THE LANDSCAPE OF ENERGY

post carbon institute

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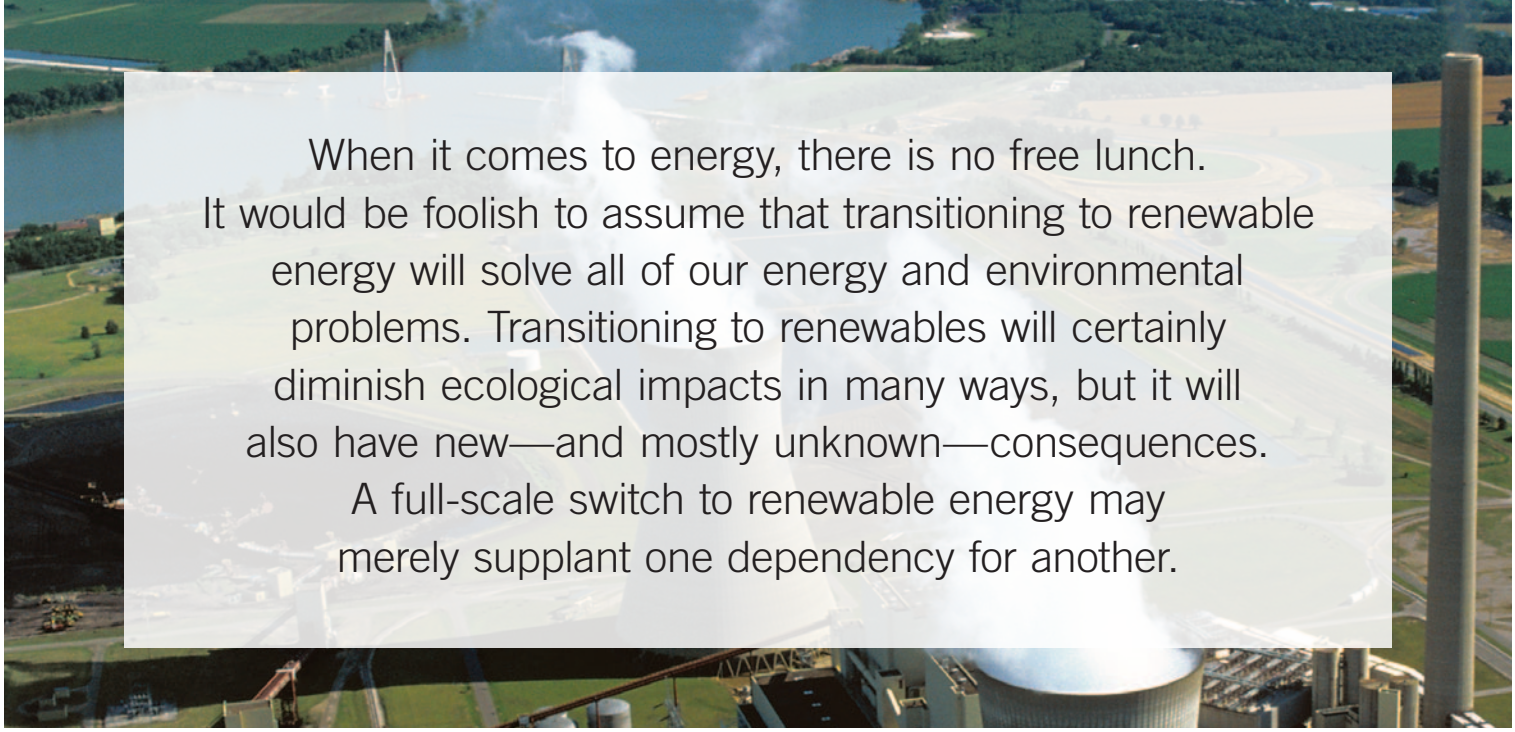


When it comes to energy, there is no free lunch. It would be foolish to assume that transitioning to renewable energy will solve all of our energy and environmental problems. Transitioning to renewables will certainly diminish ecological impacts in many ways, but it will also have new—and mostly unknown—consequences. A full-scale switch to renewable energy may merely supplant one dependency for another.

INTRODUCTION, by David Murphy

David Murphy is an assistant professor within the Department of Geography and an associate of the Institute for the Study of the Environment, Sustainability, and Energy at Northern Illinois University. His research focuses on the role of energy in economic growth, with a specific focus on net energy.

The next decades will witness a global battle between geologic depletion and technological advancement, as modern society demands ever-increasing quantities of energy from an aging fossil fuel supply and a nascent renewable energy sector.

The fossil fuel industry is already straining to deliver increasing quantities of energy from geologic reservoirs that are old and depleting quickly, or from new ones that are more energy intensive and expensive to develop. Meanwhile, companies and governments alike are rushing to develop renewable energy technologies that can compete on a cost basis with fossil fuels. Renewable energy optimists believe that once these price barriers are defeated (through technological advancement or market manipulation), both our energy concerns and the environmental problems associated with the present-day energy industry will be vastly reduced.

The outcome of this battle can only be analyzed retrospectively, but as we search for oil under the Arctic ice cap and coat the deserts with solar panels, we can anticipate that it will extend across all landscapes thought to be energetically bountiful.

One thing is clear: When it comes to energy, there is no free lunch. It would be foolish to assume that transitioning to renewable energy will solve all of our energy and environmental problems. Transitioning to renewables will certainly diminish ecological impacts in many ways, but it will also have new—and mostly unknown—consequences. For example, both solar and battery technology in their current iterations depend on rare metals and other natural resources that are unevenly distributed around the world. A full-scale switch to renewable energy may merely supplant one dependency for another.

It would be wise to approach our energy future with two related thoughts in mind: first, the precautionary principle, and second, the law of unintended consequences. Using that perspective, this section of the book reviews the major energy resources and their transportation methods. We consider the current status of each resource as well as any other major concerns, environmental and otherwise, that may exist.

Of course the energy economy is constantly in flux; the following overview of the energy landscape can necessarily provide only a snapshot in time. It is intended to offer the reader a foundation of understanding about the current energy mix, building on the "energy literacy" series in part one.

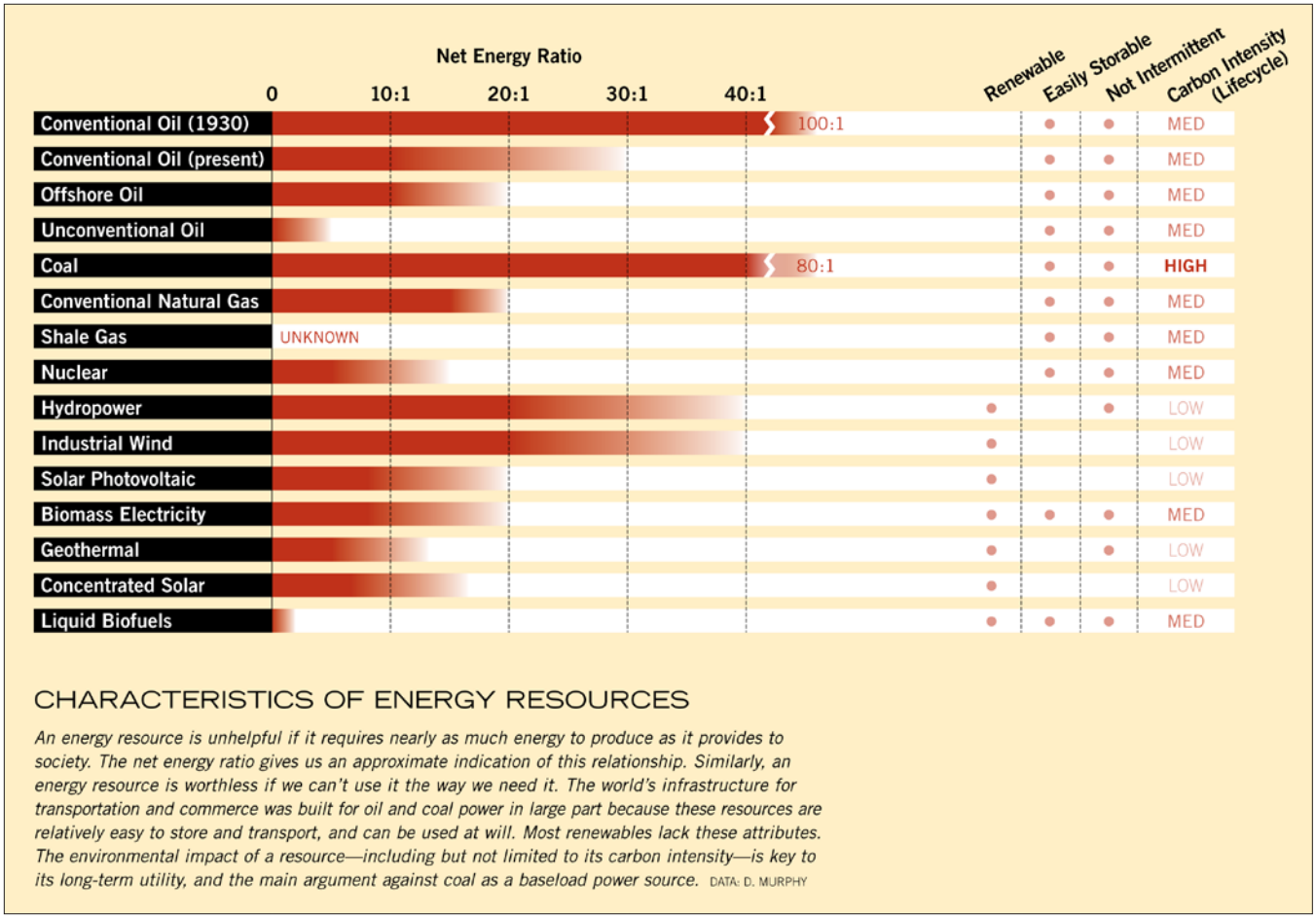
THE LANDSCAPE OF ENERGY

Our global system of energy production and consumption faces systemic challenges that have been centuries in the making—and that no one technology or fantastic new resource will solve. As the figures on the following pages illustrate, we face major obstacles to continuing our recent energy bonanza through the twenty-first century and beyond.

The global economy requires a massive, uninterrupted flow of energy every single day, the vast majority in the form of fossil fuels. These nonrenewable energy resources are constantly depleting, so we must continually find and successfully exploit new sources so that tomorrow we can meet the same demand as we did today—plus additional resources for the world's growing population and economies.

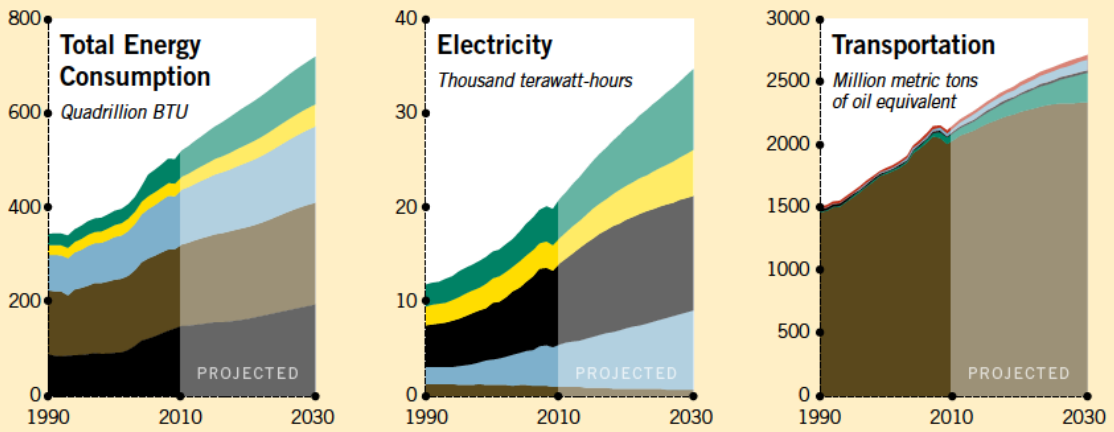
But the transition to new sources will be far from seamless: The physical infrastructure of modern society is designed to run primarily on cheap, powerful conventional fossil fuels. Unconventional fossil fuels come with greater economic and environmental costs, significantly reducing their energy benefit, while renewables fall short at matching many of the characteristics we so value in fossil fuels.

An analysis of the available energy resources shows that there are no easy answers.



CHARACTERISTICS OF ENERGY RESOURCES

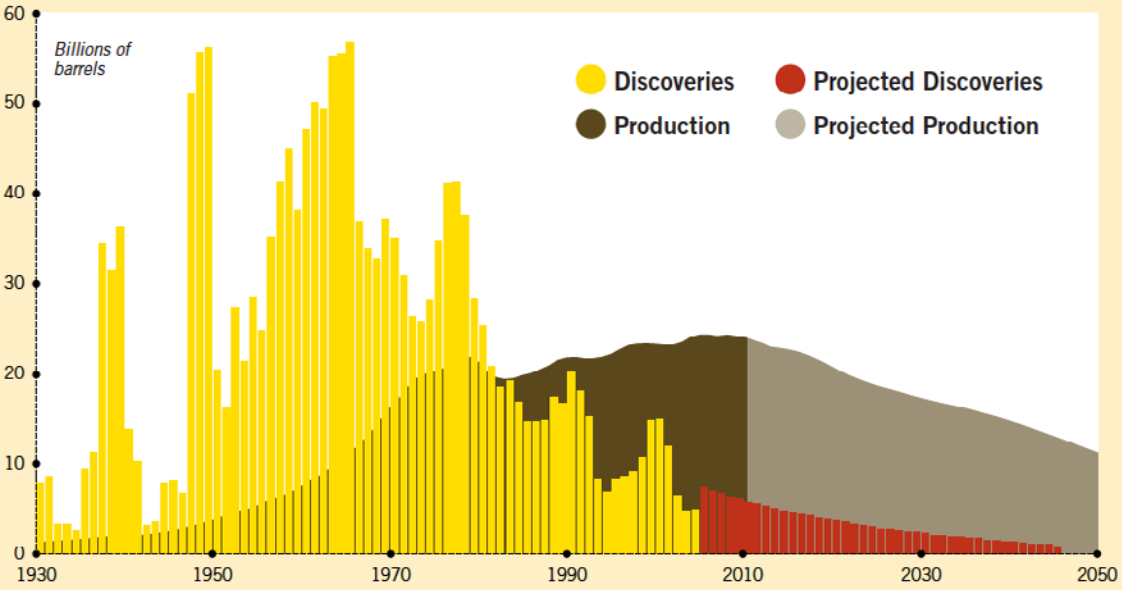
An energy resource is unhelpful if it requires nearly as much energy to produce as it provides to society. The net energy ratio gives us an approximate indication of this relationship. Similarly, an energy resource is worthless if we can't use it the way we need it. The world's infrastructure for transportation and commerce was built for oil and coal power in large part because these resources are relatively easy to store and transport, and can be used at will. Most renewables lack these attributes. The environmental impact of a resource—including but not limited to its carbon intensity—is key to its long-term utility, and the main argument against coal as a baseload power source. DATA: D. MURPHY



BUSINESS-AS-USUAL ASSUMPTIONS

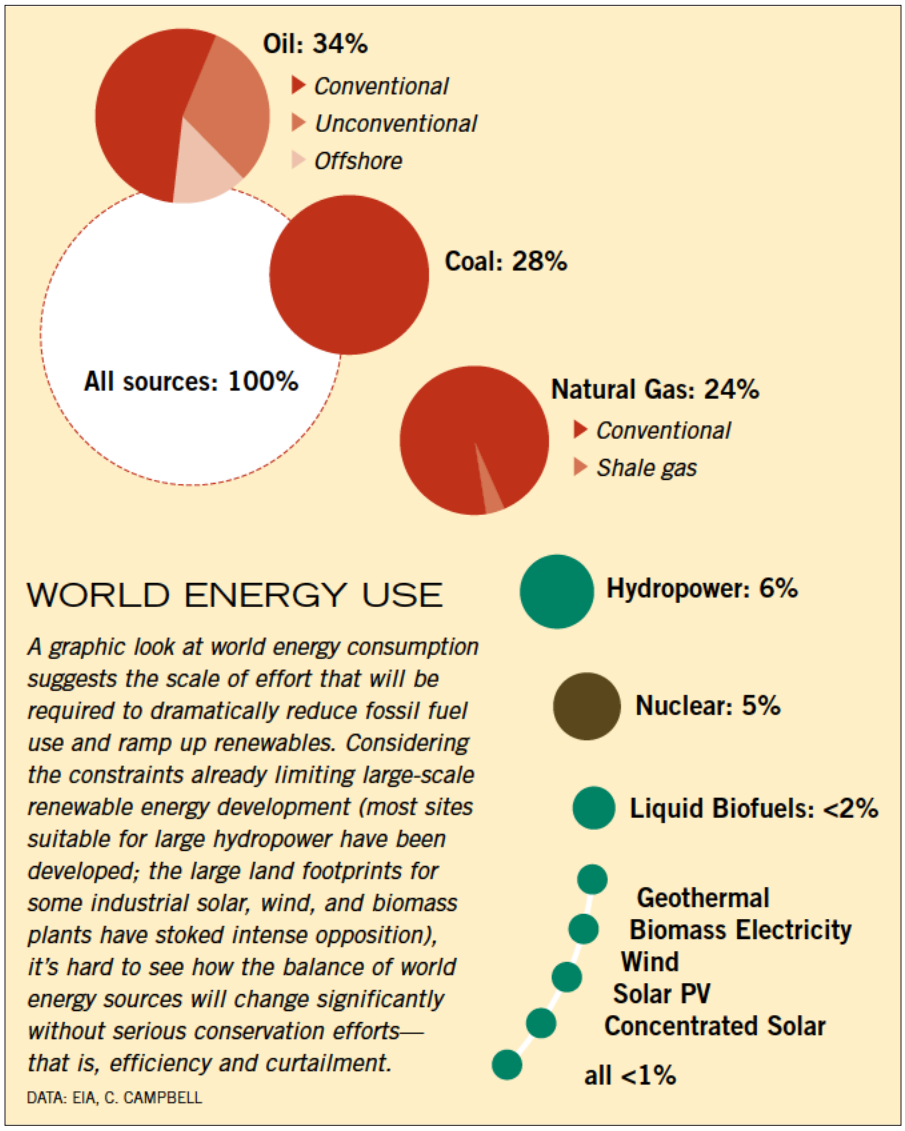
Governments and the oil industry generally assume that market demand and improving technologies will continue to drive increased fossil fuel production. The above forecasts are based on business-as-usual economic growth models and assume that the resource will be exploitable given the right market conditions. Unfortunately, such predictions tend to ignore constraints that cannot necessarily be solved by higher energy prices (e.g., lack of remaining sites suitable for large-scale hydropower, or the long-term nuclear waste problem). Worse yet, even in these rosy scenarios renewable energy is expected to play only a minor role in total energy consumption, in electricity generation, and especially in transportation. DATA: EIA, BP

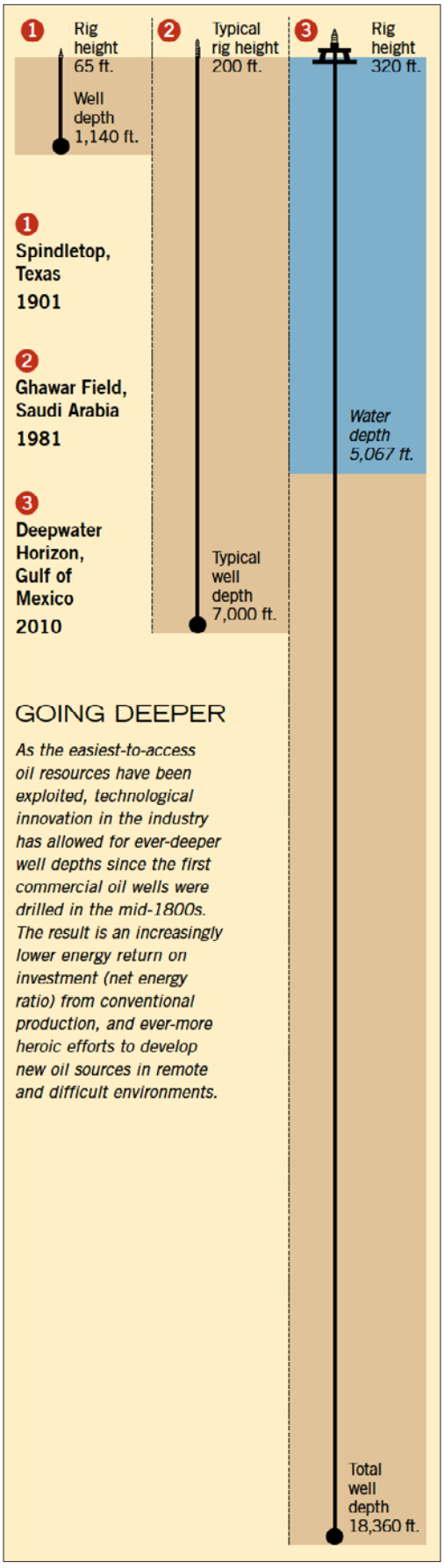
- Coal
- Petroleum
- Natural gas
- Nuclear
- Hydro/Renewables
- Electricity



THE REALITIES OF DECLINE: CONVENTIONAL OIL

Discoveries of conventional oil peaked in the 1960s and have since slowed to a trickle. Thus it is widely expected that production of conventional oil will soon enter terminal decline—indeed, production has essentially leveled off since 2005. Discoveries of unconventional oil (such as tar sands and shale oil) are still on the rise, but they too will eventually hit their peaks, as will coal and natural gas. DATA: ASPO, EXXONMOBIL


Oil: 34%
Conventional
Unconventional
Offshore
Coal: 28%
All sources: 100%
Natural Gas: 24%
Conventional
Shale gas
WORLD ENERGY USE
A graphic look at world energy consumption suggests the scale of effort that will be required to dramatically reduce fossil fuel use and ramp up renewables. Considering the constraints already limiting large-scale renewable energy development (most sites suitable for large hydropower have been developed; the large land footprints for some industrial solar, wind, and biomass plants have stoked intense opposition), it's hard to see how the balance of world energy sources will change significantly without serious conservation efforts—that is, efficiency and curtailment.
DATA: EIA, C. CAMPBELL
Hydropower: 6%
Nuclear: 5%
Liquid Biofuels: <2%
Geothermal
Biomass Electricity
Wind
Solar PV
Concentrated Solar
all <1%


1
Rig height 65 ft.
Well depth 1,140 ft.
2
Typical rig height 200 ft.
3
Rig height 320 ft.
1
Spindletop, Texas
1901
2
Ghawar Field, Saudi Arabia
1981
3
Deepwater Horizon, Gulf of Mexico
2010
Water depth 5,067 ft.
Typical well depth 7,000 ft.
Total well depth 18,360 ft.
GOING DEEPER
As the easiest-to-access oil resources have been exploited, technological innovation in the industry has allowed for ever-deeper well depths since the first commercial oil wells were drilled in the mid-1800s. The result is an increasingly lower energy return on investment (net energy ratio) from conventional production, and ever-more heroic efforts to develop new oil sources in remote and difficult environments.

CONVENTIONAL OIL

Oil is the lubricant of modern civilization, and a major driver of the global eco-social crisis, manifest in unraveling ecosystems and loss of traditional cultures. By fueling an insatiable industrial-growth economy, oil's aggregate damage to ecological, cultural, and political integrity is incalculable.

Inexpensive and abundant supplies of oil and other fossil fuels have been used to support virtually every aspect of economic life in the overdeveloped countries. Unparalleled as a transport fuel, more than 30 billion barrels of oil are consumed globally every year. The United States uses roughly 7 billion barrels annually, or 22 percent of world oil consumption. Oil is easily stored and transported and is extremely energy dense. A single liter of oil has an amount of energy equivalent to a human performing hard labor for hundreds of hours.

Oil is the residue of ancient marine plankton transformed by heat and pressure over millions of years. After an underground reservoir is discovered, drilling and pumping bring the oil to the surface where it is sent to refineries. At refineries, which are among the worst of all industrial polluters, the crude is processed into heating oil, kerosene, aviation fuel, diesel, gasoline, etc. Other products derived from oil range from cosmetics to plastics to asphalt. We even "eat" oil: The energy inputs that undergird industrial agriculture, including synthetic pesticides, largely come from oil. By some estimates, our food system uses more than seven calories of energy for every calorie of food consumed.

Finding, extracting, refining, and burning oil produces enormous land, water, and air pollution, including greenhouse gas emissions. Conventional oil field development creates massive networks of roads and pipelines that destroy and fragment wildlife habitat, and a vast global distribution network essentially guarantees ongoing oil spills, from leaking car motors and storage tanks to occasional Exxon Valdez– and Deepwater Horizon–scale disasters.

The oil age began in the 1850s when wells were drilled in Canada and the United States, launching a century and a half of explosive economic and population growth. The first oil to be found and produced was, naturally, the easiest to extract and therefore the cheapest; it also happened to be of superior quality, generally offering a net energy ratio of well over 25:1. Worldwide discoveries of this "conventional" oil peaked in the 1960s, however, and worldwide production has flattened over the last decade, despite record-high prices. It is widely accepted that the age of "easy" oil is coming to a close. Society is turning toward deepwater offshore oil, tar sands, oil shales, and other more challenging resources to meet ever-growing global demand for oil.

Key Limiting Factor: *Discoveries peaked in the 1960s; production in terminal decline.*

Net Energy Ratio:

OFFSHORE OIL

Offshore drilling, particularly in deepwater, is one of the frontiers for oil exploration in what security expert Michael Klare calls "the era of extreme energy." The deeper the water and the farther from land, the more complex the production challenges, leading to increased risk of catastrophic accidents.

Significant offshore oil development has occurred in many parts of the world including the Gulf of Mexico, along the coasts of Newfoundland and Labrador in Canada, coastal Mexico, the Gulf of Guinea off the coast of West Africa, the North Atlantic, and coastal Brazil. Offshore drilling has been going on for more than a century, with the first saltwater operations organized in 1896 off the coast of Santa Barbara, California. Offshore platforms are responsible for roughly 22 percent of oil production and 12 percent of natural gas production in the United States. As terrestrial reserves are depleted and drilling technology improves, offshore production is expected to increase.

In shallow water, offshore drill rigs are often anchored to the sea floor. In deeper water, floating platforms fixed by chains to the sea floor allow drilling in water depths of 10,000 feet or more. Drilling platforms are expensive to construct and the additional distance of drill pipe that must pass through the water column between the sea bottom and drill platform adds to the difficulty and cost of bringing oil to the surface. Logistical expenditures associated with getting supplies and highly trained crews to and from platforms also add greatly to the cost, in both money and energy, and are one of the reasons that deepwater drilling inherently has a lower net energy ratio (energy return on energy investment) than conventional oil production on land.

Offshore drilling magnifies the risk from accidents because ocean currents can easily distribute any spilled oil great distances. The 2010 Deepwater Horizon explosion in the Gulf of Mexico caused an estimated 4.9 million barrels of oil to leak before the well was capped. As offshore oil production expands into Arctic waters, the ecological risks associated with an oil spill are magnified because cold temperatures hinder the biological breakdown of oil. Moreover, Arctic rescue, repair, and cleanup operations would be severely complicated by the remote distances and harsh weather conditions. Beyond the environmental and human risks, offshore development has aesthetic impacts. Every additional drilling platform industrializes the ocean, compromises beauty, and degrades the wilderness character of the marine environment.

Key Limiting Factor: *Production challenged by extreme environments and significant technological complexity.*

Net Energy Ratio:

UNCONVENTIONAL OIL

Unconventional liquid fuels are more polluting than conventional oil. Wholesale development of tar sands, shale oil, kerogen, and other unconventional oil resources will likely doom humanity's attempt to rein in greenhouse gas emissions and almost certainly tip the world toward climate chaos.

The liquid fuels that can be produced from tar sands, oil shale (or kerogen), shale oil formations, and coal are generally lumped under the term "unconventional oil." Coal-to-liquids technology has been known for decades—Nazi Germany used it during World War II—but has never been economically competitive with conventional crude oil and is not projected to grow into a major energy source. Tar sands and shale oil, however, have received significant attention and investment in recent years, with promoters claiming that these sources could soon make North America oil-independent.

Tar sands production is already commercially viable (with oil prices over about $60 per barrel) and has increased rapidly over the past decade. Tar sands contain a viscous substance called "bitumen" (similar to very heavy crude oil) tied up in sand or clay. The greatest known reserves are in Alberta, Canada. Typically, tar sands are strip-mined and the bitumen cooked out. Natural gas has been the primary energy source to do this, making the greenhouse gas footprint of tar sands oil far larger than that of conventional oil. The process also causes deforestation and leaves toxic lakes of wastewater slurry. Some of the environmental impacts associated with tar sands may decrease in the future as the industry adopts in situ extraction methods that are claimed to make the environmental impacts comparable to conventional oil operations.

Oil shales are widely distributed around the world but the largest deposits are in the western United States. Roughly two-thirds of known oil shales, containing an estimated 1.7 trillion barrels of oil equivalent, are found in Wyoming, Utah, and Colorado. In oil shales, the hydrocarbons are in the form of kerogen, a precursor to oil that has not been heated long enough by geological processes to become oil or natural gas. Oil shales can be converted to oil and natural gas through a variety of techniques, most of which require heating the rock above 600°F (315°C).

Shale oil, also known as "tight oil," is high-quality light crude that is trapped in rock formations of low permeability. The horizontal drilling and hydraulic fracturing ("fracking") techniques used for shale gas production have recently been successfully applied to shale oil production, primarily in North Dakota and Texas. Costs are high and from early data it appears that, like shale gas wells, shale oil wells may have fairly low lifetime productivity.

Some estimates put the total resource in tar sands, oil shales, and shale oil at 6 trillion barrels, more than known conventional oil reserves. But extracting oil from these sources has proven to be much more energy-intensive and damaging than conventional oil production, and poses a grave threat to both local ecosystems and the global climate. The enormous technical complications of unconventional oil suggest that it will be extremely challenging to ramp up their production to fully replace declining conventional oil resources at the scale and rate needed.

Key Limiting Factor: *Significant energy, water, and infrastructure investments required.*

Net Energy Ratio:

NATURAL GAS

The "clean" fossil fuel, natural gas is often mistakenly thought to have very little environmental impact. But newer extraction methods and the sheer quantity of natural gas consumed make it one of the largest greenhouse gas contributors globally.

Oil's sibling is natural gas. Methane, the primary constituent of natural gas, is formed by the breakdown of organic material. In landfills, the rapid breakdown of organic material in the absence of oxygen creates a mix of gases that includes methane; under the Earth's crust the breakdown of prehistoric plankton forms both oil and natural gas. To form natural gas, the plankton is simply "cooked" at higher temperatures and pressures for longer periods of time than for oil, breaking the molecules into shorter chains of carbon atoms. But since the pressure and temperature can vary even within one hydrocarbon reservoir, oil and natural gas are often found together.

Global natural gas production equals 3,139 billion cubic meters annually, which is the energetic equivalent of 21 billion barrels of oil per year—roughly two-thirds the energy content of all the oil produced in the world. Global proved reserves of conventional natural gas are distributed widely, with the largest shares belonging to Russia (24 percent), Iran (16 percent), and Qatar (14 percent). The United States is currently the world's top natural gas producer, followed by Russia.

Natural gas is a highly coveted resource; it can have a high energy density (when pressurized into a liquid form), and it produces fewer greenhouse gas emissions at the burner tip than oil and coal. While natural gas is traded globally, its transport by sea in the form of liquefied natural gas (LNG) requires significant specialized infrastructure, making it more of a regional resource compared to oil. In the United States, natural gas is used prominently in the electricity sector to meet peak demand, as well as in a variety of functions in the industrial and manufacturing sectors. Natural gas also serves as the main heating and cooking fuel for much of the United States and world.

Conventional natural gas has the lowest greenhouse gas emissions per unit of energy of all the fossil fuels, but since it is used in such high quantities it accounts for over 20 percent of U.S. carbon dioxide emissions. Hydraulic fracturing (or "fracking") is now being used to produce harder-to-access shale gas deposits, and this may increase considerably the greenhouse gases per unit of energy from natural gas. Recent studies suggest that this increase may nullify any potential savings in greenhouse gas emissions from burning natural gas instead of oil or coal. Some climate and energy experts argue, however, that with strong regulation of the industry, including standards on preventing unburned methane leakage systemwide, significant greenhouse gas reductions can be achieved from burning natural gas rather than coal.

Key Limiting Factor: *Largely a regional fuel because of overseas transport complications.*

Net Energy Ratio:

SHALE GAS

Whether the current boom in hydraulic fracturing ("fracking") for shale gas is a short-lived bubble or a natural gas revolution, it threatens to increase pollution, destroy habitat, and keep America hooked on a "bridge fuel" to nowhere.

Fracking fluid is a mixture of chemicals, water, and sand that is injected under extreme pressure into a shale formation, opening cracks in the shale that release the natural gas trapped in the rock. Shale gas deposits are widespread in North America, Europe, Asia, and Australia. In the United States, the Marcellus Shale running from New York to West Virginia is the epicenter of the shale gas rush. The Barnett Shale of Texas, the Hayesville Shale in Louisiana, and the Fayetteville Shale of Arkansas are other important U.S. shale gas deposits. Many landowners and rural communities see shale gas development as an economic windfall.

U.S. conventional natural gas production peaked in 2001 and was thought to be in terminal decline before the fracking boom, which has reversed the production trend and prompted the U.S. Energy Information Administration to increase its estimate of recoverable domestic natural gas reserves. In 2009 shale gas provided 14 percent of U.S. natural gas supplies and is officially projected to grow to 46 percent by 2035. But some energy experts think that is unlikely because of high per-well costs and steep decline rates in shale gas wells.

As with conventional gas production, shale gas development entails clearing land for drill pads, access roads, and pipelines. But unlike conventional gas production, fracking consumes copious quantities of water—up to several million gallons per well—which may lead to intense competition for water in more arid parts of the country. Furthermore, the drilling fluid and wastewater that remain after fracking are full of largely undisclosed chemicals, some toxic, that may contaminate groundwater if spilled or leached into nearby streams.

While natural gas has been viewed as the least-polluting fossil fuel, analyses of the life-cycle greenhouse gas emissions of shale gas production by some scientists have suggested that it is not much better than coal power, largely due to increased methane release during drilling and transmission. If confirmed, this undermines the idea that shale gas is a less polluting "transition fuel" toward renewables.

Key Limiting Factor: *Young sector with uncertainties about long-term productivity.*

Net Energy Ratio:

UNKNOWN

COAL

It launched the Industrial Revolution, birthed the modern energy economy, and put civilization on a trajectory toward hypercomplexity and exponential growth. And now that remarkable rock that burns is helping cook the planet.

Coal is the fossilized remains of ancient plants that accumulated on the bottom of shallow water bodies before being buried by sediment during the Carboniferous and Permian periods some 363–245 million years ago. There are four basic kinds of coal, which vary in their energy density due mainly to carbon content: Anthracite has the highest energy content, followed by bituminous, subbituminous, and lastly lignite (also called "brown coal").

Large coal deposits are located in the United States, Russia, China, and Australia. Globally, coal use is increasing rapidly, particularly in China, which burns roughly half of the world's annual coal production. Consequently, China has become the world's leading emitter of greenhouse gas pollution. The United States, sometimes called the "Saudi Arabia of coal," has roughly 29 percent of the world's coal reserves, which are used to provide nearly half of U.S. electricity generation. There are more than 600 coal-fired electricity generating facilities in the United States, with dozens of new ones either under construction or seeking permits. Clean energy activists have successfully blocked more than a hundred proposed coal plants in recent years, and low natural gas prices are leading utilities to close some older, heavily polluting coal plants or convert them to natural gas.

Coal is relatively easy to mine, transport, and store and is perceived to be a cheap source of energy. It is very expensive, however, if the associated ecological and public health costs are considered. A 2011 study published in the *Annals of the New York Academy of Sciences* attempted a full life-cycle accounting of coal's public health and environmental costs; it estimated that these "externalities" may exceed $500 billion annually in the United States alone. Coal combustion can also release large quantities of toxins including mercury, lead, arsenic, and sulfur dioxide. Particulates released by coal burning are also a major pollutant and are blamed for tens of thousands of heart attacks and premature deaths in the United States each year.

Globally, coal burning is responsible for more than 40 percent of human-caused carbon dioxide emissions, and thus is a key factor in climate change. Coal mining, processing, and burning also produce vast amounts of liquid and solid pollution including coal combustion ash, which has caused contamination in dozens of states according to EPA and conservation group studies.

Recent efforts have sought to clean up coal's image with promises of carbon capture and storage (CCS) and smokestack scrubbers. But there are serious doubts about the scalability of CCS technology, and both sequestration and scrubbers require additional energy—meaning yet more coal must be burned to generate the equivalent energy delivered to consumers.

Key Limiting Factor: *Worst polluter of the fossil fuels.*

Net Energy Ratio:

NUCLEAR

Nuclear plants can generate large quantities of relatively dependable baseload electricity but are tremendously costly to build, produce dangerous radioactive waste, and present an attractive target for terrorism. Other options cost less and produce no deadly long-lived waste, for which there still is no permanent storage option in the United States.

There are more than 400 nuclear power plants currently operating in 31 countries around the world. Roughly 13–14 percent of the world's electricity comes from nuclear power. The United States produces the most nuclear energy of any country, although this accounts for only 19 percent of its electricity. France, by comparison, generates about half as much power from nuclear energy, but that amount represents almost 80 percent of its electricity production, the highest proportion in any nation.

Proponents argue that nuclear power is a safe, carbon-free source of power, and that it presents a green alternative to dirty, climate-killing coal. This claim does not hold up well to critical scrutiny. Although nuclear plants do not emit carbon dioxide while heating water to run a steam turbine (as coal-burning power plants do), life-cycle analysis of nuclear power shows that the entire process emits significant greenhouse gases. Deforestation and mining to procure uranium, nuclear plant construction with massive amounts of steel and concrete, and decommissioning and waste storage responsibilities that stretch thousands of years into the future all are significant greenhouse gas contributors.

High-profile accidents including the Chernobyl, Three Mile Island, and Fukushima Daiichi reactor meltdowns have periodically focused world attention on the potential for catastrophic breakdown of these highly complex systems. While major accidents are rare, "near misses" occur more frequently, and small releases of radioactivity are common. After many decades of trying to solve the waste disposal problem, the United States still has no permanent repository for high-level nuclear waste. Moreover, nuclear plants are an obvious target for terrorists, and a civilian nuclear industry can be used by rogue nations to develop nuclear weapons capability. Finally, a key objection to nuclear power is its tremendous cost: Without government support including loan guarantees and insurance underwriting, private capital markets in the United States would not finance new nuclear plant construction.

Key Limiting Factors: *No good solution yet available for extremely long-lived radioactive wastes; not economically viable without government underwriting.*

Net Energy Ratio:

HYDROPOWER

Humans have long harnessed the kinetic energy of falling water—but it was the development of modern construction methods that allowed for the rise of megadams around the globe. Large-scale hydropower is lauded as a greenhouse gas-free energy source, but it effectively kills wild rivers, dramatically altering ecosystem structure and function to generate electricity.

Like windpower, hydropower has a long history of use around the world. Ancient societies used watermills for grinding grain and other mechanical needs. Hydropower is now the largest and lowest-cost source of renewable energy in the world, with some 777 gigawatts of installed capacity. China's Three Gorges Dam is the single largest electricity-generating facility in the world, producing 20 gigawatts of power—more than 20 times the size of the average coal power plant.

The first hydroelectric dams were installed in the United States in the late 1800s; today hydropower accounts for 6 percent of all U.S. electricity generation and 60 percent of the electricity production from all renewable resources. Hydropower is considered one of the least-polluting energy sources because of its low greenhouse gas emissions, but it does have serious ecological impacts. Damming a river can completely alter the natural ecosystem by flooding the upstream portion and altering flow rates and natural silt deposition downstream. The resulting habitat fragmentation, loss of water quality, and changes in species diversity may put increased pressure on vulnerable species. In the Pacific Northwest, for example, the vast network of hydroelectric dams installed on the Columbia River system in the twentieth century decimated regional salmon populations, wiping out entire runs and endangering many others.

The future growth potential of hydropower in most developed countries is limited. More than 45,000 large dams already degrade rivers across the Earth. Since much of the hydropower infrastructure in the United States is old, there are efficiency improvements that can be realized by upgrading dams, but most major rivers that have potential for producing electricity are already dammed. Small-scale hydropower ("micro-hydro") and so-called "run of the river" technologies that generate power without dams or impoundments can be ecologically benign and a useful part of regional distributed energy efforts; their total potential generating capacity, however, is modest. Other emerging hydropower technologies, including tidal and wave power, have not yet proven commercially viable and are far inferior (in terms of cost and power generation) when compared to traditional hydropower.

Key Limiting Factors: *Best sites already developed; megadams destroy natural hydrology of river systems, may imperil species and displace human communities.*

Net Energy Ratio:

GEOTHERMAL

Geothermal energy utilizes the heat produced by the Earth's core to create electricity and to heat homes. Only certain locations have the appropriate mix of resource availability and high population densities to make this resource substitutable for fossil fuels.

Geothermal energy is naturally vented at the Earth's surface in the form of volcanoes, geysers, and hot springs. Large amounts of geothermal energy are vented at the intersections of tectonic plates as well, such as along the Pacific Rim. Geothermal energy can be used to produce electricity by either harnessing steam directly from geothermal resources or by using hot geothermal water to produce steam to run a turbine. It is also used to heat and cool buildings.

With 15 gigawatt-hours of electricity generated in 2010 from more than 70 power plants, the United States is the world's leading producer of electricity from geothermal sources—but this amounts to less than 1 percent of total nationwide electricity consumption. Few countries produce a significant share of electricity from geothermal sources; only Iceland, El Salvador, and the Philippines use it to generate more than 15 percent of their electricity. Since the footprint of a geothermal plant is fairly small, most of the environmental damage that comes from geothermal energy production is associated with the construction of the facility and its related transmission infrastructure.

Unlike wind and solar energy, which are intermittent sources of power, geothermal energy is consistent, and thus is one of the only renewable energy technologies that substitutes well for coal generation. (Coal power plants take hours to become hot enough to produce electricity efficiently, and then hours again to cool down—so plant operators try to use coal plants as always-on baseload power to decrease wasted energy during the start-up and shutdown periods.)

Geothermal energy may also be used to regulate temperature in buildings, providing an alternative to conventional heating and air conditioning. Hot water from a geothermal source can be pumped directly into buildings for heat. Alternatively, geothermal pumps can utilize the constant temperatures (between 50 and 60 degrees Fahrenheit) found only a few feet underground to cool buildings in the summer and heat them in the winter.

The next generation of geothermal energy, "enhanced" geothermal, aims to harness underground heat sources that otherwise lack water or permeability but are broadly distributed geographically. There is considerable interest in and hope for enhanced geothermal, but the technology is still in development and, like other emerging energy resources, would take time and investment capital to grow to any significant scale.

Key Limiting Factor: *Very small sector, would take decades to develop to significant scale.*

Net Energy Ratio:

LIQUID BIOFUELS

Liquid biofuels, and ethanol in particular, have been touted as the solution to U.S. dependence on foreign oil. But most biofuels actually require almost as much energy to produce as they provide. Despite years of development, biofuels remain uncompetitive with fossil fuels.

Biofuels are derived from plant material and fall mainly into two categories: ethanol and biodiesel. In the United States most ethanol comes from corn, but globally it is produced from a variety of plants, including corn, sorghum, sugar, sugar beets, and switchgrass. In a simple chemical process, biodiesel is made from vegetable oil.

The United States currently produces roughly 13 billion gallons (300 million barrels) of ethanol a year, almost entirely from corn—nearly a tenfold increase in over a decade. The ethanol industry has benefited from both an import tariff of 54 cents per gallon on foreign-produced ethanol as well as a subsidy of 45 cents per gallon, costing U.S. taxpayers billions of dollars. The ethanol industry also benefits from laws mandating the blending of ethanol with gasoline.

Unfortunately, producing ethanol is at best a poor use of resources, and at worst a net energy loser. The energy content of ethanol is about two-thirds that of gasoline. An analysis by the think tank Environmental Working Group indicates that blending 10 percent ethanol with 90 percent gasoline (the ratio mandated by the renewable fuel standard) reduces the miles per gallon achieved by almost 4 percent on average. From an energy standpoint, this means that the 10.6 billion gallons of ethanol produced in 2009 in the United States replaced the equivalent of only 7.1 billion gallons of gasoline.

The net energy ratio (energy return on energy invested, or EROEI) for biofuels in general, and corn ethanol in particular, is abysmal. Various studies have estimated the EROEI of corn ethanol at between 0.8:1 and 1.3:1, meaning that we get between 0.8 and 1.3 joules of energy from ethanol for every joule of energy invested in producing that ethanol. The EROEI of gasoline, by comparison, is between 5:1 and 30:1, depending in part on the source of the petroleum.

Additionally, in recent years the ethanol industry's huge purchases of corn as a feedstock for fuel production have caused corn prices to increase, raising the cost of basic food items for the global poor. In response, many ethanol advocates are optimistic about cellulosic ethanol (in particular, switchgrass), since it supposedly would not compete directly with food crops. But cellulosic ethanol also has low net energy, and carries the potential for increased competition for food-growing land.

The EROEI of biodiesel is only somewhat better than that for ethanol. While biodiesel produces fewer emissions (except for nitrogen oxides) than petroleum diesel, its production at industrial scales would inevitably mean further increased competition for arable land and possibly for certain food crops, such as soybeans.

Key Limiting Factors: *Extremely low net energy ratio; competes directly with food production for land and feedstock.*

Net Energy Ratio:

BIOMASS ELECTRICITY

While small-scale biomass heating and cogeneration plants may be a legitimate advance toward a renewable energy economy, large-scale biomass electricity presents the Faustian choice of burning the forest to keep the lights on.

Electricity from biomass is increasingly promoted as a "green" alternative to fossil fuels. As in a coal- or natural gas-burning power plant, biomass fuels are burned to make steam, which drives a turbine to generate electricity. Although biomass can refer to many different potential fuels including crop residue, construction waste, and garbage, the majority of existing biomass-fueled power plants burn wood. As of 2012, hundreds of new biomass-fueled facilities are proposed or under construction around the United States.

The U.S. Energy Information Agency's 2009 electricity generation data shows about 1 percent coming from biomass. Wood has a much lower energy density than fossil fuels, which means that the mass of raw material input per electrical energy output is much higher for biomass than for either coal or natural gas. To meet even a modest percentage of current U.S. electricity demand with biomass would require dramatically increased logging of the nation's forests, and increased removal of woody debris, which is vital for wildlife and healthy forest soils. Industrial biomass energy production, particularly whole-tree harvesting for wood chip–burning power plants, is a growing threat to forest ecosystems.

Biomass burning also produces dangerous air pollution, which is why many physician and medical groups are opposing biomass energy projects. Although biomass energy in theory has no net contribution to global greenhouse gas emissions because the carbon dioxide released during combustion will be recaptured by future forest growth (some question this assumption because climate change may reduce overall forest cover), there is a timing issue that is often overlooked by biomass proponents. The important time horizon for greenhouse gas reductions is the next fifty years. While CO_2 emitted by burning wood will eventually be sequestered, full recovery can be on the order of several centuries. Thus burning wood today may exacerbate global warming in the near term, especially since more wood must be burned compared to other fuels to get the same amount of energy.

Key Limiting Factor: *Large-scale development would put pressure on forests and agricultural land.*

Net Energy Ratio:

INDUSTRIAL WIND

Wind power is one of the most successful renewable energy resources, but it does require backup systems to keep generating energy when the wind is not blowing. Additionally, industrial wind developments can have considerable local aesthetic impacts.

Wind power has been utilized by societies for millennia for a variety of functions, including sea transport and milling. Wind turbines today can be small, powering single homes or businesses, or large enough to power a thousand homes. The average industrial wind turbine today stretches roughly 20 stories into the air with a blade diameter of 200 feet and produces enough power for a couple of hundred homes (approximately one or two megawatts of energy).

More than 80 countries around the world have some sort of modern wind power, totaling almost 200 gigawatts of installed capacity. This installed capacity equates to just over 2 percent of annual global electricity consumption. The United States was recently surpassed by China as the world's largest wind power producer, with a total of 44 gigawatts. Denmark, followed by Portugal, and then Spain have the highest proportion of electricity generation from wind, at 21, 18, and 16 percent, respectively. By comparison, the 40 gigawatts produced from wind in the United States represent only 2 percent of total electricity consumption.

The energy return on energy invested for wind power is upwards of 20:1–30:1, which is comparable to that of fossil fuels, and higher than most other renewable resources. However, this figure does not reflect that wind is an intermittent source of energy. Achieving the full benefits of wind power at a large scale requires solving the problem of intermittency with better energy storage technology and smooth integration of baseload generating sources and renewables. Numerous efforts in these areas are underway, including development of smarter electrical grids that may accommodate a high percentage of renewably generated power, but these infrastructure improvements will be expensive.

Although concerns about the negative effects of wind turbines on birds have largely been resolved, other nonenergy-related complications remain, namely local complaints about noise and shadow flicker from blades, and concerns about the visual impact of large facilities. Additionally, wind power tends to be best on mountaintops or offshore—areas that can be tough to reach and may lack electrical infrastructure. New transmission capacity can fragment wildlife habitat. Lastly, due to the fact that wind power is not energy dense, the footprint for a system of wind turbines compared to that of a coal mine or oil and gas field is much larger per energy unit, which may cause increased land-cover degradation and habitat destruction.

Key Limiting Factors: *Intermittent, requires backup energy source; large land footprint.*

Net Energy Ratio:

SOLAR PHOTOVOLTAIC

The Sun delivers enough energy to the Earth every day to power global society many times over. Solar energy's potential is enticing; photovoltaic technology is improving and the cost is falling. Intermittency, lower energy return on energy investment, institutional barriers, and dependence on rare metals for manufacturing are challenges to solar photovoltaic (PV) gaining a significant share of the global energy portfolio.

Solar PV panels use the energy from the Sun to "excite" electrons into a high energy state, at which point they are converted into electricity. Most photovoltaic panels use crystalline silicon as a base material, but recent advances have led to the use of more scarce elements such as cadmium, tellurium, indium, and gallium. "Thin film" PV panels have also been developed that use less silicon than traditional PV panels. Total global installation of solar PV was roughly 40 gigawatts in 2010, distributed in more than 100 countries. The rapid expansion of manufacturing capacity, particularly in China, has caused solar PV panel prices to drop dramatically, and maturation of the industry is projected to similarly reduce "balance of system" (design, installation, etc.) costs in coming years.

Solar PV offers numerous advantages over fossil fuels for generating electricity. Greenhouse gas emissions are considerably lower over the life of the panel, even when accounting for emissions during construction. Additionally, solar energy is distributed (albeit not evenly) throughout the world, which means many remote populations can produce electricity without constructing inefficient, expensive, and habitat-disrupting long-distance-transmission infrastructure.

Like wind, however, solar energy is intermittent. Not only are there diurnal fluctuations in solar energy but cloud cover, fog, seasonal light availability, and even dust on the panels can severely affect photovoltaic electricity generation. The conversion efficiency (i.e., converting incident solar radiation into electricity) of PV panels is quite low as well, around 15 percent, although estimates vary widely and new technology is incrementally increasing efficiency. The conversion of coal to electricity, by comparison, is over two times more efficient than solar panels. New thin-film PV has been integrated into building facades and roofing, expanding the possibilities of where solar systems can be installed, although it currently has lower conversion efficiencies than conventional PV.

The countries with the fastest growth rates in solar installation are also those with the most aggressive subsidy programs. In Germany, for example, the government for a time was paying more than 60 cents per kilowatt-hour for power from small solar PV systems, which is almost ten times higher than the price of electricity in some parts of the United States. Spain had a similar program that boosted solar electricity generation there. Federal and state incentives, as well as innovative financing programs, have helped stimulate the growth in U.S. solar PV installations, and recent declines in the price of PV panels have prompted some proposed utility-scale solar thermal generating stations to switch to PV.

Key Limiting Factors: *Intermittent, requires backup energy source; scalability may be constrained by dependence on scarce or expensive natural resources.*

Net Energy Ratio:

CONCENTRATED SOLAR THERMAL

Focusing the relatively dispersed energy from the Sun to produce electricity from steam is a high-tech way of capturing solar energy. Unfortunately, the places where concentrated solar technology works best—deserts—are the same places where a critical component, water, is limited and where impacts on wildlife habitat, including for endangered species, is sometimes inevitable.

Concentrated solar power (CSP) is different from PV systems in that it uses a series of mirrors to focus the Sun's energy into one location where the heat is collected to make steam. Concentrated solar systems therefore produce electricity using the same mechanics as fossil fuels: Steam drives a turbine, which generates electricity. The most popular setup for CSP is called the "parabolic trough" system, which consists of long U-shaped mirrors that reflect sunlight onto a tube positioned above the array. The fluid (generally a synthetic oil) flowing through this tube is heated and is then used to turn water into steam. Concentrated solar power accounts for roughly one gigawatt of global electricity production, with much of the installed capacity located in Spain and the United States.

In CSP, the electricity generation process itself has zero emissions. There are emissions associated with the construction, maintenance, and decommissioning of the facility, but they pale in comparison to those from an average coal- or other fossil fuel-burning plant. But concentrated solar facilities do have a significant physical footprint (like any power plant) and require adequate transmission infrastructure to get electricity to consumers. Conservationists have opposed some CSP plants proposed to be built on U.S. public lands where their construction would negatively affect fragile desert habitat or endangered species. Proper siting on industrial brownfields near existing transmission lines would eliminate these negative impacts of CSP development.

Concentrated solar shares some of the shortcomings of solar PV-generated power. Since both rely on sunlight, they are intermittent sources of energy, which generally means that either natural gas or hydroelectricity must be used as a backup to offset the rapid fluctuations in power output from solar facilities. Additionally, cooling the steam produced at CSP facilities requires massive amounts of water, which is a scarce resource in the sunny, desert environments where CSP facilities are most efficient. On average, CSP plants consume as much water per megawatt of electricity generated as coal plants.

Key Limiting Factors: *Intermittent energy source; heavy water user.*

Net Energy Ratio:

HYDROGEN

A future hydrogen economy may be technologically possible but is unlikely to be developed on a global scale because of its inherent inefficiencies and capital costs. Hydrogen use may become widespread in some countries, however, and excel for limited uses.

Hydrogen is not, strictly speaking, a primary energy source like coal or oil, since there are no hydrogen reserves to drill or mine. Thus any energy system involving hydrogen will have the added cost of first forming the hydrogen.

On Earth, hydrogen is found only in combination with other elements. The familiar H_2O water molecule, for example, has two hydrogen atoms bound to a single oxygen atom. To acquire hydrogen in a useable form, it has to be split from other substances. The most common method is to split hydrogen off of the methane molecule, CH_4. The vast majority of hydrogen currently produced in the United States comes from a process known as steam reforming, in which steam is reacted with methane at high temperatures and in the presence of a catalyst, releasing carbon dioxide and hydrogen. Another method is electrolysis—ideally using electricity from a renewable source—which strips hydrogen from oxygen in water molecules.

Hydrogen can be burned to power machines such as cars and trucks, to heat homes, or to generate electricity in fuel cells. Its only waste product is water, formed by the reaction with oxygen. Hydrogen fuel cells can be either large centralized facilities or small enough to power a single home. It is a proven, workable fuel: Liquid hydrogen boosts the space shuttle into orbit and hydrogen fuel cells power its electrical systems. A hydrogen economy, however, would be difficult to scale up globally. Fuel cells currently are expensive to build, though once in place, they can provide greenhouse gas–free electricity, especially if the initial electricity used in electrolysis is derived from a renewable energy source such as solar or wind.

Currently, hydrogen use is very modest, but interest in hydrogen is growing because there are no greenhouse gas emissions from burning hydrogen (although greenhouse gas pollution may result from hydrogen production), and the only "waste" product is water. The main barriers to expanded hydrogen use are the huge capital outlays required to develop a national-scale hydrogen production and distribution system, and the low energy return on energy invested.

Key Limiting Factor: *Massive investment needed to create hydrogen-related infrastructure.*

MICROPOWER

During the past half century, the energy economy in the developed world has emphasized size: big dams and large, centralized generating stations burning fossil fuels or splitting atoms to generate massive quantities of electricity that is distributed regionally by the grid. Now that trend seems to be reversing.

Small-scale distributed generation, or "micropower," has come to be defined as the growing sector of electrical supply that encompasses combined heat and generation facilities (whether biomass or fossil fueled) plus renewables, excluding large hydro. In 2008 micropower produced 17 percent of the world's electricity, surpassing the global output of nuclear power plants by several percentage points.

Micropower harnesses the most appropriate local energy resources for local use. In practice this may mean solar PV arrays in sunny areas, wind turbines in windy areas, combined heat and power facilities burning crop residue to run a factory in India, or micro-hydro dams in Patagonia. The overarching goals are to democratize power production, improve dependabilility of the grid, rapidly deploy renewables, and lower costs and emissions by producing electricity near where it is used, thereby eliminating the line losses inherent to long distance transmission.

Micropower generating capacity is usually connected to the grid both to sell excess electricity and to ensure uninterrupted electricity when local generation isn't possible. Even if based on fossil feedstocks such as natural gas, the "radical efficiency" of combined heat and power stations, according to micropower boosters at Rocky Mountain Institute, "typically save at least half—often two-thirds or more—of the fuel, emissions, and cost of making electricity and heat separately." Further greenhouse gas emissions reductions are possible with renewables.

Micropower is the heart of a future distributed power system in which producers of different scales—homeowners, voluntary associations, businesses, schools, or municipalities—generate electricity for their needs and sell the excess back into the grid. This approach has numerous benefits compared to centralized generation, where one large facility produces power and distributes it to an entire region.

Unfortunately, the current grid is ill-equipped to handle a large share of distributed generation based on intermittent renewables such as solar and wind, but efforts to modernize the grid are under way. Various efforts to establish "microgrids" are making progress as well, with notable examples at the University of California at San Diego and on U.S. military bases.

Key Limiting Factor: *Economics increasingly favors micropower but institutional barriers and resistance to distributed generation remain in some energy markets.*

REFINERIES

Converting crude oil into its various derivatives (gasoline, diesel, jet fuel, etc.) is no easy task. Refineries have some of the highest rates of greenhouse gas emissions in all of industry, they operate continuously, and, with all of the volatile fuels passing through them, they have a history of dangerous fires and explosions.

Refineries are responsible for turning the various forms of crude oil extracted from underground reservoirs into usable petroleum products, from familiar energy-dense fuels such as gasoline and heating oil to waxes and lubricants. Most of these products are created through a process called fractional distillation, which separates hydrocarbons with different boiling points. The total amount of equipment necessary to refine the petroleum consumed every day is massive, leading to refineries that appear more like small cities. The United States has well over 100 refineries with a total capacity of nearly 18 million barrels per day, the highest in the world. The single largest refinery on Earth is in India, with a capacity of over 1 million barrels per day.

Refining oil requires an immense amount of energy. Refineries power their machinery and processes almost exclusively with oil and natural gas, contributing significantly to greenhouse gas emissions. According to the U.S. EPA, carbon dioxide emissions from on-site energy consumption at refineries are responsible for upwards of 10 percent of all emissions from U.S. industry. Refineries also generate air pollution that can threaten nearby communities. EPA documents have noted that "the petroleum refining industry is far above average in its pollutant releases and transfers per facility" and these chemicals include "benzene, toluene, ethylbenzene, xylene, cyclohexane, 1,2,4-trimethylbenzene and ethylbenzene," which can be harmful to human health.

In addition to threats to human health caused by pollutants from refineries, the combination of flammable substances, numerous chemical reactions, and high temperatures at refineries leads invariably to accidents. In 2010, four employees were killed in a refinery fire in Anacortes, Washington, and in 2005 a refinery explosion in Texas City killed 15 workers and injured more than 100 others. These are just two of the more egregious recent accidents, and a full history would highlight myriad violations, accidents, and unfortunate deaths.

PIPELINES AND TRANSPORT

The globalized transport network for moving oil, gas, coal, and other fuels is staggeringly large and complex. Every day countless trains, ships, and tanker trucks deliver the fuel that keeps the world economy humming. This transport infrastructure, including hundreds of thousands of miles of pipeline, is vulnerable to accidents and terrorism and is costly in money, energy to maintain, and greenhouse gas emissions.

After the discovery of oil, pipeline transport was quickly adopted as the cheapest delivery method. Pipelines are primarily made of steel, with diameters ranging from a few inches to a few feet, and they are often buried at depths between three and six feet. Oil is pushed through the pipelines by pumping stations—and natural gas by compressor stations—scattered along the route. For natural gas, the United States has more than 300,000 miles of pipeline, 1,400 compressor stations, 11,000 delivery points, 24 hubs, and 400 underground storage facilities. For oil, there are tens of thousands of miles of additional pipeline.

Pipelines are generally considered the safest transport method, although accidents do occur. In 2010, while most public attention was diverted to the Deepwater Horizon oil spill in the Gulf of Mexico, a pipeline in Michigan leaked 800,000 barrels of oil into the local river system. In 2010, a natural gas pipeline exploded in California, killing eight people and creating a crater more than 40 feet deep. However, the biggest regular environmental impact from pipelines is habitat fragmentation: Although much of the pipeline infrastructure is buried, the land cover must remain clear to avoid root obstruction.

Where pipelines are impractical, energy resources are transported by ship, train, or truck. As of 2009, more than one-third of all major shipping vessels in the

world were moving oil. Bulk carriers, responsible for coal, grain, iron ore, and other commodities, make up another third. Liquefied natural gas (LNG) vessels account for only 3 percent of all vessels but grew at an annual rate of 11 percent from 2009 to 2010.

Building ships, trains, and trucks requires immense amounts of steel; steel production is a significant source of greenhouse gas emissions. There is also a long history of spills associated with transport, especially oil tankers, which can severely affect regional environments. One can readily find oil-soaked sand on the beaches of Prince William Sound more than two decades after the Exxon Valdez spill. The long-term impacts of the Deepwater Horizon spill are yet to be determined.

The contribution of the energy transport system to climate change is difficult to calculate but as the world shifts from high-energy-content fossil fuels to lower quality forms like tar sands and subbituminous coal, the volume of fuel transported will need to increase proportionally. This will require even more pipelines, ships, trains, and trucks, more fuel to construct and operate them, and will result in more greenhouse gas pollution from the energy sector.

POWER LINES

Power lines serve for electricity the same function that pipelines serve for oil and natural gas. They often produce similar ecological impacts, including habitat fragmentation, and are an aesthetic blight on landscapes. The expanding network of transmission lines has resulted in linear clearcuts through ecosystems around the globe.

Electricity has two drawbacks that oil, natural gas, and coal do not have. It does not exist in nature in a way that humans can harvest directly (we must convert other energy into electricity), and it cannot be stored easily. Yet it is electricity—providing power to illuminate the night and run myriad machines from cell phones to computers—that we most equate with modern society. Electricity consumption tends to grow steadily in developing economies, even while the underlying sources of that electricity (i.e., coal, nuclear, and natural gas) may shift over time. Power lines play the crucial role of transporting the electricity from the point of production to the point of consumption.

Power lines are typically categorized in two groups. *Transmission lines* are high voltage lines used to carry electric current from generating stations to consumption hubs. From hubs, where the current is downgraded to house current, *distribution lines* deliver electricity to the point of consumption.

Power lines can have the same fragmenting effects on wildlife habitat as pipelines. High voltage power lines are allotted a 120-foot right of way (60 feet on each side of the transmission tower) to ensure that the lines are unobstructed from vegetation. This allows companies to clear-cut all natural vegetation within that distance. Clear-cutting forests and other vegetation for pipelines and to accommodate power distribution networks has fragmented forest ecosystems around the world, with substantial impacts on ecosystem integrity. The variety of "edge effects" from such fragemention, particularly the invasion of exotics or weedy species and loss of interior forest habitat, is well described in the scientific literature.

The aesthetic impacts of power lines are more difficult to quantify than ecological costs but are very real to affected communities. New transmission capacity is expensive to build and often highly controversial. There are numerous current campaigns under way fighting proposed power lines, from the "Northern Pass" project in New Hampshire that would bring additional HydroQuebec-generated electricity to the U.S. energy market, to the coalition of activists working to stop a new, roughly 1,200-mile transmission line through southern Chile. That project, proposed in conjunction with a scheme to build multiple large dams on wild rivers in Patagonia, would bisect numerous national parks and national reserves to supply power to urban areas in central Chile.

EMERGING ENERGY TECHNOLOGIES

Virtually every day corporate and university press releases tout the latest technological breakthroughs that will revolutionize the energy sector. Ultimately, some of these innovations will find niche markets, but they generally lack one or more crucial characteristics that make fossil fuels so addictive to a growth-obsessed society.

Thanks to rising oil prices and growing concern about climate change, myriad new energy technologies have emerged in recent years; many are hyped as "game-changing" alternatives to fossil fuels. Freeing society from fossil fuel dependence is undoubtedly a crucial objective, but no single new technology or incremental improvement in existing technology is likely to be the silver bullet that cornucopians expect the market to produce.

Most new energy technologies have significant technical challenges that keep their net energy ratio (energy return on energy invested) relatively low. Wave and tidal power schemes need to operate in corrosive salt water over vast areas under extreme conditions. Algal biofuel needs just the right mix of sun, water, and nutrients and may be difficult to produce at industrial scales. Next-generation solar and wind power relies on scarce or constrained resources like tellurium, gallium, and indium. Fusion power seems perpetually only twenty years from being commercially feasible.

Optimists argue that given sufficient research and development, new energy technologies will evolve, economies of scale will be realized, and costs will be reduced. Very likely this is true, to some degree. Technology improvements will certainly happen. And, much like wind and solar power, there will be specific markets in which these technologies will be useful and possibly even come to dominate. But the fact is, fossil fuels have superlative energy density, versatility, and high net energy (the early conventional oil and coal industries, for example, realized EROEIs of 50:1 or even 100:1). Moreover, our massive globalized economy perches atop a century's worth of physical infrastructure that was built to run on fossil fuels. Emerging energy technologies generally fail in one or more of the crucial categories in which fossil fuels excel: energy density, accessibility, transportability, storability, and sheer abundance.

So while tomorrow's technologies may reduce the toxic effects of the current energy economy, there is no miracle cure for a system that needs structural reform. Perhaps the most worrisome aspect of emerging technologies is the hope they instill in us that technology can ultimately defeat all environmental limits, allowing economic and population growth to continue exponentially, indefinitely. In a finite world, that is a false hope.

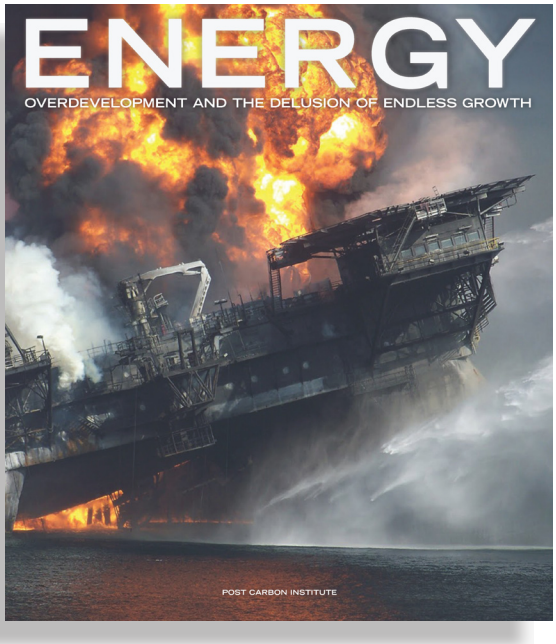
ENERGY

Overdevelopment and the Delusion of Endless Growth

Edited by Tom Butler and George Wuerthner

We have reached a point of crisis with regard to energy... The essential problem is not just that we are tapping the wrong energy sources (though we are), or that we are wasteful and inefficient (though we are), but that we are overpowered, and we are overpowering nature.

— from the Introduction, by Richard Heinberg



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The ENERGY Reader

Edited by Tom Butler, Daniel Lerch, and George Wuerthner

What magic, or monster, lurks behind the light switch and the gas pump? Where does the seemingly limitless energy that fuels modern society come from? From oil spills, nuclear accidents, mountaintop removal coal mining, and natural gas "fracking" to wind power projects and solar power plants, every source of energy has costs. Featuring the essays found in ***ENERGY*** plus additional material, ***The ENERGY Reader*** takes an unflinching look at the systems that support our insatiable thirst for more power along with their unintended side effects.

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