THE CARNEGIE PAPERS

THE CARBON CONTAINED IN GLOBAL OILS

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CP 166

Contents

Summary

Immense opportunities and challenges lie ahead in shaping the world's energy future. Triple digit oil prices spurred technological advances that have unlocked an array of unconventional oils—from carbon-laden tacky oils that resist flow to ultra-light petroleum liquids trapped in tight shale oil. Policy guidance is needed to strike a balance between exploiting these energy assets and protecting the climate.

Key Themes

- While oils have historically been relatively homogeneous, new oils have very different makeups. The techniques and the amount of energy needed to extract and process them vary widely.
- Oils, once extracted, are separated into intermediary products that are then transformed into an array of marketable petroleum products. New oils yield a different slate of products.
- A barrel of lighter oil, such as tight shale oil, contains less carbon than a barrel of heavy oil, such as bitumen oil sands.
- Ultra-light oils contain more gas condensates—a mixture of various lighter hydrocarbon compounds, including natural gas liquids—that can be used as petrochemical feedstock rather than burned as transportation fuel.
- Extra-heavy oils have more carbon residue and yield more high-carbon co-products, such as petroleum coke, than lighter oils. When combusted, some of these petroleum products emit more carbon dioxide than coal, with negative environmental and climate consequences.
- Main policy objectives include using oil and its byproducts as efficiently as possible across the economy, prioritizing the use of lighter oils, avoiding combustion of high-carbon co-products, and reducing carbon emissions from oil throughout the oil value chain.

Recommendations for U.S. and Global Policymakers

Expand knowledge about new oils: There are serious information gaps when it comes to the makeup and climate impacts of new oils. Industry and policymakers should remedy this by fully characterizing the carbon potential of oils, sharing knowledge, and establishing open and accessible databanks of information.

Put a price on carbon: Oil markets are expanding as new oils are identified and become economically and technologically viable. Placing a price on carbon can help balance energy and climate security goals.

Curb the development of new oils that have the largest impact on climate: High-carbon potential oils and their carbon-intense co-products should only be considered for development when methods or practices to mitigate their climate impacts are perfected and widespread.

Maximize energy efficiency: Reducing energy demand is a powerful antidote to mounting carbon in new stores of oils. Targeting efficiency measures and reductions for higher-carbon oils is a top priority.

Changing Reality of Oil

So much has changed in the oil market and the global economy over the past year and a half. The International Energy Agency suggests that, when it comes to the current oil situation, the world is "in search of the new normal,"[1] faced with an array of recently unlocked unconventional supplies—solid ancient bitumen adhered to sand and clay in oil sands, extra-heavy tacky oils that resist flow, dense immature kerogen fused to oil shale, and ultra-light petroleum liquids trapped in tight shale oil.[2]

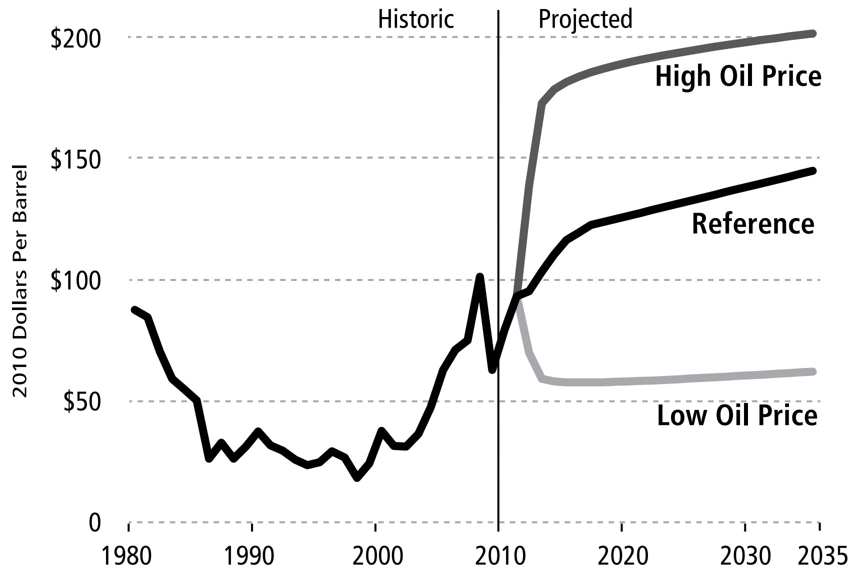
Until as recently as a couple of years ago, the prevailing wisdom was that global oil reserves were reaching the point of exhaustion. An "all of the above" resource strategy was pursued to address the perceived shortfall. Renewable fuels, fuel economy standards, and vehicle electrification were advanced by public policy, and researchers were pursuing ways to convert coal and natural gas to liquid fuels economically. The oil industry drilled deeper and ventured farther afield for new oils. And deposits of unconventional hydrocarbons were considered to be of strategic importance given increasingly insufficient conventional oil supply.[3]

Meanwhile, China and other emerging nations were motorizing rapidly, increasing worldwide oil demand. Strong and sustained economic performance led China's oil consumption to more than double, jumping from 4.6 million barrels per day (mbpd) in 2000 to over 9.4 mbpd in 2010.[4] These growth patterns were replicated across the developing world throughout the decade.

Today there are an estimated 160 types of crude oils being traded worldwide, and the number is growing.

Mounting oil demand paired with long-held notions of peaking oil supplies drove global oil prices up to historic highs (see figure 1). High oil prices, in turn, drove technological advances in oil extraction and processing innovations, which led to unprecedented resource accessibility and transformational capabilities. Today there are an estimated 160 types of crude oils being traded worldwide, and the number is growing.[5] Some of these oils originate from resources that are not actually oil, instead resembling gas or coal.

Figure 1. **World Oil Prices (Historic and Projected)**



Source: EIA, *Annual Energy Outlook*, June 2012

The one thing that all oils have in common, regardless of their source, is that carbon is their major component—typically between 82 and 85 percent, by weight. Yet, despite this relative similarity, some oils are much denser than others. That is, contained in the same volume, some weigh much more, which means there is more carbon in every barrel of heavier oils than lighter oils.

That also means these oil resources are quite distinct from one another when it comes to their carbon footprints. In terms of new oils, abundant supplies of lighter liquid tight oils in the United States—which are liberated through hydraulic fracturing, also known as fracking, yet yield a relatively light conventional slate of petroleum products—and massive stores of solid bitumens in Canada, which must be separated, upgraded, and blended into a range of heavier petroleum products, underscore the stark contrast between the options now available. While oils have historically been relatively homogeneous, new oils have very different makeups, extraction techniques, processing requirements, energy inputs, product yields, demand profiles, and climate impacts. Absent robust climate policy, investments in new oils—and the extent to which they enter the market—will be determined largely by oil prices.

Future oil prices are projected to range wildly, moving between $60 and $200 per barrel.[6] Even according to the middle-of-the-road scenario—the reference case—oil market conditions are expected to be increasingly dynamic and opportunistic. According to the International Energy Agency, it is likely that "supply and demand will balance, albeit in new and ever-changing ways."[7] Oils will need to be managed in order to minimize their carbon footprints amid shifting market forces.

Given the varied carbon footprints of these new oils, tradeoffs will have to be made between exploiting energy assets and protecting the climate. Today, the majority of petroleum products fuel the transportation sector. But as oils change, a greater share of the products that are created along the value chain—from extracting to processing and transporting to consuming—are finding their way into power generation, cement and steel production, the chemicals industry, and perhaps over the long term and in a new configuration back into the auto industry. Oils are repositioning themselves as part of an increasingly complex, highly capitalized, geographically distributed, export-driven industry. This makes tracing their carbon footprints quite important.

There is a need for public policy and increased government oversight in this critical sector to ensure the wisest development decisions are made. The widespread availability of new oils could provide the buffer needed to think through investment strategies and adopt policy guidance to manage the changing reality of oil.

Differentiating Oils

No two oils are exactly the same. Oils from different fields and from different formations within the same field can have a similar composition or vary significantly. This has always been true, but the degree to which global oils differ from one another is increasing as development ventures into what some are calling opportunity oils. The dynamics of oil markets—driven by the price of oil and technological innovation—are expected to further differentiate oil resources.

The global economy has become so dependent on liquid fuels, and the efforts to access them so extraordinarily profitable, that the crusade for anything that can be transformed into petroleum products is persistent and pervasive. To date, the world has produced and burned an estimated 1 trillion barrels of conventional crude oil, the vast majority—75 percent—discovered before 1980.[8] The next trillion barrels will likely be consumed by 2040. ExxonMobil now predicts that by 2040 less than half of the world's currently estimated 5 trillion barrels of conventional and unconventional oils will have been extracted.[9] According to current estimates, those supplies are projected to last one hundred forty years at present rates of consumption.

As new technologies are developed and new geographies explored, the amount of remaining global oil resources is expected to continue to be revised upward and the array of hydrocarbon resources is becoming ever more diverse (see figure 2). The two major ways in which oils differ are their weight (measured by American Petroleum Institute or API gravity) and viscosity (or resistance to change in form). These physical and chemical oil characteristics relate to the ease or difficulty with which hydrocarbons make their way through the oil value chain. In turn, this determines extraction methods, processing requirements, treatment additives, transport procedures, energy inputs, and petroleum product outputs that shape the ultimate carbon footprints of different oils.

Figure 2. **Characterizing Diverse Oil Resources**

Crude Oils	Viscosity (centipoise)	Familiar Substances	Typical API Gravity Range	Sample Oil Reserves
Tar, Bitumen, and Kerogen	10^8, 10^7	Window putty Caulk Vegetable shortening	6-10	Alberta, Canada–Peace River
Extra-Heavy Oil	10^6, 10^5	Peanut butter Tomato ketchup	10-12	Venezuela–Boscan
Heavy Oil	10^4, 10^3	Molasses Honey	14-22	California–Kern River
Intermediate Oil	10^2	Maple syrup Corn oil	25-30	Saudi Arabia–Arab Heavy
Light Oil	10, 1	Water	31-40	UK–Brent
Ultra-Light Oil	10^{-1}	Nail polish remover	41-50+	Texas Shale Oil–Eagle Ford

Source: Adapted by author from BP, "Heavy Oil vs. Light Oil," March 2011, www.aoga.org/wp-content/uploads/2011/03/HRES-3.10.11-Lunch-Learn-BP-Heavy-Oil1.pdf

Some oils are far simpler and lighter—more like natural gas—while others are more complex and heavier, like coal. Lighter oils contain simpler hydrocarbon compounds with less carbon, more hydrogen, and greater shares of natural gas liquids and gas condensates. (Natural gas liquids are made up of ethane, propane, butanes, and pentane, while condensates are a broad category of mixtures of various lighter hydrocarbon compounds in the 45–75 ºAPI gravity range, including natural gas liquids, hexanes, and a small portion in the heptane–octane range.) By comparison, heavier oils have much higher carbon residues and more complex and longer hydrocarbon components, resulting in greater internal friction, higher viscosity, higher weights, and lower API gravities. Bitumens are so heavy that they do not flow at room temperature—and must be produced by unconventional means, including strip mining and a process in which high-pressure steam is injected to soften the bitumen so that it can flow out of the ground.

The oil value chain must adapt to deal with this full range of oils entering the market, and the oil industry is learning as it goes. The industry acknowledges that heavier oils are a different commodity than lighter oils with respect to "extraction techniques, technical challenges, understanding, environmental challenges, and markets."[10] Still, there is currently too little distinction drawn between different oils. Policymakers and the public have historically viewed oils as a relatively homogeneous commodity widely known as crude. As long as oils can be tapped and turned into high-value petroleum products they are viewed as essentially one resource. Moreover, some even consider oil and petroleum fuels to be the same thing, but oil is not remotely the same as gasoline or diesel fuel.

This blurring of oils and fuels hinders intelligent choices given the real tradeoffs between different oils that the public and many policymakers are not aware of. Many believe that oil and liquid fuels have few ready substitutes, which has obstructed the development of alternatives to current supplies. Even so, the oil frontier is now venturing into hydrocarbons that do not remotely resemble conventional crude oil.

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All of these new developments have broad ramifications for the climate. The introduction of new discoveries and types of oil resources coincides with the dangerous buildup of carbon dioxide in the atmosphere from the burning of fossil fuels. The science is conclusive: mounting carbon dioxide and other greenhouse gas emissions are responsible for the precipitous rise in global temperatures. Converting and combusting newfound hydrocarbons—especially those with the most carbon embedded in them—will release emissions that have a significant impact on the climate. Once released, carbon emissions last for hundreds of years, and the climate recovers only slightly over thousands of years.

This permanent impact—in terms of human lifespans—underscores why reducing oils' carbon footprint is a necessity. As such, ascertaining the different amounts of carbon embedded in global oils will be critical to managing oil development, structuring oil policy, and guiding today's energy choices, from which oils to produce and which deposits to keep stored in the ground to how to use oils even more efficiently and how to diversify to oil alternatives. This is the key moment to determine future carbon emissions from liquid hydrocarbons in North America and worldwide.

Bringing New Oils to Market

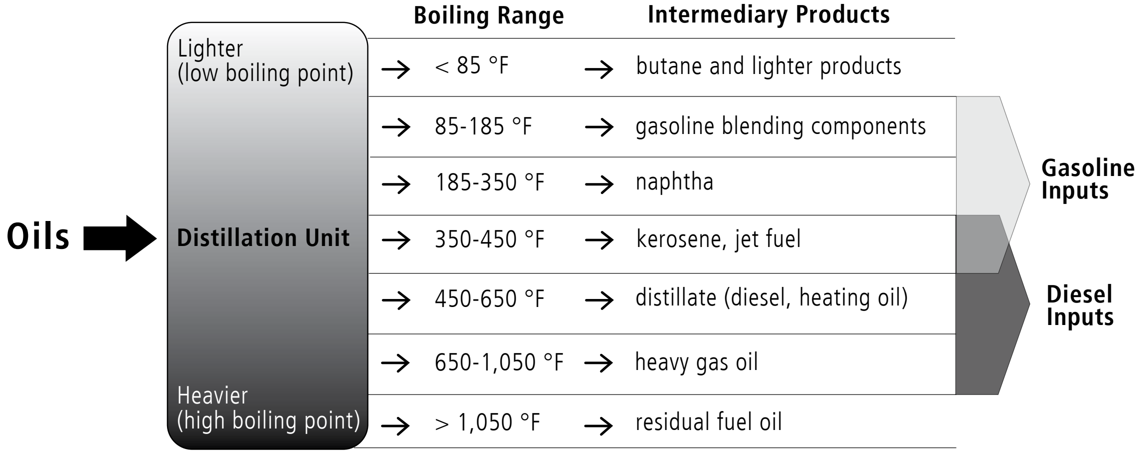
To understand the carbon footprint of various oils, it is necessary to look at the full life cycle of the oils. Though oil trades profitably as a global commodity, it is not an end product in itself. Oil is merely the input into a long, complex, and dynamic value chain. Oils, once extracted, must be transformed into an array of marketable petroleum products. Gasoline, diesel, and jet fuel are the most profitable, but not all oils have identical yields of these products. Assorted lower-valued co-products are also created during the process of transforming extracted oils, the greatest shares of which generally come from extra-heavy and ultra-light oils. The heaviest oils stand out because their transformation process involves dealing with excess carbon, which requires extensive processing, takes higher energy inputs, yields more residual fuels, and results in greater carbon emissions.

All oils are separated into intermediary products—which can be considered the building blocks of petroleum products—before they can be reassembled into gasoline, diesel, and other commercial products. Heat is used to separate various mixtures of raw oils into their constituent parts in a process called distillation, whereby oil fractions are boiled off and collected one by one. The particular building blocks of different oils provide insights into characterizing oils and their product potential, which in turn reflects the relative size of their carbon footprint.

The broad categories of intermediate products range from light to heavy components (see figure 3 for the categories of intermediary products that form the building blocks of commercial petroleum products, including gasoline and diesel fuels).[11] The lightest components, which are recovered at the lowest energy and temperature inputs under 185 degrees Fahrenheit, include the simplest hydrocarbons with four carbons (butane) or less (propane, ethane, and methane). Naphthas, a volatile, flammable, liquid mixture of hydrocarbons, are next liberated as the heat is turned up to between 185–350 °F. Add to these a small share of kerosene, which boils off at 350–450 °F, and together these are the building blocks for gasoline.

Diesel, a heavier fuel with more complex hydrocarbons, is made up of building blocks composed of more carbon, including primarily distillate (450–650 °F) and heavy gas oil (650–1050 °F). Residual fuel oil represents the bottom of the barrel, the heaviest intermediary product from raw oil that requires temperatures over 1,050 °F and extensive conversion treatments to turn it into marketable co-products.

Figure 3. **Oils' Processing and Products**

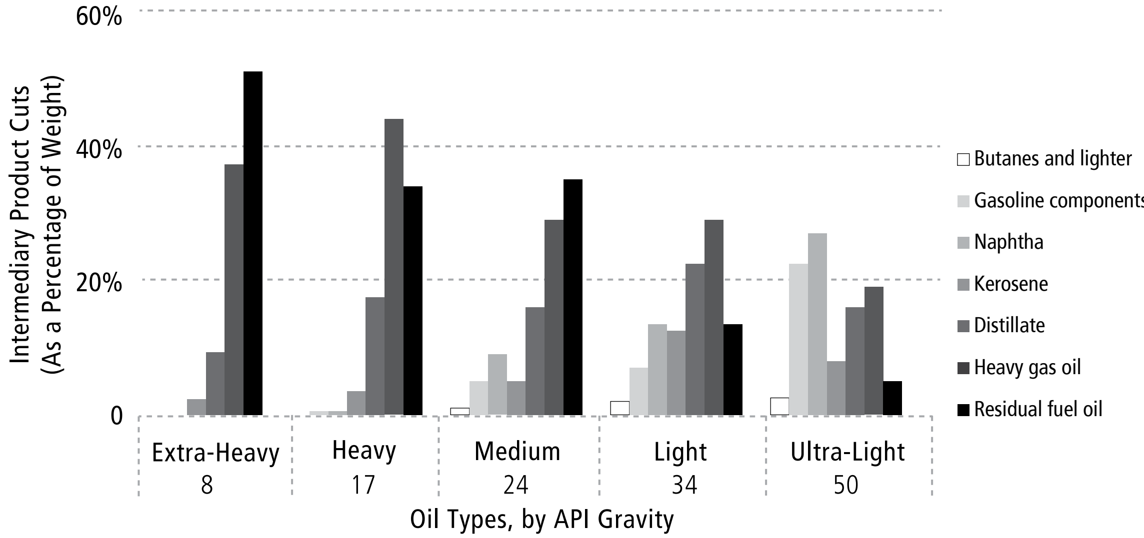


Sources: Energy Information Administration, www.eia.gov/todayinenergy/detail.cfm?id=6970 and International Energy Agency, www.iea.org/stats/defs/sources/petrol.asp

While there is limited publicly available information to widely verify the intermediary hydrocarbon contents of different oils, these resources differ markedly from one another. Conventional oils typically contain 25 percent naphtha and lighter products, 30 percent middle distillates, 30 percent gas oils, and 15 percent residual products. Higher variations are seen at the extremes. Ultra-light oils, for instance, can contain as much as one-half condensates, which is a general term for intermediate products that require temperatures of less than 185 ºF to recover. The heaviest oils, on the other hand, contain far less naphtha and middle distillates with some one-half composed of bottom-of-the barrel residuals, including upwards of 15 percent asphalt-like components that are solid, hard to handle, and do not easily dissolve. These residuals are most readily processed into petroleum coke or pet coke—one of several low-value, high-carbon by-products of the oil refining industry.

Significantly more carbon is embedded in the heaviest oils through their intermediary products than in light oils. The difference in building blocks that comprise various oils is quite striking (see figure 4).

Figure 4. **Potential Intermediary Products of Different Oils**



Sources: Crude Oil Quality Association, 2009, www.coqa-inc.org/20091022_Villalanti.pdf and The Distillation Group, 1997, http://home.earthlink.net/~villalanti/Crude.pdf

As oils change, not only do their compositions and intermediary products change, so does the oil value chain—that is, it is easier to produce the end products of diesel and gasoline, for instance, from certain oils than it is from others. The greatest challenges occur at the extremes, where the differences between unconventional and conventional oils are most pronounced. The lightest oils (those with gravities over 45 ºAPI, the lowest density petroleum feedstocks) contain shorter molecules with lower amounts of carbon, which means their intermediary products are recovered at lower temperatures. They are not as suitable for maximizing the output of gasoline and diesel fuels. As oils get very heavy (with gravities under 15 ºAPI, the highest density petroleum feedstocks), they are composed of longer and bigger molecules, which means that their intermediary products are recovered at higher temperatures. Bitumens and extra-heavy oils do not yield significant amounts of gasoline without extensive processing enhancements, energy input, and resulting carbon emissions.

Moreover, bitumen's solid state makes it unable to flow through pipelines, further complicating attempts to refine this resource. Upgrading raw bitumen into a man-made synthetic crude that flows is one option, but that requires massive energy inputs and pet coke production. Blending ultra-light and extra-heavy oils into a mixture with a gravity in the range of 19–22 ºAPI has been introduced as another way to address this problem, and the shipment of dilbit (diluent plus bitumen) is becoming common practice from Canada. For example, when very light oils (such as condensates from the Bakken—a formation that spans North Dakota, Montana, Saskatchewan, and Manitoba) are blended with bitumen from the Canadian oil sands, an oil feedstock is produced that appears to be similar to crude oil. But in reality, the product does not have the same composition as conventional oil.

Instead, dilbits are blended "dumbbell" oils that contain too few intermediary products in the middle range, which are best suited for making petroleum products without extensive processing. Such a composition thus compromises motor fuel yields. As such, more oil does not readily translate into increased production of those high-value petroleum products Americans demand the most. There is a growing gap between more oil and more fuels, creating a vastly more complex situation where climate change is the potential casualty.

Tracing Oils' Carbon Footprints

The heavier the oil, the more energy required to process it, the more unrefined hydrocarbon inputs necessary to create end products, and the more carbon emitted to achieve roughly the same petroleum product yields as lighter oils.[12] This is due to the fact that the heavier the oil, the more difficult it is to extract, move, and process into high-quality petroleum products, and the greater the potential to yield high volumes of low-quality petroleum products that rival coal in their carbon emissions. It is the development and use of the heaviest oils that could be most dangerous for the environment.

There has been extensive investigation in recent years into the life-cycle analysis of greenhouse gas emissions (that is, the amount emitted from the time of extraction through combustion) of various transportation fuels, such as gasoline and diesel.[13] This important work has begun to reveal how the amount of energy required to get transportation fuels to market and the carbon emitted as a result of that process differ from one energy input to another. Equally important are the carbon dioxide emissions that are produced when oils' co-products are combusted or utilized outside the transport sector. But the leakage across economic sectors and geographic boundaries has made these emissions difficult to fully account for.

Moreover, preliminary analysis by the Intergovernmental Panel on Climate Change (IPCC) assigns different carbon dioxide emission factors—multipliers developed to calculate greenhouse gas emissions per unit of energy—to conventional light crude oil and extra-heavy oils.[14] As discussed above, these oils differ in densities and how much raw energy they contain. When considering these different oils' measurements, an estimated 24 percent higher carbon dioxide emissions are attributed to extra-heavy oils and bitumen per barrel than light crude oil (see table 1). Although the IPCC calculations are done from the perspective of oil (and not transportation fuels, which life-cycle analyses are based on), they predate the increasing array and growing volumes of new unconventional oils and their new product streams entering the market.

Table 1. **Intergovernmental Panel on Climate Change's Carbon Dioxide Estimates Comparing Bitumen to Light Oil**

Oil Category	**IPPC CO_2 Emission Factors** *Kilogram/Terajoule*	**Energy Content** *Terajoule/Gigagram*	**Oil Density** *Kilogram/Barrel*	**CO_2 Emission** *Pounds/Barrel*	**Percent Increase CO_2 Emission per Barrel** *Compared to Light*
Light Oils	73,300	42.3	135	926	
Extra-Heavy Oils and Bitumens	80,700	40.2	161	1149	+24%

Sources: GHG Protocol, www.ghgprotocol.org, IPCC, Energy, www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

If policymakers are to make the most prudent choices about the development of these oils, more information about the composition and impacts of new oils and their products are needed. Updated data will be critical to selecting oils that maximize market value and minimize environmental impacts. But characterizing oils to figure out precisely how they are transforming is no small task.

Conventional oils have long been identified by an assay—a chemical analysis of a sample of the crude oils' properties, qualities, and basic distillation cuts (as shown in figure 3). But this rudimentary information about oil is changing as assays are expanded and fine-tuned in order to take stock of the full range of new oils with their vastly different compositions and product potentials.

New oils will require more detailed databanks to inform both private and public interests. A wider array of oils needs to be catalogued based on their distinct chemical compositions, compatibility with other oils, processing specifications, energy inputs, safety guidelines, refinery yields, market values—and embedded carbon. In order to obtain greater specificity, experts have suggested that the following information is needed to characterize opportunity or unconventional oils: carbon residue (the tendency of carbon deposits to form at high temperatures), total acid number (acids corrode metals and require additional energy and produce carbon dioxide to remove), heavy metal contents, proportion of light intermediary products that distill at lower temperatures, and specificity on heavy residuals.[15]

One method for identifying the share of heavy residuals in these oils, which relates to the amount of carbon embedded in them, is high temperature simulated distillation (HTSD). This method identifies the potential to create petroleum products through an extremely broad temperature range, up to 1,380 °F. Assays, by contrast, have only tested oils up to 1,050 °F; at these temperatures the heaviest shares do not appear—it is as if they are invisible. As such, HTSD is needed to classify extremely complex, heavy, and high-carbon components, containing up to 120 carbon molecules.[16]

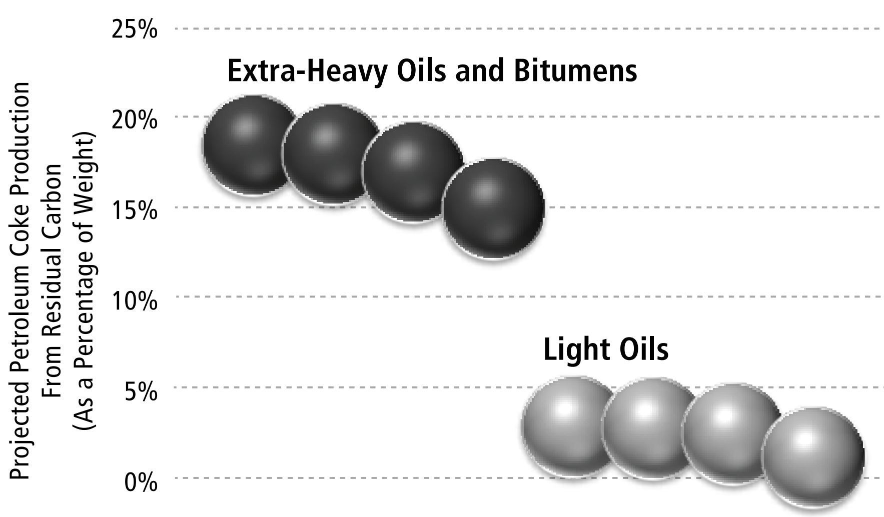
HTSD differentiates oils by providing additional data to help better understand, model, and operate oil pipelines, processes, and refineries (see sample curves in appendix). This method is thought to be precise enough to determine how impure a product is and sensitive enough to spot tampering. It can also reportedly be used as a tool for environmental forensics, providing a more accurate assessment of oils that contain high carbon residues and thus have more of an impact on the climate.[17] Using HTSD to identify potential product yields from different oils also highlights the potential carbon dioxide emitted from their end use if all oil co-products were combusted.

The Proliferation of Pet Coke

One of the most problematic oil co-products is petroleum coke, the majority of which is produced from the residuals in the heaviest oils (see figure 5 for estimates of the portion of oils' carbon residue, which quantifies the propensity of the oil to form petroleum coke). Pet coke is a coal substitute composed almost entirely of carbon—92 percent or more.[18] Although it is created from liquid oil, pet coke is an insoluble solid that is deficient in hydrogen; high in heavy metals, sulfur, and other impurities; and the end result of extensive, high-temperature processing known as cracking, which requires its own large energy inputs. Only complex, highly capitalized refineries can manage the heaviest oils and their large pet coke production volumes.

Increased production is making pet coke a burgeoning source of energy that rivals coal, not just an unwanted co-product. Combusting this oil remnant has significant environmental and climate consequences.

Figure 5. **Residual Carbon Levels in Bitumen and Light Oils**



Sources: www.ercb.ca/data-and-publications/statistical-reports/st39 and http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/44_1_ANAHEIM_03-99_0005.pdf

Pet coke is "priced to move" so that it does not have to be stockpiled and stored for extended periods. While transporting pet coke to market is costly because of its high weight and volume, business has been expanding as pet coke competes with coal and natural gas as an alternative energy source for electricity generation. Pet coke is also used as a fuel source in cement production and by the smelting industry to manufacture aluminum and steel. And it is used in refineries to provide power and steam, for conversion into methane gas, or to produce hydrogen.

Pet coke directly emits 3.4 tons of carbon dioxide for every ton combusted (or 1,356 pounds carbon dioxide per barrel of coke).[19] As such, the carbon contained in pet coke is 10 percent greater than bituminous coal, the most common coal used to generate electricity, per British thermal unit or BTU, which indicates the energy content of fuels. Compared to natural gas, pet coke has two times the carbon dioxide per BTU, considering combustion alone.[20] The additional carbon emissions from pet coke, which are significant, have not figured fully—or at all—into the climate impacts of bitumen oil sands and extra-heavy oil. Instead, inaccurate assumptions have been made that pet coke is not sold and combusted or merely replaces coal, which understate the full climate impact of the heaviest oils.

Despite its many drawbacks, world pet coke consumption has been growing, and increased pet coke yields from extra-heavy oil and bitumen are shifting energy markets and global trade patterns. Some 60–130 pounds of pet coke are now produced for every barrel of bitumen processed in Alberta's oil sands upgrading facilities—where the oils are processed into synthetic crude feedstock for refineries by removing pet coke—with expected annualized production of 8.3 million metric tons in 2012.[21] Because Alberta is a landlocked location and facilities there do not have ready access to markets, in excess of 70 million metric tons of pet coke were stockpiled as of May 2012.[22] Still, the province considers pet coke a potential future source of energy and not a waste byproduct.

Mounting pet coke supplies from heavier oils are spurring global demand. According to trade statistics, in April 2012, Canadian pet coke exports were up 87 percent from the same month one year earlier, of which nearly three-quarters were exported to China.[23] Still, the United States is the world's largest producer of petroleum coke from heavy crude oil, accounting for 40 percent of global supply in 2011. In fact in 2011, pet coke, along with diesel, made America a net exporter of petroleum products for the first time since 1949. One-half of America's 130 refineries—more than any other nation—are equipped with delayed cokers to convert oil's residue waste into pet coke.[24]

At the same time, global refineries are being retrofitted to produce pet coke because the technology is well understood and economically attractive. Pet coke production in China and India is growing and now accounts for nearly one-quarter of global output. By 2016, China and India are projected to contribute one-third of the world's supply, which is projected to reach 170 million metric tons.[25] This could have wide-ranging impacts on the climate because pet coke rivals power production from renewable energy sources, natural gas, and nuclear power generation.

Managing the Carbon in Unconventional Oils

Unconventional oils are a clear departure from business-as-usual practices in terms of their risks and rewards. Long-term planning and a consideration of all of their impacts are necessary to ensure these oils are appropriately priced and prudently developed, and their byproducts are carefully regulated, at home and abroad. Consumers and decisionmakers may not yet fully grasp the changing makeup of oil, but new liquid fuels will bring a fresh set of economic, environmental, public safety, and security challenges. As industry rushes to develop these new resources, the technological complexity involved in extracting, processing, and refining the oils, the damage done combusting their evolving end products, and the potential for leakage given their geographical distribution will make protecting both the global climate and local environments a formidable burden for governments.

Oil innovations are occurring at a rapid pace, fueled by optimism, and in a virtual public policy vacuum.[26] Simple light oil refineries (for ultra-light shale oil from the Bakken, for example) and complex extra-heavy oil refineries (that can handle diluted bitumen from Alberta's oil sands) are very different operations with vastly different inputs and product outputs. In an effort to adjust to the changing oil landscape, numerous U.S. refineries have undergone billions in recent retrofits to handle heavier and heavier oils, but these refineries are poorly equipped to process the recent bonanza in lighter tight U.S. oils.[27] That means that as oils grow more distinct, so too will refineries and other processing facilities. Refiners and the petrochemical industry will continue to search for the most profitable combinations of capabilities as oils transform over time.

Moreover, there are handsome profits to be made through oil and petroleum product exports by stakeholders that do not currently account for the carbon emissions of new resources. The heaviest oils being produced in North and Latin America and refined in the United States yield larger shares of heavier products, like diesel and petroleum coke, that are being exported to Asia and Europe. The high naphtha content of light shale oils along with natural gas liquids will result in a good deal more gasoline and petrochemical production, much of which will be exported. Gas condensates produced from the lightest shale oils will be used to blend with bitumen in order to facilitate its pipeline shipment. The increasing diversity of oils will likely create convoluted import-export patterns with oils and petroleum products crisscrossing each other around the globe.

As oil supplies transform, policymakers will have to manage changing local and global circumstances. Sound policy guidance will be needed to structure the development of unconventional oils in a way that best meets climate goals, both in North America and worldwide. The public must be kept informed if industry expects productive market opportunities to take hold and endure. And diagnostics are urgently needed, followed by strategic regional, national, and transnational management structures to guide the development and use of new oils and their byproducts.

U.S. and global policymakers' main objectives should be to use oil and its byproducts as efficiently as possible across the economy, to prioritize the use of lighter oils, to reduce carbon emissions from oil throughout the oil value chain, to avoid combustion of high-carbon byproducts, and to assure that use of new oils does not create a barrier to market penetration of new, low-carbon energy resources.

With so many dynamic changes playing out on a global scale, the evolution of oil will need to be made extremely transparent in order to manage and prevent leakage of carbon emissions into other economic sectors and nations.

A framework for managing the carbon in unconventional oil includes first and foremost expanding oil knowledge. With so many dynamic changes playing out on a global scale, the evolution of oil will need to be made extremely transparent in order to manage and prevent leakage of carbon emissions into other economic sectors and nations.

There are serious information gaps. Reporting on the condensate byproducts from ultra-light oils and pet coke from extra-heavy oils and bitumen are buried inside Energy Information Administration statistics for crude oil, impossible to find in most state data, and generally not reported separately by producers in their financial statements and investor presentations.[28] As such, industry and policymakers have a central role to play in sharing knowledge and establishing databanks of information that are open and accessible. The future of oil will entail new choices that must be guided by full disclosure.

Policies are needed to navigate the dual challenges of meeting energy needs in a way that protects the climate and enhances global security. This will become increasingly important as new oils, with their variably sized carbon footprints, vie for market positions. The most promising policy to bring about a balance between security and demand is carbon pricing. This approach will create competition between oils, prioritizing which are slated for development and will shift petroleum products to noncombustible uses. It will help inform markets and guide investments in a low-carbon energy future and will help moderate demand, especially for high-carbon oil products. Furthermore, it will enable a more diversified energy portfolio in the United States and abroad, which in turn will enhance national, energy, economic, and climate security.

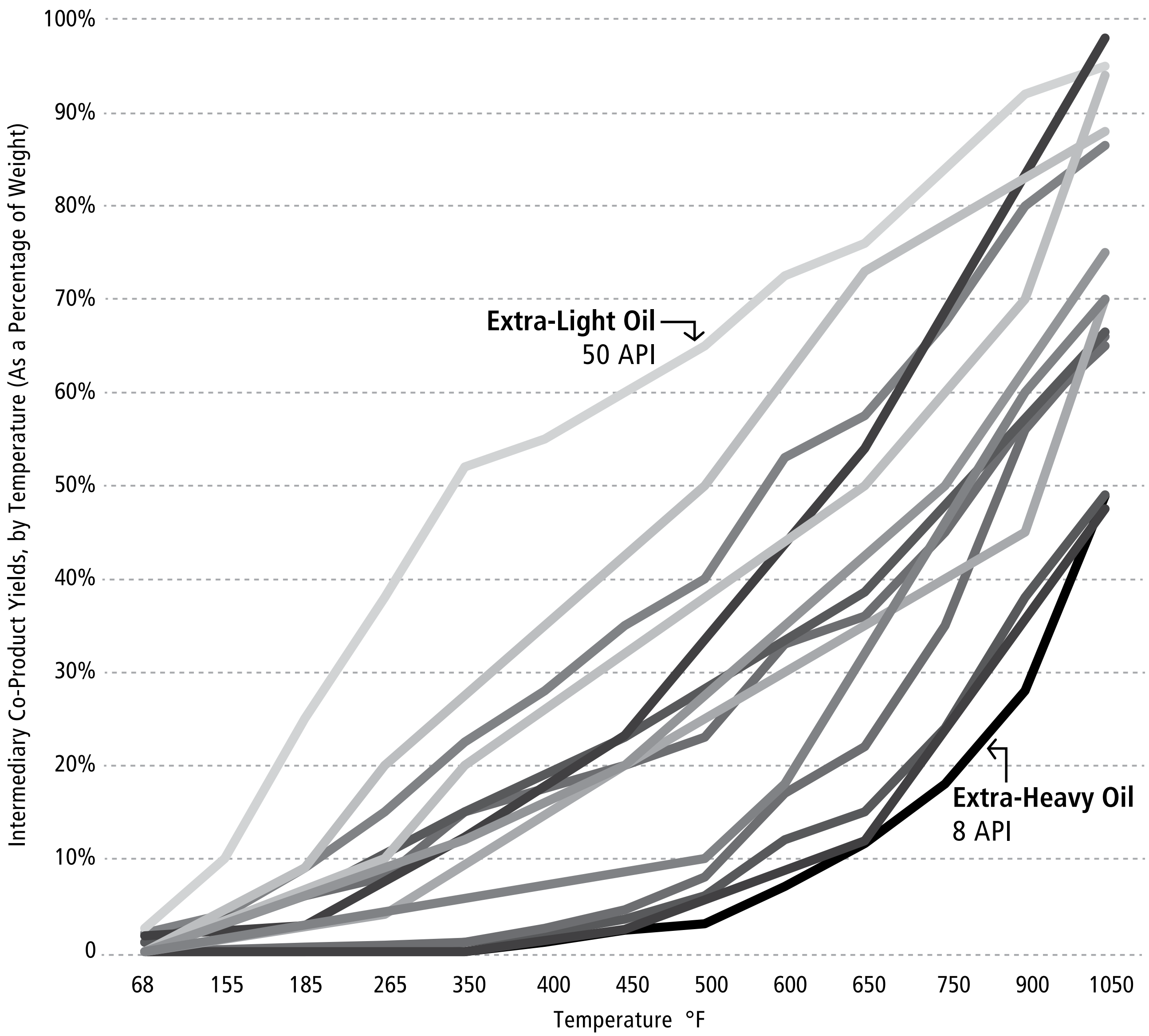
It is important to enact policy that curbs the development of new oils that have the largest impact on climate. At a time of unprecedented oil abundance, the somewhat haphazard development of the highest-carbon oils and their carbon-laden co-products, such as pet coke, must be addressed. These oils and their co-products should remain sequestered in the ground as a future investment, and they should only be considered for development when man-made carbon capture and sequestration is perfected, enabling the climate impacts of these oils to be kept to a minimum. This strategy banks on nature's own carbon-capture and sequestration processes as part of the short-term solution.

To further curb emissions, policymakers should take steps to improve efficiency throughout the oil value chain to make reductions in oil demand commensurate with the increasing carbon in new oil supplies. Economy-wide efficiency gains are certainly needed, but targeted efficiency improvements among high-carbon oils are a top priority.

To further curb emissions, policymakers should take steps to improve efficiency throughout the oil value chain to make reductions in oil demand commensurate with the increasing carbon in new oil supplies.

Oil markets are shaping up to be a chess game of opportunistic moves in which the most important thing to have is options. And the nature of the highly risky, politically potent, and massively capitalized oil business deflects attention away from the serious environmental and climate impacts of oil. Over the past century of oil's reign, a comprehensive oil policy has never really existed. But the time is now. The ascendance of new oils with varied and little-understood carbon footprints calls critical attention to the need for policymakers to set priorities based on how to manage oils so they do not negatively impact an already overloaded climate.

Appendix



Sources: Jacobs Consultancy, "EU Pathway Study," Figure 1-10, March 2012, www.energy.alberta.ca/Oil/pdfs/OSPathwayStudyEUjacobs.pdf; Jacobs Consultancy, Life Cycle Associates, and Alberta Energy Research Institute, 2009, http://eipa.alberta.ca/media/39640/life%20cycle%20analysis%20 jacobs%20final%20report.pdf; The Distillation Group, 1997, http://home.earthlink.net/~villalanti/Crude.pdf; Crude Oil Quality Association, 2009, www.coqa-inc.org/20091022_Villalanti.pdf; http://www.ucalgary.ca/ENCH/AER/theses/2012%20MSc%20Thesis%20Pawan%20Agrawal.pdf

Notes

1 International Energy Agency (IEA), "Oil Market Report," October 12, 2012, http://omrpublic.iea.org/currentissues/full.pdf.
2 Deborah Gordon, "Understanding Unconventional Oil," Carnegie Paper, May 2012, www.carnegieendowment.org/files/unconventional_oil.pdf.
3 Mitra Motaghi, Priyank Sexena, and Rahul Ravi, "Partial Upgrading of Heavy Oil Resources," KBR Technology, Winter 2010, www.kbr.com/Newsroom/Publications/Articles/Partial-Upgrading-of-Heavy-Oil-Reserves.pdf.
4 Energy Information Administration (EIA), "China," September 4, 2012, www.eia.gov/countries/cab.cfm?fips=CH; IEA, "China 2012 Update," 2012, www.iea.org/publications/freepublications/publication/name,28189,en.html.
5 Patrick DeHaan, "The Difference Between Types of Crude Oil—Brent, WTI, and More," February 9, 2011, http://blog.gasbuddy.com/posts/The-difference-between-types-of-crude-oil-Brent-WTI-more/1715-434612-493.aspx.
6 For new projections of oil prices projected to 2040 see EIA, "Annual Energy Outlook 2013," Early Release, December 5, 2012, www.eia.gov/forecasts/aeo/er.
7 IEA, "Oil Market Report," 2012.
8 ExxonMobil, The Outlook for Energy: A View to 2040, 2012, www.exxonmobil.com/Corporate/files/news_pub_eo.pdf.
9 Ibid.
10 British Petroleum (BP), "Heavy Oil vs. Light Oil: A Legislative Brown Bag," March 2011, www.aoga.org/wp-content/uploads/2011/03/HRES-3.10.11-Lunch-Learn-BP-Heavy-Oil1.pdf.
11 For a complete dictionary of petroleum product and processing terms see Energy Information Administration, "Definition of Petroleum Products and Other Terms," May 2010, www.eia.gov/petroleum/supply/annual/volume1/pdf/psmdefs.pdf.
12 Parviz M. Rahimi and Thomas Gentzis, "The Chemistry of Bitumen and Heavy Oil Processing," 2001, http://chentserver.uwaterloo.ca/aelkamel/che720/che735/lectures_che735_students/new-book-practical-advances-refinery/chapter19-bitumen-and-heavy-oil-processing.pdf and James Speight, "Natural Bitumen (Tar Sands) and Heavy Oil," www.eolss.net/Sample-Chapters/C08/E3-04-05.pdf.
13 Adam Brandt, "Variability and Uncertainty in Life Cycle Assessment Models for Greenhouse Gas Emissions from Canadian Oil Sands Production," *Journal of Environmental Science and Technology*, 2012, 46 (2): 1253–61, http://pubs.acs.org/doi/abs/10.1021/es202312p.
14 Intergovernmental Panel on Climate Change, "GHG Protocol," www.ghgprotocol.org/ and www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.
15 Hydrocarbon Publishing Company, "Third Opportunity Crudes Conference," May 2012, www.opportunitycrudes.com/houston2012/papers.php.
16 D. Villalanti, J. Raia, and J. Maynard, "High-Temperature Simulated Distillation Applications in Petroleum Characterization," *Encyclopedia of Analytical Chemistry*, 2000, http://home.earthlink.net/~villalanti/HTSD.pdf; L. Carbognani, J. Lubkowitz, M. Gonzalez, and P. Pereira-Almao, "High Temperature Simulated Distillation of Athabasca Vacuum Residue Fractions," August 18, 2007, http://pubs.acs.org/doi/abs/10.1021/ef070106g.

17 Triton Analytics, "High Temperature Simulated Distillation," 2010, www.tritonanalytics.com/htsd.html.

18 U.S. Environmental Protection Agency, Technical Support Document, "Petroleum Products and Natural Gas Liquids: Definitions, Emission Factors, Methods and Assumptions," Final Rule for Mandatory Reporting of Greenhouse Gases, September 15, 2009, www.epa.gov/climate/ghgreporting/documents/pdf/2009/SubpartMMProductDefinitions.pdf.

19 Ibid.

20 Matthew McCulloch, Marlo Raynolds, Rich Wong, "Carbon Neutral 2020: A Leadership Opportunity in Canada's Oil Sands," Oil Sands Issue Paper no. 2, Pembina Institute, October 2006, www.pubs.pembina.org/reports/CarbonNeutral2020_Final.pdf.

21 Energy Resources Conseravation Board, "Alberta Mineable Oil Sands Plant Statistics," www.ercb.ca/data-and-publications/statistical-reports/st39. Note: This pet coke production rate is the average for Suncor, Syncrude, and CNR Horizon facilities (annualized during January–May 2012). Pet coke production varies based on the processing specifications for hydrotreating and hydrocracking and type of oil intermediate produced. At the Nexen upgrader in Alberta, pet coke is produced at double this rate (127 lbs/bbl bitumen). At Shell's Scotford facility, no pet coke is produced. Instead, hydrogen is added to the carbon residuals (hydroconversion) to transform them into petroleum products. An estimated 1.5 tonnes of hydrogen are needed to upgrade 1 barrel per day of bitumen.

22 Ibid.

23 Energy Publishing LLC's Domestic and International Petcoke Report, www.energypublishing.biz/Petcoke-Report.html; also see: USGS, Minerals Information, http://minerals.usgs.gov/minerals/pubs/country; for 2012 China statistics see www.texreport.co.jp/xenglish/energy/index.html.

24 Lawrence Wisdom, AFPM, Debottlenecking a Delayed Coker to Improve Overall Liquid Yield and Selectivity Towards Diesel Fuel, March 11, 2012, www.axens.net/document/956/debottlenecking-a-delayed-coker-to-improve-overall-liquid-yield-and-selectivity-towards-diesel-fuel---afpm-march-2012/english.html.

25 Roskill, "Petroleum Coke: Global Industry Markets and Outlook, 2012," August 16, 2012, Commodities Now, "Petroleum Coke Demand Forecast to Rise," October 2, 2012, www.prnewswire.com/news-releases/roskill-petroleum-coke-capacity-and-markets-set-to-rise-166434496.html; www.commodities-now.com/reports/power-and-energy/12659-petroleum-coke-demand-forecast-to-rise-by-4py-through-to-2016.html.

26 Total, "Oil," 2012, www.total.com/en/our-energies/oil/exploration-and-production/our-skills-and-expertise/heavy-oil-940841.html.

27 RBN Energy, "Fifty Shades of Condensates—Where is All This Condensate Going?" December 6, 2012, www.rbnenergy.com/fifty-shades-of-condensates-where-is-all-this-condensate-going.

28 Ibid.

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A glossary of commonly used terms in this paper is available at http://carnegieendowment.org/files/global_oils_glossary.pdf.

About the Author

Deborah Gordon is a nonresident senior associate in the Carnegie Energy and Climate Program, where her research focuses on climate, energy, and transportation issues, with a special focus on unconventional oil and fossil fuels in the United States and globally. Gordon founded the transportation program at the Union of Concerned Scientists, taught at the Yale School of Forestry and Environmental Studies, and worked at the U.S. Department of Energy's Lawrence Berkeley Laboratory under a grant from the Environmental Protection Agency.

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