THE
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PAPERS

UNDERSTANDING UNCONVENTIONAL OIL

Deborah Gordon

ENERGY AND CLIMATE | MAY 2012

CARNEGIE ENDOWMENT
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Summary

Conventional oil production has peaked and is now on a terminal, long-run global decline. However, contrary to conventional wisdom, which many embraced during back-to-back oil crises in the 1970s, oil is not running out. It is, instead, changing form—geographically, geologically, chemically, and economically.

These dynamics point to a new reality. We are approaching the end of easily accessible, relatively homogeneous oil, and many experts claim that the era of *cheap* oil may also be ending.[1] The realignment of world oil prices upward, settling above $100 per barrel over the past year, is spurring a transformation of oil technology and markets. The oil industry is posting substantial profits, reinvesting significant capital, and gaining new capacities to identify, probe, recover, and process oils that were once unknown, inaccessible, unmanageable, or uneconomical. As such, oil corporations and national oil companies are developing a wide array of new oils worldwide.

Though they have been recognized as new sources of petroleum, according to the U.S. Energy Department, unconventional oils have yet to be strictly defined. In reality, new oils are emerging along a continuum from conventional crudes to transitional oils to unconventional oils, with their classification varying according to the ease of extraction and processing. While no two crudes and oil processes are identical, petroleum products—at least for the time being—are expected to remain relatively unchanged in appearance and use despite burgeoning changes in oil quality. That gasoline, diesel, and jet fuel will likely remain unchanged at the pump will obscure the fact that oils are transforming upstream, with unintended societal consequences—from increased climate forcing and groundwater contamination to forest destruction and impacts on indigenous cultures.

Many new breeds of petroleum fuels are nothing like conventional oil. Unconventional oils tend to be heavy, complex, carbon laden, and locked up deep in the earth, tightly trapped between or bound to sand, tar, and rock. Unconventional oils are nature's own carbon-capture and storage device, so when they are tapped, we risk breaking open this natural carbon-fixing system. Generally speaking: the heavier the oil, the larger the expected carbon footprint.

From extraction through final use, these new oils will require a greater amount of energy to produce than conventional oil. And as output ramps up to meet increasing global demand for high-value petroleum products, unconventional oils will likely deliver a higher volume of heavier hydrocarbons, require more intensive processing and additives, and yield more byproducts that contain large amounts of carbon.

This is a key moment to determine the future energy balance between oil and low-carbon alternative fuels. This paradigm shift in petroleum sources, if left to the marketplace alone, will likely have profound local and global impacts. Understanding the trade-offs associated with unconventional oils will be instrumental to managing them prudently. Only with sound policy guidance can we arrive at a decarbonized fuel system to drive our transportation sector and fuel the global economy. Moving forward to replace conventional oils in a structured, safe manner will require the following steps:

Define the Problem

- Acknowledge that oil prices will likely trend upward in the long term as light and accessible crude stocks dwindle, and that unconventional oils will cost more directly (to produce and process) and indirectly (in terms of their societal impacts)
- Recognize that markets will induce carbon-laden, energy-intensive, and environmentally damaging petroleum supplies
- Understand that it will take concerted policy intervention to diversify petroleum markets to include low-carbon alternatives

Gather Information About New Oils

- Differentiate new oils by exploring their emission data by well, block, basin, field, and subfield and move toward a harmonization of emission-accounting methodologies
- Identify knowledge gaps in the new geographies, chemistries, and carbon implications of unconventional oils through robust global data collection that is made publicly available
- Create enduring structures for international and national oil oversight and track changes in oil makeups, processing techniques, and byproducts
- Encourage continuous evaluation of unconventional oils as new information comes to light, including updated life-cycle analysis of new oils that considers emerging processes and byproducts

Make Prudent Policy Decisions

- Promote the efficient use of liquid fuels and their byproducts as a backstop strategy for long-term decarbonization
- Develop durable policy frameworks for managing the upward trend from unconventional oils in carbon budgets in all economic sectors

Unconventional Wisdom About New Petroleum Sources

Global oil supplies have plateaued and are slowly decreasing. Until recently, conventional wisdom posited that as oil ran out, petroleum would be largely replaced by an array of potentially lower-carbon alternative sources, including electricity, hydrogen, biofuels, and natural gas, as shown in figure 1a.[2]

Instead, a new reality is emerging. As conventional oil dwindles, liquid fuels have begun to change form. The International Energy Agency, in its 2011

Figure 1a. Projected Oil Alternative Scenario

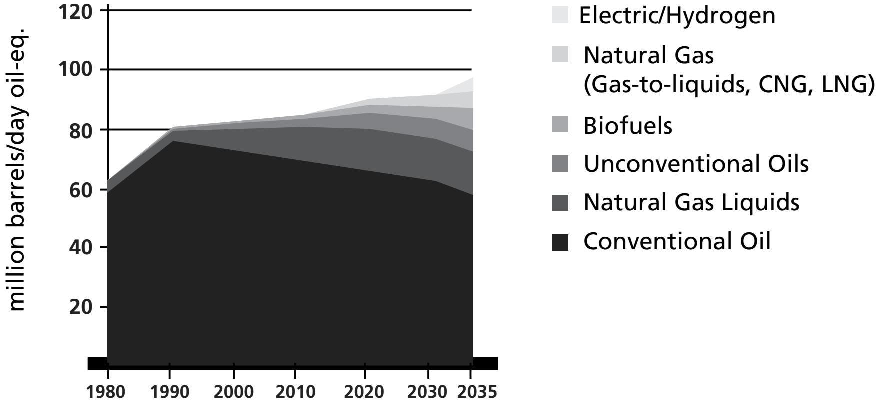
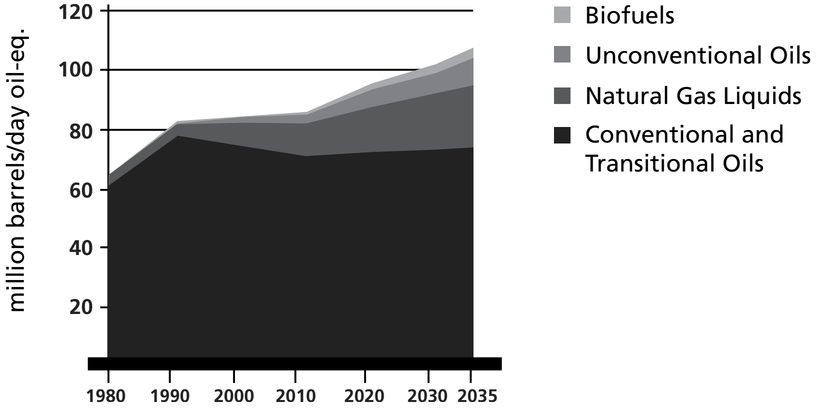


Figure 1b. Projected New Oil Scenario



Source: Adapted by author from Ogiso, Toyota, www.thetruthaboutcars.com/2011/11; and International Energy Agency (IEA), "World Energy Outlook 2011," Paris: OECD Publishing, November 2011. Accessed via OECD i-Library: http://www.oecd-ilibrary.org/energy/world-energy-outlook-2011_weo-2011-en

World Energy Outlook, projects that by 2035 several new oil types will replace the loss of nearly one-half of global conventional oil production. ExxonMobil concurs. Conventional crude is projected to account for only 60 percent of liquid-fuel supply by 2040, down from 80 percent in 2010, as shown in figure 1b.[3] An array of new oils—oil sands, tight oil, new heavy oils, deepwater oil, and eventually oil shale—are projected to fill the gap, as demand for liquid fuels continues to rise.

The plateau in conventional oil and the corresponding increase in the demand for liquid fuels have motivated markets to respond with higher oil prices. And the current economics of oil are spurring a technological transformation of petroleum supplies, not a transition away from oil. The industry estimates that less than half of the world's known oil will be produced by 2040 and that the amount of global petroleum resources remaining could continue to be revised upward as new technologies are developed.[4]

The current economics of oil are spurring a technological transformation of petroleum supplies, not a transition away from oil.

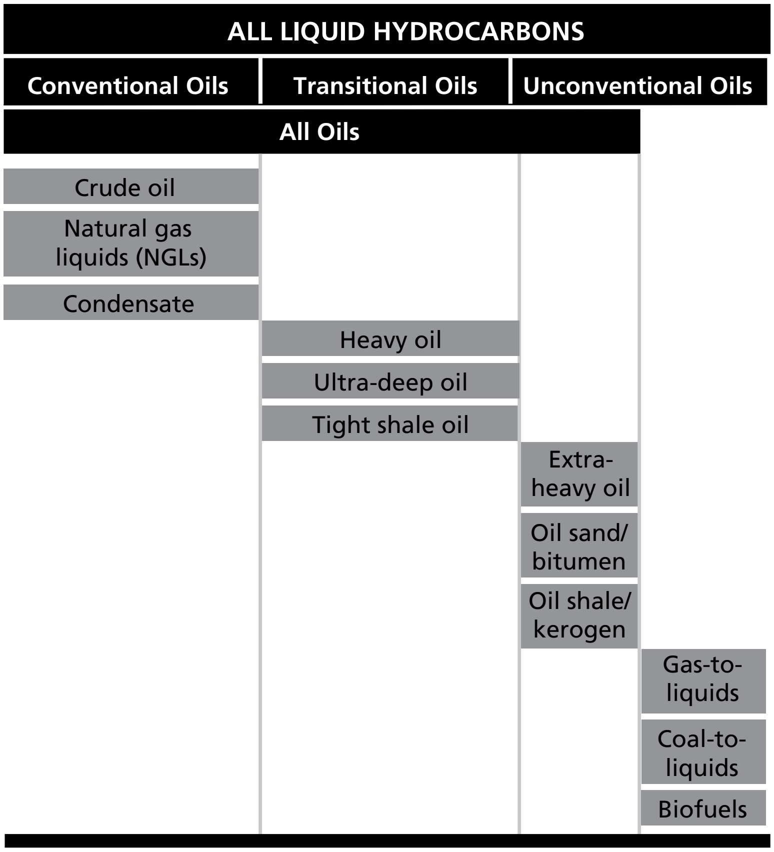
New oils, left to market forces alone, are expected to dominate liquid-fuel supplies through the twenty-first century, powering the transportation sector and gaining shares in other economic sectors. The oil industry is expected to invest huge sums in petroleum production and oil infrastructure in the years ahead, up to an estimated $1 trillion over the next decade alone.[5] The opportunity costs are massive. Without a concerted policymaking effort, these investments will likely continue to flow disproportionately toward unconventional oil. The only way the transition to clean energy will ultimately succeed is if new rules are established for new fuels that require the private sector to invest in a low-carbon future.

Defining New Oils

The conventional oils that dominated the twentieth century may differ from one another in color, thickness, sulfur content, and other impurities, but they are a relatively homogeneous lot, flowing from relatively easily accessible deposits in limited locations around the world. The makeup and geography of tomorrow's oil, however, will be dramatically different from the black gold that gushed forth at Spindletop, Texas, back in 1901.

As conventional crude oil supplies have peaked and leveled off globally in recent years, oil has begun to transition, as shown in figure 2. Many current forms of oil that were once considered *unconventional* are now grouped into the *conventional* category, from ultra-deep oil in the Gulf of Mexico to Maya heavy oil in Mexico. These and other new *transitional* oils are being developed as well—from shale rocks saturated with oil over a broad, continuous area, with the fabric of the rock itself trapping the hydrocarbons in place. This oil transition is in turn giving way to an oil transformation. Non-flowing oils are being

Figure 2. Transformation of Liquid Fuels



produced from non-crude sources in processes that require emergent technologies, as is happening with the oil sands in Alberta, Canada, Venezuela's Orinoco belt, and eventually the kerogen (an oil precursor) in oil shales in U.S. mountain states, Western Europe, and beyond. Ultimately, oil need not be a building block in liquid fuels, which can also be converted from biological materials, natural gas, or coal.

Over time, oils themselves are expected to change: what they are, where they are located, how much they cost, how much carbon and other impurities they contain, what byproducts they yield, what wastes they leave behind, what their greenhouse gas emissions are, and how to handle them. Given this shift, when it comes to managing new sources of petroleum, the past will not necessarily serve as a good indication of the future.

Still, according to the U.S. Department of Energy, although new liquid hydrocarbon supplies have been acknowledged, *unconventional oils* have yet to be strictly defined. Generally speaking, unconventional oils cannot be produced, transported, and/or refined using traditional techniques. They require new, highly energy intensive production techniques and new processes to deal with their inaccessible placements or unusual compositions.

Unconventional oils require new, highly energy intensive production techniques and new processes to deal with their inaccessible placements or unusual compositions.

This heterogeneous bundle of resources not only represents a departure from conventional oil, new oils differ widely from one another as well (see box 1). The spectrum of new oils runs the gamut: some of tomorrow's liquid hydrocarbons are akin to today's oil, others will evolve but remain more oil-like, and still others will be synthesized from coal or natural gas.[6] Transitional oils, for example, tend to have conventional makeups but are difficult to extract. These include *tight* oils, which is oil trapped in shale that can be accessed by hydraulic fracturing or fracking, a procedure by which rock formations are fractured by injecting fluids to force them open, allowing oil (and gas) to flow out. Ultra-deep oils that are buried as remotely as 10 miles below the water's surface are also considered transitional.

More coal-like oils include semisolid extra-heavy oils such as bitumen in tar and oil sands, kerogen in oil shale, and liquid oils derived from coal itself.

Box 1. Defining Oils: Conventional vs. Unconventional

The International Energy Agency defines conventional oil in its 2011 World Energy Outlook as "a mixture of hydrocarbons that exist in liquid phase under normal surface conditions." Unconventional oils are defined as those oils obtained by unconventional production techniques because they cannot be recovered through pumping in their natural state from an ordinary production well without being heated or diluted.

The U.S. Department of Energy divides unconventional oil into four types: heavy oil, extra heavy oil, bitumen, and oil shale. Some analysts also include gas-to-liquids (GTL) processes for converting natural gas to oil and coal-to-liquids (CTL) processes for converting coal to oil in the unconventional oil category. These unconventional oil-processing techniques broaden the feedstock of unconventional oils to include unconventional natural gas, such as tight gas, shale gas, coal-bed methane, and methane hydrates.

GTL processing entails converting natural gas and other simple gaseous hydrocarbons into more complex petroleum products. Methane-rich gases are converted into liquid synthetic fuels through direct conversion or through syngas as an intermediate using the Fischer Tropsch or Mobil processes.

CTL processing entails liquefaction of solid coal. This can be done directly by dissolving coal in a solvent at high temperature and pressure and then refining these liquids to yield high-grade fuel characteristics. Indirect liquefaction gasifies the coal into a mixture of hydrogen and carbon monoxide (syngas), condensing this over a catalyst and using the GTL processes to produce liquid petroleum products.

For images of different oils see:

tight shale oil (http://commons.wikimedia.org/wiki/File:GasDepositDiagram.svg);

bitumen (http://commons.wikimedia.org/wiki/File:Bitumen.jpg);

oil shale/kerogen (http://commons.wikimedia.org/wiki/File:Oilshale.jpg);

methane hydrates (http://commons.wikimedia.org/wiki/File:Seafloor_mounds.jpg)

Gas-based oils can be derived through gas-to-liquids processing from natural gas supplies found in shale gas, tight gas, coal bed methane, coal seam gas, and deep-ocean gas hydrates.

The Changing Oil Landscape

Industry has gotten quite skilled at extracting and refining conventional crude for sale and distribution. But the oil landscape is changing rapidly, and along with it, the processes employed and the quality of products. The shift to unconventional oils can be viewed as a technologically and economically driven redefinition of the resource base for liquid hydrocarbons. Over time, new oils are expected to change the entire oil value chain, from upstream production byproducts to downstream refined petroleum products.

Conventional Crude Oils

Conventional oils are hydrogen-rich compounds with relatively short hydrocarbon chains, fewer carbon atoms—C_1 to C_{60}—and lower molecular weights than most unconventional oils (around 200). Since hydrogen packs all of the energy while carbon goes along for the ride, conventional oils tend to deliver more productivity with less waste than unconventional oils.

There can be a great deal of variation within that range—there is no one formula for crude oil. Instead, these natural resources range from high-quality "light, sweet" crudes to lower-quality "heavy, sour" crudes (see box 2). The density of the oils is measured on a scale known as API gravity—the lighter the oil, the higher the gravity; the heavier the oil, the lower the gravity. Heavier oils are tricky to extract, requiring gas injection and other invasive techniques due to their high, molasses-like viscosities that approach those of unconventional oil. Other factors being equal, the lower the API gravity, the more expensive the oil is to extract and process, and the lower the price the oil will bring.

Transitional oils are oils with conventional compositions that are extracted by unconventional means. As conventional oils become less accessible, new, more technical, energy-intensive methods are being developed for their recovery, from ultra-deep wells drilled miles below the sea to fracturing shale rock in order to tap oil trapped in low-permeability siltstones, sandstones, and carbonates deep in the earth. But no two source rocks are alike. Therefore, no two shale oils are exactly alike. The lighter and sweeter the oil, the less involved the processing and the higher the yield of high-value petroleum products, including gasoline, diesel, and jet fuel. But the more extensive the recovery method, the more energy is required for extraction, which means that these oils tend to result in higher carbon emissions and other societal impacts.

Box 2. Oil Quality: API Gravity and Sulfur Content

The American Petroleum Institute and the National Bureau of Standards developed a scale of the density of liquid petroleum products. The gravity scale is calibrated in terms of degrees API, which equals:

$$(141.5/\text{specific gravity at 60 degrees F}) - 131.5$$

The higher the API gravity, the lighter the compound. If the API gravity is greater than 10, the oil is lighter and floats on water; if less than 10, it is heavier and sinks. Light crudes generally exceed 38 degrees API and heavy crudes are commonly below 22 degrees. Intermediate crudes fall between 22 and 38 degrees. Oils are extra-heavy below 10; the API gravity of bitumen approaches zero.

Sour crude oil is defined as a crude oil containing larger amounts of the impurity sulfur, an extremely corrosive element that is difficult to process, and deadly when released (hydrogen sulfide gas). When the total sulfur level in the oil is over 0.5 % the oil is called sour; lower sulfur oils are sweet.

The crude barrel composition is changing and ranges from heavy/sour to light/sweet, by region:

Location	Low Quality Range	High Quality Range
Africa	Angola (Kuito) 19°, 0.68%	Nigeria (Agbami Light) 47°, 0.04%
Asia	China (Peng Lai) 22°, 0.29%	Indonesia (Senipah Condensate) 54°, 0.03%
Australia	Enfield 22°, 0.13%	Bayu Undan 56°, 0.07%
Europe	UK (Alba) 19°, 1.24%	Norway (Snohvit Condensate) 61°, 0.02%
Mid East	Saudi Arabia (SA heavy) 27°, 2.87%	Abu Dhabi (Murban) 39°, 0.8%
North America	Canada (Albian) 19°, 2.1%	US (Williams Sugarland Blend) 41°, 0.20%
Latin America	Venezuela (Bascan) 10°, 5.7%	Columbia (Cupiaga) 43°, 0.14%
Central Asia	Russia (Espo) 35°, 0.62%	Kumkol (Kazakhstan) 45°, 0.81%

Benchmark Crudes: Brent 38°, 0.37%; WTI (West Texas Intermediate) 40°, 0.24%; Dubai 31°, 2.0%

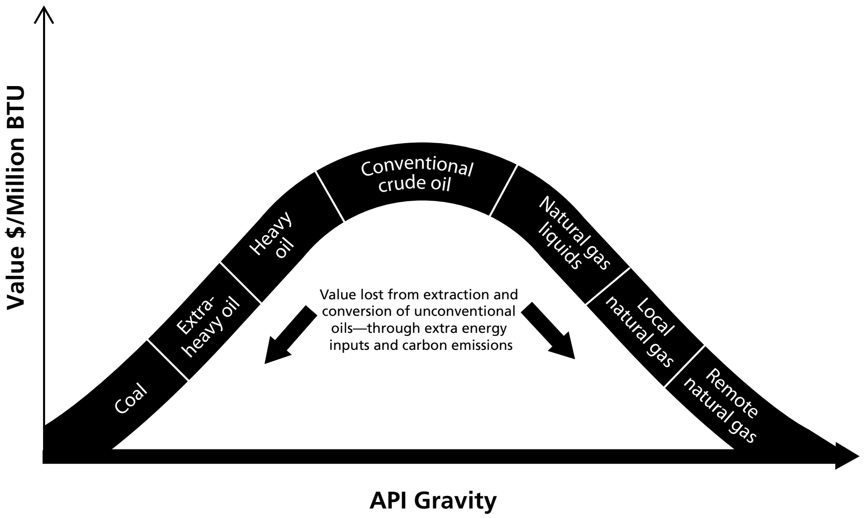
For more information see: http://205.254.135.7/pub/oil_gas/petroleum/data_publications/weekly_petroleum_status_report/current/pdf/glossary.pdf and http://energy.cr.usgs.gov/oilgas/addoilgas/WEC07NBEHO.pdf http://en.wikipedia.org/wiki/List_of_crude_oil_products

Unconventional Oils

Lacking a clear definition, unconventional oils are typically identified by their characteristics. The heavier the oil is—for example, oil sand (bitumen) and oil shale (kerogen)—the more carbon laden, higher in sulfur, and filled with toxic impurities. Unconventional oils are typically much heavier and sourer than even the lowest-quality conventional oil.

An array of unconventional solid, liquid, and gaseous hydrocarbons can be processed into petroleum products, as shown in Figure 3. But these extra-heavy, impure oils require very large energy inputs to upgrade and preprocess into synthetic crude oil that is then processed by a refinery (known as

Figure 3. Hydrocarbon Value Hierarchy



Source: Adapted from Statoil, September 30, 2007, www.statoil.com/en/technologyinnovation/refiningandprocessing/oilrefining/hydrocarbonvaluehierarchy/pages/default.aspx.

feedstock). Some new oils are effectively solid and must be removed through mining or heated in place (in situ) until they flow. These new oils tend to be less valuable than conventional crude, which is readily transformed into the most marketable petroleum products by today's standards.

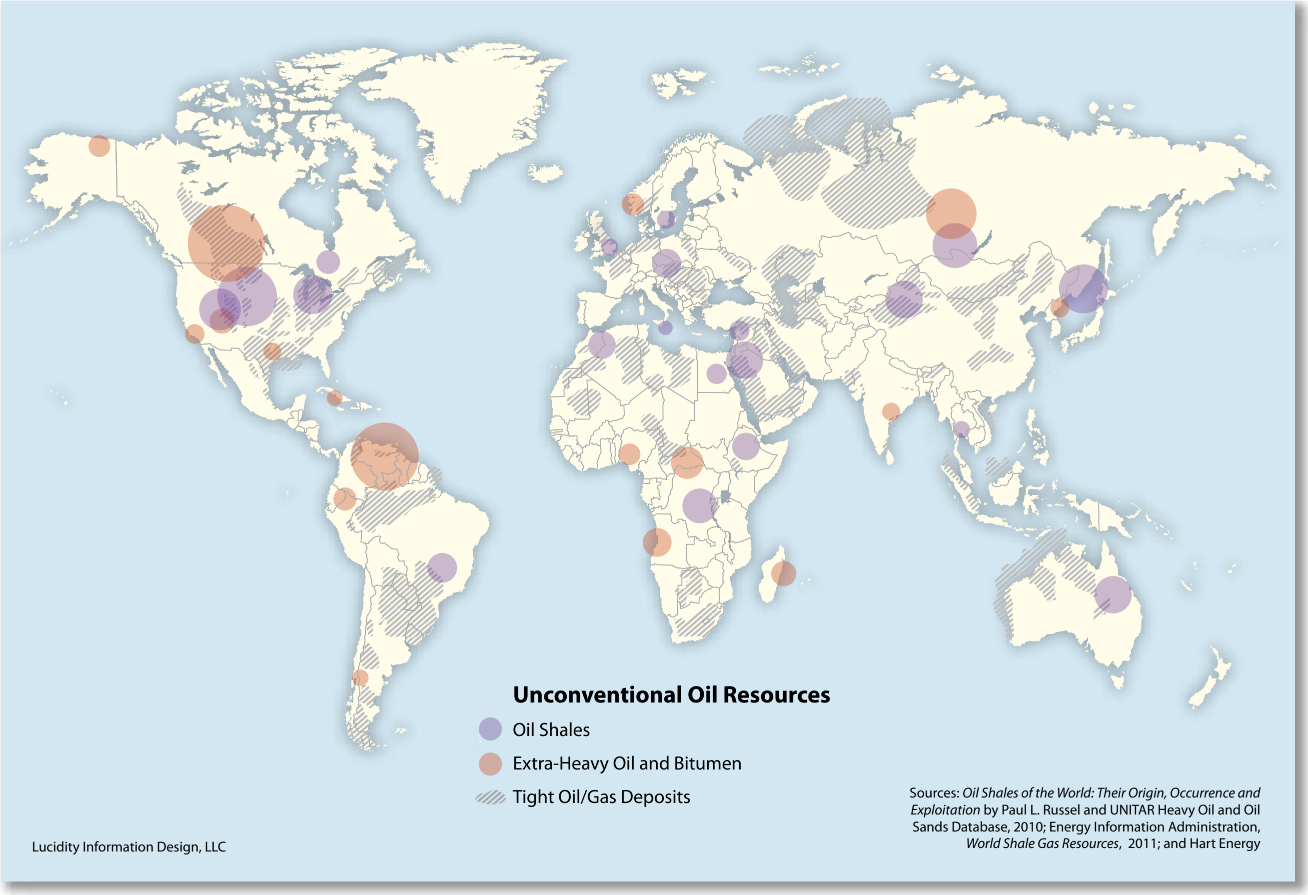
Oil sands are a combination of quartz sand, clay, water, trace minerals, and a small (10–18 percent) share of bitumen, and their sulfur content can be in excess of 7 percent. Bitumen is made up of organic components ranging from methane—the simplest organic molecule—to large polymeric molecules having molecular weights in excess of 15,000. This extremely complex hydrocarbon mixture can be synthetically processed into oil.[7] However, it cannot be transported to market by pipeline without adding diluting agents—such as gas-processing condensates including the diluent pentanes plus—to meet pipeline density and viscosity limitations. A large portion of Alberta's bitumen production is currently upgraded to synthetic crude oil and other products before shipment to refineries.

Oil shale is "immature oil" that has not been in the ground long enough to form oil. It is mostly composed of clay, silt, and salts, with a small (12 percent) share of insoluble organic matter (kerogen) and even smaller (3 percent) share of soluble bitumen.[8] The organic kerogen, once extracted and separated from the oil shale, can be processed into oil and gas. Like oil sands, oil shale has similarly high sulfur content—up to 7 percent.[9]

Changing Geography of Oil

Not only is the makeup of oil drastically changing, so too is its political geography. As shown in figure 4, which depicts the projected geographies of new oil (and oil derivatives) based on current knowledge, the world's oil supplies will no longer remain concentrated in the Middle East, Africa, and Russia. Twenty-first-century oil reserves will be found in the Western Hemisphere and, over the long term, they will be unearthed globally. The International Energy Agency projects 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.[10] Eastern Europe and Eurasia, followed by Latin America, have also been identified as part of the new geography of oil.

Figure 4. New Geographies of Unconventional Oils[11]



Sources: *Oil Shales of the World: Their Origin, Occurrence and Exploitation* by Paul L. Russel and UNITAR Heavy Oil and Oil Sands Database, 2010; Energy Information Administration, *World Shale Gas Resources*, 2011; and Hart Energy

Lucidity Information Design, LLC

Heavy Oils

In the latter part of the twentieth century, as conventional oils started to become more heterogeneous, their geography became increasingly more diversified. Heavy oils in California, Venezuela, China, Indonesia, the Middle East, and along the Alberta-Saskatchewan border initiated the oil transition.

Tight and Transitional Conventional Oils

Conventional oils are also being found in difficult-to-reach places. Ultra-deep oil in the Gulf of Mexico, for example, can be trapped many miles below the ocean floor. Oils have been discovered under 4 miles of water, salt, sand, and rock as well. Deep pre-salt fields—generally high-quality oil located in deep-sea areas under thick layers of salt and requiring large-scale investment to extract—are offshore of Brazil and West Africa. They are the first of their kind being drilled around the globe.

In North America, tight shale oils are being fracked in the northern Bakken (spanning North Dakota, Montana, Saskatchewan, and Manitoba); in Eagle Ford, Barnett, and the Permian basin in Texas and New Mexico; in the Cardium play in Alberta; in the Miocene Monterey and Antelope deposits in California; in Mowry-Niobrara in Wyoming and Colorado; in Oklahoma's Penn Shale; in Montana's Exshaw Shale; and in Utica Shale in Colorado, Wyoming, and New Mexico. Additional transitional tight shales are being probed for oil (and gas) in New York, Maine, Mississippi, Utah, and Alaska's North Slope and Cook Inlet.[12] There is an even-greater potential for new tight oils on a global scale in China, Australia, the Middle East (especially Israel), Central Asia (Amu Darya Basin and the Afghan-Tajik Basin), Russia, Eastern Europe, Argentina, and Uruguay.

New oil conditions in the Arctic are unlike any other and will require drilling in some of the coldest waters, far from civilization, amid areas of high environmental sensitivity and unpredictable weather. Still, the Arctic Circle nations, including Russia, the United States, Canada, Norway, and Denmark—with one-sixth of the world's landmass and spanning 24 time zones—may constitute the geographically largest unexplored prospective area for petroleum remaining on earth.[13] The United States Geological Survey has assessed the area north of the Arctic Circle and concluded that about 13 percent of the world's undiscovered oil and 30 percent of the world's undiscovered gas may be found there.

Extra-heavy Oils

The bitumen contained in oil sands is the most prevalent extra-heavy oil. The province of Alberta, Canada—including the Athabasca Wabiskaw-McMurray, Cold Lake Clearwater, and Peace River Bluesky-Gething regions—has the globe's largest deposits of bitumen. Outside of Canada, 21 other countries have bitumen resources, including Kazakhstan (in the North Caspian Basin), Russia (in the Timan-Pechora and Volga-Ural basins), Venezuela, and Africa,[14] including the Republic of Congo, Madagascar, and Nigeria. In the United States, oil sands are deposited in at least a dozen states, including (in relative order) Alaska, Utah, Alabama, California, Texas, Wyoming, Colorado, and Oklahoma. However, the U.S. and other nations' oil sand reserves are currently considered to be far smaller in volume than Canada's reserves and may also be less easily recovered due to different physical and chemical compositions.

Extra-heavy oil (non-bitumen) is recorded in 166 deposits worldwide, the largest in eastern Venezuela's Orinoco Oil Belt. The deposits are found in 22 countries, with thirteen of the deposits located offshore.[15]

Oil Shale

Kerogen has the potential to be one of the largest unconventional hydrocarbon resources in the world. In North America, the richest and thickest oil shale deposits are in the Green River Formation, which covers portions of Colorado, Utah, and Wyoming. Prudhoe Bay, Alaska, and additional basins in Colorado (Piceance), Utah and Colorado (Uinta), and Wyoming (Washakie) are also known locations of oil shale. A block of U.S. states bordered by Michigan, Missouri, Alabama, West Virginia, and Pennsylvania contains a grouping of large oil shale plays, that is, promising areas targeted for exploration. Internationally, Brazil, Israel, Jordan, Sumatra, Australia, China, Estonia, France, South Africa, Spain, Sweden, and Scotland all have notable oil shale deposits.

* * *

At the core, geologic and chemical factors determine the geography of new oils. Global oil—that beyond confirmed assets currently owned by companies or contained in countries (proven reserves)—is being remapped. Looking ahead, it is increasingly likely that international oil companies will be involved in developing the "frontier" oils—shale, tight, deep offshore, Arctic—due to their expertise and experience. Innovative, asset-rich, profit-driven, and technologically capable international oil companies may be a significant factor in identifying North America's large unconventional oil reserves. This will not diminish the longer-term dominant role of state-run national oil companies, which own some 75 percent of the world's proven conventional oil reserves and still reap the benefits of their comparatively low production costs. Still, these national companies have historically lagged on commercial reserve replacement given tensions to use national capital budgets to fulfill important social and economic goals.[16]

The production of these new oils will be highly influenced by economic, technological, political, and policy factors.

International oil companies will have to take on more risk, developing new oils in new geographies and under new conditions. But the prospects for profit are driving these difficult plays. The production of these new oils will be highly influenced by economic, technological, political, and policy factors.

Changing the Carbon Footprints of Unconventional Oils

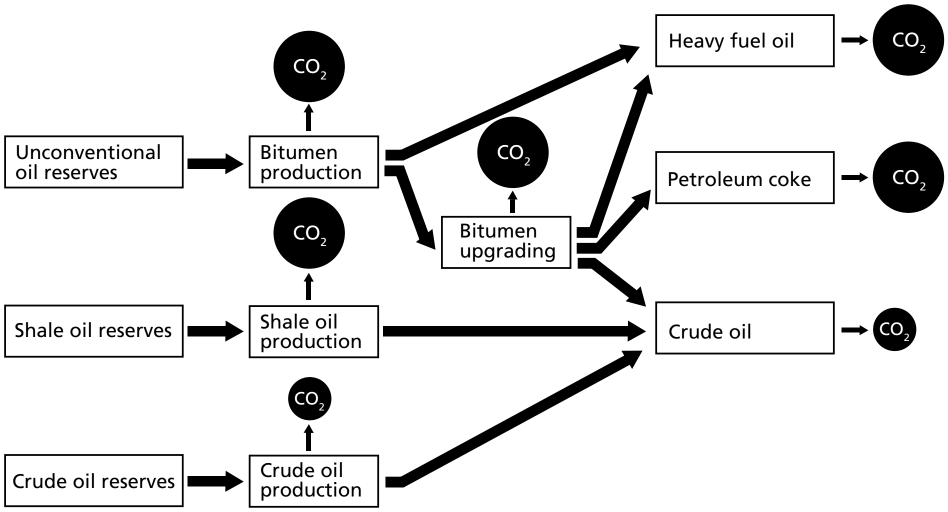
Oil quality is changing worldwide with respect to its weight and impurities. So as the world increasingly turns toward unconventional oil supplies, it must consider the larger carbon footprints of these oils throughout the fuel cycle.

Life-cycle greenhouse gas emissions increase the heavier the oil and the lower its API gravity—heavier oils emit more carbon than their lighter counterparts, as shown in figure 5.[17] Chemically, they are bound up with more carbon and yield greater volumes of bottom-of-the-barrel residual products, such as petroleum coke and heavy fuel oil. One-half of each barrel of bitumen, for example, consists of residual products, and an estimated 60,000 metric tons of petroleum coke is removed during the upgrading process for every barrel of bitumen extracted.[18]

The complex methods used to extract and process these heavier oils before they are able to be refined into petroleum products require greater energy inputs and more energy-intensive additives, such as hydrogen. Their use means a reduced product yield, degraded product quality, and more oil input for comparable amounts of petroleum products.

Uncertainties abound about which processes for upgrading these extra-heavy oils to suitable feedstock are the least damaging, especially in terms of overall carbon footprints. Mining bitumen, for example, has a distinct set of impacts while in situ removal has another.[19] In Canada at present, in situ oil sands production is in a period of significant growth, as more than 80 percent

Figure 5. Carbon Footprint of Oils



Source: Adapted from John Reilly, Surgey Paltsey (MIT) and Frederic Choumert (MIT and Total), "Oil Market: Transition or Evolution?" In D.L. Greene, *Modeling the Oil Transition*, 2007. http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0501-01.pdf/$File/EE-0501-01.pdf of Canada's oil sands are too deep to be mined and must be extracted with in situ methods. That type of production is associated with peatland destruction, an area of growing environmental concern.[20] While in situ oil sand removal may have less direct land-use impacts than surface mining because it avoids massive earth removal and disturbs less land per unit of production, this technique may have equal or greater impacts in terms of its land-intensive natural gas requirements and land-use fragmentation due to its spatial dispersion over a massive area.[21]

As the world increasingly turns toward unconventional oil supplies, it must consider the larger carbon footprints of these oils throughout the fuel cycle.

Yet, there has been too little research to firmly assert the overall effects of heating oil sands and removing them in place. Early indications are that in situ removal may be even more greenhouse gas intensive than strip or open-pit mining.[22] Similar concerns surround the in situ removal of oil shale and coal-to-liquids processes. These geography-dependent unintended consequences must be probed more fully, and policymakers must keep the implications of land-use changes in mind.

Where these and future processes are taking place also matters. There will be a huge need for sophisticated upgrading capacity in the future, with strong, increasing demand for gasoline and diesel fuel, slow or little demand growth for the heavier oil fractions, and the "heavying up" of the oil slate. The location of that new upgrading capacity is likely to depend on climate policy—the path of least resistance is often the most attractive for development. Uneven policies on a global scale could lead to significant carbon leakage as high-carbon oils travel to locations without effective greenhouse gas emission controls for upgrading.

Furthermore, refineries will need to take a close look at their bottom lines when updating their existing processes to meet the needs of new oils. Refineries produce a variety of products from a barrel of oil, but the product slate has begun to change because the makeup of a barrel of crude is changing.[23] While refineries can be optimized to a certain extent to maximize the amount and types of products they put out, refinery specs are influenced by exogenous factors (see box 3). Shifts in the carbon-equivalent emission intensities of new oils will require improved monitoring, reporting, and verifying as century-old oil-refining processes adapt to new oil makeups.

The petroleum industry has been remarkably adept at inventing processes and products from lower-quality feedstock—to the point where the public is not even aware that oil itself has been changing. For example, burgeoning foreign markets, with fewer environmental protections, have begun to absorb low-priced, high-carbon exports of petroleum coke from oil-sand-mining production in Canada. Petroleum coke, or pet coke, is similar to coal but sells at a lower price than thermal coal because this solid residue consists of 90–95 percent carbon. One step above industrial waste, when burned, petroleum coke emits high levels of greenhouse gases that are comparable to coal emissions but with more accompanying ash and toxic metals. Today, U.S. exports consist

Box 3. Oil Refining: Changing Yields from a Barrel of Oil

In 2011, there were 655 refineries worldwide located in 116 countries with a collectively daily capacity of 88 million barrels per day (b/d). Refining is the process of changing the carbon-to-hydrogen (C/H) ratio naturally occurring in oil feedstock into lighter, high hydrogen-to-carbon ratio petroleum products. In recent years, refiners have confronted two opposite forces—crude oil supply that was increasingly heavier, with higher sulfur content (the most difficult to refine) while consumers' and government mandates increasingly required light products of higher quality (the most difficult to produce).

The finished product slate (yield) of a refinery is determined by oil quality (heavy/sour), market conditions, and refining capabilities (equipment and processing design). Different refineries are designed to handle crudes of differing makeups and produce different types of fuels, petrochemical, and waste products.

In competitive markets the refinery margins change daily as the market prices of both crude oil and products change. Today, a barrel of oil refined in the U.S. currently yields 45 percent gasoline, 30 percent diesel, 9 percent jet fuel, 5 percent pet coke, 2–4 percent each of liquefied petroleum gas, residual fuel oil, asphalt, and chemical feedstock. The share of U.S. refined diesel yield is up significantly from 22 percent in 1993 due to heavier crudes and higher diesel export to Europe and Asia. In Europe and Asian developing countries, crude oil refining has an even heavier product slate, favoring diesel over gasoline and as much as triple the volume of fuel oil.

New refinery design must consider the chemical properties of the crude oil feedstock, market demand, expected selling price of the refined products, environmental limits on the byproducts of combustion, and long-term project economics. Environmental and climate regulations seeking to improve product quality are a key driver of refinery process configuration and economics.

For more information see:

Petroleum Online, www.petroleumonline.com/content/overview.asp?mod=8

Energy Information Administration, March 2012, www.eia.gov/dnav/pet/pet_pnp_pct_dc_nus_pct_a.htm

ICCT, "An Introduction to Petroleum Refining," October 24, 2011, www.theicct.org/sites/default/files/publications/ICCT05_Refining_Tutorial_FINAL_R1.pdf

en.wikipedia.org/wiki/List_of_crude_oil_products

primarily of heavier products that are not in high demand domestically—diesel, residual fuel oil, asphalt, and petroleum coke.[24] Pet coke in particular is used as a feedstock in coke ovens for the steel industry, for heating purposes, for electrode manufacture, and for production of chemicals. Left to the world market, it is easy for these oils to become widely used—and to overlook their significant carbon impacts.

And the availability of this unconventional oil could change petroleum product flows to U.S. (and global) oil markets with resulting changes to carbon footprints. In the 1970s, for instance, the United States backed oil out of the power sector and shaved the share of oil in the industrial and residential sector, leaving the majority of oil for transportation. Now and in the future, the high-carbon petroleum products borne from new oils could readily find their way into the industrial, building, and power sectors.

The potential to increase carbon and other greenhouse gas emissions pervades new oils—from extraction to upgrading and refining and use. With so many emission outlets, oil policy must be looked at closely.

Managing New Oils With New Policies

Unconventional oils are nature's own carbon-capture and storage device. When they are tapped, we risk breaking open this natural carbon-fixing system. According to the National Petroleum Council, critical aspects of unconventional oils—including their greenhouse gas emission intensity—are currently not well understood.[25]

Until recently, the environmental effects of the petroleum fuels that power the transportation sector were also not well understood. But great strides have been made toward a better understanding of the life-cycle greenhouse gas emissions from these fuels.[26] Yet, while the tailpipe emissions attributed to automobile combustion may not differ markedly regardless of which type of today's conventional oil is used, the debate over what constitutes the actual life cycle of unconventional oils reveals the complex and dynamic nature of the full impact of new hydrocarbons.

In the absence of complete information, this issue is sometimes attacked with emerging if imperfect tools: fuel standards. There are current policies in place or in the planning phase in certain regions that impose emission standards on vehicles, including California's Low Carbon Fuel Standard, which requires a 10 percent reduction in the carbon intensity of gasoline and diesel in the state by 2020, and the European Commission's Fuel Quality Directive, which requires a 10 percent reduction in the emission intensity of transport fuels by 2020. But fuel policies, while necessary and important, may not be sufficient to manage the wide-ranging climate impacts of new oils. As more unconventional oil enters the economy and its byproducts make their way into other sectors for other uses, regulating new oils based on their end-use transport components may not offer ample protection.

The oft-cited full fuel-cycle statistic that oil sands have 5–15 percent higher greenhouse gas emissions than conventional oil underscores this limitation. Oil sands themselves contain roughly three times more carbon than conventional oil, similar in fact to coal.[27] And oil shale likely contains the same high weight in carbon.[28] Much of the carbon imbedded in these unconventional oils has the potential to form carbon dioxide—the principal greenhouse gas—when extracted and burned. Yet the impact of such large stores of carbon is not reflected in the cited emission increases because fuel standards are computed for motor vehicles (per mile driven) and the driving cycle in today's inefficient cars and trucks masks the carbon intensity of the upstream processes involved in using gasoline and diesel fuels. Using a driving basis is useful in carbon accounting for motor vehicles running on different types of fuel. But a broader oil policy is needed to accurately depict the carbon intensity of new oil feedstocks economy-wide, accounting in the aggregate for all of their byproducts.

As oils transform, so too will their emissions. It is often assumed that a unit of fuel feedstock is equivalent to a unit of a specific fuel product. But as oils get heavier, it will take greater volumes of feedstock to yield the same volume of each byproduct. Further complicating matters, to the extent that unconventional oil represents an increasing share of crude oil supplies, less gasoline and jet fuel will be produced relative to other, often heavier and dirtier, petroleum products. And refineries, due to their complex and dynamic inputs and outputs, will introduce larger errors when accounting for their carbon impacts, making it more difficult to determine the exact extent of emissions. Attributing carbon flows from each of the upstream processes and byproducts (such as petroleum coke) to downstream petroleum products (such as gasoline) poses another challenge in terms of accurate carbon accounting.

The knowledge gaps on unconventional oils are extensive, as shown in figure 6. New economy-wide methodologies need to be developed to measure

Figure 6. Knowledge Gaps on Greenhouse Gas Emissions From Oils

	DIRECT EFFECTS									INDIRECT EFFECTS			
OIL TYPE	Exploration	Production	Methane Losses	Refining	Transport	Land Use	Waste	Vehicle (CO_2)	Vehicle (other GHGs)	Co-products	Economic Effects	Security	Infrastructure Construction
Conventional	✕	✓	✓	○	○	✕	–	✓	✓	✕	✕	✕	✕
Deepwater	✕	✕	✕	○	○	–	–	✓	✓	✕	✕	–	✕
Heavy oil	✕	✕	✕	✕	○	✕	–	✓	✓	✕	✕	✕	✕
Oil sands	✓	○	✕	○	○	✕	✕	✓	✓	✕	✕	–	✕
Oil shale	✕	✕	✕	✕	✕	✕	✕	✓	✓	✕	✕	–	✕

✓ **Included in traditional fuel life-cycle analysis**

○ **Included in traditional fuel life-cycle analysis and requires additional study**

✕ **Not included in traditional fuel life-cycle analysis**

– **Not applicable**

Source: Adapted from Life Cycle Associates, February 2009, http://www.newfuelsalliance.org/NFA_PImpacts_v35.pdf the carbon emissions associated with a growing number of unconventional oil processes and products.[29]

Yet, there are obstacles to overcome. The lack of a widely accepted definition of unconventional oils could lead to growing confusion about what they are and how they are produced. This will be increasingly problematic if it obscures public awareness, policy attention, and government oversight. As such, governance structures established for conventional crude oil, its processing specifications, and its byproducts will need to be revisited with new oils in mind. For example, will vehicle emission control standards provide ample protection as fuel quality changes worldwide? Will stationary source emission standards, especially regarding new oils' methane and other hydrocarbon leakage, prove difficult to measure and control? Will unconventional oils have a major impact on short-term climate-forcing agents, including methane and ozone (nitrogen oxides and reactive organic gases)?

Governance structures established for conventional crude oil, its processing specifications, and its byproducts will need to be revisited with new oils in mind.

New rules will likely be required to deal with new fuels. This includes managing their impacts and determining the mix of unconventional oils in the future mix of petroleum products.

Oil Policymaking for a New Century

The International Energy Agency, in its 2011 *World Energy Outlook*, makes it clear that urgent action is needed to reduce both conventional and unconventional oil use to ensure that global warming does not exceed the 2° C (3.6° F, 450 ppm atmospheric concentration) *safe* threshold agreed upon by many world governments. Experts project that, absent a strategic effort to manage unconventional oil development, global carbon dioxide levels are likely to rise well above safe levels, given limited policy action. We can and must do more to advance an oil policy agenda.

Despite the clear need to move to a lower-carbon future, that transition has been a long time coming—and there is still a long way to go. In the interim, various forces—including industry, which is already accustomed to dealing in oil—will invest heavily in the extraction and processing of various kinds of new oils. And the implications of that shift could be even more damaging for the environment than the use of conventional crude. Just how damaging is impossible to determine. Policymakers and industry officials have not been able to decide how to define unconventional oils let alone determine their impacts.

Define the Problem

Effective policymaking under changing circumstances depends on the full acknowledgment of what decisionmakers know and what they do not know.

Therefore, bridging information gaps and shedding light through up-to-date data on new oils will be key to managing them.[30] The first step along this uncharted path is advancing ongoing robust global data collection, in a process that is both monitored and verified.

New oil resources and their associated impacts are not stagnant. Oil will continue to be discovered in new locations and processes will continue to evolve. Global citizens will increasingly look to policymakers and industry to demystify new oils and the risks they pose.[31] And those citizens will expect policymakers to take appropriate action to deal with the trade-offs involved with the use of unconventional oils worldwide. Thus the need for unbiased information about unconventional oils and their substitutes will be increasingly important as new facts surface about the relative trade-offs between feedstock, processes, and products.

Gather Information About New Oils

As part of this information gathering, new oils should be differentiated from one another globally by exploring the varying granularity of emission data (well, block, basin, field, and subfield). The knowledge gaps in the new geographies, chemistries, and carbon implications of unconventional oils should be identified through new worldwide data collection that is made publicly available, and governments and industry should then move toward a harmonization of emission-accounting methodologies based on geography.

Working with stakeholders who possess verifiable data on the changing nature of oil and the particular characteristics of unconventional oil, and sharing this information, will help remove barriers to effective policymaking. Partnerships will be important, with an eye toward accommodating intellectual property so that technologies and techniques with the greatest environmental benefits can be shared throughout industry and governments.[32] This information will be necessary to update analytical tools so that policymakers can develop transparent and consistent guidelines for new oils.

Governments and industry should also create enduring structures for international and national oil oversight and track changes in oil makeups, processing techniques, and byproducts while encouraging continuous evaluation of unconventional oils as new information comes to light, including updated life-cycle analysis of new oils that considers emerging processes and byproducts.

Governments and industry should create enduring structures for international and national oil oversight and track changes in oil makeups, processing techniques, and byproducts while encouraging continuous evaluation of unconventional oils.

Make Prudent Policy Decisions

With this information in hand, the next step is to develop an appropriate and durable oil policy response that entails transparency, longevity, and consistency. Moving forward to replace conventional oils in a structured, safe manner is necessary. This will require increased collaboration through a distributed intelligence network—with industry, government, academia, think tanks, and nongovernmental organizations—on unconventional oils. Ad hoc, country-by-country intervention may not deliver the desired climate results.

Ultimately, unconventional oil development will be highly responsive to prudent climate policies.[33] But such policies do not currently exist. If anything, prevailing government policies worldwide have provided fiscal subsidies to accelerate the production of new oil, with regulatory oversight limited to certain environmental impacts at the point of pollution.

National climate policies could determine and track which—and under what conditions—new oil resources are developed, what oil byproducts are created, as well as how they are processed and marketed. Policies will also be needed to address potential emissions that are produced at upgrading facilities where the oils are processed before being refined as well as imports of high-carbon upgraded byproducts. Designing flexibility into new oil rules will be important as new data surfaces.

Without policy guidelines, such as carbon taxes, new oils will have a significant market advantage over low-carbon alternatives.

The ultimate goal should be the transition to a low-carbon fuel future, which will be stimulated—along with new oils—when fuel prices rise. As light and easy crude stocks dwindle and oil prices likely trend upward in the long term, more costly resource replacements will be induced—from low-carbon alternatives to energy-intensive petroleum supplies. Without policy guidelines, such as carbon taxes, new oils will have a significant market advantage over low-carbon alternatives. The only way investment decisions are guaranteed to take climate mitigation into account is if carbon is regulated or priced.

Fuel efficiency policies—for vehicles, buildings, industry, and elsewhere—are a critical backstop strategy for long-term decarbonization. When it comes to meeting market demand for liquid-fuel feedstock and product supplies, using policies to guide supply and demand toward a more diverse array of low-carbon feedstocks and products will be critical. So too will regulations and incentives that promote the efficient use of liquid fuels and their byproducts—new oils that contain significantly more carbon in a unit of energy must be sipped and not guzzled. If successful, these policies can serve to balance climate and oil security goals.

Developing new rules for new fuels will be critical to effectively manage the transformation of oils. This is a key moment to determine the future energy balance between oil and low-carbon alternative fuels. Only with sound policy during this time of transition can we arrive at a decarbonized fuel system to drive our transportation sector and fuel the global economy.

There is no historical precedent for a coherent, enduring global oil policy. It will take new knowledge about new oils to spur cooperation and leadership, which together will enable policy guidance for moving forward. Now is the time to structure the role petroleum supplies will play in our collective energy future.

Notes

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Note that while the world oil prices are expected to trend upward in the long term, certain exogenous conditions can affect markets and reduce oil prices, such as a boost in short-term conventional oil production or OPEC members' loss of cartel pricing power control.

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