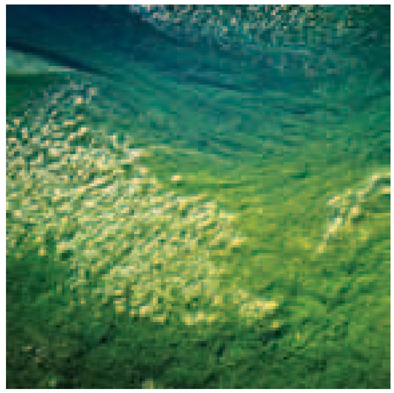
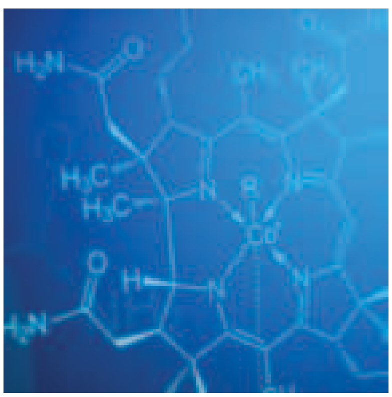
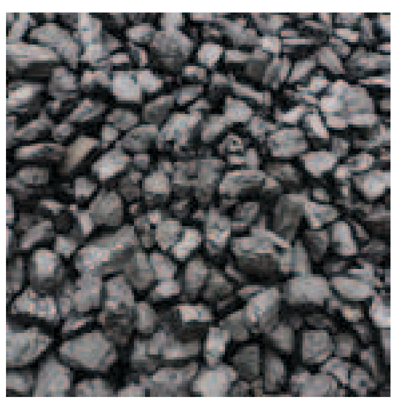
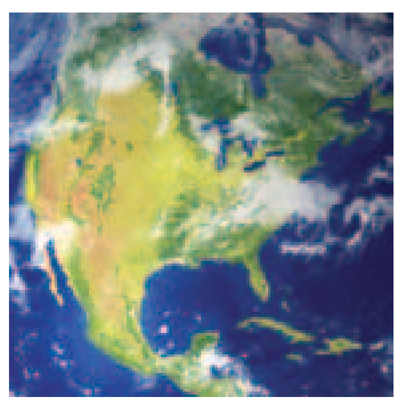
The Future of Oil and its Alternatives

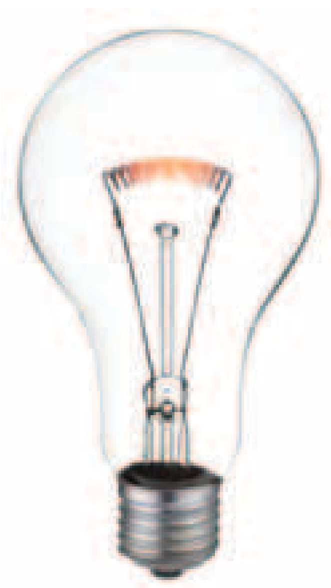


2020 INFLECTION POINT



Oil and Electricity: a Thought Experiment



If the U.S. were to make a policy decision today to stop using coal and natural gas for electricity generation by 2030, what would happen?

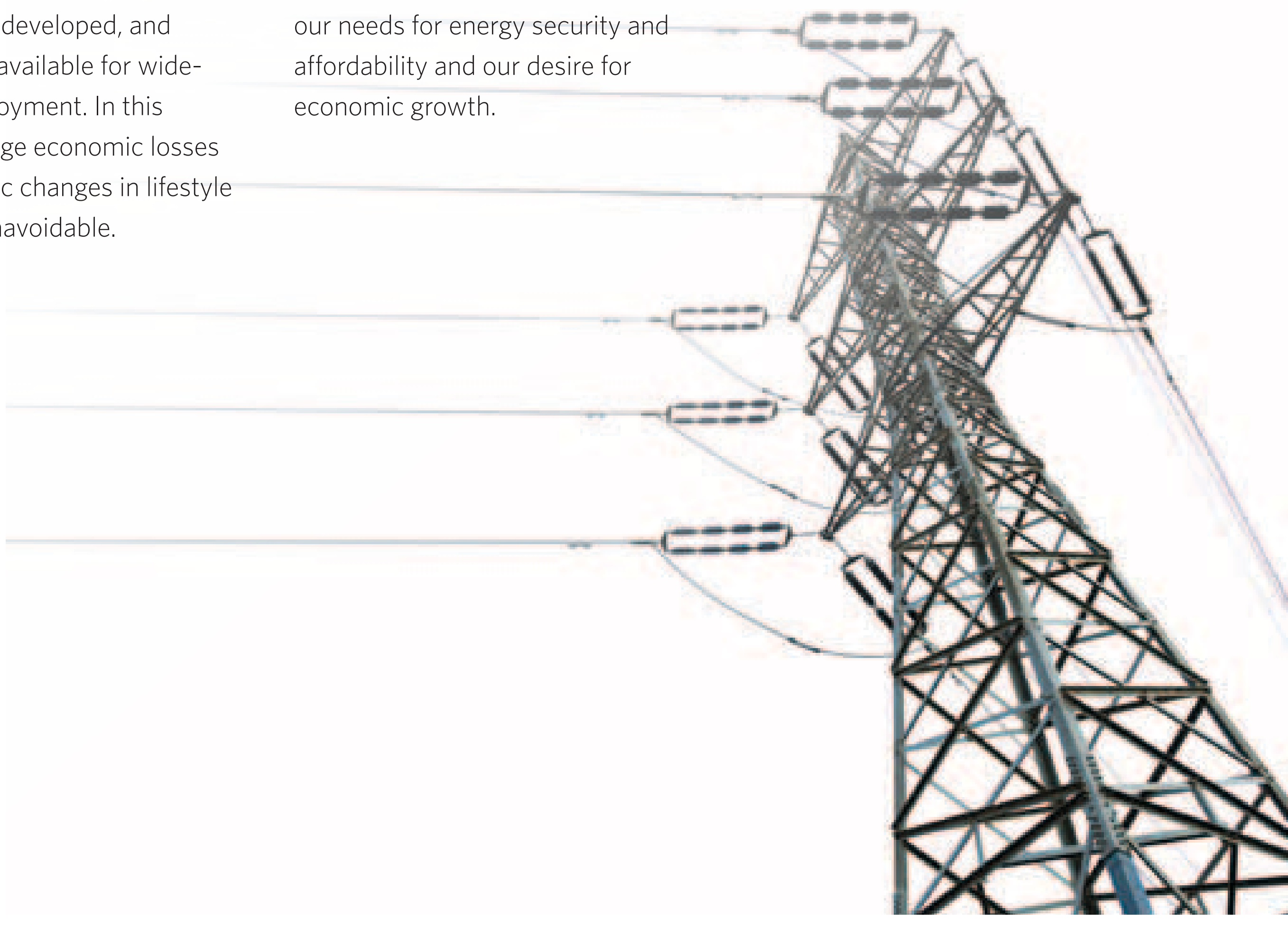
Would the lights still be on? Alternatively, if the U.S. were to decide to stop using oil by the same time, how would we react? Would we still be able to drive and fly as we do today? How would the course of events differ from what would happen in the case of electricity?

There is good reason to believe that if we stopped using coal and natural gas for electricity generation, the U.S. would find a way to get by. We would require a massive expansion in the use of nuclear power and renewables, and investments would need to be made in the grid to improve efficiency, adjust for the new supply capacity profile, and add storage for off-peak generation. While there is no doubt that this process would be painful and expensive, electricity would still be available.

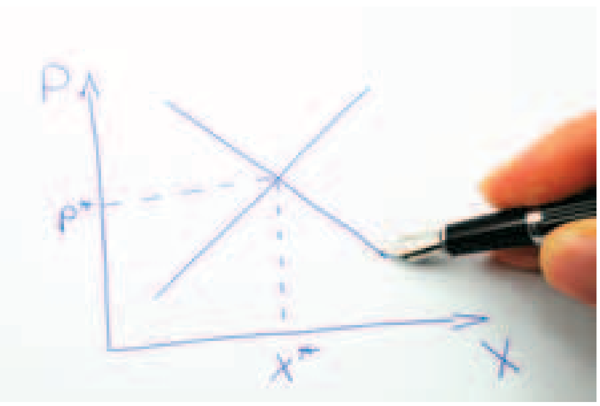
There is good reason to believe that if we stopped using coal and natural gas for electricity generation, the U.S. would find a way to get by.

The outcome with oil, however, would be far more dire. While most of the critical technologies for electricity are already available, this is not the case with oil. Oil is used almost exclusively to create liquid transportation fuels and chemicals; in the case of transportation fuels, more than 95% is derived from oil. All of today's alternatives (e.g., ethanol, biodiesel) are either incapable of being scaled up to a level comparable to U.S. oil use, or are not yet "technologically ready"—that is, sufficiently researched, developed, and tested, and available for wide-spread deployment. In this scenario, huge economic losses and dramatic changes in lifestyle would be unavoidable.

We are not presented with either of these scenarios today, and we will certainly use oil, as well as coal and natural gas, for decades to come. However, given our dependence on oil, it is important to understand what drives supply and demand and what challenges could emerge in the years to come. The growth of the developing world and rising costs of production will force us to search for alternatives, but making those alternatives viable will not be trivial. We will need to make hard choices to balance our needs for energy security and affordability and our desire for economic growth.



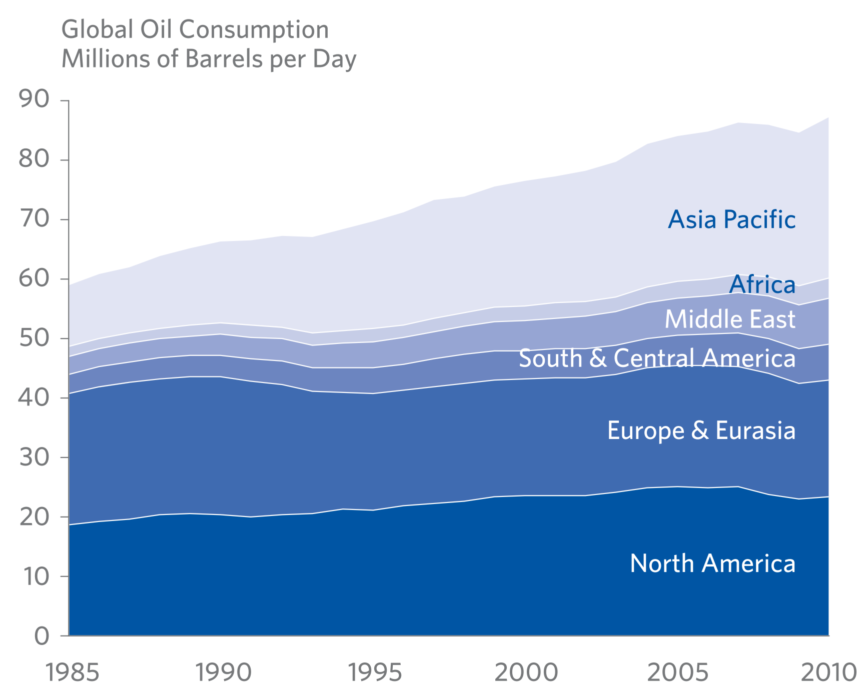
The "Oil Gap" in 2030: Supply & Demand



Oil is an indispensable resource for modern economies.

Oil-derived chemicals are used to make many things we find essential, including plastics and medicines, paints and cosmetics, clothing and pesticides, and—most importantly—oil-derived transportation fuels that power our cars, buses, planes, and trains. As the global economy has grown over the years, so too has demand for oil, rising and falling with the booms and busts of the market. Since the end of World War II, massive economic growth seen in the U.S., Europe, and Japan has been fueled by a relatively cheap and easily accessible supply of oil.

FIGURE 1. GLOBAL OIL CONSUMPTION BY REGION, 1985–2010[1]



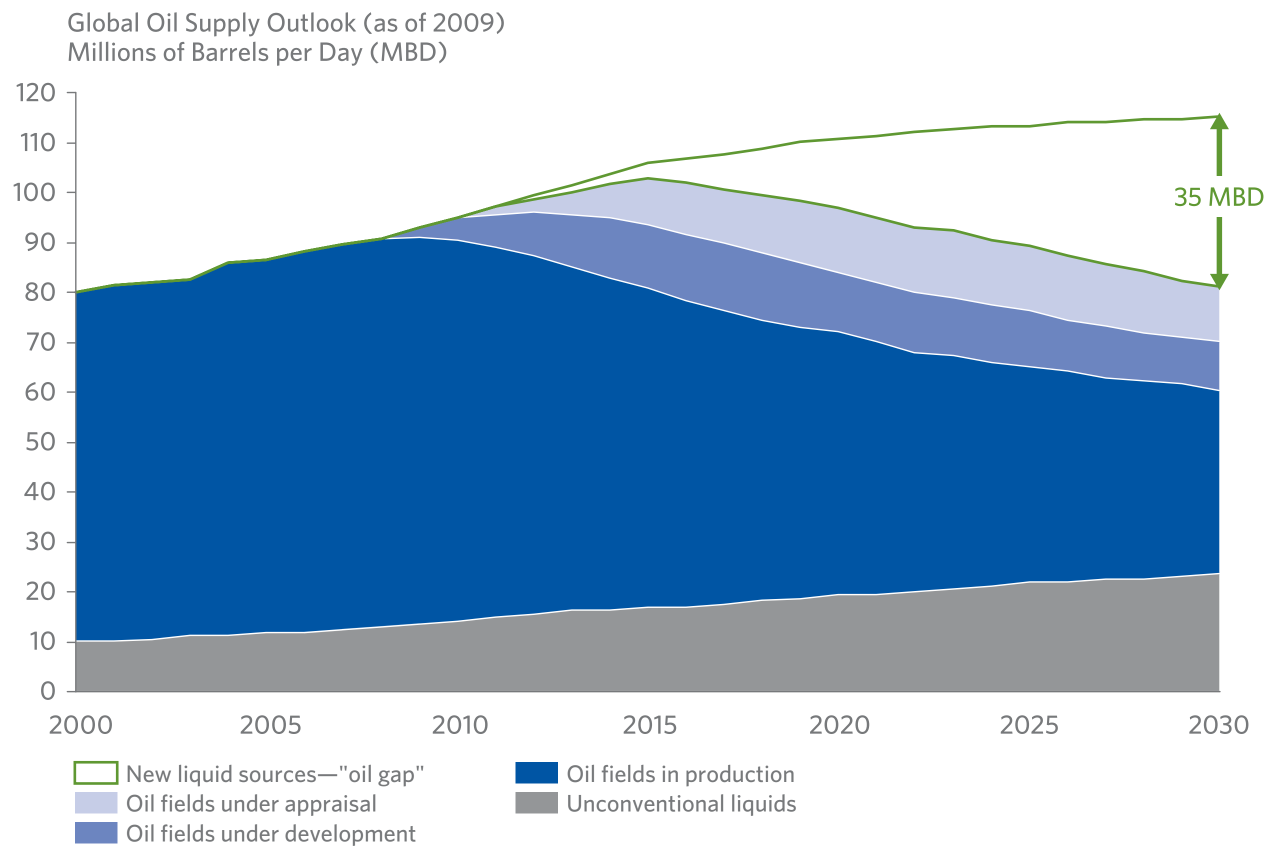
[1]BP Statistical Review of World Energy, 2011

Academic research suggests that oil price increases were a factor in causing ten of the past eleven U.S. economic recessions.

However, the world has changed remarkably over the past two decades. China, India, Brazil, and Russia have developed rapidly, causing global oil demand to rise steadily, despite little demand growth from the developed world. As shown in Figure 1, in 1985, nearly 70% of oil demand came from North America, Europe, and Eurasia; in 2010, that number was less than 50%.

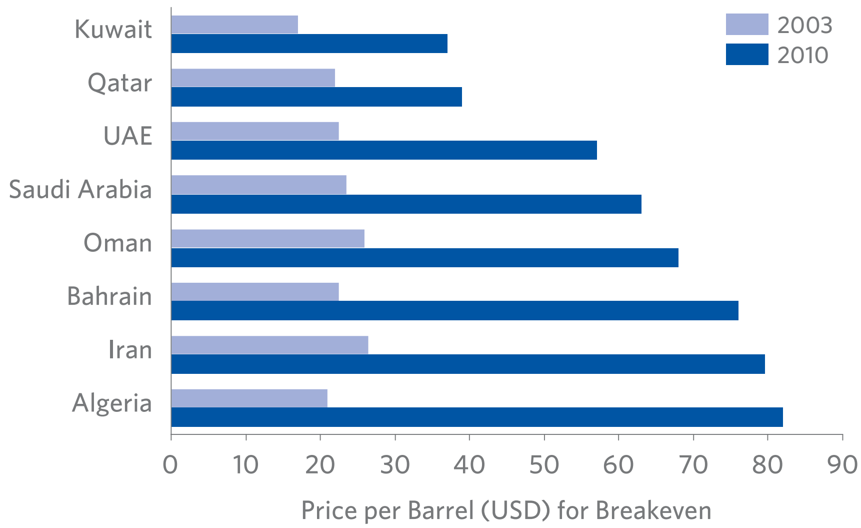
Yet despite this growth, the gap between the developed and the developing world is still vast. Today, China consumes roughly 6.2 barrels of oil per day for every 1,000 inhabitants. The U.S. consumes ten times as much. Even Poland, which has a substantially lower standard of living than the U.S. and is more energy efficient, consumes 15 barrels per day, the least of any developed country. Were China to reach Poland's level of consumption in 2030 it would need to add roughly 13 million barrels to its daily consumption. That number alone represents

FIGURE 2. OIL SUPPLY PROJECTION THROUGH 2030, ACCORDING TO IHS CERA[2]



[2]IHS CERA, 2011

FIGURE 3. BREAKEVEN COSTS OF PRODUCTION IN PETRO-STATES[3]



15% of the world's total supply today, and it does not account for the billions of other people across the developing world who are all striving to reach the same standard of living that the developed world currently enjoys.

To maintain and grow supply, additional new sources of oil must be constantly added. Fields currently under development will form a portion of future supply, but to meet global demand and contain prices, the world will need huge amounts of production from currently unidentified sources: discoveries of new oil fields, greater-than-anticipated production from identified sources, or entirely new sources, like breakthroughs that bring advanced biofuels to market. As shown in Figure 2, IHS Cambridge Energy Research Associates (IHS CERA), the world's pre-eminent energy research and consulting firm, estimates the size of this "oil gap" at up to 35 million barrels per day in 2030 (nearly 40% of today's total consumption). The consequences of leaving this gap unfilled would be severe, as resulting high oil prices would threaten the stability of the global economy. Academic research suggests that oil price increases were a factor in causing ten of the past eleven U.S. economic recessions.[4]

Even today, the tension between limited supply and growing demand has had major repercussions. Between 2002 and 2010, oil prices tripled to reach the highest prices ever seen, even when adjusting for inflation. At the same time, the so-called "breakeven cost of production"—the oil price at which the government of a petro-state is able to balance its budget—has increased dramatically, as shown in Figure 3. When oil prices fall below this limit, the government of such a petro-state is unable to pay for all of its budgeted expenditures, forcing a choice between spending cuts and greater debt.

[3]Brad Bourland, Chief Economist, Jadwa Investment Group, Riyadh
[4]Hamilton, James D. "Historical Oil Shocks". University of California, San Diego (February, 2011)

This growth is driven by two forces: greater costs of production as oil fields have matured, and a surge in the use of oil revenues for social subsidies. While these subsidies do not correspond to an actual increase in oil extraction costs, the reliance of these petro-states on oil and gas to provide upwards of 80% or 90% of government revenues means that, over the long term, prices below these levels will cause OPEC members to cut production in order to raise prices. Given the influence that these countries have on setting world oil prices through production quotas, and the importance of their political stability to the stability of the oil market, these breakeven costs represent a de-facto price floor below which oil prices cannot be sustained. This dynamic, in addition to growing demand, puts substantial upward pressure on prices.

While future oil prices are notoriously difficult to predict, experts see little hope for relief in the next few decades. Both the International Energy Agency (IEA) and the U.S. Department of Energy's Energy Information Administration (EIA) project a steady increase in price to near USD 200 per barrel in 2030, despite ongoing efforts to reduce dependence on oil through the use of more efficient engines, electric vehicles, and mass transit. Countries like the U.S. that are highly dependent on oil to fuel their economies will be seriously threatened by sustained high prices, which contribute to an enormous imbalance in trade and balance of payments, and cripple economic growth.

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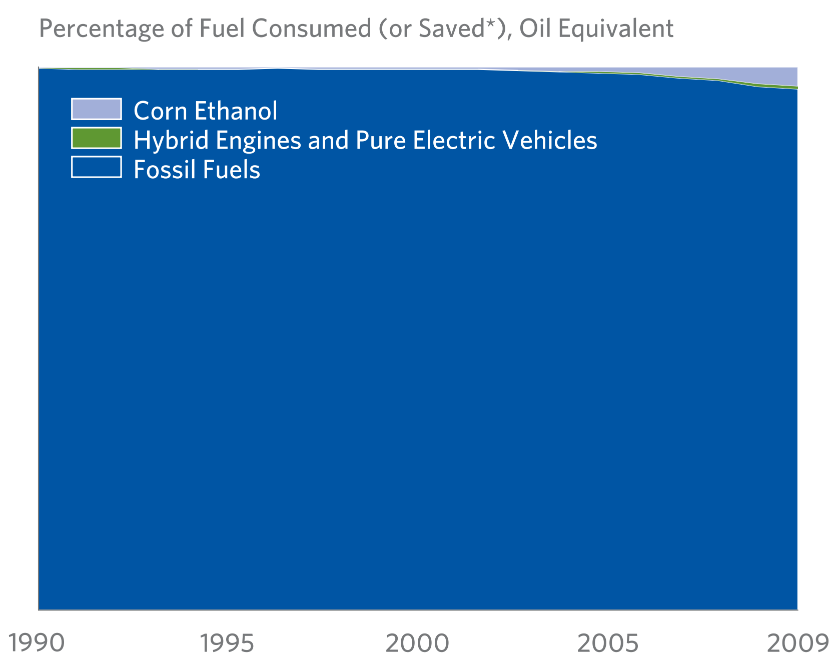
Current Trends Towards Filling the Gap

What, then, has been done to fill this coming oil gap?

As it turns out, aside from searching for new sources of oil in the ground or under water, very little. In the U.S., upwards of 95% of all transportation fuels are derived from oil, as shown in Figure 4. The remainder is made up almost exclusively by corn ethanol, which has lower energy content than petroleum-based fuels, can only be burned in low concentrations in traditional engines, and is incompatible with existing pipeline infrastructure.

To fill the oil gap and keep the global economy growing, we will

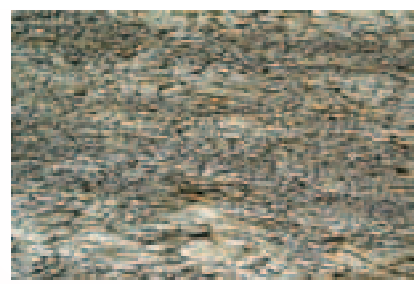
FIGURE 4. PENETRATION OF TRANSPORTATION FUEL TECHNOLOGIES IN THE U.S.[5]



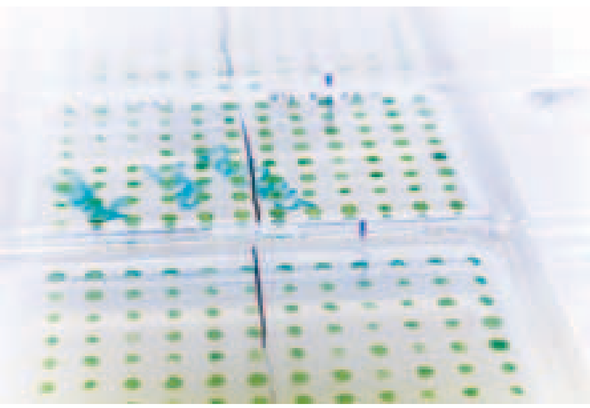
*In the case of hybrids or electric vehicles.

[5]U.S. Energy Information Agency, 2011; excludes the use of natural gas as a pipeline fuel

need all available sources of oil and all alternative fuels. While the search for viable new alternatives has gone on, oil companies have developed new technologies to produce resources that were untouchable until very recently. These technologies include rigs capable of drilling through miles of rock located nearly two miles beneath the ocean's surface, mining and processing equipment capable of producing oil from semi-solid tar sands, equipment capable of drilling horizontally, fracturing shale rock, and producing and processing the hydrocarbons contained within these "tight" formations, and soon, factories capable of synthesizing oil from natural gas on an enormous scale. Yet, alone, these resources will not be enough to fill the oil gap.



Technology Readiness and the Prospects for New Solutions



Every form of oil production and electricity generation that has ever been pioneered reached a state of "technology readiness" before being deployed at scale.

Achieving technology readiness takes years or even decades of work—and billions of dollars—and represents the most critical obstacle that a new technology must overcome to reach the market. Once this inflection point has been reached, the technology can be deployed at a meaningful scale in a relatively short amount of time—each of these oil technologies reached, or is projected to reach, roughly 1 million barrels per day of production within about 10 years.

In addition to the oil production technologies which have risen to prominence recently, many alternative electricity generation technologies, like wind power, conventional geothermal power, and hydropower are technologically ready. Similarly, first-generation biofuels—ethanol produced from sugarcane and corn starch, and biodiesel produced from rapeseeds and soy beans—are ready. By contrast, advanced biofuels, such as cellulosic fuels, bio-butanol, and

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algae-derived oil, while promising, are not yet technologically ready for large-scale deployment. Similarly, electricity generation from ocean tides and waves and "enhanced" geothermal systems, as well as utility-scale electricity storage, carbon capture and sequestration, and oil shale production using in situ heaters are not yet ready, though efforts are underway to develop each of these options.

To fill the oil gap, all transportation fuel technologies, especially those capable of directly displacing oil, must reach technology readiness. A conceptual breakdown of future fuel sources is shown in Figure 5. The right side of the circle includes the unconventional sources described in the previous section—liquids synthesized from natural gas, ultra deepwater oil, tar sands, and tight oil produced from shale formations—as well as other fossil fuel sources (e.g., compressed natural gas, liquids formed during natural gas extraction and processing, liquids synthesized from coal). The left side includes non-fossil fuel oil alternatives.

The non-fossil oil alternatives—crude replacements, efficiency gains, and fuel additives—are not all equally efficacious. While some of these technologies have already reached a state of readiness, many of the most promising options remain in the research and development stage. These technologies will take years to become viable, or may fail in the established oil-dominant marketplace if not given proper policy support.

FIGURE 5. FUTURE SOURCES OF TRANSPORTATION FUELS

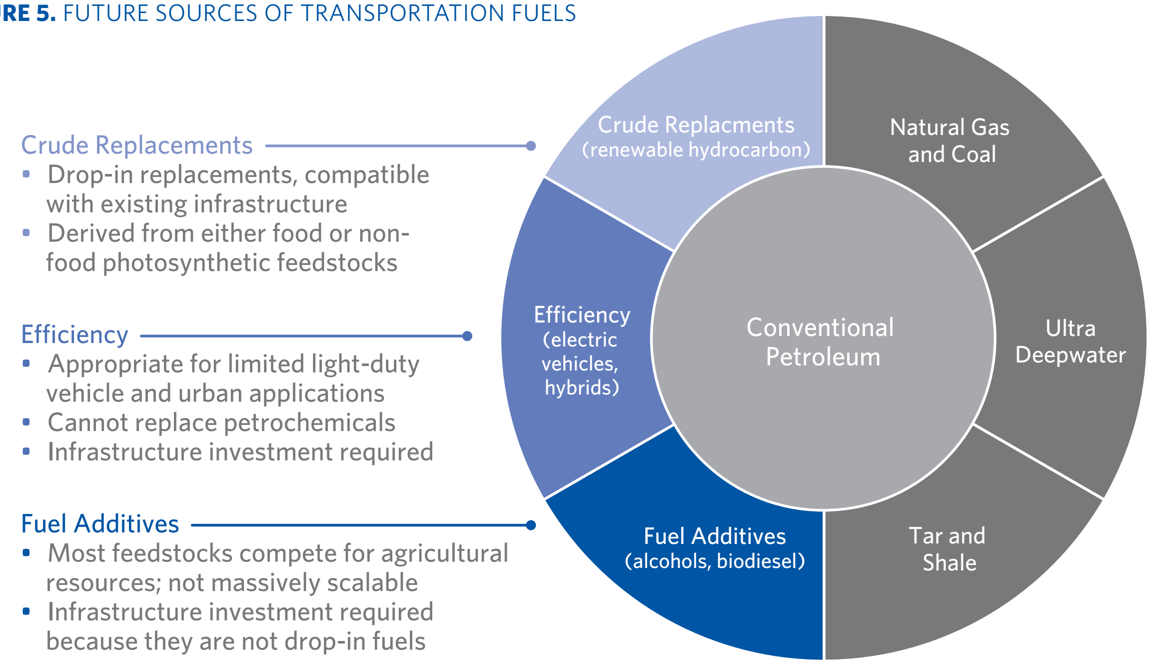
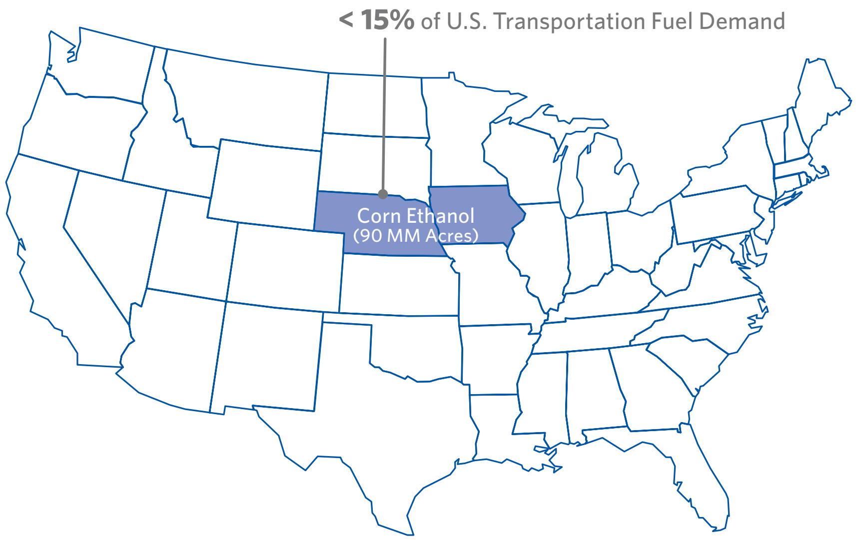


FIGURE 6. LAND REQUIRED TO OFFSET 15% OF U.S. TRANSPORTATION FUEL DEMAND WITH CORN ETHANOL[6]



Fuel additives are perhaps the most technologically ready set of crude alternatives. This category of liquids, which encompasses alcohols, including ethanol and butanol, and biodiesel, can be blended with petroleum-based fuels and used in existing vehicles, but cannot be burned in a pure form without engine and infrastructure modifications. While these fuels have been successfully scaled up to almost 5% of U.S. transportation energy, they face limitations to how much they can continue to grow. For example, as shown in Figure 6, replacing 15% of U.S. transportation fuel with corn ethanol would require all 90 million acres of U.S. corn production and then some, leaving none for food and animal feed.

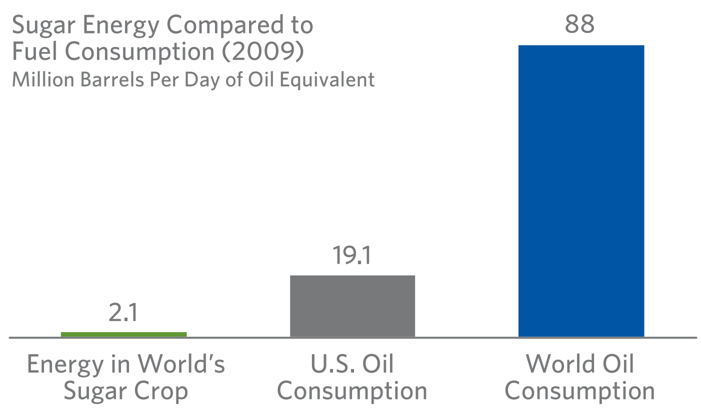
Energy efficiency technologies, similarly, are largely technologically ready. This category encompasses internal combustion engine technologies, such as direct injection, cylinder deactivation, and turbo-charging, as well as improved transmissions, weight reductions, hybrid-electric drivetrains, plug-in hybrids, and fully electric vehicles (EVs). These technologies can be highly effective, and recent legislation in the U.S. has directed annual increases in efficiency through 2025 for light trucks and passenger cars and, for the first time in history, additional efficiency standards that will apply to heavy-duty vehicles. While this trend is promising, there are limits to the impact of electrification and other efficiency gains, as well, including: limited resources and production capacity for lithium and rare earth elements, which are critical to making EV batteries, costs and range limitations of EVs, and the difficulty of finding continued opportunities for optimizing internal combustion engines.

The third category of oil alternatives—crude replacements—is potentially the most important, but is also the least technologically ready.

[6]California Air Resources Board, GREET model, 2009; Walter, Yang, "Corn stover removed without compromising soil quality," University of Nebraska-Lincoln

These fuels are completely compatible with existing infrastructure—meaning that they can be processed in oil refineries and burned in a pure form in conventional gasoline, diesel, and jet engines. This is a very important feature of "crude replacements" in terms of scale and economics, given the world's multi-trillion-dollar investment in the existing infrastructure for moving, refining, and using petroleum. Significant progress has been made over the past several years in moving closer to technology readiness, but the most ready of the technologies still face scale and cost constraints. Specifically, as shown in Figure 7, fuels produced from sugar are limited in scale by the amount of sugar that can be procured (which in practice amounts to approximately 2 million barrels per day of oil, if using only the sugar component of the cane and beet crops). The opportunity for sugar crops to meet greater demand will be enhanced when the cellulosic (i.e., non-sugar) component can also be used for producing hydrocarbons.

FIGURE 7. SCALE LIMITATION OF SUGAR-TO-FUEL PATHWAY[7]



Properly incentivized and supported, the most promising crude replacements can overcome these scale and cost constraints and significantly reduce U.S. dependence on foreign oil. However, there is an enormous amount of work that remains to be done to reach technology readiness.

Unfortunately, nearly seven-eighths of global clean energy investment goes to existing, technologically ready options, rather than to more innovative alternatives that could offer breakthrough solutions to the world's problems.[8] Much more effective leadership, in both the public and private sectors, will be needed to bring these promising technologies to fruition, fill the oil gap, and provide a secure source of fuels to meet the needs of a growing global population.

[7] U.S. Energy Information Agency, 2011; Food and Agriculture Organization of the United Nations, 2010; GMO Compass, 2010
[8] Victor, David G., and Kassia Yanosek. "The Crisis in Clean Energy." Foreign Affairs (July/August, 2011)

The 2020 Inflection Point, and What Must be Done

One defining characteristic of energy, whether transportation fuel technologies or electricity, is that transitions to new sources take time.

The enormous scale of energy demand, the intense competition for market share, the drive for lower costs, and the difficulty of engineering and constructing scalable, dependable equipment fit to the task means that one or more decades are required to progress from technology readiness to a meaningful level of market penetration.

The advent of civilian nuclear power, which was carried out in a remarkably short amount of time in energy terms, is a perfect example of how such a transition takes place. An illustration of the key milestones that took place is shown in Figure 8. Although fundamental research was being carried out throughout the 1930s, the key breakthrough that enabled the development of the technology occurred in 1942, when scientists at the University of Chicago created the first controlled nuclear chain reaction. At the same time, the U.S. government was embarking on the Manhattan Project. In less than three years, that project culminated in the detonation of

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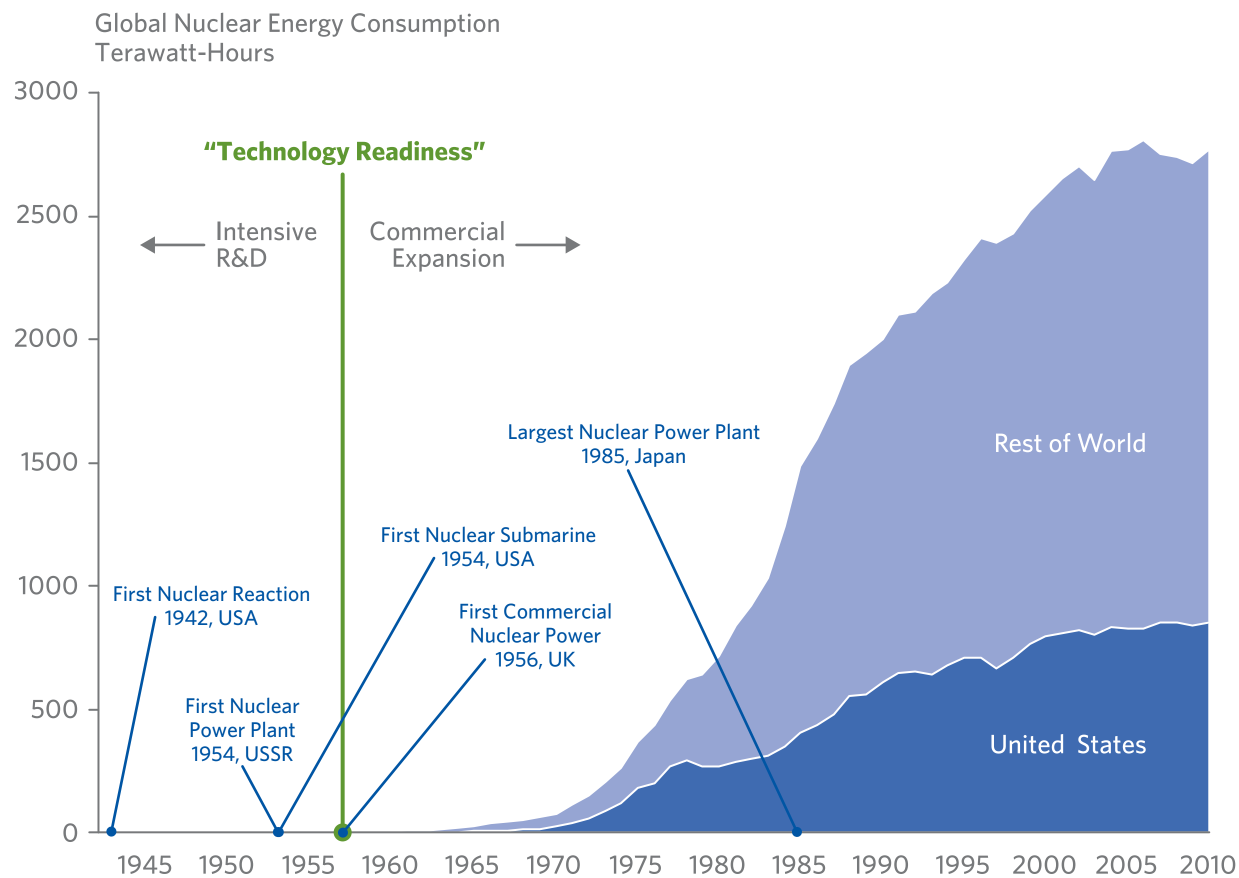
FIGURE 8. RESEARCH, DEVELOPMENT, AND DEPLOYMENT OF NUCLEAR POWER[9]



a test device in the New Mexico desert and the use of two bombs on Hiroshima and Nagasaki.

While the use of those bombs is controversial to this day, their development undoubtedly accelerated the development of nuclear electricity. By 1954, aided by stolen American research, the Soviet Union launched the world's first nuclear power plant to produce electricity for a grid. In the same year, the U.S. Navy commissioned the first nuclear-powered submarine—the same basic design would be used to create early commercial nuclear power plants. In 1956, the Calder Hall power station, the first commercial nuclear power plant in the world, commenced operations in the U.K. At that point, 14 years after the first man-made chain reaction, nuclear power had achieved technology readiness, and a period of massive deployment began. Yet it was not until 1977 that nuclear power made up 10% of the U.S.'s electricity supply—35 years after the technological break-through that launched the nuclear era.

[9]BP Statistical Review of World Energy, 2011; U.S. Energy Information Administration, 2011

If the world is to have a reasonable hope of bringing new fuel sources to scale by 2030 to help fill the oil gap, technology readiness must be achieved by 2020.

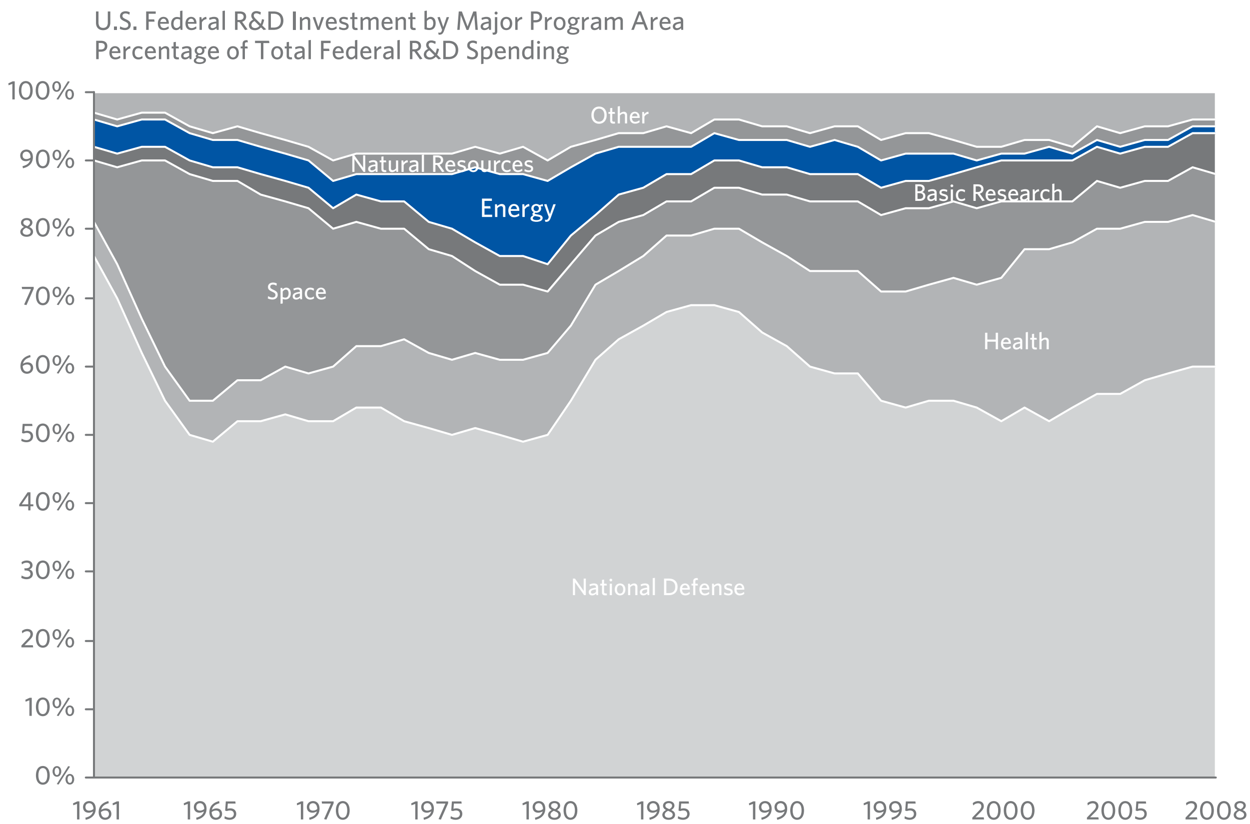
If the world is to have a reasonable hope of bringing new fuel sources to scale by 2030 to help fill the oil gap, technology readiness must be achieved by 2020. Doing so will require three elements:

- **Investment in R&D:** governments and the private sector must collectively accelerate the pace of technological development, with the goal of creating commercially viable technologies by 2020.
- **Stable and supportive government policies:** governments must maintain support for energy investment and accelerated regulatory clearance for decades, not election cycles.
- **Massive private sector capital deployment:** once a technology is ready, the private sector must invest billions of dollars in projects to bring the technology to a meaningful scale.

More than anything else, lack of investment in energy R&D explains why viable alternatives to petroleum have not yet materialized. Developing crude replacements is expensive, complex, and fundamentally different from the process of developing new fossil fuel extraction techniques.

As a result, there is no large industry that will shoulder the costs of this research alone. And while the U.S. government has provided some funding support to energy, the bulk of it has come through subsidies to ready technologies (e.g., corn ethanol) rather than through support of R&D for less mature, but promising, technologies.

FIGURE 9. FEDERAL ENERGY R&D SPENDING AS A PERCENTAGE OF TOTAL FEDERAL R&D[10]



As Figure 9 shows, federal spending on energy R&D has always been low, even in the context only of R&D expenditure—excluding all other uses of federal funds. While a substantial increase in investment was made in the 1970s in reaction to the oil shocks of that decade, political commitment to this level of spending gradually waned, and for the last decade and a half, the energy R&D budget has been less significant (in 2008, it was less than USD 4 billion out of roughly USD 2.9 trillion in total federal spending, or roughly 0.1%). While some incremental investments have been made as of late, the change has not been enough: according to a report released by the Bipartisan Policy Center and the American Energy Innovation Council, 2010 spending on energy R&D was USD 5.1 billion, or less than 0.2% of total federal spending. An illustration of this analysis is shown in Figure 10.

The U.S.'s oil dependence cannot be addressed without the federal government playing a major role in the development of alternatives, but for that to happen, the government's priorities must fundamentally change. There is precedent for this: the federal government, and in particular the Department of Defense, was critical to the creation of nuclear power, and was an influential early adopter of oil as a transportation fuel.

[10]Pacific Northwest National Laboratory, 2008

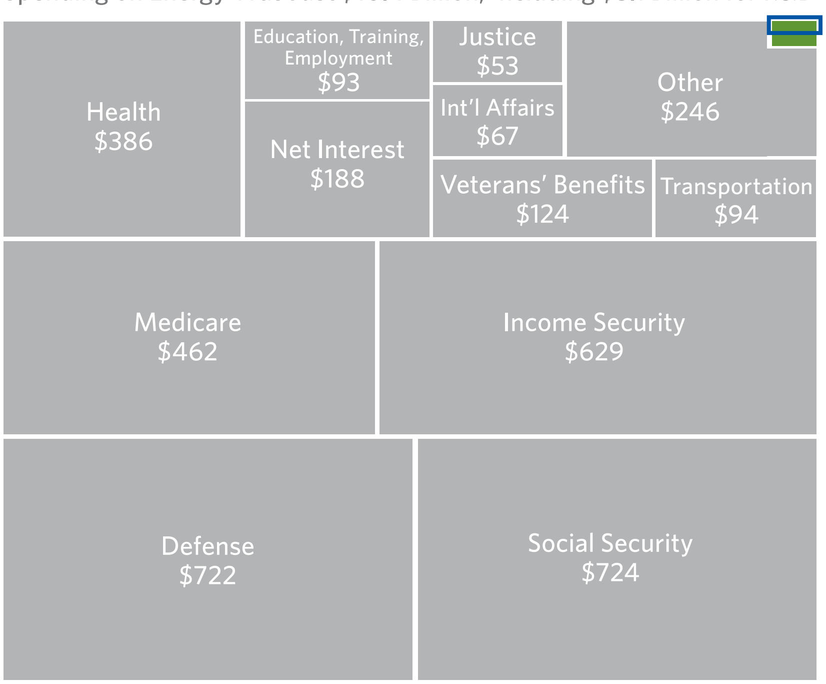
The U.S.'s oil dependence cannot be addressed without the federal government playing a major role in the development of alternatives, but for that to happen, the government's priorities must fundamentally change.

Outside of energy, the military has partnered with the private sector to create numerous technologies with important civilian uses, including radar, the Internet, and GPS. Today, the military is once again emerging as a leading force, with the Navy in particular putting emphasis on crude alternatives.

While this development provides some hope, much more must be done—and soon. The economic, environmental, and national security implications of oil use affect the U.S. as much as any nation on Earth, and the drastic changes underway in the oil market will not be addressed without sustained commitment. If the U.S. is serious about changing its trajectory, it will need: government leaders who prioritize our long-term national energy security over cries for short-term deficit reductions; military leaders who embrace this challenge as a national security imperative; business leaders who see the potential for growth and will work with the government to confront the technology challenges; and technology leaders who will devote themselves to bringing promising technologies to fruition.

FIGURE 10. 2010 U.S. FEDERAL BUDGET ($3.60 TRILLION TOTAL)[11]

Spending on Energy Was Just $10.4 Billion, Including $5.1 Billion for R&D



[11]American Energy Innovation Council/Bipartisan Policy Center, 2010; budget does not include tax credits because they are not technically a form of spending; spending on energy, including tax credits, is approximately $25 billion (Pew Subsidyscope, 2010)

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2020InflectionPoint.org

Info@2020InflectionPoint.org