, creating pressure for greater reliance on alternative sources of energy supply such as natural gas, biofuels, and unconventional oil. Third, in the absence of a price on carbon, emergence of these alternatives may 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, including in the United States where, for example, the state of California has successfully launched a cap-and-trade program. In June of 2014, the United States Environmental Protection Agency announced a Clean Power Plan that would achieve by 2030 CO_2 emission reductions from the power sector of approximately 30 percent from CO_2 emission levels in 2005. China has committed to reduce its CO_2 emissions per unit of GDP by 40 to 45 percent from 2005 levels by 2020. China has also pledged to use non-fossil fuels for about 15 percent of its energy and increase forest cover by 40 million hectares and forest stock volume by 1.3 billion cubic meters by 2020 (from 2005 levels).[154]

> *Implication:* Even in scenarios that foresee natural gas, biofuels, and EV systems achieving their greatest potential, oil is expected to remain a majority of the global fuel supply for several

[153] International Energy Agency (2012). "World Energy Outlook, Executive Summary."
[154] Natural Resources Defense Council. "From Copenhagen Accord to Climate Action: Tracking National Commitments to Curb Global Warming." Available at: http://www.nrdc.org/international/copenhagenaccords/

decades and specifically for commercial road freight. Therefore, 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 #2: While the future mix of fuel is impossible to predict, we do expect it to become more-diversified and a "poly-fuel" economy to emerge. While there is a wide range of outlooks about the roles of specific transportation fuels in the future, one thing seems relatively clear: We face a long period of transition in which the global energy mix and North American transportation fuel system will become increasingly diverse, with alternatives such as natural gas, biofuels, EVs, and hydrogen expanding to take market share from oil.

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

Another dimension that will require more attention, especially as transportation becomes more electrified and electric grids become sophisticated, 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. The potential for electric vehicles to store energy when wind and solar produce energy for use when they do not produce energy, for example, could enable additional low-carbon renewable electricity integration.

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 manage fuel sustainability should embrace a diversified portfolio approach, transitioning to low-GHG alternatives such as biofuels and electric vehicles when possible. However, both incumbent and emerging fuels alike have additional sustainability issues to manage throughout the value chain. Therefore, there is unlikely to be a single "silver bullet" fuel solution in the near term, and companies should focus on increasing the benefits and reducing the negative impacts of the whole breadth of fuel sources.

Finding #3: Advanced technologies such as biofuels and electric vehicles are taking off, but will require major investments and policy support in order to scale up. Over the past decade, low-GHG and renewable technologies, such as biofuels and EVs, have begun to take off and research bringing technologies like hydrogen closer to commercialization has increased. However, hydrogen, DME, advanced biofuels, and several other technologies may require many more years of investment and policy support to become commercially viable.

In Brazil, the most advanced biofuels market in the world, virtually all new cars can run on any mix of gasoline and ethanol.[155] 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 will be key to capturing the climate benefits of EVs, is the fastest-growing segment of the energy sector.

[155] Zilberman, D. (2011). "The role of biofuels in the energy future: Lessons from Brazil." The Berkeley Blog. Available at: http://blogs.berkeley.edu/2011/09/22/the-role-of-biofuels-in-the-energy-future-lessons-from-brazil/ ["The industrial effort to produce ethanol for vehicle transportation started in 1975, and in the 1980s the Brazilians introduced cars that only ran on alcohol. However after some crop failures, the experiment with the 'alcohol car' ended and the industry had to rebound and rebound it did. The government introduced a standard that required use of 25 percent alcohol with gasoline, and in 2003 flex cars were introduced."]

Generating capacity for solar and wind has been expanding by double and even triple digits annually, and today both technologies are commercially competitive 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 for development and large-scale deployment of alternative, low-carbon energy solutions is one of the key assumptions shaping expectations about 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.

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: decades rather than years. New energy technologies have historically required decades of sustained government support and growth to achieve even 1 to 2 percent share of the energy mix. The further buildup of advanced fuels will not happen on its own, it faces many roadblocks, and it 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 aggressively 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.

2. WHAT WE KNOW ABOUT FUEL SUSTAINABILIITY

The second broad theme is that **the impacts of fuels are significant, and we need to act now to improve our understanding of their complex and interconnected sustainability impacts**. Fuel use is responsible for some of the greatest sustainability impacts that companies face, and yet there remains a significant gap of knowledge about what these impacts are.

Finding #4: Fuels create many critical sustainability impacts and addressing them should be a high priority for companies and policymakers. Transportation fuels create many substantial sustainability impacts. Foremost among those is climate change, which is a serious and urgent threat to businesses and the communities they depend on. Transportation is responsible for nearly 25 percent of global CO_2 emissions and could be associated with 40 percent or more when considering the whole life cycle of fuels and related vehicles and infrastructure. Fuels create many additional environmental, health and other social impacts through both their direct combustion and extended life cycles of production.

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, criteria pollutants, and specific land-use impacts). Additionally, we can distinguish between impacts that are a relatively universal attribute of the fuel resource in question (e.g., combustion impacts), 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.

The significant impacts relate mostly to incumbent fuels that exist at scale—meaning diesel and gasoline derived from oil, which makes up more than 90 percent of the supply. This category is responsible for 90 percent of climate impacts from fuel. The science on sustainability of fuel is most advanced with oil because it has been around at scale for the longest. While shifting to lower-impact fuels must be an urgent priority, we believe that maintaining a focus on improving the impacts of ongoing oil supply is important because even with a rapid shift to different fuels, oil is likely to be around for many years.

Alternatives to oil also have impacts. For example, natural gas (CNG and LNG) could have one-third lower life cycle GHG emissions than gasoline or diesel. However, being an attractive climate alternative depends on whether or not the sector can (1) minimize fugitive emissions and (2) play a role to promote a swift transition to low- or zero-GHG emissions fuel without creating delays or barriers to doing so. Additionally, there are many concerns about community and water impacts at the wellhead that are not yet well-regulated and need to be resolved.

Other emerging fuels also create impacts to varying degree. Some biofuels have worse GHG emissions than oil (but most do not) and are associated with other water and potential social impacts. As a rule, low-GHG alternatives have better sustainability profiles than oil, but we need to actively manage their broader sustainability attributes as they scale up.

> *Implication:* Fuel sustainability efforts should include a focus on reducing the significant climate change and other sustainability impacts of large-scale incumbent fuels and emerging fuels even as we work to accelerate the development of new low-carbon fuels.

Finding #5: Our knowledge of the total sustainability impacts of fuels has numerous gaps, and we should strive for better science and understanding. When looking for comparisons of broad sustainability impacts across many fuel types, even the most data-driven, state-of-the-art information does not lend itself to simple conclusions, owing in part to the complexity of different inputs, diverse methodologies, and numerous gaps in our current knowledge. Many sustainability impacts of fuel have been studied, though typically 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.

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. Also of significance is the region in which the diesel or biodiesel is derived. 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.

Figure 24: Areas of Further Study

Key areas that require further development include:

- Comparative water, societal, and economic impacts among fuel types
- Integration of life cycle assessments with evaluations of social, market, spatial, and temporal impacts
- Downscaling assessments of production impact to specific ecosystems and sites
- Establishment of better community and public knowledge. In many cases, data exists 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

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 during 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- or 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.

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. 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.

As a result, knowledge about fuel sustainability is moving forward in certain corners of the fuel industry, but there is no guiding framework that reconciles the different approaches and bodies of information. 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 knowledge gaps even in mature sources such as crude oil. With new sources and technologies—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 assessments beyond climate 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 supplies rapidly expand, 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.

> *Implication:* Companies and wider society need to place a greater priority on filling in the knowledge gaps about energy in general and fuel sustainability specifically, and applying more-measured analysis across all fuel sources. 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. There are major opportunities for businesses to invest, lead, and shape a sustainable future, and the diverse networks of business, civil society, and governments need to be a part of solutions that apply sustainable development principles.

Finding #6: Systemic remedies require taking 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 fuel use, 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 region has been developed (about the same area as Chicago), but 99 percent of the more than 54,000 square miles of oil sands region (an area roughly the size of England) has been leased.[156] This implies an ongoing challenge for the government to manage the pace of growth versus the pace of reclamation.

[156] Oil Sands InfoMine (2014). "Oil Sands CountryMine."

At the same time, the development cycles of fuel technologies are long, which presents a paradox. On the one hand, the time is now for companies to act in order to prepare for the future. On the other hand, they will need access to capital with enough patience to accept returns on a long time frame, potentially of a decade or longer.

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.

3. 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 bold, system-wide action is needed to accelerate low-carbon fuels and manage the sustainability impacts of 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 we explore further in our paper, "Transitioning to Low-Carbon Fuel: A Business Guide for Sustainable Trucking" (BSR, 2014).

Finding #7: 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 the 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 issue areas we considered.

Efficiency should be a starting point for fuel sustainability discussions. Efficiency improvements are more within the scope of business operations than options that require sustainability investments farther up the fuel supply chain. It therefore makes business sense to pursue these efficiency options first. Furthermore, efficiency should be considered the organizing principal, not just using less fuel, but less feedstock, or making the best use of feedstocks to drive better outcomes. In other words, efficiency calls for creating a more-efficient fuel production process, not just focusing on the end-user.

Conventional oil and gas are somewhat less carbon-intensive than unconventional fossil fuels 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 water, land, and biodiversity impacts that must be managed, and even their GHG benefits are dependent on agricultural practices related to land use.

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 and solar development taking hold. However, infrastructure and vehicle systems (especially for HDVs) 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. Also needed are government action to fund development of technologies, pilot programs to test fuels and the vehicles that use them, and the creation of a favorable policy environment, such as through a price on carbon.

> *Implication:* Understanding and addressing the full range of fuel impacts—environmental, social and economic—should be a top priority in order to ensure that new low-carbon solutions are not undermined by the creation of new problems and/or failure to address key stakeholder concerns. This is a basis for creating the interest and demand among the various stakeholders—customers, investors, and policymakers—needed to promote the development of more-sustainable fuels.

Finding #8: Despite some tradeoffs and uncertainties, the case for bold action is clear. Increasing the sustainability of fuels involves complex interdependencies. In some cases, scaling up low-GHG fuels creates the potential for tradeoffs or adverse effects. Such potential effects include increased material use, the expansion of farming and crops that may influence food prices, and road safety issues that result from quieter engines. Another potential issue is that the direct economic benefits will be uneven—companies and sectors that are positioned to thrive with low-GHG transportation fuels will do better than those that are not.

However, despite these potential tradeoffs and the uncertainties mentioned previously, the benefits of bold action far outweigh the costs. The primary reason is the profound consequences of inaction. Earth is on a path to a mean temperature rise of 3.7°C to 4.8°C by the end of the century, which threatens to undermine the range of sustainability benefits across the range of issues, from ecosystem to societal to economic impacts.

Additionally, the potential tradeoffs that do exist are offset by co-benefits which are generally more significant. Mitigation scenarios leading to a 2°C target are associated with significant co-benefits for air quality, human health, biodiversity, human development, and energy security, which on balance have greater and positive societal repercussions. This is supported by substantial literature that has emerged from and since the publication of IPCC's Fourth Assessment Report in 2007 and Fifth Assessment Report in 2014.

Finally, the potential for adverse side effects that do exist can be managed through good policies and case-by-case project evaluations. The problem of emissions from indirect land-use change created by biofuel production, which initially flared up in Europe, have become largely manageable in the United States, where regulators in leading states such as California are instituting life cycle sustainability measures. Higher energy prices can be avoided through directed policies. Environmental impacts such as water use can be minimized through appropriate technology selection and siting. In general, life cycle management approaches provide strong tools for minimizing adverse effects when looking at projects on a case-by-case basis.

> *Implication:* Transitioning to a new fuel economy brings about tradeoffs and uncertainties, but the costs and risks of inaction are increasing, the net balance is towards co-benefits rather than adverse side effects, and the potential for tradeoffs can be managed. Therefore the status quo is unacceptable, and intervention is needed. The sector must engage fully in actions to avoid the worst consequences of climate change through bold emissions reductions.

Finding #9: Practical solutions exist to accelerate low-carbon fuels and avoid or reduce their sustainability impacts. Actionable strategies for commercialization and sustainability management are here and continue to develop. Even in the two years since this paper was first drafted, new standards on biofuel sustainability and clarity on indirect land-use impacts have emerged with government and third parties, research has clarified the threshold at which methane leakage in natural gas results in higher life cycle emissions than diesel, best practices for fracking water management and pilot water quality management and testing programs have been launched by a partnership with industry, government, and NGOs, and several major OEMs have announced commercialization timelines for hydrogen fuel cell light-duty vehicles.

There are many things we can and should do now, as demonstrated in “Transitioning to Low-Carbon Fuel, a Business Guide for Sustainable Trucking,” which provides a systematic approach for managing the impacts of fuel:[157]

» **Understand your total footprint:** Measure and characterize the total impacts of fuels, identify potential strategic fuel sustainability issues, and determine the significance of fuel sustainability.

» **Optimize the use of available fuels and vehicles:** Maximize the fuel efficiency of the current fleet, determine the desired mix of fuels and supporting technology, and establish a fuel-sustainability policy.

» **Collaborate to enable low-carbon solutions:** Accelerate the innovation and deployment of advanced technologies, encourage better upstream impacts, and promote systems for supply chain accountability and ownership.

» **Advocate for a better policy environment:** Align on principles for fuel sustainability, encourage dialogue on key issues, work with government to strengthen policies for fuel sustainability.

An increasing number of partnerships have emerged to address the sustainability challenges of fuel production, distribution and use today. BSR’s Future of Fuels is one such initiative, but there are others, as highlighted in the report above. Together, these opportunities show that fleet operators and their value chain partners have a broad menu of options to proactively improve the impacts of fuels.

> *Implication:* We must use fuel that has very low emissions and that is broadly sustainable. Companies are already acting and reducing emissions, and we need to build on these efforts to accelerate and amplify outcomes. At the same time, we must avoid or reduce the most important sustainability impacts of all our fuels.

[157] Olson, E.; Schuchard, R. (2014). “Transitioning to Low-Carbon Fuel: A Business Guide for Sustainable Trucking in North America.” BSR.

Next Steps

This paper has identified an array of areas where better understanding, higher levels of investment, and more-creative partnerships are needed to make transportation fuels do their part to achieve climate change and sustainability objectives.

Based on this, BSR will produce a set of issue briefs in early 2015 that provide more-granular assessments and identify specific opportunities for the main fuels highlighted in this paper—petroleum, natural gas, biofuels, electric vehicles, and hydrogen. This report and the fuel briefs will provide a foundation for development of a “fuel tool” for use by fleet owners and fuel buyers to accelerate deployment of low-carbon, sustainable fuel by understanding and a managing the impacts of fuels for commercial trucks. More broadly, BSR will seek to continue to lead dialogues that improve shared understanding and that drive analysis that is grounded for decision-makers in support of greater fuel sustainability.

We invite you to join us and welcome feedback. Please contact us at futureoffuels@bsr.org.

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Appendix 1: Dimensions of Sustainability Impacts

The “Sustainability Impacts of Fuel” section outlines the state of knowledge about the sustainability impacts of fuels. It reveals that the impacts of fuels have many dimensions: They can be negative or positive, probable or actual, objective or relative, direct or wide, frequent or infrequent, and scientifically validated or reflective of unresolved issues. These multiple dimensions make comparison and universal quantification challenging. As the science of fuel sustainability develops, decision-makers are advised to understand these different dimensions which may be made more or less explicit in a given research finding or claim.

Negative Impacts vs. Positive Impacts: In the context of corporate sustainability and life cycle analysis, impacts are often thought of as downsides or risks that should be mitigated or avoided. Examples include GHG emissions, violations of human rights, and fatalities.

Fuel also creates many positive impacts, many of which are fundamentally important. Energy is a driving force for modern society, and access to low-cost fuel is a precondition for reducing poverty. As a driver of growth and development, energy may provide the foundation for jobs and stimulate and support new investment in social institutions including education and health infrastructure.

Probable Impacts vs. Actual Impacts: Impacts that are attributable to fuel sectors (e.g., emissions from oil sands or soy-based biodiesel) are generally based on models that provide probabilistic figures, or “expected values.” Such studies provide vital gauges for high-level understanding. At the same time, actual impacts may vary from these estimates based on an individual company’s management practices.

One illustration is with life cycle emissions from natural gas. If the average impact of methane leakage from natural gas is under 1 percent, then natural gas will have a superior life cycle GHG footprint than diesel and coal, while if it is higher, then the opposite may be true.[158] Research suggests that climate benefits from natural gas fuel substitution are uncertain for gasoline and the light duty sector, and even more challenging for diesel and the heavy-duty sector.[159] Understanding the average footprint of natural gas is needed in order to characterize the promise of the fuel overall. However, in practice, leakage will vary as a result of technology, policies and procedures, and worker expertise—all things that can be managed to an extent.

Another is found in the role of companies working in challenging environments. The Yale Environmental Performance Index shows that fugitive emissions are more likely to be prevalent in a refinery in Russia than a similar one in Norway. However, the act of operating in a more-challenging environment does not guarantee that worse impacts will occur. Furthermore, the company could potentially encourage higher standards of practice in the local business community and influence governments to adopt more sustainability-oriented policies. Therefore, a lower regulatory environment could lead a company to cause greater negative impacts, but the company’s presence there could also be an opportunity to improve existing conditions.

Objective Impacts vs. Relative Impacts: Impacts are often expressed in universal measures so that they may be objectively understood. For example, each 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. Such objective measures lend to quantification and in turn the ability to synthesize large amounts of information.

However, in many cases it is difficult to use universal measures because the effect depends on context. For example, the impact of consuming a million gallons of water is greater in a desert and less in a rainforest and the impact of chemical exposure to biodiversity depends on the value and sensitivity of the local ecosystem services.

[158] Bradbury, J., Obeiter, M., (2013). “Clearing the Air: Reducing Upstream Greenhouse Gas Emissions from U.S. Natural Gas Systems.” World Resources Institute.
[159] Brandt, A.R., et al. (2014). “Methane Leaks from North American Natural Gas Systems.” Science. Vol. 343: 733-735.

Timing also bears on the impact. The greatest load on electrical power grids is in the afternoon and evening, during which time electric “peaker plants”—which tend to consume natural gas and have higher emissions than renewables—come online. Also, congestion and air pollution are worst during rush hour. Therefore, the timing of vehicle charging and traveling can affect whether the systems stay safely under or go beyond critical thresholds.

Direct Impacts vs. Wider Impacts: From the perspective of a fuel user (e.g., fleet operators), the use of fuel creates a combustion that leads to emissions, which can be thought of as its direct impact. The fuel use, however, is associated with a wider chain of non-direct impacts. Those impacts include:

» *Indirect impacts:* Impacts from the production of goods in the supply chain (sometimes called “co-product” effects) and economic impacts from goods and services that are essential to the construction of a production project (sometimes called “supplier impacts”). This category is included in life cycle assessments (LCA) and the Greenhouse Gas Protocol’s Value Chain (Scope 3) standard, which is widely used by companies to account for and report on climate impacts.[160]

» *Market-Mediated Impacts:* Changes to market forces. Increased demand for biofuels can lead to expanded croplands, which could cause forests to be converted to farms, thereby creating new emissions (this is called indirect land-use change or ILUC), and affect prices of food or fibers. This category has proven more difficult to incorporate into LCAs than indirect impacts.

» *Induced Impacts:* The impact from job or revenue creation that occurs when wages and salaries are spent in communities, for example on food, housing, transportation, and medical services.

» *Lock-In:* Lock-in refers to barriers created through the buildup of infrastructure by one category of fuel that delays the transition to alternatives that are more sustainable and economically advantageous. Today, lock-in is most relevant with natural gas. Natural gas holds the potential to have lower life cycle GHG emissions than diesel and gasoline, but the development of new development, storage, distribution, and vehicle systems, which are capital-intensive, may prolong that transition and undermine the idea of natural gas is an aid or “bridge” for the transition.

» *Cumulative Impacts:* Effects from a group of sites or companies that together affect the balance of ecosystems or communities beyond the sum of their individual parts. For example, at a certain pace and scale, oil sands development could impinge wildlife corridors. By definition, cumulative impacts are diffused among many actors.

» *Leakage and Shuffling:* Leakage and shuffling refer to impacts being diverted rather than reduced or eliminated. For example, greater regulation in California could lead production to move to Texas. Leakage and shuffling can have neutralizing or counterproductive effects on impacts as a whole. Such movement can also occur without directed policies. For example, a rise in natural gas demand in the United States is leading coal to being diverted to Europe.

Chronic Impacts vs. Acute Impacts: Impacts tend to be associated with either relatively low-level occurrences linked to everyday operations, such as levels of local air emissions, or alternatively to events that occur infrequently but whose consequences can be dramatic, such as crashes, explosions, and other accidents. Companies and communities can prepare for low-probability, high-impact events that have

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[160] U.S. Environmental Protection Agency. “Life Cycle Assessment (LCA).” Risk Management Sustainable Technology. [Life Cycle Assessment (LCA) is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by compiling an inventory of relevant energy and material inputs and environmental releases, evaluating the potential environmental impacts associated with identified inputs and releases, and interpreting the results to help you make a more informed decision. The major stages in an LCA study are raw material acquisition, materials manufacture, production, use/reuse/maintenance, and waste management.]; Results are highly dependent on assumptions about location, materials used, and production and vehicle technology. For more on the Greenhouse Gas Protocol, see http://www.ghgprotocol.org.

familiar parameters (e.g., oil spills). But their occurrences can be difficult to predict precisely and their consequence on ecosystems and communities are hard to anticipate.

Scientifically Validated Impacts vs. Unresolved Issues That Merit Precaution: Empirical study is needed to understand the nature of impacts, and provides a basis for making broadly accepted models used in decision-making tools like life cycle assessments. However, scientific study has so far encountered a number of important obstacles to comprehensively characterizing impacts. They include:

» *Data Availability is Inadequate.* Much information about production processes is proprietary and operators do not readily share data that may invite new regulation. Thus many research questions exist that have not been studied.

» *Technology Change Outpaces Research.* New techniques and technologies can be adopted in the 1-2 years it may take to complete a study; additionally, it may take years to properly document health and long-term environmental effects. Relatedly, it is difficult to extrapolate what the future impacts will be with technologies or subsectors that are rapidly growing in size.

» *Social Interactions Resist Quantification*. Issues that involve social interactions such as human rights are difficult to quantify. Also, stakeholders have different tolerances for the risks involved with low-probability, high-consequence threats. Life cycle assessments do not readily incorporate these issues.

» *Studies Disagree.* Multiple reviews find science unresolved on issues of profound consequence. In practice, even the most developed areas—such as life cycle emissions—have dueling studies that are attributable to groups with different objectives and approaches.

It is not practical to address all concerns without scrutiny. At the same time, while deeper and broader empirical study is needed on a range of fuel issues, it is not prudent or just to simply wait for the science, since many questions have proven challenging for science to answer.

CONCLUSIONS

The dimensions above highlight some key issues for decision-makers to bear in mind when considering the impacts of fuel. A comprehensive, unified understanding of the sustainability impacts of fuels is lacking, and major methodological challenges stand in the way. This means that while progress has been made on measuring impacts of key aspects of fuels, it is not yet possible to fully synthesize and compare the breadth of issues, let alone characterize trade-offs.

Findings or claims about impacts involve a number of potential dimensions that can make it difficult to draw comparisons. These dimensions may or may not be made explicit, and they are also not commonly understood and acknowledged. For example, “lock-in” is an important concept but does not have clear metrics. Advocates routinely treat probable impacts as the only impacts and ignore critical opportunity for improving actual impacts on the ground.

Sustainability impacts have multiple dimensions. Impacts are also typically linked to one another and difficult to categorize. 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.

More information about impacts from certain sources does not mean that that impact has the greater relative impact. For example, production emission and environmental performance data is generally not available for crude oils produced outside of Organization for Economic Cooperation and Development (OECD) countries. In this case, governments with greater safeguards tend to be more transparent, which means that, in many cases, the greatest impacts (and opportunities to create change) may be found precisely where information is lacking.

In summary, while much work has to be done to better understand the sustainability impacts of fuel, there is an equally important need to better understand and publicize these underlying dimensions so that business and government decision-makers can more usefully compare information.

Appendix 2: Market Outlook Reference Data

Several forecasts and scenarios provide medium- to long-term energy outlooks (see “The Transportation Fuel Market”). 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 uncertain. While hopes for a comprehensive global climate deal were greatly dimmed in the aftermath of the COP15 summit in Copenhagen in 2009, 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, 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, biofuels, and even hydrogen vehicles are beginning to enter the light-duty vehicle market, it may take decades for any alternative fuel pathway to make a major difference in the global energy mix for heavy-duty vehicles and their 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.

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.

<u>The Reference Case</u>

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 paints a sobering picture of our potential energy future under their version of business-as-usual assumptions:

- » World energy consumption increases by more than 30 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 25.

Figure 25: 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.

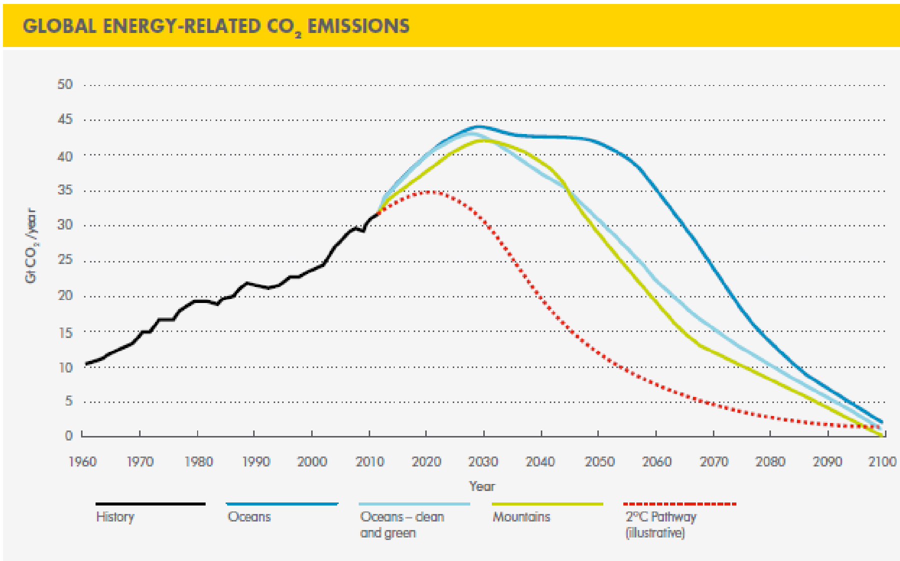
The Shell Energy Scenarios

Shell's most recent energy scenarios to 2100, published in 2014, 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
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—*Mountains* and *Oceans*—each based on a different set of assumptions with respect to policy and related business-investment decisions and behavior. Figure 27 and Figure 28 below show the expected changes in energy mix from 2010 to 2060 under each of these two scenarios. In both scenarios, Shell projects global emissions reductions are not sufficiently aggressive to hit the 2°C most experts agree is necessary to avoid the worst impacts of climate change (Figure 26).

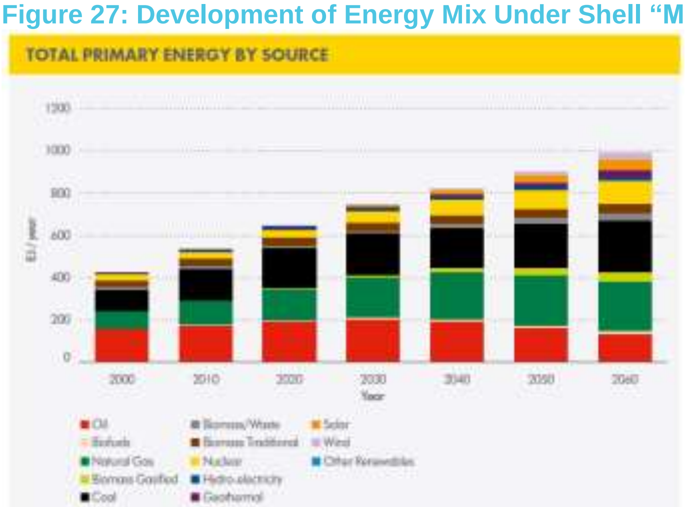
Figure 26: Shell Scenarios: Projected CO_2 Pathways



Source: Shell, 2014

Mountains reflects a focus on status quo and stability. The most influential people and institutions cautiously unlock resources, not solely dictated by immediate market forces. Positive advances in secondary policy areas (compact urban development, energy, environmental stress) are possible given fewer power brokers. Positive resource expectations are realized and natural gas becomes a backbone of the global energy system. Increasing CO_2 and environmental stresses are moderated by slower overall growth, substitution of coal by natural gas, and success of carbon capture and storage technologies. However, the global average temperature rise overshoots the current 2°C goal.

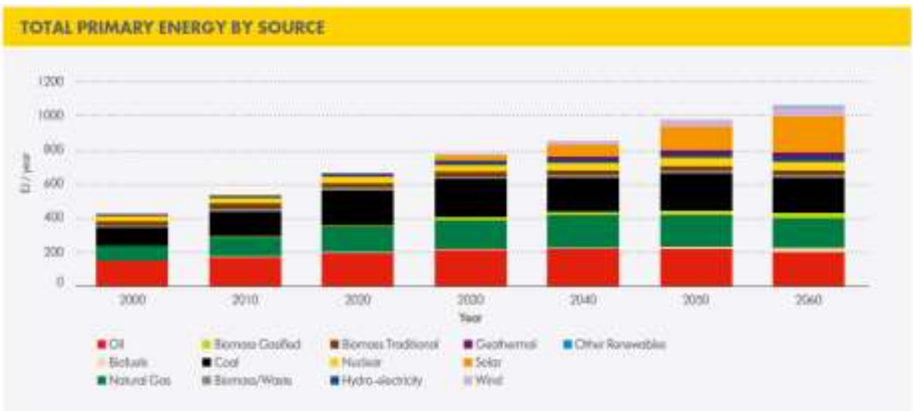
Figure 27: Development of Energy Mix Under Shell "Mountain" Scenario



Source: Shell. Scenarios 2013

Oceans details a more-dispersed power-sharing among interests, who achieve results through compromise. It predicts a surge in economic productivity amidst a wave of reforms that can result in eroded social cohesion and political destabilization. Liquid fuels and coal play a leading role in the energy mix until solar overtakes in the middle of the century. Natural gas grows but undershoots high expectations due to inadequate policy frameworks and resource disappointments. GHG emissions peak and remain high for a prolonged period until reduced by a combination of biomass, carbon capture and storage, and solar technologies.

Figure 28: Development of Energy Mix Under Shell "Ocean" Scenario



Source: Shell. Scenarios 2013

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:

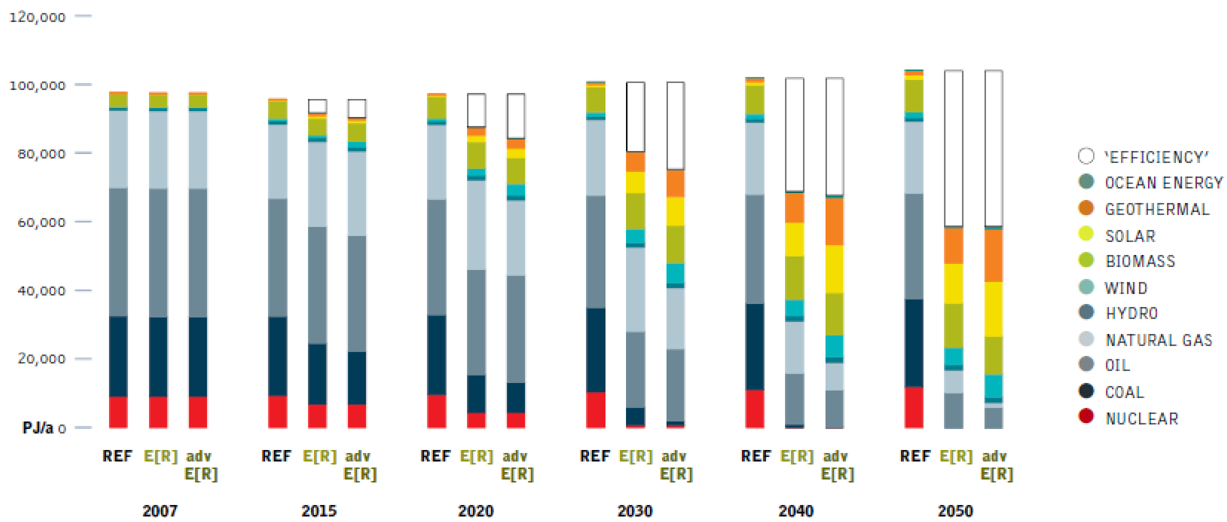
- Climate change has fallen down the list of priorities for the public and governments, and below-average growth in developed economies will restrict their governments' freedom to maneuver as they inevitably tighten spending and raise taxes.
- The impact of political delay is amplified by the necessary 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.

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*.

<u>Greenpeace Energy (R)evolution</u>

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 29.

Figure 29: 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, under the Greenpeace scenarios, 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 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 propose 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.

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 30: 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**

* Updated 2012
Source: CIA Factbook and BP.

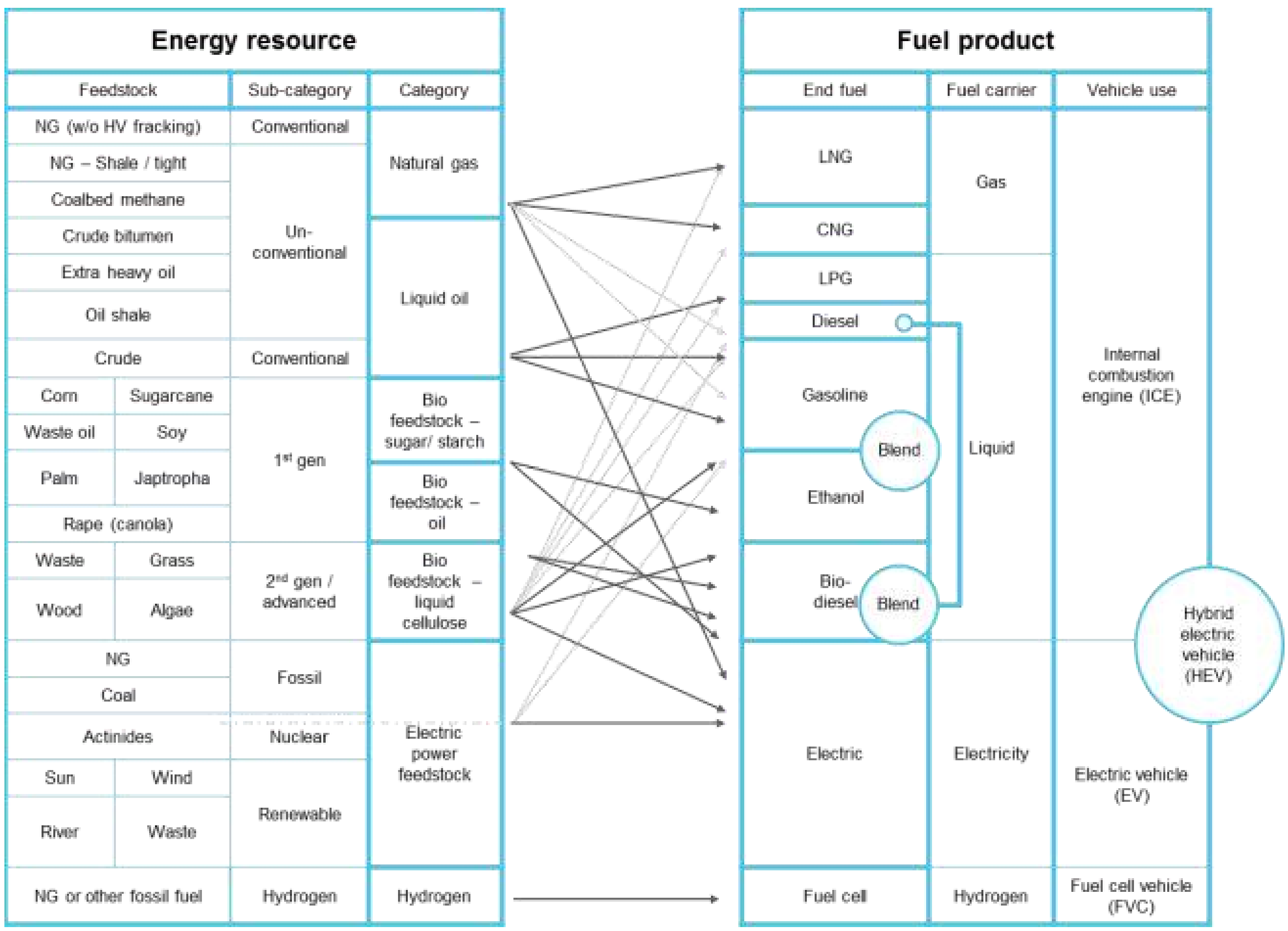
Notes: Asterisk denotes countries that have either substantial unconventional reserves or giant reserves of conventional oil. Biofuel includes ethanol and biodiesel.

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 31). 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 31: Fuel Value Chain Process Overview



Source: BSR

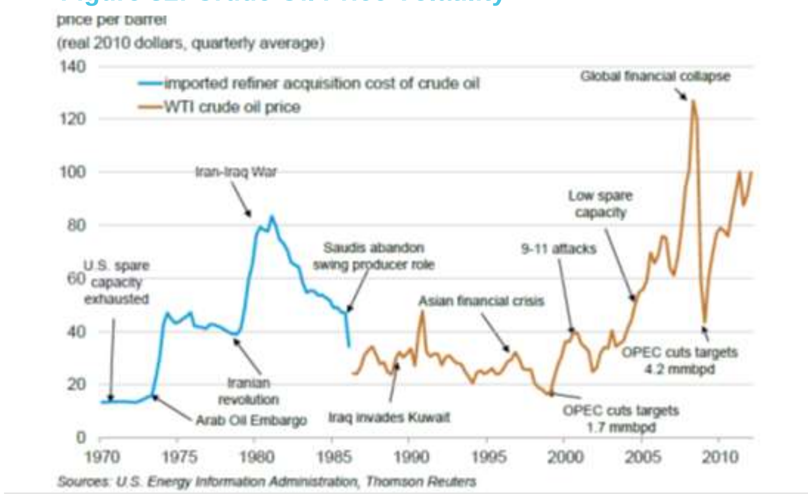
In practice, between 90 and 95 percent of transportation fuels in North America are currently petroleum-based, with gasoline taking up around 70 percent and diesel around 22 percent. Biofuels and natural gas comprise most of the remaining 5 to 10 percent somewhat evenly (2 to 4 percent each). Electric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

Figure 32: Crude Oil Price Volatility



Source: US 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 32). 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 with which companies differentiate themselves.

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 33: 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 Sugarcane 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, husks	Landscape waste Wood chips Other agricultural, 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, 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: Biofuel Regulatory Standards

The greenhouse gas emissions benefits of biofuels vary greatly based on feedstock, direct and indirect land-use impacts, cultivation practices, and other factors. U.S. policies have been crafted to address these differences. The federal Renewable Fuel Standard (RFS) and the California Low-Carbon Fuel Standard (LCFS) have different approaches, but with similar goals to promote advanced biofuels and optimal levels of conventional renewable fuel for economic and energy-security gains as well as GHG reduction. While the LCFS ranks fuels individually and promotes those with the highest carbon benefits relative to their economic costs, the RFS defines broad categories of eligible fuels.

The largest category defined by the U.S. EPA is Conventional Renewable Fuel. Conventional Renewable Fuel must reduce GHG emissions by 20 percent relative to average 2005 petroleum fuel. Corn ethanol is the most common fuel in this category. The market for corn ethanol is driven primarily by the need for a low-cost oxygenate in gasoline. The RFS provides a backstop against price manipulation in the international crude oil market that could otherwise wipe out domestic competition through short-run price manipulation. Renewable fuel producers that existed prior to 2008 are grandfathered from the 20 percent GHG reduction threshold. However, they must all certify that their feedstock comes from existing agricultural land. No conversion of non-agricultural land is allowed. Indirect land conversion is also considered for those non-grandfathered facilities, because the GHG life cycle analysis must include indirect land-use change. The EPA has concluded that corn ethanol meets these requirements.[161] California included 10 percent ethanol in its baseline gasoline for the LCFS, which makes it difficult for corn ethanol to find a policy benefit from the LCFS.

The definition of "advanced biofuel" was promulgated by the U.S. EPA and set forth in federal law under the Energy Independence and Security Act. An advanced biofuel must reduce GHGs by a minimum of 50 percent compared to average 2005 petroleum fuel. Corn ethanol is excluded from this category by law, even if it were to meet the GHG threshold. An advanced biofuel must also come only from waste or existing agricultural land. No direct land conversion is allowed, and indirect land conversion is quantified by life cycle analysis. GHG reduction must exceed the 50 percent threshold, even with indirect effects included. The major fuel types in this category include biodiesel, sugarcane ethanol, and cellulosic ethanol. Commercial production of cellulosic ethanol remains small due to technology hurdles. Imported sugarcane ethanol has the potential to displace both domestic biodiesel and conventional corn ethanol. Biodiesel is the only advanced biofuel with significant domestic production. The EPA has determined that biodiesel from vegetable oils like soybean oil, canola, and camelina all meet the requirements of advanced biofuel.[162] The EPA also included biodiesel made from used cooking oil, recycled grease, animal fats, distiller's corn oil, and algae.[163] Biodiesel made from palm oil does not meet the 50 percent GHG threshold, and does not qualify as an advanced biofuel. Grandfathered facilities may comply as conventional renewable fuel if they certify their feedstock is deforestation-free. Non-grandfathered palm oil producers are ineligible. While the minimum GHG reduction for advanced biofuel and biomass-based diesel is 50 percent, the biomass-based diesel in use today exceeds that minimum requirement by a wide margin. According to the latest published life cycle analysis for various feedstocks[164] and the feedstock mix reported by the Energy Information Administration and the U.S. EPA for 2013,[165] the average GHG reduction for biomass-based diesel exceeds 80 percent. Biomass-based diesel includes biodiesel and eligible forms of renewable diesel.

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[161] Federal Register, March 26, 2010, pages 14788-14789.

[162] United States Environmental Protection Agency (2010). "EPA Life Cycle Analysis of Greenhouse Gas Emissions from Renewable Fuels."

[163] Federal Register, March 26, 2010, pages 14788-14789.

[164] Pradhan, S., et al. (2012). "Reassessment of Life Cycle Greenhouse Gas Emissions for Soybean Biodiesel." American Society of Agricultural and Biological Engineers."

[164] California Air Resources Board (2011). "Production of Biodiesel from Corn Oil Extraction at a Dry Mill Corn Ethanol Plant."; Federal Register, March 26, 2010, pages 14788-14789.

[164] Wang, M. (2011). "Methods of dealing with co-products of biofuel in life cycle analysis and consequent results within the U.S. context." Energy Policy.

[164] U.S. Environmental Protection Agency (2010). "EPA Life Cycle Analysis of Greenhouse Gas Emissions from Renewable Fuels."

[165] U.S. Environmental Protection Agency (2013). "2013 RFS2 Data." Fuels and Fuel Additives.

[165] U.S. Energy Information Administration (2014). "Monthly Biodiesel Production Report." Petroleum & Other Liquids.

California ranks fuels individually by production pathway rather than consolidating fuels into broad categories as the EPA does. All fuels compete in that market with low-carbon fuels having the greatest competitive advantage. The California Air Resources Board (CARB) originally ranked biodiesel made from used cooking oil, animal fats, or distiller's corn oil with very low (favorable) carbon intensity.[166] CARB's original quantification of indirect land-use change penalized agricultural products quite severely. While biodiesel made from soybean oil and canola was still favorable to petroleum, it did not equate to fuel made from wastes and other by-products. CARB has proposed to update their quantification of indirect land-use change by capitalizing on the tremendous efforts in the scientific community to improve the data and analysis of predicted land-use change. CARB's proposed changes would be much more consistent with the EPA's findings that all domestically produced biodiesel qualifies as an advanced biofuel.[167]

Corn ethanol receives very little benefit in the LCFS. In fact, the LCFS does more to drive the importation of sugarcane ethanol to displace corn ethanol as a fuel oxygenate. This importation of ethanol from South America is often matched by exporting U.S. -produced corn ethanol to South America. South America wins economically in this because they make money selling sugarcane ethanol to the northern hemisphere and they use low-cost corn ethanol imported from the United States. U.S. consumers and climate policies lose because we end up paying to ship ethanol back and forth across the equator as ships pass going opposite directions. This indirect impact is not yet included in any renewable fuels policy.

The renewable and low-carbon fuels policies currently in place in the United States influence the availability of fuels to the consumer. Advanced biofuels and low-carbon intensity fuels enjoy preferential treatment. Conventional renewable fuels have a place in policy as well. Non-qualifying fuels receive no preferential treatment and are disadvantaged relative to fuels that do qualify. For the consumer buying fuel at a retail pump, common choices include blends of ethanol in gasoline and blends of biodiesel in diesel fuel. The majority of ethanol currently available comes from corn, with some sugarcane and sorghum promoted in the LCFS in California. Small volumes of cellulosic ethanol are currently in use with policies aimed at increasing cellulosic feedstocks.

Most gasoline is sold with a 10-percent ethanol blend. Any blends greater than 10 percent must be labeled as such, and vehicles must be compatible with higher blends of alcohol. Feedstocks used for biodiesel are diverse. Slightly less than half of the biodiesel currently produced in the United States is made from soybean oil; the other half is made from approximately equal portions of animal fat, recycled grease, and other by-products. Blends of 5 percent biodiesel are common, but not universally available. Blends of and below 5 percent are generally not labeled as biodiesel. These low blends are considered fungible diesel fuel, and any blends above 5 percent biodiesel must be labeled as such. This means that consumers choosing gasoline are likely to receive a blend of conventional renewable fuel and consumers choosing labeled blends of biodiesel or biomass-based diesel are likely receiving blends of advanced biofuel. Fleets purchasing bulk quantities of fuel may be able to request specific blends and feedstocks, but it likely makes sense to use what is produced and available locally.

[166] California Air Resources Board (2011). "Production of Biodiesel from Corn Oil Extraction at a Dry Mill Corn Ethanol Plant."
[167] California Air Resources Board (2014). "ILUC Analysis for the Low-Carbon Fuel Standard (Update)." California Environmental Protection Agency.

Appendix 7: Biodiversity Hotspots

What follow 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

- **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, Columbia, 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

- **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)

Source: World Wildlife Fund (2014). List of Ecoregions.

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	Environment	Human Rights	Society	Labor	Economic	Security
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[a] Data on carbon Intensity is from the following sources:

- British Columbia Ministry of Energy and Mines (2013). Determination of Carbon Intensity for The Renewable and Low Carbon Fuel Requirements Regulation. Available at http://www.empr.gov.bc.ca/RET/RLCFRR/Documents/RLCF006%20-%20Determination%20of%20Carbon%20Intensity.pdf.
- California Air Resources Board (2013). “Table 6: Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline.” Renewables Portfolio Standard. Available at: http://www.arb.ca.gov/fuels/lcfs/lu_tables_11282012.pdf
- Oregon Department of Environmental Quality (2011). Life Cycle Analysis Approach of Transportation Fuels http://www.deq.state.or.us/aq/factsheets/11aq017.pdf
- Oberon Fuels (2014). Oberon DME Receives EPA’s First Biogas-Based Fuel Approval Under the Renewable Fuel Standard. Available at: http://www.oberonfuels.com/2014/09/03/oberon-dme-receives-epas-biogas-based-fuel-approval-renewable-fuel-standard

Carbon Intensity is adjusted for Energy Economy Ratio (EER) with electrification (3.05), hydrogen (2.1), and natural gas (0.95). Source: Oregon Department of Environmental Quality (2010). Supporting Documentation for Calculating Credits and Deficits. Available at http://www.deq.state.or.us/aq/committees/docs/janLCF/itemBsummary.pdf).

For fuels with emissions that have an indirect land-use component (*italicized*), data for the low-end of range are only used from sources that include indirect land use.

Figures included reflect the best-available science published by government bodies and are under revision as conditions change and scientific understanding develops. New changes to the figures by the California Air Resources Board as of November 2014 reduced the high end of CI for biodiesel by 15.6 g/MJ (e.g. the highest ILUC component would be 46.4, not 62.0), and reduce the high end of ethanol by 26.0 g/MJ (e.g. the highest the highest ILUC component would be 20.0, not 46.0). See Air Resources Board (2014). Low Carbon Fuel Standards Re-Adoption Indirect Land Use Change Analysis. Available at http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/112014presentation.pdf