

The Costs and Implications of Our Demand for Energy: A Comparative and Comprehensive Analysis of the Available Energy Resources

How Fossil Fuels Have Created an Energy Crisis

Exploring Our Alternatives

The Future of Energy



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I. BACKGROUND AND GENERAL REMARKS

With the exception of remote and uncharted places, what we use now as sources of energy are a far cry from the one and only energy source humans have used for a very long time: wood. A major fuel, it was used to cook food and heat homes. Over time, they invented machines to do the work for them. Along came windmills and waterwheels used to provide the energy needed to grind grains. Animals were also used both to provide energy and transportation. The industrial revolution of the 18th century, which started in England and spread throughout Europe, the United States, and the rest of the world, was the driving force behind the switch from manual labor to machine-based manufacturing. The introduction of machines in the daily life will catapult the demand for energy as living comfortably and acquiring more commodities became the new normal. In the United States, although water power resurfaced in the 19th century with the discovery that water could be used to generate electricity, coal remained the primary source of energy, especially for generating electricity. In the 20th century, another fossil fuel, petroleum, was discovered and quickly became a prime source of energy. In the process, natural gas was also found to be useful for cooking, heating, and generating electricity. After World War II, by 1947, the use of petroleum surpassed that of coal. A new era was born. The production of cars and trucks in the US and worldwide increased the demand for oil, thus, created an unprecedented need to dig deeper underground. With the oil boom came wealth but also great challenges and uncertainties as fossil fuels are not forever and are subject to depletion. They also represent a constant threat to the environment.

Today, the world is experiencing the full brunt of an energy crisis. What energy crisis? You might ask. My home is heated. I can cook whenever I want. I can drive my cars, both the hybrid and the gasoline-powered one. The streets are well lit. I just came back from a cruise in the Caribbean. So, I don't see where the crisis comes from. For the sake of this analysis, energy crisis is not meant in the sense of shortage. As a matter of fact, energy resources abound on our planet, which gives us a large repertoire of choices. Energy is free and virtually unlimited. The problem lies within its conversion and popularization. The world is facing an energy crisis because our energy resources are a global challenge. From their discovery, their exploitation, and their storage to their distribution and their usage, they pose tremendous risks and threats both to our health and the environment. The challenge also stems from the facts that: technology does not create energy, transforming energy is expensive, and energy transitions – for example, switching from fossil fuels to, say solar energy – take time. Before I go on, I would like to note that the health and the environmental risks apply only to non-conventional resources, which include fossil fuels such as coal, petroleum, and natural gas and nuclear power. Coal, petroleum – commonly called oil – and natural gas are called fossil fuels because they derive from fossils of plants and living organisms which populated the Earth millions of years ago. Fossil fuels account for 80% of global energy usage. But fossil fuels will eventually run out, in a few centuries to be more precise. Like it or not, they will have to be excluded from the list of available energy resources. We already know what

other sources of energy will still be around when that happens. They constitute a category of energy sources called renewable energy. Renewable because they cannot be depleted.

At any time, energy can be pushed at the forefront of both national and international attention as a result of several factors, including: increase of demand for energy, dependence on imports – of oil – from foreign sources, uncertainties created by political instability, climate change, instability of energy prices, and inadequate investments in energy infrastructure. What complicates the situation is the fact that these factors also depend on government policies on both national and international levels. And policies are not always easy to implement because they are affected by a mix of scientific, technical, economic, social, and political elements.

Can something be done now to avoid a possible crisis – this time in terms of shortage – in the future? It depends on who you ask. There are many viewpoints on the subject. An alternative would be to make our planet energy efficient, meaning retrofit it with homes, commercial buildings, transportation means, and appliances that use energy in an efficient manner. This is being done but on a very small scale and is accessible only to those who can afford it. So, right now energy efficiency looks more like a paradox. To pay less money – thus saving money – you must have money. It resembles this saying in finance: “to make money, you must have money”. This is to say that energy efficiency comes with a price tag and somewhere along the line someone will have to pay for it. But who? Policy makers or political actors should establish strict rules and take the initiative. The problem is politicians tend to think in the short term. Most of them do not want to take responsibility for Earth’s problems. The future global challenges that energy resources will pose must be dealt with now in a proactively manner. It is easier said than done because the issue is an ethical one. It is not a factual issue. We tend to act following a major adverse event or an accident. For example, environmental disasters such as the Chernobyl nuclear power plant accident, the British Petroleum oil spill, or more recently the Fukushima nuclear powerplant accident caught briefly people’s attention and raised a short-lived awareness on the use of non-conventional energy resources. We must not let disasters or accidents determine how we should use energy. That can easily be achieved through debate, dialogue, and consensus. But to talk about energy and establish rules and guiding principles in terms of its use, both policy makers or political actors, leaders in the energy industry, technocrats or economic actors, and the general public or the consumers must be fully knowledgeable about energy, what it entails, and what are its implications, which is not an easily achievable goal because energy is a science in itself and draws on many other disciplines such as economics, politics, history, engineering, biology, chemistry, physics, and geophysics (the physics of Earth).

Let’s consider a few factual and ethical assertions. Example: offshore drilling. An ethical assertion might be: offshore drilling is bad. Well, there is nothing to discuss here. A factual assertion might be: the British Petroleum oil spill of 2010 leaked 4.9 million barrels into the Gulf of Mexico. You

might think that this factual assertion is wrong. That could prompt you to study the fact and come up with a different number. We could debate it. Factual assertions are often quantified. We could always round off the 4.9 billion to 5 billion. But when we consider the costs to the fishing industry, tourism, the cost of the cleanup, the effects on the planktons and seagulls, there are many factual assertions we can make about offshore drilling: it provides X amount of oil; it creates X number of jobs; it reduces the cost of gasoline at the pump by X cents per gallon; it reduces our dependence upon foreign oil by X barrels per day. Some of the assertions are easy to calculate; some of them aren't. Think about buying a car. You want the car to be affordable, safe, energy-efficient, attractive, functional, reliable, long-lasting, easy to clean, and environmentally friendly. The problem is: you can't have all these things. Say you go to a car dealer. You can get factual assessments on these facts for each car, but that won't tell you which car to buy. You might have a family of seven. So, you're looking at a minivan. You might use it for hauling large objects. So, you want a pickup truck. You might really like the color red. So, there is always going to be tradeoffs. A safer car is always going to be heavier and less energy efficient, will cost more to run and less environmentally friendly. What you don't want to do is not make a decision. And the decision will not encompass all your choices. It's the same thing with the future of energy. We need to get all our facts about our energy sources, but it's also tricky because these facts also change overtime. We'll need to make conscious decisions. One thing to remember is that there is no single energy source that's going to save humanity because every single source of energy has its pluses and minuses. In the foreseeable future, we'll need a diverse portfolio of energy sources geographically variable in order to meet all our needs. We'll need cooperation and coordination. All of us are already familiar with diverse types of energies in many intimate ways: you pay for electricity to light your house, you pay for natural gas to heat it, you pay at the pump for fuel to power your car or truck, you pay indirectly those fuel costs in all the food you eat and all the stuff you buy.

Energy is big business. For instance, on the 2015 Fortune 500 companies, 4 of the top eight of these companies were energy companies: Exxon Mobil, Chevron, Phillips 66, and General Electric. So much of the global economy is energy and it affects our jobs, our incomes, and our personal economics. Politics is also important in the dynamics of energy development. Internationally, government subsidies have helped the development of new technology for solar and wind power. For example, governments subsidize the oil and nuclear power industries. Politics plays a role in the coal industry which has survived and thrived in the US because of exemptions from federal pollution regulations. The same is true for hydrologic fracturing or fracking, which has survived in the US because of the 2005 Clean Water Act. The US government also subsidizes pipelines and support military actions in the Middle-East as part of ensuring a continuing supply of gasoline. Energy has also been a leading focus of most political tensions between countries. Oil in the Middle-East, OPEC, gas pipelines out of Russia, countries fighting for oil resources in the South China Sea. These tensions shape the decisions all countries make about their energy resources.

The story of energy is, at its core, the story of human civilization. Economy, energy, and environment are interrelated. Energy impacts the economy and the environment more than it is impacted by them. While the economy is driven primarily by supply and demand and the environment is driven by both spontaneous changes and Anthropocene – modification of the environment by human activities – energy, especially fossil fuel energy, is one of the most seminal indicators of wealth. It's plentiful, diverse, and only a few nations have the ability to extract and distribute it.

What is our next source of energy? Chris Martenson thinks that it's the most important question of our time and it remains unanswered. Oil is not the only critical resource that will be in shorter-than-hoped-for supply in the future...This is not a story of "running out"; this is a story where resource extraction gets just a little more challenging and a little bit more expensive. Consequently, fewer and fewer more resources come up out of the ground to sustain the economy that we know and love. Will all economic activity cease with the depletion of a few key elements? No, of course not. But neither can our economy continue to operate in precisely the same way that it did when demand alone dictated supply...We can no longer constrain our thing to just one E, the economy; we must include the other two E's, energy and the environment. For far too long, economists have been allowed to behave as if the economy was an independent system all on its own. It is not. It is a subset of the larger world. (Martenson, 2011)

What Is Energy?

Energy is the ability to do or produce work, that is make something tangible or visible occur. Energy comes in different forms such as heat (thermal), light (radiant), motion (kinetic), electrical, chemical; nuclear, or gravitational. That production of work may be actual or potential. Forms of energy are different from types of energy that usually comes from a source which can either be renewable or non-renewable. Non-renewable sources of energy are called fossil fuels and include coal, petroleum, and natural gas. Renewable sources of energy include solar, wind, nuclear, geothermal, hydropower, and biofuel (biodiesel, ethanol). There are two types or forms of energy: stored (potential) energy and working (kinetic) energy. Say you push a sofa or move a piano, you produce the energy required to make it happen thanks to your muscles. When you stretch a rubber band, it stores potential energy that can be released to produce a work in the process. For example, the food a person eats contains chemical energy, and a person's body stores this energy until he or she uses it as kinetic energy during work or play. The energy that lights up our homes, the energy that makes our cars run, or the energy we use to cook do not depend on our muscles but something, somewhere, had to make something else produce a work to make it happen.

To understand the concept of energy, we also need to understand the differences between primary energy and useful energy and the differences between resources, reserves, and potential. National Academy of Sciences et al. (2009) tells us that:

- *Primary energy sources* include those that exist in nature and from which the energy that powers our civilization is obtained. These sources fall into two categories: flows of energy and stored energy. Examples of energy flows include sunlight, wind, and waves. Stored energy includes fossil energy (coal, petroleum, and natural gas), bioenergy (contained in biomass), and nuclear energy (stored in atomic nuclei in radioactive elements such as uranium) and the heat stored in Earth's upper crust. Primary energy sources can be converted into useful energy.
- *Useful energy* is primary energy that is converted and that lights a building, or supply heat for an industrial process, although the conversion process inevitably involves energy losses (which can be quite considerable) and often entails substantial costs.
- *Resource* refers to quantities of stored energy – i.e., solid, liquid, or gaseous fuels derivable from petroleum, natural gas, coal, uranium, geothermal, or biomass – that exist in nature and may be feasible to extract or recover, given favorable technology and economics.
- *Reserve* refers to that portion of the resource that can be economically extracted or recovered with current technology.
- *Potential energy* is used instead of resource to describe energy flows – such as from sunlight, wind, or the movement of water – that occur in nature and may be feasible to recover, given favorable technology and economics.

Humans use tremendous amounts of energy. Ever since the first humans discovered how to make fire, our love affair with energy has evolved into something increasingly profound over time and now it's inconceivable to even think that we could do without energy. Anthropologists tell us that the ability to use fire to cook our food, with the fire releasing chemicals out of the woods, allowed for the evolution of more powerful brains, which allowed us to construct communities that then began to harness energy in lots of other creative ways. For agriculture, we hooked up animals to plows to have the power to grow crops. We still use the unit of the horsepower, for example when we talk about the power of a car engine. We use the sun to grow our crops and heat our homes; we harness the energy of the wind for windmills and to power ships to carry trades and armies all around the world. We harness the energy of water to run watermills to grind grains and power the earliest factories. We learn to release the concentrated energy of coal and petroleum. And this led

us to the industrialized era powered first by coal, and then oil and gas. Starting with WWII, we even learn how to harness the nuclear energy inherent to the very fabric of atomic matter. Whichever type of energy we use, that energy must be available, affordable, and uninterrupted and the decisions regarding its consumption are made at local, national, and international levels.

The demand for energy is here to stay because the two fundamental factors that fuel it are inherent to mankind. These are population growth and economic activities. The world population is increasing at an astonishing rate of 1.1 percent per year or 83 million people per year. It's projected that the current world population of 7.3 billion is expected to reach 8.5 billion by 2030; 9.7 billion in 2050 and 11.2 billion in 2100. Energy is the cornerstone of our survival. Unfortunately, the picture is not perfect considering that each source of energy has its downsides and challenges. Among recent controversies: risk of accidents and leaks posed by offshore drilling, the Keystone pipeline, the Fukushima nuclear plant accident, health and environmental risks of coal mining, hydrologic fracturing, nuclear wastes, rising costs of mineral resources, and rising carbon dioxide levels in the atmosphere.

Overall Risks Presented by Non-Renewable Energy Sources

The oil & gas business is a delicate one. Drilling and completing a shale well brings together heavy equipment and usually heavy men to force steel miles into the earth and then to put more steel, cement, water, sand, and chemicals downhole. The exercise extracts inflammable, undrinkable oil and gas. Moving it, storing it, and refining it so that oil and gas just show up, like the oxygen in the air, when you light your stove or fill up your car relies on infrastructure of varying age and maintenance. Accidents happen. Annoyances occur...Water pollution is not the most common source of local aggravations, but it is the chief risk for people living in areas swept up in a shale boom. (Sernovitz, 2016) There are three main types of fluids that can pollute ground water: chemicals before they are mixed into the flack fluid or used in other oilfield applications; frack flowback, the chemical-treated water injected into the well that returns uphole; and produced water¹. The last, innate to oil and gas reservoirs, contains a lot of salt and also nasties like iron, chromium, and radium, some of which are NORMs – naturally occurring radioactive material. (Fox, Josh)

Many people's lives – many whole companies' existence – are centered on providing tools to safely handle these fluids. And all oil and oilfield service companies have intensive health, safety, and environmental (HS&E) processes and ongoing training to make sure that the fluids are optimally managed and contained. Yet accidents occur. While the industry had developed many solutions for both flowback and produced water, none totally eliminates the possibility of environmentally

¹ Produced water is a term used in the oil industry to describe water that is produced as a byproduct along with the oil and gas. Oil and gas reservoirs often have water as well as hydrocarbons, sometimes in a zone that lies under the hydrocarbons, and sometimes in the same zone with the oil and gas. (Source: Wikipedia)

harmful mistakes. The plastic lining of the open-air pits that store clean water can tear, especially if operators are recklessly stingy and don't construct them properly. Violent storms can cause even perfectly constructed pits to overflow. (Sernovitz, 2016) A company can pay to send oilfield water to privately-owned – or in rare cases, municipal – treatment plants, where the water is cleaned and pumped into the river. Some of those plants are oftentimes doing the same with sewage of us pill-popping, preserving-eating, plastic-loving people. But this strategy puts the onus on those plants to have the right technology and capability to treat the produced water. In Pennsylvania, some municipal treatment plants were unprepared for the six-fold increase in water from the Marcellus boom and didn't have the proper technology to treat the water. (Haliburton Cements Wells) Pennsylvania operators stopped sending water to municipal treatment plants in 2011. (Based on Data from Pennsylvania Department of Environmental Protection) Risks to water come not just from extracting oil and gas. Tanks that store oil at the wellhead can leak. When tornadoes come to places like Oklahoma – and tornadoes love Oklahoma – the tanks can get tossed around like beanbags. Connections between those tanks and trucks can be improperly sealed because a truck driver is thinking about his girlfriend. Trucks can flip over. Additional risks exist in local gathering and distribution systems, in the national oil and gas pipeline networks, and increasingly along rail lines carrying shale oil by – too often tipping and exploding – trains (Sernovitz, 2016)

On the other hand, air quality and community disruption issues have accompanied every oil and gas boom in history. Drilling and fracking rely on convoys of trucks belching diesel exhaust. A modern well pad, according to oil company Encana, requires about 3,000 or so daily truck trips spread over nine months. These trips peak for a couple of weeks at fifty or sixty trucks passing by someone's house each day. (Sider, 2014)

Is this boom-affected air noticeable, annoying, dangerous? The industry reminds people that chefs don't die from being in a kitchen all day, with stove tops constantly burning gas – and converting methane to carbon dioxide and water. But flaring, organic compounds, equipment exhaust, and dust in unusual circumstances can start to add up. A family living sixty miles northwest of Dallas was unlucky enough in 2008 to find their house surrounded by twenty-two new gas wells during the manic period of Barnett Shale boom. In 2014, the family was awarded \$2.9 million in a lawsuit against the oil company most responsible for the drilling because they convinced the jury that the drilling activity – and the wells themselves – had led to migraines, dizziness, nosebleeds, burning throats, and rashes. (Fracfocus, 2015) Oil and gas boom change a place. Some of the changes aren't even quantifiable. Wild animals have traditional roaming areas altered. Livestock are fickle, even if their water isn't polluted. Loud industrial activity can cause stress and neurological or reproductive problems. (Tsai, 2011)

Climate Change

The burning of fossil fuels among other things has dumped many tons of carbon dioxide into the atmosphere, leading to global warming, the loss of ice and glaciers in the far north and everywhere vast changes in our climate system. (Goldstein & Intriligator, 2017) The combustion of fossil fuels releases carbon dioxide (a major “greenhouse” gas) into the atmosphere, and most climate scientists believe that the buildup of those gases is the primary cause of global warming in recent decades. Moreover, many uses of fossil fuels, as well as their extraction from the earth, contribute to air pollution and can cause severe damage to our health and the environment. Responsible stewardship of our planet demands that we find new ways to minimize or eliminate those effects. That goal appears attainable, and considerable progress is already evident. (National Academies Press, 2008)

“It is now more certain than ever, based on many lines of evidence, that humans are changing Earth’s climate. The atmosphere and oceans have warmed, accompanied by sea-level rise, a strong decline in Arctic sea ice, and other climate-related changes. The evidence is clear. However, due to the nature of science, not every single detail is ever totally settled or completely certain. Nor has every pertinent question yet been answered. Scientific evidence continues to be gathered around the world, and assumptions and findings about climate change are continually analyzed and tested. Some areas of active debate and ongoing research include the link between ocean heat content and the rate of warming, estimates of how much warming to expect in the future, and the connections between climate change and extreme weather events.

Climate change means not only changes in globally averaged surface temperature, but also changes in atmospheric circulation, in the size and patterns of natural climate variations, and in local weather. La Niña events shift weather patterns so that some regions are made wetter, and wet summers are generally cooler. Stronger winds from polar regions can contribute to an occasional colder winter. In a similar way, the persistence of one phase of an atmospheric circulation pattern known as the North Atlantic Oscillation has contributed to several recent cold winters in Europe, eastern North America, and northern Asia. Atmospheric and ocean circulation patterns will evolve as Earth warms and will influence storm tracks and many other aspects of the weather. Global warming tilts the odds in favor of more warm days and seasons and fewer cold days and seasons. For example, across the continental United States in the 1960s there were more daily record low temperatures than record highs, but in the 2000s there were more than twice as many record highs as record lows. Another important example of tilting the odds is that over recent decades heatwaves have increased in frequency in large parts of Europe, Asia and Australia.

Is the climate warming? Yes. Earth's average surface air temperature has increased by about 0.8 °C (1.4 °F) since 1900, with much of this increase taking place since the mid-1970s. A wide range of other observations (such as reduced Arctic sea ice extent and increased ocean heat content) and indications from the natural world (such as poleward shifts of temperature-sensitive species of fish, mammals, insects, etc.) together provide incontrovertible evidence of planetary-scale warming. The clearest evidence for surface warming comes from widespread thermometer records. In some places, these records extend back to the late 19th century. Today, temperatures are monitored at many thousands of locations, over both the land and ocean surface. Indirect estimates of temperature change from such sources as tree rings and ice cores help to place recent temperature changes in the context of the past. In terms of the average surface temperature of Earth, these indirect estimates show that 1983 to 2012 was probably the warmest 30-year period in more than 800 years. A wide range of other observations provides a more comprehensive picture of warming throughout the climate system. For example, the lower atmosphere and the upper layers of the ocean have also warmed, snow and ice cover are decreasing in the Northern Hemisphere, the Greenland ice sheet is shrinking, and sea level is rising. These measurements are made with a variety of monitoring systems, which gives added confidence in the reality that Earth's climate is warming." (NAS, 2014)

It is a fact that climate change due to carbon dioxide emissions into the atmosphere (see "*Understanding carbon dioxide*" below) by fossil fuels is a major implication of our demand for energy. According to the International Energy Agency, we face a moment of opportunity, but also of great risk. The world is counting on the UN climate talks in Paris...to achieve a global agreement that puts us on a more sustainable path. As IEA analysis has repeatedly shown that the cost and difficulty of mitigating greenhouse-gas emissions increases every year, time is of the essence. And it is clear that the energy sector must play a critical role if efforts to reduce emissions are to succeed. While we see growing consensus among countries that it is time to act, we must ensure that the steps taken are adequate and that the commitments made are kept. In recent years, progress has been made in developing cleaner, more efficient energy technologies. Indeed, we are seeing signs that economic growth and energy-related emissions – which have historically moved in the same direction – are starting to decouple. The energy intensity of the global economy continued to decline in 2014 despite economic growth of over 3%. But increased effort is still needed if we are to keep open the possibility of limiting the rise in global mean temperature to 2°C. The pledges – or Intended Nationally Determined Contributions (INDCs) – made by individual countries for the 21st UN Conference of the Parties (COP21) in December 2015 determined whether this goal will remain attainable.

Promoting sustainable development and combating climate change have become integral aspects of energy planning, analysis and policy making. Because energy accounts for two-thirds of total greenhouse gas emissions and 80% of CO₂, any effort to reduce emissions and mitigate climate

change must include the energy sector. Global CO₂ emissions remained flat in 2016 for a third consecutive year, although the global economy grew. Changes to the fuel mix and energy efficiency played key roles. Meeting the long-term climate objectives of the Paris Agreement requires urgently tackling energy-related greenhouse gas emissions. Individually and collectively, countries need to define and implement policies for accelerated clean energy transitions that are enabled by real-world solutions, supported by analysis, and built on data. The IEA works with countries across the globe to implement climate-resilient decarbonization pathways.

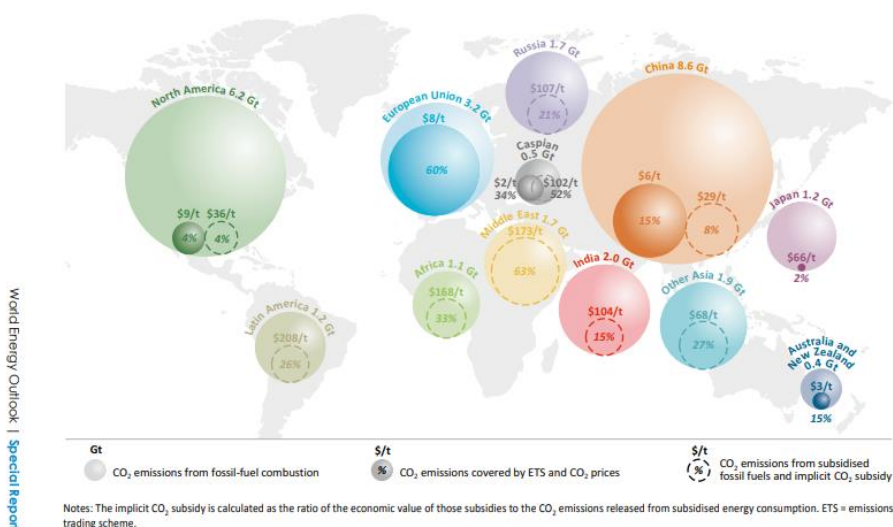
The world is at a critical juncture in its efforts to combat climate change. Since the first Conference of the Parties (COP) in 1995, greenhouse-gas (GHG) emissions have risen by more than one-quarter and the atmospheric concentration of these gases has increased steadily to 435 parts per million carbon-dioxide equivalents (ppm CO₂-eq) in 2012 (EEA, 2015). The International Panel on Climate Change (IPCC) has concluded that, in the absence of fully committed and urgent action, climate change will have severe and irreversible impacts across the world. The international commitment to keep the increase in long-term average temperatures to below two degrees Celsius (2° C), relative to pre-industrial levels, will require substantial and sustained reductions in global emissions. The long lifetime of greenhouse gases means that it is the cumulative build-up in the atmosphere that matters most. In its latest report, the Intergovernmental Panel on Climate Change (IPCC) estimated that to preserve a 50% chance of limiting global warming to 2° C, the world can support a maximum carbon dioxide (CO₂) emissions “budget” of 3 000 gigatons (Gt) (the midpoint in a range of 2 900 Gt to 3 200 Gt) (IPCC, 2014), of which an estimated 1 970 Gt had already been emitted before 2014. Accounting for CO₂ emissions from industrial processes and land use, land-use change and forestry over the rest of the 21st century leaves the energy sector with a carbon budget of 980 Gt (the midpoint in a range of 880 Gt to 1 180 Gt) from the start of 2014 onwards. The carbon legacy that is locked-in by new development of fossil-fueled energy infrastructure underlines the importance that attaches to success in achieving a step change in efforts to contain GHG emissions in the COP21 meeting held in Paris in December 2015.

Greenhouse-gas emissions from the energy sector represent roughly two-thirds of all anthropogenic greenhouse-gas emissions and CO₂ emissions from the sector have risen over the past century to ever higher levels. Effective action in the energy sector is, consequentially, essential to tackling the climate change problem. While OECD countries have accounted for a major share of historical energy-related emissions, this picture has been changing rapidly in recent decades and continues to shift in the INDC Scenario, with the non-OECD share of total global emissions increasing from less than 60% in 2013 to nearly 70% in 2030. In per-capita terms, however, levels in the OECD (7 tons CO₂/capita per year) are projected to still far-exceed the average non-OECD per-capita level – the OECD level being nearly double the non-OECD average in 2030 – although significant national disparities occur within both groups.

“Total final energy consumption in the United States is projected to be at a level similar to 2013 in 2025, while the related emissions decline. In the transport sector, tougher fuel economy standards for passenger vehicles and heavy trucks build on the improvements that have already been achieved, making the sector the second-largest contributor to emissions reductions in the INDC Scenario (310 Mt – 17% – lower in 2025 than 2005). US Corporate Average Fuel Economy (CAFE) standards for PLDVs (54.5 miles per gallon [23.2 kilometers per liter] by 2025) significantly reduce oil demand, while policies to reduce average on-road fuel consumption by trucks help push emissions per kilometer down by around one-quarter, relative to 2013. From 2020 onwards, total transport emissions in the United States decline by around 2% per year, on average. In line with the targets set in the Renewable Fuel Standard Program, demand for biofuels increases by 80% to reach 1.1 mb/d in 2025, of which around 90% is ethanol and the remainder biodiesel. In the same time frame, the United States sees sales of electric vehicles (including plug-in hybrids and battery-electric vehicles) increase to around 1.5 million, while the use of natural gas for fleet vehicles and trucks also sees significant growth from today’s low levels.” (IEA, 2015)

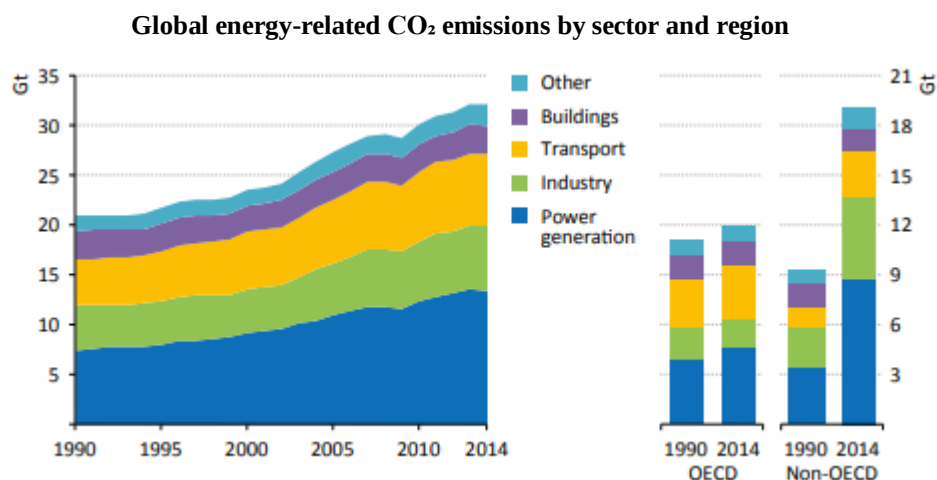
Putting a meaningful price on CO₂ emissions is viewed by many as integral to achieving the 2° C climate goal. The current picture, however, reveals significant challenges relating to the geographic coverage of carbon markets, the prevailing price levels and, in some cases, the need for market reform. Carbon emissions trading schemes in operation in 2014 covered 3.7 Gt (11 %) of global energy-related CO₂ emissions and had an aggregate value of \$26 billion. The average price was around \$7 per ton of CO₂ (see figure below). In contrast, 4.2 Gt (13%) of global energy related CO₂ emissions from the use of fossil fuels receive consumption subsidies, with the implicit subsidy amounting to \$115 per ton of CO₂, on average.

Energy-related CO₂ emissions in selected regions, 2014



The global distribution of GHG emissions has shifted with changes in the global economy. At the beginning of the 20th century, energy-related CO₂ emissions originated almost exclusively in Europe and the United States. This ratio dropped to around two-thirds of total emissions by the

middle of the century and today stands at below 30%. Over the past two-and-a-half decades, global CO₂ emissions increased by more than 50% (see figure below). While emissions increased by 1.2% per year in the last decade of the 20th century, the average annual rate of increase between 2000 and 2014 accelerated to 2.3%, particularly driven by a rapid rise in CO₂ emissions in power generation in countries outside the OECD: since the start of the 21st century, emissions from electricity and heat generation in emerging and developing countries have doubled, with around two-thirds of this increase coming from China. CO₂ emissions from the industry sector in these countries doubled from 1990 to today being driven by large increases in the production of energy-intensive materials, such as cement and steel. In the same period, total CO₂ emissions from the industrial sector in OECD countries fell by a quarter, though these countries still lead global emissions from the transport and buildings sectors. For transport, this is due to the higher level of vehicle ownership in OECD countries even though, over the past 15 years, CO₂ emissions from transport doubled in non-OECD countries as a result both of higher levels of private vehicle ownership and strong growth in freight traffic. For buildings, the higher level of emissions in OECD countries is because most non-OECD countries are located in more temperate climates, requiring lower levels of space heating.



Notes: “Other” includes agriculture, non-energy use (except petrochemical feedstock), oil and gas extraction and energy transformation. International bunkers are included in the transport sector at the global level but excluded from the regional data.

A large share of energy-related CO₂ emissions comes from a small number of countries. In 2012, three countries – China, United States and India – gave rise to almost half of global CO₂ emissions from fossil-fuel combustion, while ten countries accounted for around two-thirds. Since 1990, total emissions in the United States and Japan have increased slightly, while they declined by about a fifth in the European Union. After a fall of almost 30% in emissions from Russia in the early 1990s,

the emissions increase thereafter has remained limited. In 2006, China overtook the United States as the biggest CO₂ emitter, while India overtook Russia as the fourth-largest emitter in 2009.

Even though CO₂ emissions increased almost three-fold in China and two-and-a-half times in India between 1990 and 2014, per-capita emissions in both countries are still below the average level in OECD countries. China's per-capita emissions in 2014 reached 6.2 tons, matching the level of the European Union, but a third lower than the OECD average. India's per-capita emissions were 1.6 tons in 2014, or about 10% of the level in the United States and 25% of the level in China. Significant differences across regions exist, not only in terms of per-capita emissions but also in terms of CO₂ emissions per unit of economic output. While all of the major regions reduced the CO₂ intensity of their economy, China emitted 0.82 tons CO₂ per thousand dollars of economic output in 2014, which compares to 0.3 tons in the United States and 0.18 tons in the European Union.

While the assumptions on economic and population growth are the same, energy price paths vary across the ... scenarios, in part due to differences in the strength of policies to address energy security and environmental challenges, and their respective impacts on supply and demand. The extent of carbon pricing schemes and the level of CO₂ prices vary across the scenarios, according to the assumed degree of policy intervention to curb growth in CO₂ emissions. It is assumed in each scenario that all existing carbon trading schemes and taxes are retained and that the price of CO₂ rises throughout the projection period. In the INDC Scenario, the CO₂ price in the European Union increases from less than \$8/ton in 2014 to \$53/ton (in year-2013 dollars) in 2030, while for China it is assumed that a national CO₂ price is introduced in 2020, rising to \$23/ton by 2030. In the 450 Scenario, it is assumed that carbon pricing is eventually adopted in all OECD countries and that CO₂ prices in most of these markets reach \$140/ton in 2040. Several major non-OECD countries are also assumed to put a price on carbon in the 450 Scenario, with prices rising to a slightly lower level in 2040 than in OECD countries. (International Energy Agency, 2015)

Methane emissions from upstream oil and gas activities in the Middle East are projected to increase from around 235 Mt CO₂-eq (around 25% of the global total) to 295 Mt CO₂-eq in 2030 (around 30% of the global total), linked to significant growth in both oil production (nearly 34 mb/d in 2030) and gas production (765 billion cubic meters in 2030). Efforts, such as those in southern Iraq and elsewhere, are underway to try and capture and utilize associated gas in power generation, petrochemicals and industry.

Greenhouse-gas emissions in Latin America have historically been dominated by land use, land-use change and forestry, and, not wholly unrelated to this, agriculture. Energy related CO₂ emissions in Latin America are significantly lower than the global average, not 64 World Energy Outlook | Special Report only in terms of per-capita emissions, but also in terms of emissions per

unit of economic output. The main reason is the dominance of low-carbon technologies in the electricity mix (particularly hydropower in Brazil), but also the high share of biofuels in the transport sector. The regions' energy sector is becoming a more significant source of emissions growth and will be important in determining whether Latin America can maintain its low carbon profile as domestic energy demand increases rapidly. In the INDC Scenario, energy related CO₂ emissions increase from 1.2 Gt in 2013 to 1.4 Gt in 2030, equivalent to an 18% increase. The emissions increase is largely driven by rising industrial activity, including in steel production and chemicals production, and by higher vehicle ownership. Emissions from electricity generation decrease by around 7% to 2030, as the power sector is able to meet additional demand for electricity through increased generation from hydropower, natural gas and wind. Since 2005, Brazil (the region's largest emitter) has embarked on a large-scale campaign to slow deforestation, with a particular focus on how to contain growth in energy-related emissions. In 2008, Brazil announced a National Energy Efficiency Plan and in 2013 introduced the Inovar-Auto program to increase the efficiency of road vehicles; but these measures are not yet sufficient to tap into the large unrealized energy efficiency potential.

Africa ... accounts for a small share of global GHG emissions: in 2013, the entire continent accounted for just 3% of global energy-related CO₂ emissions, with South Africa accounting for more than one-third of the total. Yet Africa is expected to suffer severely from the impacts of a changing climate. Gabon is the first African nation to submit its INDC, pledging to keep 2025 emissions at least 50% below a business-as-usual (or "uncontrolled development") level, primarily through land management, but also by reducing flaring from the oil and gas sector, boosting energy efficiency, increasing hydropower supply and setting up a domestic carbon offset market. In the INDC Scenario, electricity consumption in Africa doubles from 2013 to 2030, as households purchase more electrical appliances as living standards increase. Around 500 million people are projected to gain access to electricity for the first time by 2030, and the regions' small industrial base expands significantly. Despite this, access to reliable, affordable modern energy remains a major challenge in many parts of the continent, stifling economic and social development. Africa starts to unlock its vast renewable energy resources, with half of the growth in power generation capacity coming from renewables. New hydropower capacity in the Democratic Republic of Congo, Ethiopia and Mozambique, among others, plays a major role in bringing down the region's average cost of power supply. Other renewables, led by solar technologies, make a growing contribution to supply, while geothermal is an important source of power in East Africa.

African energy-related CO₂ emissions are projected to increase by around 40% to 2030, with Nigeria, parts of North Africa, Angola, Mozambique and others contributing to this growth (but often starting from very low levels). Emissions in South Africa are projected to follow a "peak, plateau and decline" trajectory, as announced by the South African government in 2009.

Specifically, emissions peak in the period from 2020 to 2025, plateau for a several years and then start to decline in the 2030s. Key drivers of this trend are improved energy efficiency in end-use sectors and the power sector becoming less dependent on coal, as it turns more towards renewables and nuclear. (IEA, 2013)

Finally, it is important to also acknowledge the importance of methane, along with CO₂, in climate change. “Methane is a powerful contributor to global warming, many times more potent than CO₂. It remains in the atmosphere for a shorter period of time, compared with CO₂, but these characteristics, taken together, mean that reducing methane emissions has the potential to yield a relatively rapid climate response. This is no substitute for long-term measures to cut CO₂ emissions, but the potential to slow the near-term rate of warming means that action to minimize methane emissions plays an important role in our Bridge Scenario. Methane releases to the atmosphere occur both during the production of oil and gas and during their transmission and distribution, in particular in the case of natural gas. We estimate that downstream releases amounted to around 24 Mt in 2013 (710 Mt CO₂-eq), or 42% of methane emissions from the oil and gas sectors. Methane leakages from natural gas pipelines are largest in the United States, Russia, the Middle East and China (which are the countries with the largest pipeline networks), particularly where the pipelines are old or poorly maintained. The main causes of leakage are the high permeability of some pipeline materials (the oldest pipelines are more than 100 years old and made of cast iron), maintenance activities and incidents due to corrosion, damage or equipment failure.

Now, other than health and environmental concerns, why should we be concerned about climate change due to the use of biofuels? “Identified concerns about climate-national security linkages, and associated research areas and needs, can be divided into two categories.

First, both climate change and efforts to respond to it may have significant effects on the operations, assets, and missions of the U.S. military. Many U.S. bases are located in areas that may be affected by sea level rise and tropical storms, and some future military operations may take place in areas subject to extreme high temperatures and droughts, compounding logistic problems. U.S. military operations are also substantial consumers of fossil fuels and thus will be affected by shifts in fuel prices and availability, as well as new technologies intended to displace fossil fuels.

Second, the impacts of climate change on specific assets and resources of international significance may affect multiple issues in bilateral and multilateral relations, shifting national strategic interests or perceptions thereof, or providing new bases for international conflict or cooperation. For example, declines in sea ice thickness and extent could result in increased access to and conflict over offshore resources in the Arctic Ocean associated with the opening of the Northwest and Northeast passages. Other examples include the effects of sea level rise and extreme events on

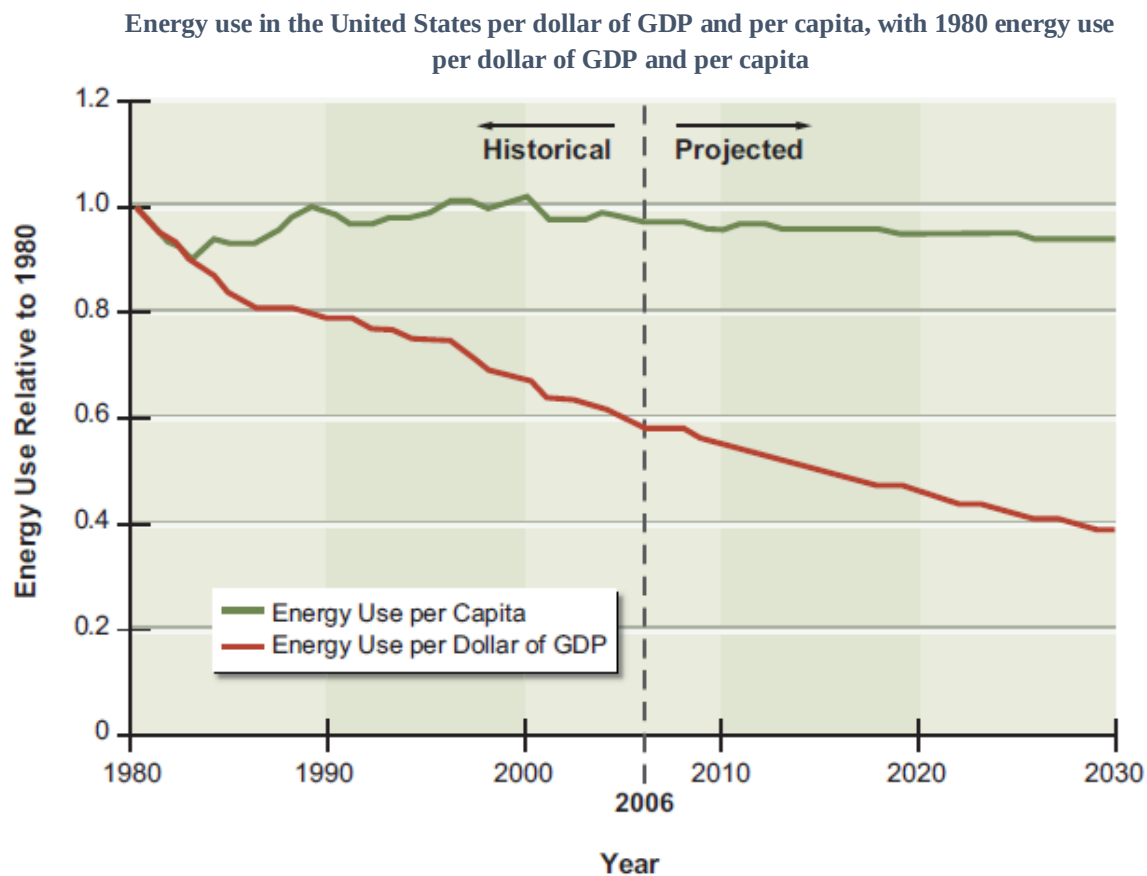
coastal ports, navigable waterways, runways, roads, canals, or pipelines of international significance; changes in precipitation regimes that affect international river systems and ground vehicle mobility; and increases in humanitarian aid/disaster response stemming from changes in climate extremes.” (NAP, 2010)

It's important to note that climate change could also “trigger a massive reduction in global population. People need land, water, food, and shelter and often satisfy these needs by destroying wild nature. But it is not just a matter of sheer numbers, for the amount of resources consumed by each person is what really makes a difference to our impact on the planet. Paul Ehrlich devised his famous $I = P \times A \times T$ equation (pronounced IPAT) to make this point” (O'Neill et al., 2004). I stands for impact, P for population, A for affluence, and T for technology. Human impact is a product of the last three terms, so that it is possible to have a high population, so long as people do not overconsume. In the current economic climate, all the terms on the right-hand side of the equation are increasing alarmingly. Today's, the world's middle-class numbers about 20 percent of the population but consumes about 80 percent of the available resources. (Crist & Rinker, 2010)

The replacement of ageing infrastructure can make a major difference to the incidence of leaks but is a challenging and expensive task. Significant improvements can be made by using materials with lower permeability (such as polyethylene) wherever possible and optimizing the network to reduce the number of joints (i.e. the area most vulnerable to leakage). Emissions during maintenance are often unavoidable but can be mitigated through the flaring of the leaked methane. Reducing the incidence of leakage is a continuous challenge, involving regular monitoring and efficient and prompt responses. The benefits have been documented in a study in 2015, sponsored by the US Environmental Defense Fund and various downstream operators, which included bottom-up measurement of thirteen urban US distribution systems. The study produced estimates for downstream emissions from 36% to 70% lower than data from the 2011 EPA inventory, with the decrease attributed to better maintenance activities and improved infrastructure components. Preventing methane leakage is in the first place a matter of safety, as the accumulation of gas leaked from pipelines can lead to explosions and is therefore particularly dangerous in urban distribution networks. Regulation to ensure proper maintenance of pipelines for safety reasons can have important co-benefits for the climate (measuring the gas amounts between inlet and outlet stations can help identify major leaks, if the relevant metering stations are in place). But beyond the assumption of regular maintenance schedules, no major pipeline rehabilitation is included in the Bridge Scenario, since this can easily take between 10 to 15 years to implement, involving major investment and large construction works.” (IEA, 2015)

The Economics of Energy

The world is in economic crisis, and there are easy fixes to our predicament. Unsustainable trends in the economy, energy, and the environment have finally caught up with us and are converging on a very narrow window of time...As a society, our imagined responses to the future make the implicit assumption that we will always remain within a complex economy that is capable of operating in an effective and orderly manner...What if this assumption is untrue? and that the economic status quo cannot be taken for granted, at least not in the form to which we've become accustomed? Our money system places impossible demands upon a finite world. Exponentially rising levels of debt, based on assumptions of future economic growth to fund repayment, have shuddered to a halt and are reversing, with severe and lasting consequences. Oil is essential for economic growth. The reality of dwindling oil supplies is now internationally recognized, yet virtually no developed nations have a plan B. the economic risks to individuals, companies, and countries are varied and enormous. Best case: living standards will drop steadily worldwide. Worst case: systemic financial crises will toss the world into jarring chaos. (Martenson, 2011)



“The system of production and use of oil is a classic oligopoly, with a few suppliers and many, many users. That is true of the companies that extract oil, the countries that have oil and even of natural gas, an important substitute for oil. In the United States, attempts to break up the largest oil producing entities have met with mixed success. In today’s world, the demand for energy is mainly from industry, both public and private, although there is also a smaller and not inconsequential demand from households and governments. Since energy is fundamental to the operation of industry, its demand is relatively price inelastic, which means that changes in the prices of various energy sources have relatively little effect on their demand. In other words, prices can vary over a wide range, but demand stays relatively constant. The demand for energy is also income inelastic in that the users of energy, mainly industry, do not change their use of energy over wide ranges of their income.

Economists refer to the demand for energy as a ‘derived demand’, meaning that it stems from the demand for the products produced by this energy. Thus, the demand for coal is largely a derived demand stemming from the demand for electricity since most electricity is produced in coal-fired power plants. In general, the demand for energy has been steadily increasing, and this is expected to continue given the rising demand for products that use it, including heating and transportation – the primary use of oil and gas – and electricity – the primary use of coal. Estimates of future world demand for these fuels depend on projection of economics growth, which are intrinsically subject to uncertainty. Nevertheless, it is clear that a major challenge will be to find new energy sources, as well as devising new technologies to enhance their production and use to meet rising global energy demand.

The supply of energy depends on its production, which varies depending on whether it is in the form of fossil or renewable fuels. The supply of fossil fuels is subject to what economists call ‘increasing returns to scale’, meaning that doubling that the various inputs – including capital, labor and energy – in a commodity’s production more than doubles its output. As a result, most of these fuels’ production is concentrated in the hands of a few, very large producers that have acquired substantial political as well as economic influence. As these producers expand their output to meet rising demand, they have been compelled to invest increasing resources in the quest for and production of fossil fuels. Oil, for example, which was once relatively easy to discover and extract, is now considerably less plentiful and, relatively, much harder and costlier to find and extract. Oil rigs have had to go offshore and drill to greater depths in more and more remote and risky locations, with all the attendant potential environmental hazards. We saw this in the 2010 Gulf of Mexico Deep Horizon massive oil spill. Other such spills, even much larger ones, could well occur worldwide, such as in the Arctic region as drilling expands there. A spill in this region would be a much more serious problem and one much more difficult to treat than the one in the Gulf of Mexico.

Similar considerations apply to coal. Although the innovation of mountaintop removal has partially changed the economics of coal production, this development has come at the cost of negative and even disastrous environmental impacts. Natural gas is relatively plentiful worldwide, but, as with oil, producers have had to obtain it from increasing remote locations. This has required them to make major investments in pipeline construction and technology, thus raising its cost. These costs are passed on to consumers, as is the case with the costs of other technologies for energy production.

As regards to renewable fuels, there are very substantial fixed costs in developing these fuels for operational use, whether in the form of dams for hydro (water) power, nuclear power plants, solar collecting arrays, turbines for windfarms, etc. these costs have to be repaid in the process of supplying the associated energy; and the payback period, the time when these fixed costs are finally covered, tends to be very long indeed.” (Goldstein & Intriligator, 2017)

From 2002 to 2012, the oil business experienced a Golden Decade. In the first part of the decade, with the economy rising everywhere, global oil prices quadrupled, and U.S. gas prices tripled. In 2008, just as that commodity-price-driven wealth creator for the industry ended with the global recession, the U.S. oil and gas renaissance expanded in the best and biggest of the basins. This renaissance created mountains of wealth for the oil industry completely unrelated to the causes in the first six and a half years, except as far as the rising prices from that first half of the decade had encouraged the experimentation of the second. Indeed, the second half of the Golden Decade killed off the first half, as swelling production volumes had...already crashed natural gas prices and capped the prices of oil. From 2000 to 2007, U.S. oil production steadily declined at 2 percent per year and gas production at 1 percent. From 2007 to 2014, oil production grew at an 8 percent annual rate and at nearly double that pace in 2012, 2013, and 2014. Gas production grew more slowly, at 4 percent per year, only because of limited demand. These old and new trends mean that in eight years, the United States produced about 6 billion barrels of oil and 28 trillion cubic feet of gas more than it would have, had we continued on our old trajectory. (Sernovitz, 2016)

And then, the shale revolution came. By year-end 2014, the United States’ 48 billion barrels of proved oil reserves were 57 percent higher than five years earlier. Its 345 trillion cubic feet of proved natural gas reserves were 67 percent higher than at the start of the shalemania in 2005. (British Petroleum, 2015) And that’s just proved reserves. Research firm ITG estimated in 2015 that the total “resource” extractable in the continental United States alone, across reserve categories and at reasonable long-term prices, was 1,440 cubic feet of gas (fifty-four years of domestic consumption) and 123 billion barrels of oil (eighteen years of consumption) (ITG, 2015)

In 2014, in the United States, one third of the gas consumed was used by powerplants to generate electricity. A slightly higher amount was burned to heat homes and offices. A slightly lower

amount was used for industrial use, such as fuel to manufacture glass or as direct feedstock to make plastics and fertilizers. Transportation here consumed an insignificant amount of gas, mainly in gas-powered buses and other fleet vehicles but also in a few cars owned by half-crazy-half-brilliant guys who also, for convenience, wear the same blue outfit every day. (Sernovitz, 2016) The three-demand sources that gas producers' mouth water with possibilities of higher sales and potential higher prices are more use by the chemical industry, more liquefied natural gas export, and higher consumption by power plants. There are two particular reasons for enthusiasm for the last source. Gas-fired power plants tend to be used, for technical reasons, at peak time when an area needs more electricity. In 2012, U.S. gas-fueled generators, operating part-time, produced only 29 percent of the power they could have at theoretical full capacity... Though the combination of gas gaining market share on price and the opposition to coal on local and global environmental concerns, the United States used 17 percent less coal in 2014. In April 2012, perhaps in an unwitting nod to Earth Day, we consumed less coal than any month since May 1981, when there were 84 million fewer Americans. (EIA, 2015)

Analysts at the Boston Consulting Group put cheaper gas as one of the four key factors that rebalanced global manufacturing costs. From 2004 to 2014, according to its research, U.S. natural gas costs fell by 25 percent and electricity costs rose by 30 percent. In the rest of the world's twenty-five largest economies, gas prices doubled, and electricity costs rose 75 percent. Of the world's ten largest exporters, only China and South Korea still have any cost advantage over the United States – and China, broadly speaking, by only 5 percent. (Sirkin et al., 2014)

The U.S. shale revolution has scrambled the economies, national budgets, and influence of all thirty of the major exporters as well as dozens of smaller ones, like South Sudan. The scale of U.S. fracking's influence on other countries is partly due to the asymmetry of oil and gas's importance in any nation's welfare. To oil and gas importers, import prices and volumes will influence economic health. Extreme high prices can send countries into recession. But oil and gas import levels over the long term rarely determine importers' existential state. A trillion dollars of oil and gas exports, after all, is equivalent to only 1.3 percent of the global economy. (Morse et al., 2012) To oil and gas exporters, however, the revenue from hydrocarbons is sometimes the determining factor of the country's economic health and its rulers' political legitimacy. Oil and gas represented 68 percent of Russia's export revenue in 2013 and 95 percent of Nigeria's. (Canadian Association of Petroleum Producers, 2015)

There is another asymmetry. The shale revolution's lower global oil and gas prices are unsettling international relations far more than its volumes, whether we are buying specific barrels from specific enemies or friends. Crude oil is easy to transport. In a balanced market, it will find a customer, with regional pricing adjusting. The United States, in 2014, imported 21 percent less oil from Saudi Arabia than it did in 2007, but Saudi Arabia produced 12 percent more oil than seven

years earlier. (Tarr et al.) As energy scholar Michael Levi has pointed out, when oil price spikes can't crash the economy, the flexibility of American foreign policy increases. In 2013 and 2014, the United States implemented sanctions against Russia for annexing Crimea, did not intervene in a chaotic civil war in Libya, and led the tightening of global sanctions against Iran. Oil prices barely budged in response to any of these actions – or nonactions – even though those three countries produced one-fifth of the world's oil. (Bureau of Labor Statistics, 2015)

As you can see from the above arguments, the economics of energy is complicated because we're dealing with more than one source of energy. This complexity gives rise to implications that are equally sophisticated and multipronged. The fallouts of the energy crisis are financial, social, ethical, and, of course, environmental. National Academy of Sciences et al. (2010) summarizes the issue best by saying that energy, which has always played a critical role in our country's national security, economic prosperity, and environmental quality, has over the last two years been pushed to the forefront of national attention as a result of several factors:

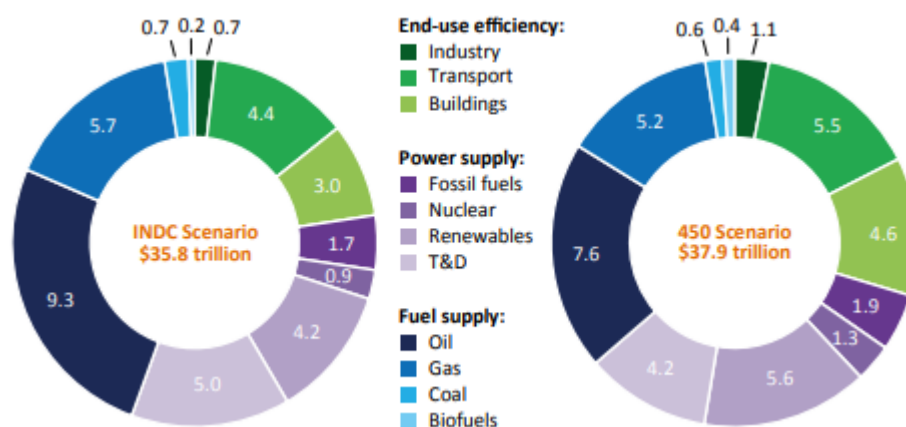
- World demand for energy has increased steadily, especially in developing nations. China, for example, saw an extended period of double-digit annual increase in economic growth and energy consumption.
- About 56 percent of the U.S. demand for oil is now met by depending on imports supplied by foreign sources, up to 40 percent in 1990.
- The long-term reliability of traditional sources of energy, especially oil, remains uncertain in the face of political instability and limitations on resources.
- Concerns are mounting about global climate change – a result, in large measure, of the fossil fuel combustion that currently provides most of the world's energy.
- The volatility of energy prices has been unprecedented, climbing in mid-2008 to records levels and then dropping precipitously – in only a matter of months – in late 2008.
- Today, investments in the energy infrastructure and its needed technologies are modest, many alternative energy sources are receiving insufficient attention, and the nation's energy supply and distribution systems are increasingly vulnerable to natural disasters and acts of terrorism.

According to the International Energy Agency, the transition away from fossil fuels is gradual in the INDC Scenario, with the share of fossil fuels in the world's primary energy mix declining from

more than 80% today to around three-quarters in 2030. World demand for coal shows signs of reaching a plateau by around 2020; but there are differing trends across OECD and non-OECD regions, with the former declining and the latter continuing to increase. Global emissions from coal use increase only slightly, relative to today, and are around 14.5 Gt in 2030. Global oil demand reaches 99 million barrels per day (mb/d) in 2030, around 9% higher than today, with actions in the INDC Scenario helping to slow demand growth in the transport sector. World natural gas demand increases by around 30% by 2030, helping to suppress growth in emissions when acting as a substitute for other fossil fuels but adding to emissions when acting as a substitute for renewables and nuclear. By 2030, coal accounts for 41% of energy-related CO₂ emissions, oil for 34% and natural gas for 25%. While significant hydropower potential remains in some regions, the global expansion of hydropower capacity is relatively modest. Solar and wind capacity increase more rapidly. All low-carbon options collectively account for around one-quarter of primary energy demand in 2030.

Neither the scale nor the composition of energy sector investment in the INDC Scenario is suited to move the world onto a 2 °C path. Cumulative investment in fossil-fuel supply accounts for close to 45% of the energy sector total, while low carbon energy supply accounts for 15% (See figure below). Global investment in fossil-fueled power generation capacity declines over time, to stand at around \$100 billion in 2030, but investment in coal-fired plants still accounts for more than half of the total at that time. Investment in renewable-based power supply remains relatively stable over the period to 2030, averaging \$260 billion per year, with ongoing reductions in unit costs masking higher levels of deployment. Global investment in nuclear power remains concentrated in just a few markets. On the demand side, around \$8 trillion is invested in energy efficiency from 2015 to 2030 in the INDC. One-third of this is spent by motorists on more efficient cars, while more than another third are on improved efficiency in buildings (mainly insulation, efficient appliances and lighting) and the rest is split between energy efficiency in industry and road freight.

Cumulative global energy sector investments by sector in the INDC and 450 Scenarios, 2015-2030 (trillion dollars, 2013)



Note: T&D is transmission and distribution.

Source: IEA

In the INDC Scenario, energy supply investment in the United States averages around \$255 billion per year through to 2025, nearly 30% higher than the average since 2000. This reflects the need to replace ageing power plants that are due to retire and a continuation of the shift in power sector investment (\$86 billion per year to 2025) away from coal and towards gas and renewables. Upstream oil and gas continue to require significant investment (around \$125 billion per year collectively), while coal supply investment gradually declines. Projected investment in energy efficiency (around \$100 billion per year) is a clear step up from historical levels. Efficiency investment increases in industry, but investment in CCS² does not grow significantly by 2025. Efficiency investments in transport double over the period to 2025, while investments in buildings increase even more rapidly, accounting for around 55% of all efficiency investments in the United States to that year.

On the other hand, energy demand has grown strongly in the Middle East in recent years, but often with important distinctions between major energy exporters (such as Saudi Arabia, Qatar, Kuwait and others), and smaller energy exporters or importers in the region. Can policymakers get spiraling energy demand growth under control. Emissions growth is high in industry, both due to low energy prices encouraging the growth of energy-intensive industries (foremost the petrochemical industry) and wasteful use of energy because of the extent of fossil-fuel subsidies. Although Saudi Arabia announced fuel-economy standards for imported vehicles in 2014, average fuel consumption per vehicle in the Middle East is projected to remain the highest in the world in 2025. Energy demand growth in buildings is less than in other sectors, as several countries in the region introduce thermal insulation standards for new buildings and minimum energy performance standards for air conditioners (by far the largest source of electricity consumption).

² Carbon capture and storage

Despite electricity demand increasing by around 75% from 2013 to 2030, emissions increase by only around 15%, as the power sector shifts from inefficient oil-fired power plants to gas-fired power plants and low-carbon technologies. Some countries in the region have targets and policies in place to expand low carbon sources in the power sector (such as Saudi Arabia, Kuwait, and Dubai), but progress has typically been limited so far.

“In the near future, humanity as a species will have to grapple with a condition that it has never faced before: less and less energy will be available each year. In the past, there was always another continent brimming with energy resources to tap; another well that could be drilled; more hydrocarbon wealth that could be brought up from the depths. We have always had access to increased resources when we wanted them, and during that long run of history, we have fashioned an enormously complicated society and global economic model around the idea that there always would be more.

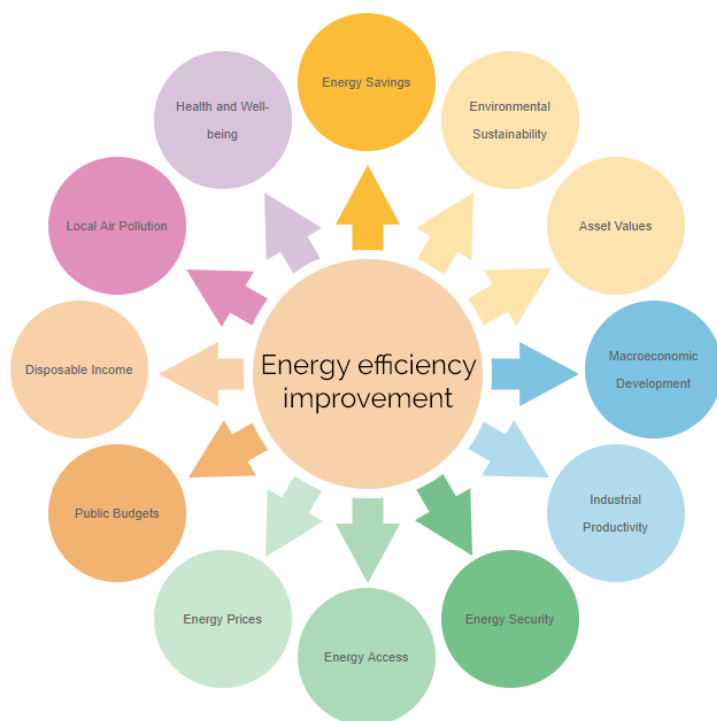
Along the way, we move from burning wood to burning coal, then to whale oil, and then to petroleum. The unanswered question is this: *After oil, what comes next?* What is the next source of energy? Nobody has a truly viable answer for that as we cross the threshold of Peak Oil, a concept that represents the moment after which slightly less and less energy comes up out of the ground for us to use as we wish. Many hold out hopes that technology will ride to the rescue, perhaps in the form of nuclear power, natural gas, or alternative sources of energy. But the issue of time, scale, and cost loom large, because we have taken so long to finally recognize the imminence and severity of the petroleum predicament.

With a peak in energy extraction, a host of environmental issues suddenly come into play. Agricultural soils that were forced to produce higher yields via the continuous application of fertilizers derived from fossil fuels will turn out to have been fundamentally depleted. Minerals of increasingly dilute concentrations that require more and more energy to produce will suddenly cost exponentially more each year to extract and process. Where markets once allocated our energy resources according to ability to pay, true scarcity will soon form the dividing line between economic progress and decline for the world’s nations. How soon will all of this happen? If not this year, then, within 20 years, which is a blink of an eye given the scale and scope of the potential disruptions implied by this structural shift.” (Martenson, 2011)

What Is Energy Efficiency?

Energy efficiency is often defined as achieving the same services with less energy. This definition grossly understates the power of energy efficiency to provide benefits beyond energy savings for

society and for the economy. The IEA study of the multiple benefits of energy efficiency seeks to



Source: IEA, 2014

expand the perspective of energy efficiency beyond the traditional measures of reduced energy demand and lower greenhouse gas (GHG) emissions by identifying and measuring its impacts across many different spheres. By revealing the potential of energy efficiency to support economic growth, enhance social development, advance environmental sustainability, ensure energy-system security and help build prosperity, this work repositions energy efficiency as a mainstream tool for economic and social development.

Early investigations of these multiple benefits suggest that they are significant, however they are left out of most policy and program evaluations for various reasons, including lack of relevant data and evaluation methods, estimation challenges and perceived credibility risk. A multiple-benefits perspective helps to understand the impacts, as well as the sources and causes, of an observed rebound effect and accordingly to manage better any trade-offs that might take place. The term "multiple benefits" aims to capture a reality that is often overlooked: investment in energy efficiency can provide many different benefits to many different stakeholders. In other literature, the multiple benefits of energy efficiency have been variously labelled "co-benefits", "ancillary benefits" and "non-energy benefits" – terms often used interchangeably with "multiple benefits". The IEA uses the term multiple benefits, which is broad enough to reflect the heterogeneous nature of outcomes of energy efficiency improvements and to avoid pre-emptive prioritization of various benefits; different benefits will be of interest to different stakeholders. The IEA's Efficiency Exchange Platform contains up-to-date information on the multiple benefits, including reports and case studies. (International Energy Agency, 2014)

There is always a cost factor associated with energy efficiency. To understand energy efficiency, it is important to first make sense of what is called levelized cost of electricity (LCOE) which is defined as the average cost of generating a unit of electricity over the generating facility's service life. The LCOE is computed by dividing the present value of the estimated full life-cycle costs of the generating facility by its estimated lifetime electricity production. The result is usually expressed in terms of cents per kilowatt-hour. The full life-cycle costs of the generating facility include: 1) capital costs for construction; 2) financing costs; 3) operations and maintenance costs; 4) fuel costs; and 5) decommissioning costs.

Facility lifetime is typically taken to be between 20 and 40 years, depending on the generating technology. The LCOE is less than the cost of electricity to the consumer (i.e., less than retail price) because it does not include the costs of transmission and distribution or the electricity generator's profit. These additional costs can typically add several cents per kilowatt-hour to the wholesale cost of electricity.

So, what does it mean for something – be it a machine, a home, an appliance – that uses energy to be energy efficient? First, we need to figure out how much energy we actually use. The current amount is so large it's hard to fathom. A commonly number for our total human energy consumption is 18 Terawatts (TW) (1 Terawatt = 1 trillion Watts). Let's figure it out. Watt (W) is the unit of power or rate of energy use per time. $1W = 1 \text{ joule} / \text{second}$. The Joule is the standard unit for energy. What makes it difficult to define is that most of us don't have a sense of how much energy this is. $1 \text{ joule} = \text{lifting an apple to the height of 1 meter}$. If you do it every second, that's 1 Watt. So, $1W = \text{lifting 1 apple 1 meter} / \text{second}$. If you have 60 people doing it at the same time, that's the equivalent of one 60W light bulb. 18TW is 18 trillion apples lifted 1 meter each second. Lift an apple 1 meter per second, and you'll find out how tiring it is after a while. Part of the reason is because you also lift the weight of your arm. This applies to the part of all types of energy called efficiency. No form of energy is 100% efficient. It can't be. It would break all the laws of thermodynamics. There is always energy lost to friction and heat. We strive to reduce that heat loss to make the energy as efficient as possible. The 18TW of energy is on a planetary scale. Our planet does have abundant sources of energy. We just happen to use them in inefficient ways. The way our cities are built make them energy-inefficient. That is because they have been built slowly, over time, without the awareness of energy efficiency. Inefficient means expensive. Making buildings energy efficient comes with a hefty price tag, which explains the growing market in that sector. That is tantamount to retrofitting our planet while living on it. That is all possible. New energy efficient houses can be built, old gas-guzzling cars can be replaced by new light weight carbon fiber electric cars, teleconferences will eventually prevent people fly on airplanes for unimportant meetings.

Energy efficiency is not to be confused with energy conservation, which is usually understood to mean action taken to reduce the amount of energy used by changing behavior such as turning off personal computers when not in use or setting back the thermostat in winter. It can also involve using technologies, such as room occupancy sensors for lighting, which reduce energy use without someone having to remember to turn off the light. (National Academy of Sciences, 2010) The potential for increasing energy efficiency – that is, for reducing energy use while delivering the same energy services – in the United States is enormous. Technology exists today or is expected to be developed over the normal course of business between now and 2030, that could save about 30 percent of the energy used annually in the buildings, transportation, and industrial sectors. These savings could easily repay, with substantial dividends, the investments involved. In particular, if energy prices were high enough to motivate investment in energy efficiency or if public policies had the same effect, energy use could be lower by 15 – 17 quads (about 15 percent) in 2020 and 32 – 35 quads (about 30 percent) in 2030 than the reference case projection of the U.S. Department of Energy’s Energy Information Administration (EIA). The opportunities for achieving these savings reside in hundreds of technologies, many of them already commercially available and others just about to enter the market. (National Academy of Sciences et al., 2009)

Furthermore, the challenge is to transform the U.S. energy system in a manner that increases its sustainability, supports long-term economic prosperity, promotes energy security, and reduces the adverse environmental impacts arising from energy production and use. Such a transformation could, for example, promote sustainability by using energy more efficiently and increasing the use of renewable-energy sources; support long-term economic prosperity by ensuring the availability of adequate supplies of energy; improve energy security by decreasing the nation’s reliance on petroleum imports; and reduce adverse environmental impacts by reducing CO₂ emissions to the atmosphere.

Concerns about the sustainability, security, and environmental impacts arising from energy production and use have reflected in the agendas of all US presidents since Franklin D. Roosevelt. Such concerns were reflected, for example, in:

- Richard Nixon’s “Project independence” (1974)
- Gerald Ford’s “Energy Independence Act” (1975)
- Jimmy Carter’s “National Energy Plan” (1977)
- Ronald Reagan’s “Energy Security” report (1987)
- George H.W. Bush’s “National Energy Strategy” (1991)
- Bill Clinton’s “Federal Energy R&D³ for the challenges of the 21st Century” report (1997)
- George W. Bush’s “Reliable, Affordable, and Environmentally Sound Energy for America’s Future” report (2001).
- Barack Obama’s American Recovery and Reinvestment Act of 2009⁴

³ R&D: Research & Development

⁴ The Recovery Act also invested \$2 billion in battery and electric drive component manufacturing, supporting 20 batteries and 10 component manufacturing factories. Those investments, at full scale, will support factories with the capacity to supply more than 500,000 electric drive vehicles.

Energy Security

The IEA defines energy security as “the uninterrupted availability of energy sources at an affordable price”. Energy security has many dimensions: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and sustainable environmental needs. Short-term energy security focuses on the ability of the energy system to react promptly to sudden changes within the supply-demand balance. Lack of energy security is thus linked to the negative economic and social impacts of either physical unavailability of energy, or prices that are not competitive or are overly volatile.

In cases such as the international oil market, where prices are allowed to adjust in response to changes in supply and demand, the risk of physical unavailability is limited to extreme events. Supply security concerns are primarily related to the economic damage caused by extreme price spikes. The concern for physical unavailability of supply is more prevalent in energy markets where transmission systems must be kept in constant balance, such as electricity and, to some extent, natural gas. This is particularly the case in instances where there are capacity constraints or where prices are not able to work as an adjustment mechanism to balance supply and demand in the short term. Ensuring energy security has been at the center of the mission of the IEA since its inception.

“To understand the threats to international energy security, one must take into account the possibilities of oil disruptions, the issues that arise from growing dependency on natural gas, our relations with Middle East (the principal source of oil) and the possibility of a major loss of supplies. Each of these issues deserve careful study.” (Goldstein & Intriligator, 2017)

“Two profound questions loom over all other energy concerns: Will we have enough affordable energy in the near future? What will we do for the long term? The answers depend on our inventory of sources. At present, oil accounts for 40% of total energy consumption in the United States. Coal provides 23% and natural gas provides 22% of our energy. Another 8% comes from nuclear power plants. Renewable energy sources round out the roster, accounting for 7% of consumption—mostly as the result of hydropower investments made in the last century and the use of biomass (organic matter such as wood, municipal waste, and agricultural crops) for energy production. Those sources and their proportions will have to change eventually, since the planet’s known supplies of fossil fuels are limited. But during the next couple of decades, the nation’s energy menu is unlikely to be substantially different from today’s—assuming “business as usual” conditions. That may be a lot to assume: Energy prices and availability aren’t solely determined by the size of the supply. They’re also affected by the economy, possible new laws and regulations governing energy choices (such as emissions of carbon dioxide and other gases), worldwide demand, the policies and political stability of petroleum-rich nations, lifestyle that can be done locally to

increase the oil supply. U.S. domestic production of crude oil peaked around 1970 at about 9.5 million barrels per day (MBD) and had declined to 5.1 MBD by 2006. Today America imports almost two-thirds of its oil from a handful of nations. The Energy Information Administration (EIA), a U.S. government agency that provides official energy statistics and forecasts, expects U.S. production of oil to remain approximately constant through 2030, while imports are projected to rise gradually to about 70% of consumption.

So, the basic question remains: How long can we maintain our petroleum dependency? The EIA cites known conventional oil reserves at more than 1.3 trillion barrels worldwide, and the U.S. Geological Survey estimates that there may be another 600 billion barrels undiscovered to date. At present, total world consumption is approximately 85 MBD, 21 million of which is used by the United States. The nation's dependency on oil and the rapidly rising demand for oil in other countries, such as China and India, are heightening concern that we will reach a point where the oil supply can no longer be increased to meet projected demand. While this will certainly be true eventually, there is no consensus as to whether we are already entering that period, or it is decades away. Pinning down an exact time frame is nearly impossible as estimates of the amount of "recoverable" oil available can change depending on new discoveries, technological developments, and price.

Efforts are already well under way to find suitable alternatives to oil. In the short term, the leading liquid substitute is ethanol ("grain alcohol"), now chiefly made from corn. The federal government has an aggressive program to encourage its production. As a result, in 2005 about 4 billion gallons of fuel ethanol mixed with gasoline hit the domestic market. But in the same year, the United States consumed about 140 billion gallons of gasoline and 40 billion gallons of diesel fuel, so ethanol accounted for only a small percentage of the total gasoline pool. " (National Academies Press, 2008)

"The security and sustainability of our nation's energy system have been perennial concerns since World War II. Indeed, all postwar U.S. presidents have focused some attention on energy-supply issues, especially our growing dependence on imported petroleum and the environmental impacts of fossil fuel combustion—the latter including the direct effects of pollutant emissions on human health and, more recently, the impacts of greenhouse gases, particularly carbon dioxide (CO₂), on global warming. The United States has made a great deal of progress in reducing traditional gaseous and particulate emissions (e.g., SO_x, NO_x) through regulatory controls and the technology improvements that have followed. But greenhouse gas emissions are only beginning to be addressed in any meaningful way. The United States also needs to lower its dependence on fragile supply chains for some energy sources, particularly petroleum at present and possibly natural gas in the future, and to avoid the impacts of this dependence on our nation's economy and national security. As a result of these and other factors, such as the nation's increasingly vulnerable

transmission and distribution systems, there has been a steadily growing consensus¹ that our nation must fundamentally transform the ways in which it produces, distributes, and consumes useful energy. Given the size and complexity of the U.S. energy system and its reach into all aspects of American life, this transformation will be an enormous undertaking; it will require fundamental changes, structural as well as behavioral, among producers and consumers alike. This report lays out the technical opportunities, the uncertainties, and some of the costs and benefits of initiating this transformation in earnest. Given the massive installed base of long-lived energy production and distribution assets, together with a certain inertia—caused by uncertainties with respect to new technologies and regulations and by the generally slow pace of change in existing industrial practices, public policies, and consumer habits—the challenge that the nation faces not only is great but also will not be met overnight. As a result, a meaningful and timely transformation to a more sustainable and secure energy system will likely entail a generation or more of sustained efforts by both the public and the private sectors.” (National Academy of Sciences, 2009)

The ability to respond collectively in the case of a serious oil supply disruption with short-term emergency response measures remains one of the core activities of the IEA. The long-term aspect of energy security was also included in the Agency’s founding objectives, which called for promoting alternative energy sources in order to reduce oil import dependency. The IEA continues to work to improve energy security over the longer term by promoting energy policies that encourage diversification, both of energy types and supply sources, and that facilitate better functioning and more integrated energy markets.

Energy security can also be meant in the sense of safety. In that regard, especially at a national level, it’s important to note that “in addition to reactor accidents, after the attacks of September 11, 2001, terrorist threats to nuclear power plants have become a concern. As noted above, the primary concern is that a terrorist attack on a nuclear reactor might result in a radioactive release to the surrounding area. Every U.S. nuclear plant has a security plan that must be approved by the USNRC to respond to an attack at the level of the Design Basis Threat (DBT)⁷² or below. The details of the DBT are not available to the public, but it is described as an attack carried out by a well-armed land force aided by a knowledgeable insider. The plants defend against this threat primarily through the use of a layered security system involving access controls and requirements, physical barriers (including standoff protection for bombs), armed guards, and armored firing positions. Attacks that are beyond the DBT are also a concern, including, in particular, air attacks.

The industry and its regulator (the USNRC) have stated that defending against these types of attacks is the federal government's responsibility,⁷³ not that of the plant operator.

Since the September 11, 2001, attacks, the USNRC and the nuclear industry have undertaken analyses of existing plants to determine their vulnerability to aircraft attacks and have made modifications to the designs and operations to mitigate the consequences of such attacks. In addition, the DBT has been increased in severity, with the result that the capacity to withstand terrorist attacks of all types has been enhanced. U.S. plant operators report that they have spent in excess of a billion dollars on physical upgrades and security since September 11, 2001 (www.nei.org/keyissues/safetyandsecurity/factsheets/powerplantsecurity; accessed July 2009). These include changes to plant access controls, operating procedures, and other security measures. The details of these analyses and modifications have not been released to the public (due to security concerns), and the committee has not reviewed this information." (NAS, 2009)

Energy security is all the more important if we want to prevent an incident similar to the Northeast blackout of 14 August 2003. Commenting on the event, the National Academy of Sciences said this: "A modern T&D system could have helped to avoid the circumstances that initiated the August 2003 Northeast blackout. Two major issues contributed to this blackout: first, the operators did not know the system was in trouble; and second, there was poor communication between the utilities operating the transmission lines—First Energy and American Electric Power—and also between these utilities and the ISO responsible for the area (the Midwest Independent System Operator). The U.S. Canada Power System Outage Task Force (2004) noted that four major factors contributed to the blackout:

1. Inadequate system understanding,
2. Inadequate situational awareness,
3. Inadequate tree trimming,
4. Inadequate reactive power control diagnostic support.

A modern T&D system could have provided better understanding of the state of the system, better communications, and, ultimately, better controls. Adequate monitoring, communication, and dynamic reactive power support during the initial voltage sag could have helped to prevent lines from overloading, heating up, and sagging excessively. Operators would have been better informed, and online real-time dynamic contingency analysis of potential system collapse would have helped operators stay aware of possible risks and actions to be taken in response. Finally, automatic actions could have been taken to island (isolate) portions of the system and prevent the ultimate cascading event (which spread the localized outage across much of the northeast United States and Canada). The system could also have been restored much more rapidly if a modern grid had been in place."

A blackout in a single area can cost approximately \$1 billion, and major regional blackouts can cost \$10 billion. EPRI⁵ estimates the annual cost of power disturbances to the U.S. economy to be between \$80 billion and \$100 billion (EPRI, 2004). Disturbances to power quality add to the total, and inefficiency and congestion in the current T&D systems also have significant economic costs. These costs could be reduced significantly by a modernized T&D system. Thus, improving grid reliability and efficiency could result in substantial economic benefits...A modern grid can contribute to energy security by reducing the energy system's vulnerability to terrorist attacks and natural disasters, thereby reducing the risk of a devastating long-duration blackout. In addition, the ability to handle a high level of electricity generated from domestic renewable energy sources has national security benefits as well as the environmental benefits. In other words, the enhanced controllability that a modern T&D system could provide, and the broad penetration of distributed generation, will make the transmission system far more difficult to disrupt. Moreover, sophisticated analytical capabilities can detect and prevent or mitigate the consequences of an attack or disaster, and probabilistic analytical tools can identify inherent weaknesses in the grid so that they can be integrated into an overall national security plan. (NAS, 2009)

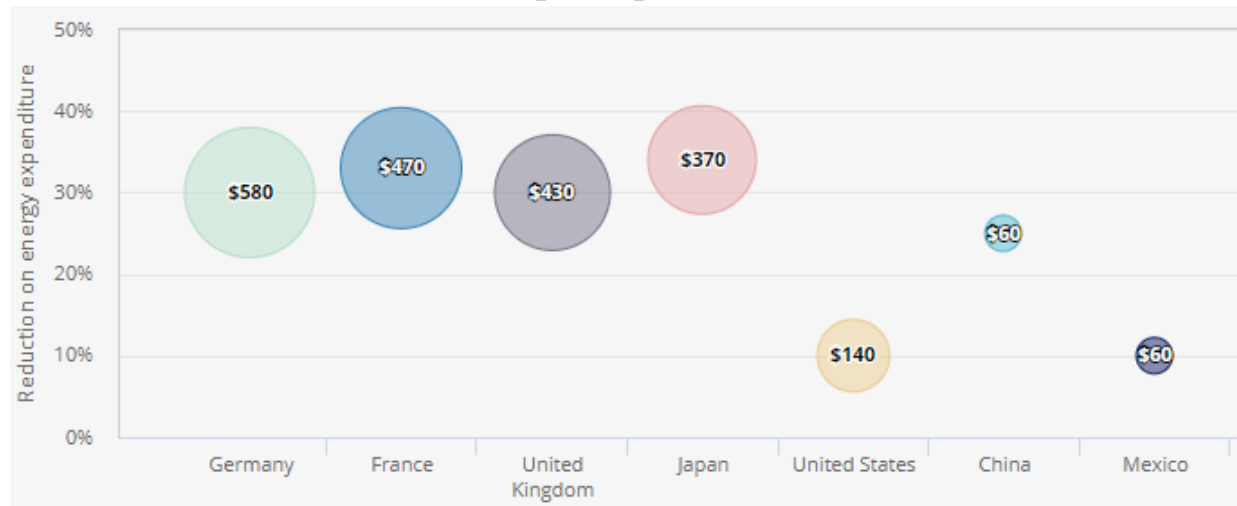
Quantifying Energy Security

Historically, energy security was primarily associated with oil supply. While oil supply remains a key issue, the increasing complexity of energy systems requires systematic and rigorous understanding of a wider range of vulnerabilities. Disruptions can affect other fuel sources, infrastructure or end-use sectors. Thus, analysis of oil supply security alone is no longer sufficient for understanding a country's energy security situation as a whole.

One of the ways in which the IEA is responding to this challenge is by developing a comprehensive tool to measure energy security. The IEA Model of Short-term Energy Security (MOSES) examines both risks and resilience factors associated with short-term physical disruptions of energy supply that can last for days or weeks. MOSES extends beyond oil to monitor and analyze several important energy sources, as well as the non-energy components (such as infrastructure) that comprise an energy system. Analysis of vulnerability for fossil fuel disruptions, for example, is based on risk factors such as net-import dependence and the political stability of suppliers. Resilience factors include the number of entry points for a country (e.g. ports and pipelines), the level of stocks and the diversity of suppliers. (IEA, 2018)

⁵ Electric Power Research Institute

Household Energy Expenditure Savings Due to Efficiency Improvements Since 2000 USD per capita, 2016



Source, IEA, 2017

On the other hand, the costs of different fuel products With and Without a CO₂-Equivalent must be factored in energy security in the short and long terms.

Because geologic CO₂ storage is key to producing liquid fuels from coal with life-cycle greenhouse gas emissions comparable to those of gasoline, commercial demonstrations of coal-to-liquid and coal-and biomass-to-liquid fuel technologies integrated with geologic CO₂ storage would have to proceed immediately if the goal is to deploy commercial plants by 2020. Moreover, detailed scenarios for market-penetration rates of biofuels and coal-to-liquid fuels would have to be developed to clarify the hurdles preventing full feedstock utilization and to establish the enduring policies required to overcome them. Further, current government and industry programs would have to be evaluated to determine whether emerging biomass- and coal-conversion technologies could further reduce U.S. oil consumption and CO₂ emissions over the next decade. (NAS, 2009)

When energy security is conceived as energy safety, as we saw above, it's associated with high costs. In 2011, it was estimated that "a planned modernization of the U.S. national power grid will cost up to \$476 billion over the next 20 years but will provide up to \$2 trillion in customer benefits over that time, according to industry experts. The so-called 'smart grid' will save energy, reduce costs and increase reliability by delivering electricity from suppliers to consumers using two-way communication that can control appliances, the charging of electric vehicles and the flow of power from renewable sources at customers' homes. 'The implementation of the smart grid is a

continuous process. As new technology is developed and becomes cost effective, it is being used to find the most effective way to meet supply and demand,' Matt Wakefield, smart grid program manager at the Electric Power Research Institute (EPRI) said...To make the power system of the future a reality, EPRI, a non-profit electric research and development company, said power companies need to invest between \$17 and \$24 billion a year over the next two decades. Much of those costs will be passed onto consumers...

'We need to tell power customers there is going to be an improved power system that will result in reduced costs even if they do not see an immediate reduction in their bill,' said Clark Gellings an EPRI Fellow. By the year 2050, EPRI estimated the average electric bill will probably go up by about 50 percent if the smart grid is deployed. If not, Gellings said, the average electric bill could go up by almost 400 percent. Some of the biggest technology firms in the world are competing to supply the smart grid infrastructure, including International Business Machines, General Electric, ABB, Siemens, Google, Toshiba, Cisco and Microsoft...Japanese multinational Toshiba agreed to buy Swiss smart grid company Landis+Gyr for \$2.3 billion." (Reuters, 2011)

According to Mike O'Boyle, Illinois has invested billions in electricity grid infrastructure, and now ranks 2nd nationally on grid modernization, but are these bulky efforts actually paying off nearly six years into the state's initiative? State utilities have markedly improved reliability and operational efficiency through innovative smart grid technologies, but Illinois' ambitious goal of adding more than 4 gigawatts (GW) of new wind and solar requires more than a modern grid - it requires more flexibility from customers. Fortunately, realistic policy solutions are within reach. The Future Energy Jobs Act (FEJA) lays a solid foundation, creating incentives for utility efficiency and demand response investment while decarbonizing Illinois' power sector. By removing market barriers to expand 'real-time' power pricing options and maximize the benefits of smart meter investments, customers could save billions and create a flexible grid capable of handling a massive expected influx of renewable energy by 2030.

Illinois' power prices have remained below the national average since 2011, but it's unclear whether cheaper power from shale gas is offsetting the increased cost of grid modernization. In its 2016 annual report, ComEd claims \$1.4 billion in societal savings for avoiding outages since 2012, which it ties to its grid modernization investments – but these savings likely won't show up in power prices. The customers with the highest levels of savings would have cut their annual costs an average of 31%, for \$104 in savings, reflecting what might be possible if consumers adjusted behavior and installed programmable appliances to respond to changing prices. Even among the 3% of customers who would have seen higher bills on hourly pricing, the median customer lost an estimated \$6.23 on the year; 90% of such customers would have lost less than 5.3% compared to their annual bill.

Grid modernization and the CUB-EDF study also have major implications for Illinois' transition to clean energy. Achieving the 25% renewables envisioned by the FEJA will add around 1.3 GW of new wind and up to 4 GW of new solar. Wind and solar are currently the cheapest forms of new generation, but they require demand flexibility to complement their variable generation patterns. A large-scale roll-out of dynamic pricing coupled with customer education and enabling technology may be the most crucial step enabling Illinois to lead the U.S. in clean energy and grid modernization while maximizing customer benefits. (O'Boyle, 2017)

Energy Efficiency and the Behavioral Gap

There are substantial opportunities to reduce energy use through the widespread deployment of energy efficiency technologies in the buildings, transportation, and industrial sectors. The costs of deploying many of these technologies are much less than the costs to purchase energy; in fact, in these cases, deployment saves money as well as energy. In spite of such advantages, many consumers are reluctant to make the necessary investments to deploy these technologies. Why the apparent dichotomy persists is the subject of ongoing research, which has already identified several reasons.

One reason for the behavioral gap between economically optimal technology choices is the low salience of energy efficiency for consumers. That is, consumers, in this case do not reflect the neoclassical economic model of the optimizing consumer. Although real-world consumers may recognize that purchasing an energy-efficient technology would be economically beneficial, the net benefits are usually so small relative to family budgets that individuals do not take the time to gather and analyze the requisite information.

Another reason for the gap has to do with the difficulty of changing consumer when makings' purchasing and use habits. Preferences learned from parents, neighbors, and friends may change only very slowly, if at all. Also, most consumers do not calculate life-cycle costs when making purchases; instead, they focus primarily on first-purchase costs. Producers who understand this bias may be reluctant to design and market energy-efficient products unless forced to do so by governmental regulation.

Part of the behavioral gap is also based on economic-incentive issues – e.g., landlords of residential rental units are not motivated to pay for technologies that are more efficient when their tenants pay the utility bills. There are also historical path dependencies. For example, many existing building codes were developed when energy costs were not seen as important; these codes were optimized for safety, not for minimum life-cycle costs. Consumers also pay attention to product characteristics that tend to be ignored by analysts. They resisted buying early-generation compact

fluorescent lamps, for instance, because they did not like the color or the light produced. Continuing research is needed to more fully understand these and other reasons for the behavioral gap and to devise appropriate strategies for closing it. (National Academy of Science et al., 2009)

Furthermore, the NAS have identified several reasons why energy efficiency opportunities aren't more attractive to consumers and businesses:

- Cost savings may not be the only factor influencing a decision to invest in an energy efficiency measure. For example, consumers purchase vehicles based on many factors, such as size, performance, and interior space, in addition to fuel economy. In reality, fuel economy may not come into the picture at all.
- Although energy and cost savings might be achievable with only a low first cost (investment), such savings may be a small enough part of the family or company budget that they are not really relevant to economic decisions.
- The up-front financial investment might be small, but substantial investments of time and effort may be required to find and study information about potential energy-saving technologies, measures, and actions.
- It is well established that purchasers tend to focus much more on first costs than on life-cycle costs when making investments. This behavior is no different when it comes to energy efficiency. There is also the phenomenon of risk aversion—new products may be unfamiliar or not work as expected. The default behavior is often simply the status quo. Knowing this, producers may never design and develop energy-efficient products.
- Some of the behavior gap can be attributed to economic structural issues. For example, landlords of rental residential buildings are not motivated to pay for technologies that are more efficient when their tenants pay the utility bills. And builders whose incentive is to minimize the cost of new homes may not offer highly efficient appliances that increase purchase prices but save buyers money over time.
- Other factors may involve retailers of equipment and appliances. If there is low demand for efficient products, retailers may not stock them. Even purchasers who might be motivated to search elsewhere for an efficient product may have to deal with limited choices in the event of an emergency purchase, such as when a refrigerator fails.

- Other reasons for the behavior gap are the subject of much social science research. They involve factors such as habits in purchasing or use, which can be very difficult to change. Some apparent consumer preferences—typically learned from parents, neighbors, and friends—may change very slowly, if at all.
- Energy-savings investments by businesses and industries are not always seen as beneficial. If energy accounts for only a small part of total costs, or if the available capital is limited, other investments may be preferred—e.g., in reducing other costs, improving products, or developing new ones. If the consequences of a new-product or production-method failure are large, this in itself can maintain the status quo.
- Firms may not be aware of the potential savings achievable by replacing equipment, such as older motors, with more efficient or variable-speed versions. When motors, large or small, are used throughout a facility, the savings from upgrading them can be substantial.
- Energy efficiency investments by companies are made in the context of complex business cultures. “Champions,” or commitment at the highest levels, may be required.

Comprehensive and sustained national policies for energy production and use will be needed to achieve a timely transformation to the more sustainable, secure, and environmentally benign energy system. However, to help shape these policies will require sound and dispassionate technical analyses of the opportunities and challenges. Such analyses should address technology capabilities, costs, times to maturity and commercial development, and impacts on the environment, economy, and national security.

Forms, Conservation, Measure, and Distribution of Energy

I previously said that for there to be energy there has to be work, which itself materializes under the action of a force. Force = Mass x Acceleration ($F = M \times A$). From a scientific point of view, there is a specific set of definitions and characteristics of energy. From a physical perspective, energy is property of objects transferable among them via fundamental interactions, which can be converted into different forms, but not created or destroyed. Does this give a clear sense of what energy really is? Not really. Energy is so fundamental to the fabric of our universe that we struggle to separate ourselves from it enough to satisfactorily define it. In a sense, the universe is energy. We can recognize energy when we see it. The matter that makes up our universe, including our body, contains a vast amount of energy. With a nuclear bomb, a very tiny of that matter gets destroyed, getting converted into an enormous amount of heat and radiation. And we can calculate exactly how much according to a very simple equation: $E = Mc^2$. Another example is Newton’s apple, which can be lifted up to create gravitational potential energy, where energy, $E = \text{masse} \times \text{gravity} \times \text{height}$ ($E = MGH$). When that apple falls, that

gravitational potential energy is converted back into kinetic energy of motion that can be converted into work. If a falling apple does not actually do a lot of work, take for example a waterfall. It creates a lot of work, which can be calculated according to the equation $E = MGH$. This is the basis for hydroelectric powerplant.

From these two examples, we can see that energy can take a lot of different forms: mass, heat, light, height, and many others. We saw that energy can be quantified with very simple equations. The best way to witness energy is when it's converted. For example, we know that there is a lot of energy trapped in a piece of coal. But, when we burn the latter, it converts into heat, and we can really see the energy contained within. Some forms of energy are useless unless converted. For example, when we convert a falling water into work or when we burn coal. We obtain the energy we need in forms that we can use. Let's talk about the general categories of the forms of energy and what it takes to convert them from one form to another. For example, nuclear power. It takes two forms of energy: nuclear fission or splitting of atoms and nuclear fusion or the fusion of atoms together. Nuclear fusion occurs within the Sun and is responsible for the heat and light that the Sun gives off. Officially, we have not yet been able to harness nuclear fusion on Earth for the generation of power, with the exception of nuclear bombs. All of our nuclear power plants work by nuclear fission, the splitting of usually Uranium atom.

The gravitational potential energy of a waterfall is part of another class of energy called potential energy or energy of position. Another form of potential energy is elastic energy. For example, to stretch the elastic band of a slingshot, you have to exert energy. When you stop pulling the elastic, there is energy stored in it. When you let go, you get that energy back. When you squeeze a metal coil, it also stores energy. Same goes when you extend a spring. How much energy is in an extended spring? It is: one-half k times the distance squared ($0.5k \times d^2$). The variable k is a constant that is particular to each different spring. It's a measure of how hard it is to compress it. So, k has values for different springs. To understand where the d^2 comes from, you need to know that energy comes from a force applied over a distance x ($E = fx$), force times distance. And the force needed to compress a spring starting at rest is $F = 0.5kx$. If you put them together, $E = 0.5kx = 0.5kx^2$.

Energy isn't always so easily computed. We can see this with another form of potential energy: chemical potential energy, like the one contained in our piece of coal. This kind of energy is the relative position of the atoms that are bonded together within the molecule of the coal. When that coal gets burned, a chemical reaction occurs within the coal, which changes the relative position of the atoms, as some bonds are broken while others form. Certain forms of energy such as combustion release energy in the form of heat and light.

There is a whole other class of energy: the energy of motion or kinetic energy. For a single object, the computing of the energy released is rendered by an easy equation: one-half the mass of the

object times its velocity: $E = 0.5mv^2$. If you double the mass, you double the energy. However, if you double the speed, you quadruple the energy. That's why a bullet fired out of a gun has the same amount of energy as a runner racing full speed. Potential and kinetic energies can be combined to form mechanical energy. Most machines work by having energy constantly converted back and forth between potential and kinetic energy. For example, a swing. A child on a swing keeps gaining and losing potential energy. This is because the potential energy keeps converting back and forth into the kinetic energy of motion. At the very top of the swing, the gravitational potential energy is the highest, but the swing also stops for a moment. So, the kinetic energy goes to zero. At the bottom of the swing, the gravitational potential energy is the lowest and this is when the swing is moving fastest.

Another form of kinetic energy is the thermal energy of an object, and it is not so easily quantified. You might ask: how is this related to kinetic energy? It's because at an atomic scale, all the atoms of an object are constantly oscillating and vibrating. Remember that motion has kinetic energy. If you heat up an object, you increase its temperature. This results from the atoms of the object moving faster, vibrating and oscillating more vigorously. Keep in mind that thermal energy and temperature are not the same. Thermal energy is the measure of the total kinetic energy of all the particles of a substance. Temperature is the measure of the average kinetic energy of all the particles of a substance. Both of these are different from heat, which is the transfer of energy into thermal energy. It's the flow of energy into an object, making its atoms vibrate a little more energetically.

The first law of thermodynamics is also known as the law of conservation of energy. It states that the total amount of energy in a closed system does not change. Energy can be transformed from one type to another, but it can never be created or destroyed. When you lift a ball, the energy comes from your muscles which use the chemical energy created by the consumption and the breaking down of the food you eat. To grow, the food you eat uses the energy that comes from sunlight through a process called photosynthesis. The energy that comes from sunlight comes itself from the thermal energy of the Hydrogen of the Sun's photosphere which releases energy that comes from the nuclear fusion at the core of the Sun where Helium is formed. The Hydrogen comes from the Big Bang. Finally, where the energy that comes from the Big Bang comes from? We don't know. However, although we don't know, we do know that within the first seconds of the Big Bang, the total sum of energy and the mass of the universe have remained constant. Since energy is never created or destroyed, it's possible to calculate how much is converted thanks to the first law of thermodynamics or law of conservation of energy. Thermodynamics is the study of energy transformation. It is the science underlying all studies of how we use energy to do work. Thermodynamics follows certain basic principles, or laws, that define how energy does or does not behave. These laws apply to all forms of energy, including heat energy, chemical energy, and electrical energy.

The second law of thermodynamics specifies the direction energy conversion follows. This law can be stated in many ways. One is that heat can never flow from a cooler object to a warmer one., heat will flow from a hot object to a cool object until the two objects' temperatures reach equilibrium or have equal temperatures. The second law can also be stated this way: in any energy conversion, there is less energy available to do work after the conversion than before it. This decrease of energy is called entropy, also known as dispersal, dissipation, randomness, disorder, and chaos. Entropy increases over time, and this process is irreversible. Obviously, in a system built to use energy as efficiently as possible, the goal is to minimize entropy and to maximize the energy available to do the work.

Another form of energy is electrical energy or electricity. it's a special case of kinetic energy. It involves the motion of electrons. Unlike the kinetic energy released by a falling object and which depends on gravity, electrons, which have a negative charge are driven by the forces of electromagnetism. Electrical energy can also be calculated: the power of electrons (moving through a wire) = resistance x current².

Energy is complicated. Not only it exists in different forms, but also, there several units of energy, which makes measuring it a challenging task. Measuring energy is different from measuring power, which includes a time element. Power is the rate at which energy is produced or used over a given period of time. Power is measured in terms of watt. One watt of power is equal to one joule of energy per second. The following table shows measure of both energy and power.

Energy Units and Their Relationships			
Unit	Symbol	Definition	Common Usage
Horsepower	Hp	The rate at which work is done. It's equal to 550 foot-pounds per second (745.7 watts)	Used to express power in mechanical form
British Thermal Unit	BTU	Amount of heat needed to raise the temperature of 1 pound (0.45 Kg) of water to 1° F (0.56° C)	Stoves, air conditioners
Quads	Quad	Unit of energy equal to 10 ¹⁵ (a short-scale quadrillion) BTU, or 1.055 × 10 ¹⁸ joules (1.055 exajoules or EJ) in SI units	Used by the U.S. Department of Energy in discussing world and national energy budgets. The global primary energy production in 2004 was 446 quads, equivalent to 471 EJ.

Energy Units and Their Relationships			
Unit	Symbol	Definition	Common Usage
Therms	Thm	Non-SI ⁶ unit of heat energy equal to 100,000 British thermal units (Btu). It is approximately the energy equivalent of burning 100 cubic feet (2.83 cubic meters) – often referred to as 1 CCF – of natural gas.	Commercial unit of heat. One therm equals 100,000 Btu or about 97 cubic feet of natural gas, or about 29.3 kilowatt hours (kWh) of energy.
Calories	Cal	The energy needed to raise the temperature of 1 gram of water through 1 °C (now usually defined as 4.1868 joules)	In terms of energy, Calories are used by physicists to describe the amount of work needed to force one newton through one meter
Watt	W	Production/use of 1 joule of energy per second	Lightbulbs, household appliances
Kilowatt	KW	1,000 Watts	Electric heaters, engines, machines
Megawatt	MW	1 million Watts	Output capacity of electric power plants
Gigawatt	GW	1 billion Watts	Output capacity of large electric power plants
Terawatt	TW	1 trillion Watts	Large-scale energy figures such as worldwide usage
Kilowatt Hours	KWh	Energy consumed by using 1 KW of power for 1 hour	Energy usage by consumers (households, businesses)
Megawatt Hours	MWh	Energy consumed by using 1 MW of power for 1 hour	Energy usage by large-scale consumers; a power plant daily output

It can get extremely confusing especially when you start converting back and forth. The most popular units are joule and watt. Besides the watt, there is the horsepower. 1 horsepower = 746 watts. So, a 250-horsepower car can run a maximum of 187,000 watts (the equivalent of 2,000 100-watt light bulbs or the electricity needed on average to power 150 US households). Calorie is an energy unit. 1 calorie = 4.19 joules. 1 kilocalorie = 4,200 joules. The total US annual energy consumption is about 100 quads. The total global annual energy consumption is 570 exajoules or 0.5 zettajoules (0.5 sextillion joules). All the energy units can be converted either into joules for the amount of energy or watt for the rate of energy per time. The names behind the most popular units are:

⁶ International system

- James Watts (1736 – 1819): Scottish engineer who perfected the steam engine.
- James Prescott Joule (1818 – 1889): English physicist who proved the first law of thermodynamics: the amount of work done on a system equals the amount of heat generated.

To put our need for energy in context, if we go back to our apple example, to create the 570 exajoules that the world needs annually, each person on the planet (we are a total of 7 billion) would have to lift to the height of one meter 2,500 apples each second continuously. For the US consumption, each person would have to lift 11,000 apples each second over and over again.

What is U.S. electricity generation by energy source?

In 2017, about 4,015 billion kilowatt-hours (kWh) of electricity were generated at utility-scale facilities in the United States.¹ About 63% of this electricity generation was from fossil fuels (coal, natural gas, petroleum, and other gases). About 20% was from nuclear energy, and about 17% was from renewable energy sources. The U.S. Energy Information Administration estimates that an additional 24 billion kWh of electricity generation was from small-scale solar photovoltaic systems in 2017.²

U.S. electricity generation by source, amount, and share of total in 2017

Energy source	Billion kWh	Share of total
Total - all sources	4,015	
Fossil fuels (total)	2,495	62.7%
Natural gas	1,273	31.7%
Coal	1,208	30.1%
Petroleum (total)	21	0.5%
Petroleum liquids	13	0.3%
Petroleum coke	9	0.2%
Other gases	14	0.4%
Nuclear	805	20.0%
Renewables (total)	687	17.1%
Hydropower	300	7.5%
Wind	254	6.3%
Biomass (total)	64	1.6%

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U.S. electricity generation by source, amount, and share of total in 2017

Energy source	Billion kWh	Share of total
Wood	43	1.1%
Landfill gas	11	0.3%
Municipal solid waste (biogenic)	7	0.2%
Other biomass waste	3	0.1%
Solar (total)	53	1.3%
Photovoltaic	50	1.2%
Solar thermal	3	0.1%
Geothermal	16	0.4%
Pumped storage hydropower ³	-6	-0.2%
Other sources	13	0.3%

Notes

1. Preliminary data for 2017. Includes utility-scale electricity generation, which is electricity generation from power plants with at least one megawatt (or 1,000 kilowatts) of total electricity generating capacity.

2. Small-scale solar photovoltaic systems are electricity generators with less than one megawatt of electricity generating capacity that are usually at or near the location where the electricity is consumed. Most small-scale solar photovoltaic systems are installed on building rooftops.

3. Pumped storage hydroelectricity generation is negative because most pumped storage electricity generation facilities use more electricity than they produce on an annual basis.

Source: Energy Information Administration (<https://www.eia.gov/tools/faqs/faq.php?id=427&t=3>). Accessed 27 March 2018.

The distribution of electricity is done by power plants and involves turbines and generators. Turbines are machines with rotating blades that spin around like the blades of a fan. Some turbines are turned by wind or water, while others are turned by steam. In thermal power units, a fuel such as coal is burned to heat water and produce steam. The steam then turns the turbines. A turbine's

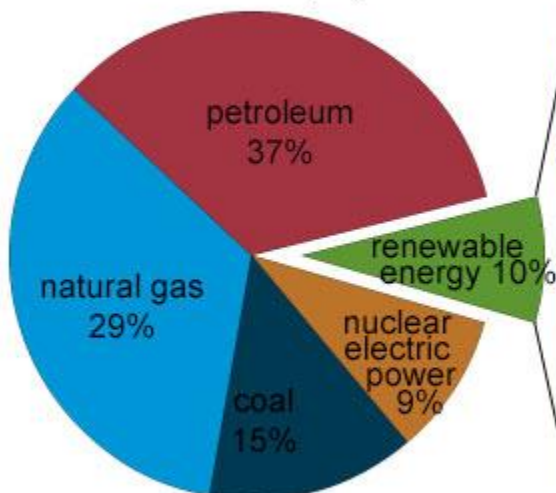
central shaft is connected to a generator. As the turbine spins, the generator transforms the mechanical energy of the spinning shaft into electricity.

Electricity travels from the power plant to homes and businesses through a network called the power distribution grid. In this system, electric power goes from the generators to a transmission substation whose transformers increase the electricity's voltage, or electrical energy potential, for transmission over long distances. From there, the electricity travels along high-voltage power lines strung between tall steel towers. In some cases, the electricity travels over underground lines. The power lines run through populated areas, where they enter another substation. Its transformers convert the high-voltage electricity to a lower voltage for customers' use. From the substation, power lines carry the electricity to homes, factories, and other businesses.

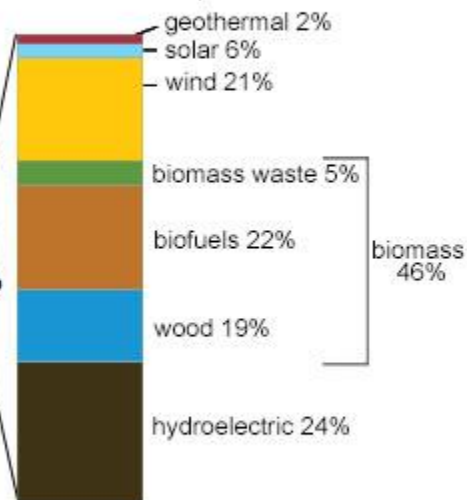
Electricity can travel hundreds of miles over a distribution grid. Thus, it can reach customers who live far from a power plant. Electricity generated by wind, solar, and other resources can hook up to the grid too. They add renewable energy to a community existing power system. (Heinrichs, 2011)

U.S. energy consumption by energy source, 2016

Total = 97.4 quadrillion
British thermal units (Btu)



Total = 10.2 quadrillion Btu



Note: Sum of components may not equal 100% because of independent rounding.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2017, preliminary data



Other forms of energy include:

- Waves, which involve physical and electromagnetic forces. This kind of energy involves the oscillation back and forth of matter, which allows for the propagation of energy.
- Light: it releases energy in the form of electromagnetic radiation. Unlike physical waves, it doesn't need any matter to move through. Light can pass through a vacuum. For example, we can see stars through the vacuum of space.

As stated previously, there are five main renewable energy sources:

1. Solar energy from the sun
2. Wind energy from the wind blowing
3. Hydroelectric power from flowing water
4. Biofuels from plants
5. Geothermal energy from the heat inside the earth

I will talk about these renewable sources of energy later. For now, I'd like to elaborate on fossil fuel energy sources, which, themselves are of three types: coal, petroleum, and natural gas.

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II. FOSSIL FUEL ENERGY

Fossil fuels – coal, petroleum, and natural gas – have been the dominant energy source in the United States for decades past and will continue to be a major source for decades to come. At present, they collectively supply about 85 percent of the nation’s primary energy. Fossil fuels have supported U.S. economic prosperity since the latter part of the 19th century. But their low market prices during most of this period encouraged high levels of energy consumption per capita and generally discouraged the development of alternative sources of energy, with two notable exceptions: hydroelectric and nuclear power, which currently account for about 7 percent and 19 percent, respectively, of U.S. electricity generation. Our nation’s dependence on fossil fuels evolved not only because they were available at low market costs but also because their physical and chemical properties are well suited to particular uses: petroleum for transportation; natural gas as an industrial feedstock, for residential and commercial space heating, and, more recently, as a fuel for electric power generation; and coal for the generation of electricity and as a feedstock for some industrial processes. Indeed, most consumer-based, industrial, and governmental activities require, either directly or indirectly, the consumption of fossil fuels. America’s enormous appetite for oil, coupled with growth in demand from other countries, puts upward pressures on world prices, increases revenues to oil exporting nations, and heightens the influence of those nations in world affairs. (National Academy of Sciences et al., 2009)

Despite of their advantages, fossil fuels come with significant risks. These concerns predominantly revolve around the pollutants they release, causing significant health and environmental problems that amount to hundreds of billions of dollars’ worth of damages. The problems do not lie within just the combustion, but in the process of retrieving fossil fuels from start to finish: exploration, mining, drilling, excavation, coal washing, spills, leaks during transportation and then combustion and finally dealing with the leftover wastes.

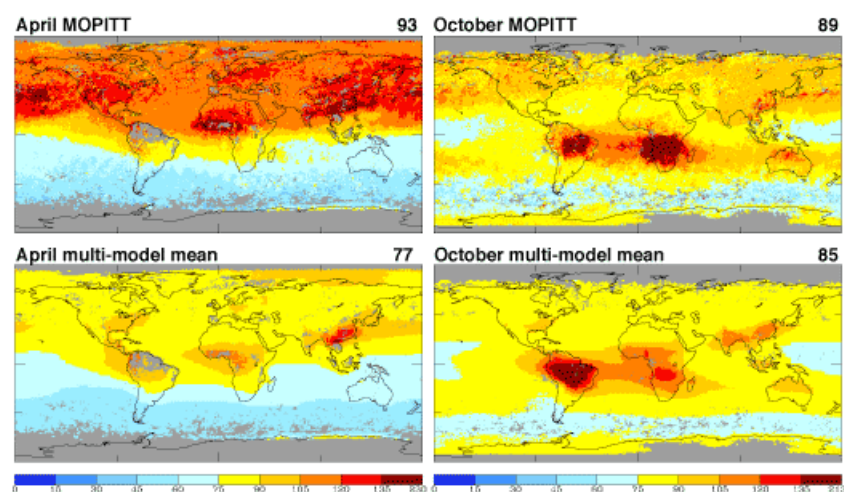
Many parts of old US cities are now abandoned and unusable because the ground is permanently polluted from oil and gas leaks that occurred long before the Clean Water Acts of the 1970s. Exemptions pose a big problem in the enforcement of these laws. For example, the fossil fuel industry is exempt from 7 environmental laws. Old coal-based powerplants are exempt from the clean Air Acts. New ones are not. The old ones are required to make modifications only for routine maintenance repair or replacement (RMRR). Even modernized plants, if they realized their modernization little by little or piecemeal over a long period of time, may end up being exempt.

There are many countries where these kinds of laws don’t exist. Still, there is a progression of environmental awareness and social responsibility that countries go through as they develop and become more industrialized. It’s a complicated function of history, population density, level of industrialization, and the type of government you have. The pollution from producing and burning fossil fuels is large. At some point the negative consequences become large enough that actions

are taken. England reached that point in the 1950s with its killer fog. The US reached that point in around 1970, and China is reaching that point now. This holds well for the future. Things do get better. It's unrealistic to expect that oil spills aren't going to happen in the US even though we have laws against it. But if you hold businesses accountable, they will have a greater incentive and will be more careful. In terms of air pollution, the understanding of fossil fuels' implications boils down to the understanding of carbon dioxide (CO₂). What is it?

Understanding Carbon Dioxide

Carbon dioxide is a significant pollutant to human civilization. If CO₂ is only 0.04% of the atmosphere, how can it be so harmful? Is global warming a natural process? What actions can we take to reduce the dangers of CO₂? These are all questions pertaining to fossil fuels which all emit carbon dioxide and are at the same time the most important sources of energy. These will be answered throughout the remaining of this book. For now, let's see what carbon dioxide entails. Carbon dioxide (CO₂) is different from carbon monoxide (CO). Carbon dioxide is a colorless,



The models show large underestimates of CO at middle and high latitudes in the Northern Hemisphere, while typically performing reasonably well elsewhere. The top row shows MOPITT observations from 2000, while the bottom row shows the equivalent for the average of the 26 models analyzed. Values in the upper right corner are the global mean area-weighted CO (ppbv). Grey indicates areas where satellite observations were not available. *Source: NASA*

odorless gas produced by burning carbon and organic compounds and by respiration. It is naturally present in air (about 0.03 percent) and is absorbed by plants in photosynthesis. According to Shindell (2007), Carbon monoxide (CO) is a pollutant that affects methane, carbon dioxide, and tropospheric (lower atmospheric) ozone. It thus plays a role in both air pollution and climate change and is therefore regulated in many parts of the world. CO is

unique among pollutants in the lower atmosphere in that it lasts for roughly a month, long enough for it to be transported long distances but not so long that it becomes distributed nearly uniformly. Further, it has been observed from satellites for several years. These features make comparison of modeled and measured CO a very useful way to evaluate our current understanding of and ability to model air pollution. As part of an effort to study future air quality and climate change, a team of researchers from ten countries recently used 26 state-of-the-art atmospheric chemistry models

to simulate present-day and projected near-future CO. We compared the present-day simulations with near-global observations from the Measurements of Pollution in the Troposphere (MOPITT) instrument flown on NASA's Terra satellite and with local surface measurements. The models show large underestimates of CO at middle and high latitudes in the Northern Hemisphere, while typically performing reasonably well elsewhere. Detailed analysis of the results suggests that year-round surface emissions of CO, probably from fossil fuel burning in East Asia, and seasonal biomass burning emissions in South-central Africa, are greatly underestimated in current inventories used to drive models. Models appear to be able to reproduce many aspects of the transport and chemical transformation of CO in the atmosphere relatively well. However, variability among models is large. This is primarily due to model-to-model differences in simulating the hydrologic cycle and in representations and emissions of non-methane hydrocarbons, which can be chemically oxidized into CO. Better information on surface emissions and simultaneous observations of additional gases would clearly help resolve the limitations of current air pollution modeling revealed in this study. Projections of the global average CO response to emissions changes in the year 2030 for three different scenarios are quite consistent among the models. Global average CO around the middle of the lower atmosphere increases by $16\pm4\%$ for a high-emissions scenario, decreases by $11\pm3\%$ for a low-emissions scenario, and changes by $2\pm2\%$ for a mid-range scenario. Projected 2030 climate changes play a smaller role, decreasing the global average CO by $2\pm2\%$. Local changes can be much larger, however. These range from decreases of 10-15% over much of the industrialized Northern Hemisphere for the mid-range scenario to CO increases worldwide under the high-emission projection, with the largest changes over central Africa (20-30%), southern Brazil (25-40%) and South and East Asia (20-50%). The trajectory of future emissions thus has the potential to greatly influence air quality over most of the world's highly populated areas.

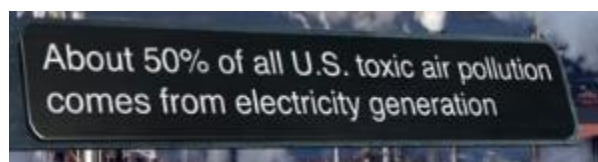
Overview of Air and Water Pollution and Health Hazards: The Three Culprits and the Facts

Now, how does each fossil fuel fare in terms of emission of CO₂ into the atmosphere or air pollution? To what extent do they contaminate water? Each fossil fuel pollutes the environment in specific manners, which I will elaborate on upon analyzing them separately. But, for now, I would like to consider them together and look at the big picture. "Fossil fuels, while abundant and portable, come with a significant list of drawbacks. People living near coal mining sites have been statistically shown to suffer from higher-than-normal rates of cardiopulmonary disease, hypertension, and lung and kidney diseases. There are also the hazards of coal mining to miners, both from mine collapses and explosion, death from lung diseases (black lungs). Furthermore, both strip-mining and mountain top mining release heavy metals, mercury, selenium, and arsenic into the atmosphere. Even when coal mining is underground there is still hazards. Coal fire

underground have been estimated to release 40 tons of Mercury into the atmosphere each year and account for 3% of the total world carbon dioxide emission. Underground coal mining also releases substantial amounts of methane into the atmosphere, which is actually a much more powerful greenhouse gas than carbon dioxide. Once the coal is on the ground, rain water can mix with it and if it isn't carefully isolated, this can carry toxic metals into streams underground water. In many cases, the crushed coal is washed on site and the tiny sediments of coal wastes spill into the water. The result is called acid mine drainage (AMD), which "refers to the outflow of acidic water from a mining site. In most cases, this acid comes primarily from oxidation of iron sulfide (FeS_2 , also known as pyrite or 'fool's gold'), which is often found in conjunction with valuable metals. Acid mine drainage is a major problem with many hard rock mines, including almost all mines where the metal ore is bound up with sulfur (metal sulfide mines). A significant number of coal mines also suffer from acid mine drainage." (Ground Truth Trekking, 2014)

On the other hand, there are also adverse events due to fly ash. By and large, fly ash is ash produced in small dark flecks, typically from a furnace, and carried into the air. In the US, almost half of the fly ash from burning coal gets recycled and used in construction materials such as concrete or plaster. The rest is put into holding pond and, when dried, into landfills. This puts streams of underground water at increased risk of contamination. The Environmental Protection Agency has found leaks at 63 different coal ash ponds. The coal fly ash in slurry ponds and landfills also contain enough radioactive elements that it has actually exposed in the US to higher levels of radioactivity than from all nuclear powerplants. While many people are concerned with nuclear radioactivity, the risks from coal are higher.

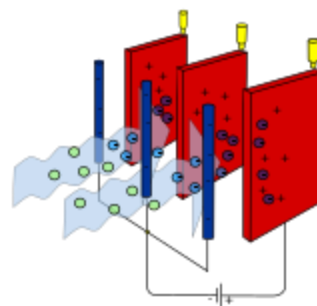
The real hazards from coal are from burning it. The combustion of coal releases a large number of pollutants (carbon dioxide, carbon monoxide, ozone nitroxide, sulfur oxide, and heavy metals such as mercury and lead). Air pollution from coal-fired power plants includes sulfur dioxide, nitrogen oxides, particulate matter (PM), and heavy metals, leading to smog, acid rain, toxins in the environment, and numerous respiratory, cardiovascular, and cerebrovascular effects. Scientific



American (2015) reports that coal combustion plants account for more than half of Americans' electric power generation. According to Coal's Assault on Human Health, a report by the non-profit Physicians for Social Responsibility (PSR), coal combustion impacts our respiratory, cardiovascular and nervous systems and air pollutants produced by coal combustion contribute to asthma, lung cancer, congestive heart failure and strokes... While the U.S. relies heavily on coal for its energy needs, "the consequences of that reliance for our health are grave," says Alan Lockwood, professor of neurology at the University at Buffalo. The report further illustrates the adverse effects of the mining of coal on the environment, water and human health. Coal mining leads U.S. industries in fatal injuries, and miners have suffered prolonged health issues, such as

black lung disease, which causes permanent scarring of the lung tissues. Surface mining destroys forests and groundcover, leading to flooding and soil erosion. Mountaintop removal mining—used widely across southern Appalachia—can bury streams with rubble and, in turn, harm aquatic ecosystems. Waterways may also become contaminated due to the storage of post-combustion wastes from coal plants, also known as “coal ash.” There are 584 coal ash storage sites in the United States, and toxic residues have migrated into water supplies at dozens of them.

There are many methods that allow to remove the pollutants during combustion. For example, mixing the coal with water containing calcium carbonate. This method is called electrostatic precipitation. An electrostatic precipitator (ESP) is a filtration device that removes fine particles, like dust and smoke, from a flowing gas using the force of an induced electrostatic charge minimally impeding the flow of gases through the unit. These add costs to electricity generation and are required by law in the US from the Clean Air Act. As a result, air quality in the US has significantly improved and is clearly better than in other places such as China which burns four times as much coal as the US but does not have the environmental regulation.



An electrostatic precipitator
Courtesy: Wikipedia

Air pollution is not limited to the burning of coal. Burning oil and gas also creates air pollution. The main facts about burning oil and gas include, but is not limited to:

- It is responsible for 70% of CO pollution
- It is responsible for 40% of VOCs and NO_x
- It is responsible for 1/3 of all CO₂
- It is responsible for ¼ of all toxic metals released

There is something called volatile organic compounds (VOCs). According to the Environmental protection agency (EPA), Volatile organic compounds (VOC) means any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates and ammonium carbonate, which participates in atmospheric photochemical reactions, except those designated by EPA as having negligible photochemical reactivity. Volatile organic compounds, or VOCs are organic chemical compounds whose composition makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure. In the United States, emissions of VOCs to the outdoors are regulated by EPA mostly to prevent the formation of ozone, a constituent of photochemical smog. Many VOCs form ground-level ozone by “reacting” with sources of oxygen molecules such as nitrogen oxides (NO_x), and carbon monoxide

(CO) in the atmosphere in the presence of sunlight. However, only some VOCs are considered “reactive” enough to be of concern. VOCs that are non-reactive or of negligible reactivity to form ozone under these conditions are exempted from the definition of VOCs used by EPA in its regulation. (EPA, 2017). Specifically, the burning of natural gas releases the fewest pollutants. The primary pollutants from burning methane are carbon dioxide (CO₂), carbon monoxide (CO), and carbon soot.

Finally, in addition to polluting the atmosphere, oil also pollutes the water. How is oil water pollution a problem? “Oceans are polluted by oil on a daily basis from oil spills, routine shipping, run-offs and dumping.

- Oil spills make up about 12% of the oil that enters the ocean. The rest come from shipping travel, drains and dumping.
- An oil spill from a tanker is a severe problem because there is such a huge quantity of oil being spilt into one place.
- Oil spills cause a very localized problem but can be catastrophic to local marine wildlife such as fish, birds and sea otters.
- Oil cannot dissolve in water and forms a thick sludge in the water. This suffocates fish, gets caught in the feathers of marine birds stopping them from flying and blocks light from photosynthetic aquatic plants.” (Water Pollution Guide, 2018)

Below is a list of the ten largest oil spills in history, according to *The Telegraph* (2011):

1. Gulf War, 1991. Kuwait. 240 to 336 million gallons
2. Deepwater Horizon, 2010. Mexican Gulf. 210 million gallons
3. Ixtoc 1 Oil Well, 1979. Bay of Campeche, Mexico. 140 million gallons
4. Atlantic Empress, 1979. Trinidad and Tobago, West Indies. 88.3 million gallons
5. Fergana Valley, 1992. Uzbekistan. 87.7 million gallons
6. Nowruz Oil Field, 1983. Persian Gulf. 80 million gallons
7. ABT Summer, 1991. Off the coast of Angola. 80 million gallons
8. Castillo de Bellver, 1983. Off Saldanha Bay, South Africa. 78.5 million gallons
9. Amoco Cadiz, 1978. Off Brittany, France. 68.7 million gallons
10. Odyssey Oil Spill, 1988. 700 nautical miles off the coast of Nova Scotia, Canada. 43 million gallons

Although detrimental in terms of their environmental impacts, fossil fuels are the engine that makes our world turn. Because the world has become mechanized, fossil fuels help us grow and harvest food, heat and cool down our homes and businesses, and going from point A to point B faster, more comfortably, and more efficiently. In other words, they constitute a necessary evil to say the least. They are: coal, petroleum, and natural gas.

1. Coal

Coal is a solid, usually brown or black, carbon-rich material that most often occurs in stratified



Coal is a solid, usually brown or black, carbon-rich material

sedimentary deposits. It is one of the most important of the primary fossil fuels. Noted coal geologist James Morton Schopf defined coal as containing more than 50 percent by weight (or 70 percent by volume) carbonaceous matter produced by the compaction and induration of altered plant remains – namely, peat deposits. The Chinese were using coal to smelt copper at least 3,000 years ago. Today, China relies on coal for almost 70% of its total energy. Coal was used commercially by the Chinese long before it was utilized in Europe. Although no authentic record is available, coal from the Fushun

mine in northeastern China may have been employed to smelt copper as early as 1000 BC. Stones used as fuel were said to have been produced in China during the Han dynasty (206 BC–AD 220). (Kopp, 2018) Coal is a huge industry there, which employs 5 million people.

Evidence of coal usage in Europe goes back even further. The Romans were big users of coal. Coal cinders found among Roman ruins in England suggest that the Romans were familiar with its use before AD 400. The first documented proof that coal was mined in Europe was provided by the monk Reinier of Liège, who wrote (about 1200) of black earth very similar to charcoal used by metalworkers. Many references to coal mining in England, Scotland, and the European continent began to appear in the writings of the 13th century.

In the New World, up to the time of the American Revolution, most coal used in the American colonies came from England or Nova Scotia. Wartime shortages and the needs of the munitions manufacturers, however, spurred small American coal-mining operations such as those in Virginia on the James River near Richmond. By the early 1830s mining companies had emerged along the Ohio, Illinois, and Mississippi rivers and in the Appalachian region. As in European countries, the introduction of the steam locomotive gave the American coal industry a tremendous impetus.

Continued expansion of industrial activity in the United States and in Europe further promoted the use of coal. (Kopp, 2018). Coal is primarily used for the generation of electricity but, just as petroleum, it has some other important industrial uses. The most important industrial use is in the smelting of metals.

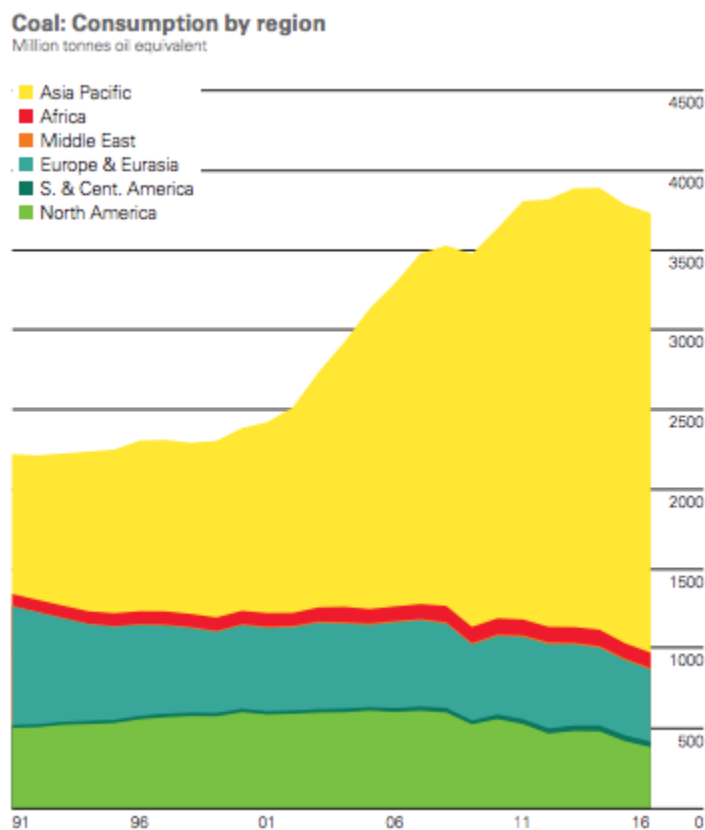
Origins and Development of Coal

Coal is the concentrated carbon left over from ancient swamp, plant debris, and mosses that were buried millions of years ago. What happens when a plant falls? It gets eaten by bacteria, fungi, worms, insects. During the process, some of its carbon goes back into the atmosphere and what's left goes back into the soil. But, for coal to form, the plant has to be put somewhere it can't rot. Swamp water is just the place for it. Without Oxygen, the worms, fungi, and bacteria can't do their work. Coal develops in stages. It goes from peat to lignite to bituminous coal and to anthracite. The stages have progressively more carbon, and it's the carbon content that determines how clean or dirty each one of these will burn. When peat is formed, it can be less than about 20% carbon. As it gets buried deeper, its carbon content increases to become lignite overtime, which contains a lot of water. Overtime, lignite becomes bituminous coal, which is globally the most abundant form of coal, which is 60 to 80% carbon. The rest is largely water, hydrogen, and sulfur. Bituminous coal is primarily burned to generate electricity. The highest carbon content is found in Anthracite, which is usually 92 to 98% carbon. It's dark, black, and shiny. The most common age of coal is between 250 to 350 million years. Coal has the highest energy density per volume. It's abundant; burns easily and controllably. But, coal is a fossil fuel. It's old and once we use it up, it's gone.

Economics of Coal

Coal provides 28 percent of the world's energy and 40 percent of the world's electricity. Coal has both economic advantages and disadvantages which depends upon whether one decides to produce and export his coal now rather than later: the more you produce for yourself, the less you have to rely upon foreign energy sources. The more you sell, the better your trade balance is. On the other hand, the more you tap into coal, the quicker it goes, and it may be more valuable later on. Coal reserves, to be tapped into, have to be economically recoverable, which is defined by three things: the cost of retrieving it, the amount retrieved, and the price you get for it. Will coal ever completely disappear from the face of the planet? Not really but overtime it will be present in smaller and smaller quantity and will be located deeper within the soil. The cost of mining it will be higher than the cost of selling it. While this can easily be understood, it can be explained further thanks to a concept called *high grading*.

For example, “one trait that humans share with all animals is that we go after the easiest, highest-quality sources of materials first. That’s just natural. Those that are more concentrated and nearer to the surface (or markets) are preferentially exploited first. We tend to farm the best soils first, harvest the tallest trees, and go after the most concentrated ores bodies. It’s a process called ‘high grading,’ and it simply means doing the obvious: using up the best and most convenient stuff before the other stuff. Which means that by the time we’re chasing the less-attractive ores as a second order of business, there’s a very good chance that these ores are inconveniently located, perhaps deeper in the ground or in a more remote location or both, and/or in more dilute form. Because of this, as we go forward, the energy required to chase the lesser ores will be even more than is implied by a simple chart comparing the ore percentages to processing amounts. Quite simply, the key point here is this: To get more and more minerals from depleting ore bodies in the future won’t require just a little bit more energy, it will require exponentially more energy.” (Martenson, 2011) Finally, transportation of coal accounts for more than a third of its cost and it’s hard to see how that could change in the future.



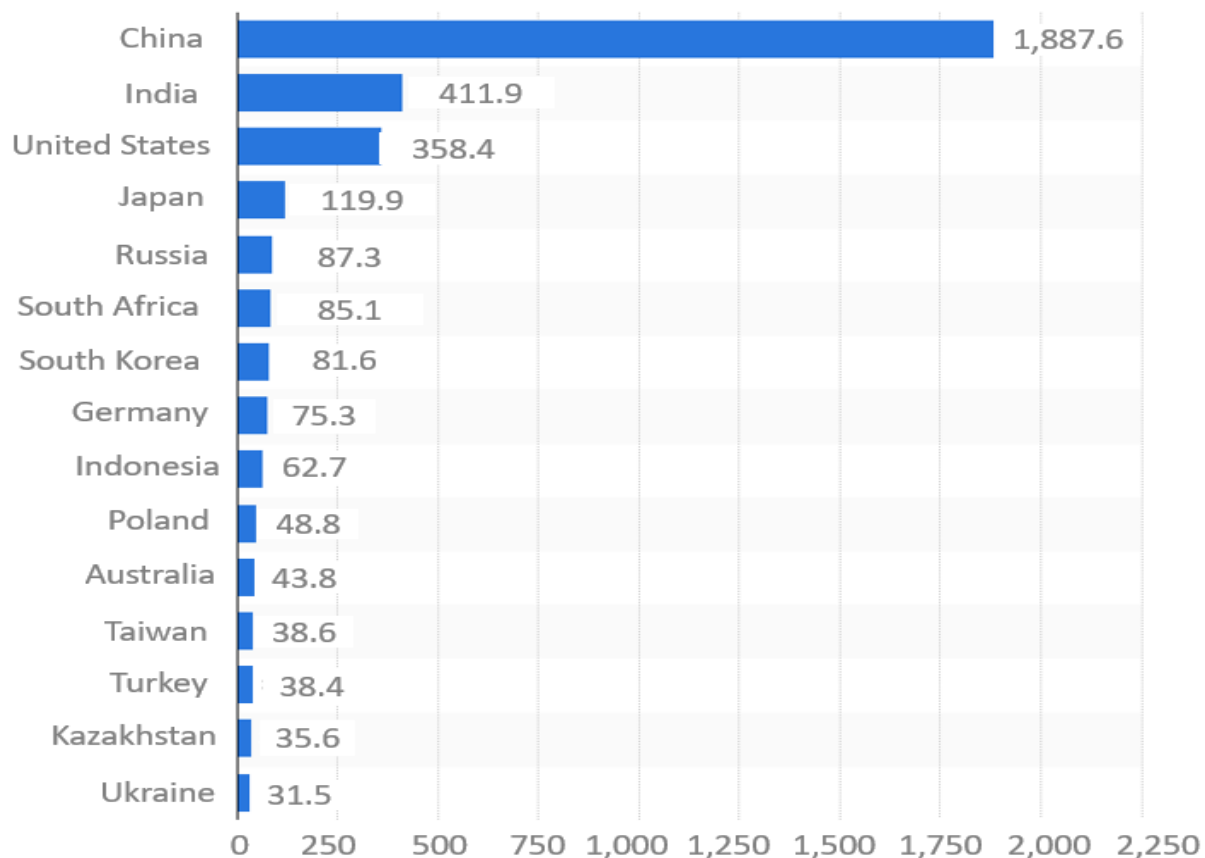
Global coal consumption fell by 1.7% in 2016, the second successive decline. BP STATISTICAL REVIEW

As of 2013, coal provided approximately 41% of the world’s electricity needs. And at 29% of total world energy supply, coal is second only to oil’s 31% share. Coal reserves and resources are widely dispersed over the globe and supply is not concentrated to a few regions only, as is the case for natural gas and oil. The key exporting countries, Indonesia, Australia, Russia, South Africa, Colombia, and the United States are politically stable. Nevertheless, the fact that around 90% of coal exports come from only these six countries suggests the need for further diversification. (International Energy Agency) Before 2016, world’s yearly usage of coal: 9 billion tons. After 2016, “world coal consumption experienced a record drop. Global consumption of coal fell by a record amount last year, driven by a rise in natural gas, increasing

deployment of wind and solar power, and a shift in China away from heavy industry, according to

BP's global review of energy trends. After increasing by an average of 1.9 percent yearly from 2005 to 2015, global coal consumption fell by 1.7 percent last year, according to the BP⁷ review. In the U.S., coal consumption dropped by nearly 10 percent, falling to levels not seen since the 1970s. In China, which accounted for about half of the coal burned worldwide, coal consumption fell by 1.6 percent in 2016, compared with an average 3.7 percent annual expansion in the preceding 11 years. In the U.K., coal demand fell by 52.5 percent as renewable energy generation increased significantly. The global drop in coal consumption means that for the third consecutive year carbon emissions saw little or no growth. "The fortunes of coal appear to have taken a decisive break from the past," BP's chief economist, Spencer Dale, said. "At the heart of this shift are long-term structural factors." In the U.S., President Donald Trump is attempting to revive coal's flagging fortunes. He touted the opening...of the first new U.S. coal mine in years, but that Pennsylvania mine will employ only 70 people — fewer than the average 92 jobs created by opening a new supermarket, according to Quartz." (E360 DIGEST, 2017)

Countries with the largest coal consumption worldwide in 2016 (in million metric tons oil equivalent) - Source: Statista



⁷ British Petroleum

Where Are the World's Largest Coal Deposits or Reserves?

More than 80% of the world's total proved coal reserves are located in just 10 countries. The US tops the list with more than a quarter of the proven coal reserves, while China, which ranks third, is the biggest producer and consumer of coal. *Mining-technology.com* profiles the 10 countries with the biggest proved coal reserves as of 2012.

United States of America

The United States holds the world's biggest coal reserves. The nation's proved coal reserves as of December 2012 stood at 237.295 billion tons (Bt) comprising more than one quarter of the total proven coal reserves in the world. The country's reserves are widely distributed across the country's geography with Montana, Wyoming, Illinois, western Kentucky, West Virginia, Pennsylvania, Ohio and Texas hosting most of the reserves. The Peabody Energy-operated North Antelope Rochelle coal mine in the Powder River Basin of Wyoming is the world's biggest coal mine by reserve. The US is also the world's second largest producer and consumer of coal. It produced 935 million tons (Mt) of coal (approximately 13% of the world's total) in 2012. The country accounted for 11.7% of the world's total coal consumption in the same year. Around 43% of the country's electricity generation is fueled by coal.

Russia

The Russian Federation possesses the second biggest coal reserves. The country was estimated to hold 157.01Bt of proved coal reserves as of December 2012, accounting for about 18% of the world's total. Russia's major deposits include the Donetskii reserves in Moscow, the Pechora basins in Western Russia and the Kuznetski, Kansk-Achinsk, Irkutsk and South Yakutsk basins in Eastern Russia. More than two-thirds of the coal produced in Russia is hard coal⁸, with Pechora and Kuznetsk basins the principal hard coal deposits. The Kansk-Achinsk Basin is known for huge deposits of sub-bituminous coal, while the Rospadskaya mine in the Kemerovo region is the largest coal mine in Russia. Russia is the sixth-largest producer and the fifth largest consumer of coal in the world. It produced 359Mt of coal and consumed 93.9 million tons oil equivalent of coal in 2012. Russia is also the third biggest coal exporter in the world – the country exported 134Mt of coal in 2012.

China

China holds the third largest coal reserves in the world. Its proven coal reserves as of December 2012 stood at 114.5Bt, constituting about 13% of the world's total proven coal reserves. China is also the world's biggest producer and consumer of coal. More than 70% of China's proved recoverable coal reserves are located in the north and north-west parts of the country. Shanxi and the Inner Mongolia provinces host a major chunk of accessible coal reserves in the country.

⁸ Also called anthracite, it's a hard-jet-black coal that burns slowly with a nonluminous flame giving out intense heat.

The Haerwusu coal mine in Inner Mongolia is the second biggest coal mine in the world, by reserve. China produced 3.55Bt of coal (47.5% of the world's total coal production) in 2012. The country, however, accounted for more than 50% of the world's total coal consumption in the same year. More than 80% of China's electricity generation is based on coal. China imported 289Mt of coal in 2012 becoming the world's biggest coal importer, followed by Japan.

Australia

The fourth largest coal reserves in the world are held by Australia. The country was estimated to possess 76.4Bt of proved coal reserves at the end of 2012, accounting for about nine percent of the total proven coal reserves in the world. The country's black coal reserves are mostly concentrated in New South Wales and Queensland, which together account for more than 95% of Australia's black coal output. Victoria hosts about 96% of the country's brown coal reserves. Peak Downs coal mine in the Bowen Basin of central Queensland, followed by the Mt Arthur coal mine in the Hunter Valley region of New South Wales, is the biggest Australian coal mine by reserve. Australia is the fifth largest coal producing country in the world. It produced 421Mt of coal (6.3% of world total) in 2012. Most (90%) of Australia's coal output is, however, exported, making it the world's second biggest coal exporter after Indonesia. Australia exported 383Mt of coal in 2012.

India

India holds the fifth biggest coal reserves in the world. The country's proved coal reserves as of December 2013 were estimated at 60.6Bt. India accounts for about seven percent of the world's total proved coal reserves. The major hard coal deposits of the country are located in the eastern parts of the country. The eastern states of Jharkhand, Chhattisgarh, Orissa and West Bengal account for more than 70% of the country's coal reserves. Andhra Pradesh, Madhya Pradesh and Maharashtra are the other significant coal producing states in India. The southern state of Tamil Nadu hosts most of the country's lignite deposits. India is the third biggest coal producer, after China and the US. India produced 595Mt of Coal (six percent of the world's total) in 2012. The country accounts for eight percent of world's total coal consumption. It imported 160Mt of coal in 2012, becoming the world's third biggest coal importer after China and Japan. About 68% of India's electricity generation comes from coal.

Germany

Germany has the world's sixth biggest amount, with 40.7Bt of proven coal reserves at the end of 2012. Germany possesses about 4.7% of the world's total proved coal reserves. The Ruhr Coal Basin in the North Rhine-Westphalia state and the Saar Basin in the south-west Germany account for more than 75% of the country's hard coal production. The Rhineland region hosts the country's largest lignite deposits. The Garzweiler open-cast coal mine in the North Rhine-Westphalia state is considered to be Europe's biggest brown coal mine. Germany is the eighth biggest coal producer and the largest brown coal producer in the world. It produced 197Mt of coal in 2012, out of which

185Mt was brown coal. The country contributed 1.2% of the world's total coal production and accounted for 2.1% of the world's total coal consumption in 2012. Germany imported 45Mt of coal in 2012. Coal accounts for 43% of Germany's electricity generation.

Ukraine

Ukraine holds the seventh largest coal reserves in the world. The country's proved coal reserves as of December 2012 were estimated at 33.873Bt. Ukraine's share in the world's total proved coal reserves is 3.9%. Most of the country's coal reserves are located in Donets Basin in Eastern Ukraine. Also known as the Donbas Coal basin, the Donets Basin is spread across three Ukrainian provinces, namely Dnipropetrovsk, Donetsk and Luhansk. Ukraine has 149 operating coal mines, out of which 120 are state-owned and 29 are private mines. The Komsomolets Donbasu coal mine in the Donetsk Oblast is one of the biggest coal mines in the country. Ukraine produced 1.2% of the world's total coal production and also accounted for 1.2% of the world's total coal consumption in 2012. It produced 18Mt of coking coal in 2012, becoming the eighth biggest coking coal producing country in the world. Most of the steam coal produced in Ukraine is used for domestic electricity production.

Kazakhstan

Kazakhstan, with more than 400 coal deposits, holds the eighth largest coal reserves in the world. The country was estimated to contain 33.6Bt of proven coal reserves at the end of 2012. It accounts for approximately 3.9% of the world's total proved coal reserves. The country's proved coal reserves are mostly concentrated in three provinces including Karaganda Oblast in Central Kazakhstan and the Pavlodar and Kostanay Oblasts in North Kazakhstan. Karaganda and Ekibastuz are the two biggest coal-producing basins in the country. Turgay, Nizhne-Iliyskiy and Maikuben basins are known for their lignite reserves. Bogatyr Access Komir is the biggest open cast mining company in Kazakhstan. Kazakhstan is the tenth largest coal producer in the world. It produced 126Mt of coal in 2012, comprising about 1.5% of the world's total coal production in the year. The country, however, accounted for just 0.9% of the world's total coal consumption during the same year.

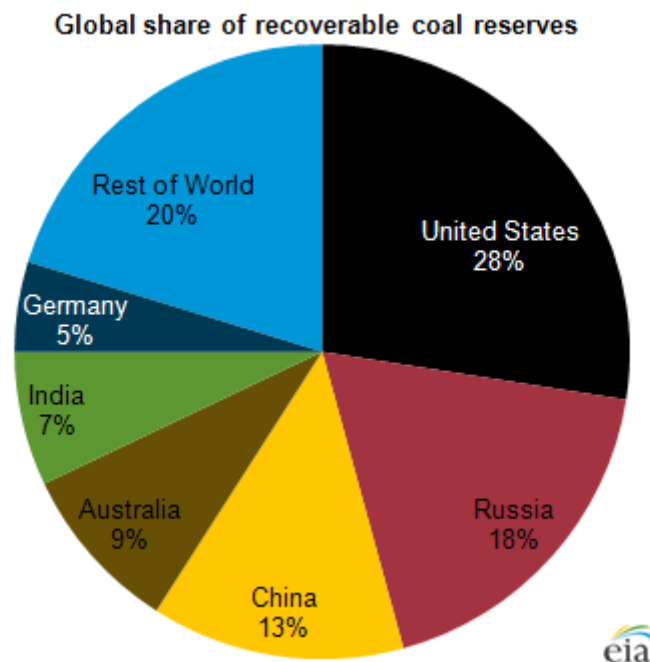
Colombia

Colombia's coal reserves put it in ninth place. Proven coal reserves of the country as of December 2012 were estimated at 6.746Bt, which amount to one fifth of the proved coal reserves of Kazakhstan, the eighth biggest. Colombia hosts the biggest coal reserves in South America, with reserves mostly concentrated in the Guajira peninsula. The La Guajira and Cesar departments of Colombia account for more than 85% of the country's coal reserves. Correjón is the biggest coal mine in Colombia, followed by the La Loma coal mine. Correjón is also the biggest coal mine in Latin America and the tenth biggest in the world, by reserve. Colombia produced 85Mt of steam coal in 2012. The country exports more than 90% of its coal output with the 2012 exports at 82Mt.

It is the fifth biggest coal exporter in the world. Correjón is the world's biggest coal exporting mine.

Canada

Canada ranks as the tenth biggest in the world, with coal reserves only slightly less than that of Colombia. The proved coal reserves of Canada as of December 2012 stood at 6.582Bt, accounting for about 0.1% of the world's total proved coal reserves. More than 90% of Canada's coal reserves are located in sedimentary basins in the western part of the country. Nanaimo, Bowser, Skeena, Moose River, Maritime and Bowron River are among the principal coal bearing sedimentary basins. Canada has a privatized coal industry. Most of the country's coal output is from open pit mines. The TransAlta-owned Highvale Mine in Alberta is the largest surface strip coal mine in the country. Campbell River in British Columbia and Grande Cache in Alberta are the only two underground coal mines operating in the country. Canada produced 0.9% of the world's total coal production and accounted for 0.6% of the world's total coal consumption in 2012. The country stands as the sixth biggest in coking coal production in the world. It produced 31Mt of coking coal in 2012. Canada is the world's seventh biggest coal exporter with exports in 2012 estimated at 35Mt. (Gupta, 2013)



Is Coal "Clean" or "Dirty"?

We have a love-hate relationship with coal. Coal is dirty. From start to finish. The mining, washing, transport, burning and disposal involves very dirty processes. It arguably causes more damage to

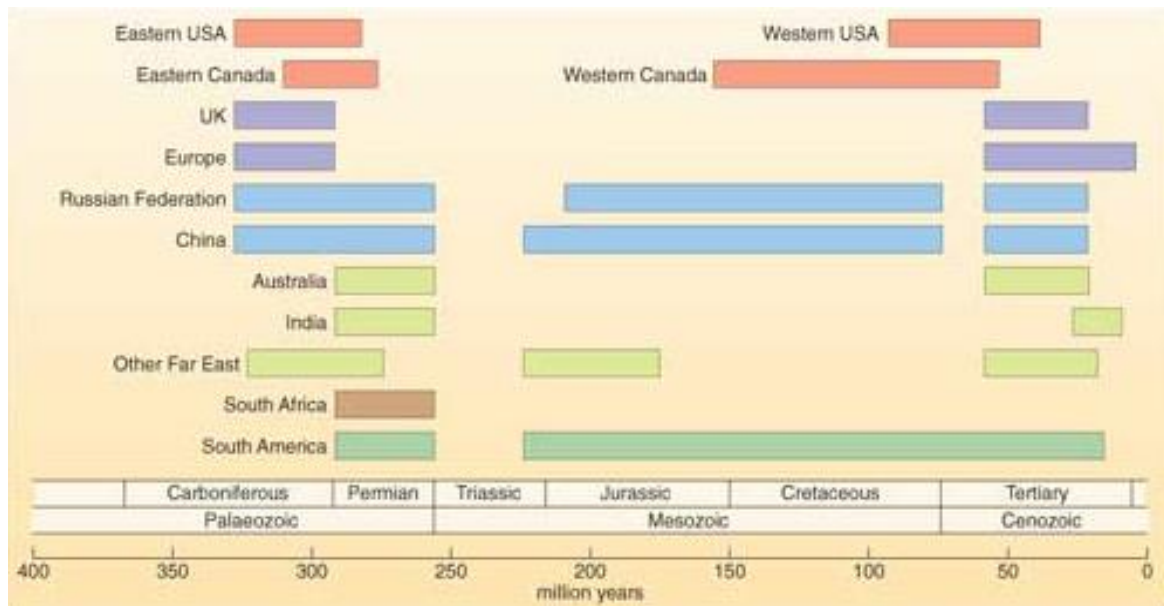
the environment than any other human activity. It tears up the land, removes mountains, contaminates rivers, causes acid rain, and is a major source of lung disease globally to the point that the true costs of burning coal have been estimated to be three times the purchase cost of coal. It releases more carbon dioxide than any other source per joule of energy, even more than oil and gas, and is therefore the largest contributor of greenhouse gases, and therefore to the global trends of increasing temperatures, sea level rise. It's like junk food: available everywhere, cheap, and high in calories but not good for your health.

Although coal is dirty, we can envision a clean future while using it. To environmentalists, “clean coal” is an insulting oxymoron. But for now, the only way to meet the world's energy needs, and to arrest climate change before it produces irreversible cataclysm, is to use coal—dirty, sooty, toxic coal—in more-sustainable ways. The good news is that new technologies are making this possible. China is now the leader in this area, the Google and Intel of the energy world. If we are serious about global warming, America needs to work with China to build a greener future on a foundation of coal. Otherwise, the clean-energy revolution will leave us behind, with grave costs for the world's climate and our economy... What would progress on coal entail? The proposals are variations on two approaches: ways to capture carbon dioxide before it can escape into the air and ways to reduce the carbon dioxide that coal produces when burned. In “post-combustion” systems, the coal is burned normally, but then chemical or physical processes separate carbon dioxide from the plume of hot flue gas that comes out of the smokestack. Once “captured” as a relatively pure stream of carbon dioxide, this part of the exhaust is pressurized into liquid form and then sold or stored...The Texas Clean Energy Project, a plant being built outside Odessa, which will apply underground-gasification technology to capture 90 percent of its carbon, more than any other commercial plant in the world. It received a \$450 million federal award, just over half from the Department of Energy's Clean Coal Power Initiative and the rest from the American Recovery and Reinvestment stimulus program (toward the \$2.1 billion total capital cost). If it works as promised, this facility will be an advance over any coal-fired plant operating anywhere: it will gasify coal underground, eliminating the cost and damage of mining; it will sell urea (for fertilizer) and other chemical by-products of the underground gasification; and it will use the captured carbon dioxide for enhanced oil recovery in the nearby Permian Basin oil fields—all in addition to generating power. (Fallows, 2010)

Why Are Coal Reserves Spread Unevenly on the Planet?

The relatively uneven distribution is the result of peat formation at different times in the geological past in predominantly tropical latitudes, and the subsequent drift of the continents to their present-day positions. The oldest coals of any economic significance date from the Middle Carboniferous Period — the earliest geological strata in which coal has been identified are of Devonian age but

they are of little economic significance. With the exception of parts of the Triassic Period, major coal deposits have been forming somewhere in the world throughout the last 320 Millennia. Sedimentary sequences of the last 2-3 Millennia do not contain coals, simply because there has been insufficient time for them to develop from plant debris. Possible future coals exist today in the form of peats that are accumulating in modern mires.



Global distribution of major coal deposits by geological age.

Some coals are known from the Devonian Period but have minor economic significance.

Source: OpenLearn

A broad chain of large coalfields of Carboniferous age extends from the eastern USA, through Europe, the Russian Federation and south into China. A second chain of Permian coalfields is found in the southern continents — South America, India, southern Africa, Australia and Antarctica. The vast coalfields of the western USA and Canada are of Cretaceous-Tertiary age. Mesozoic-Cenozoic lignites are also important global sources of coal.

Not all regions have coal reserves. They either do not possess coal-bearing rocks, or they do, but they are not considered reserves. There are several geological reasons for this:

- Regions where post-Devonian sediments were not deposited or have been completely eroded have no coal whatsoever, such as Scandinavia and much of Africa.
- Regions may have no coal-bearing rocks — although they were once deposited they have now been eroded away. Ireland once contained a substantial sequence of Upper Carboniferous coals; probably as much coal as the UK, but only a tiny fraction now remains.
- Some regions have coal-bearing rocks that are buried so deeply under younger sedimentary sequences that they cannot be worked economically. The Amazon basin is a good example.

- Few preserved sedimentary rock sequences formed under terrestrial conditions with which mires were associated. Some terrestrial sediments formed at high paleolatitudes and others in arid climatic belts, neither of which are conducive to peat formation, whilst other sediments formed on the sea floor. The Carboniferous sediments of South Africa and the Permian of the UK (dominated by terrestrial glacial and desert deposits respectively) are good examples, as neither is coal bearing, whereas Permian terrestrial sediments of South Africa and those of the Carboniferous of the UK both contain substantial coal sequences formed in a humid climate. (OpenLearn, 2018)

Disadvantages to Coal Mining

Coal mining is dangerous. About 5,000 miners die each year around the world especially in firedamp, which is flammable gas found in coal mines. It is the name given to a number of flammable gases, especially methane. It is particularly found in areas where the coal is bituminous. The gas accumulates in pockets in the coal and adjacent strata, and when they are penetrated, the release can trigger explosions.

There are two main types of coal mine explosions: methane explosions and coal dust explosions. Methane explosions occur in mines when a buildup of methane gas, a byproduct of coal, comes into contact with a heat source, and there is not enough air to dilute the gas to levels below its explosion point...In most U.S. coal mines, each ton of coal contains between 100 to 600 cubic feet (2.83 to 17 cubic meters) of methane. When air contains 5 percent to 15 percent of methane, it can explode. Methane, the main component of natural gas, is combustible, and mixtures of about 5 percent to 15 percent in air are explosive. When air contains approximately 9.5 percent of methane (the most dangerous concentration), it reaches the perfect oxidation point, which means that the right amount of fuel is mixing with the right amount of oxygen, said Luo. This produces water, carbon dioxide and a lot of amount of heat. The heat generated by this process raises the temperature of the air within the mine, which causes it to expand in volume. Since hot air cannot expand easily underground, pressure builds in the mine. If this pressure is high enough, it can cause the air ahead of the combustion zone to compress and cause a shock wave. (Chow, 2010)

The kind of mining which is more ecologically destructive is mountaintop removal. Recent examinations of the health and environmental impacts of mountaintop mining – stripping the tops off of mountains to extract coal – has the practice looking pretty guilty. It apparently spikes birth defects, worsens chronic conditions like heart disease, and ruins land, and it doesn't look like it will be clearing its name anytime soon. And PNAS – *Proceedings of the National Academy of Sciences* – has added one more strike to the list with new research that further demonstrates how mountaintop mining erodes long-term water quality and causes deformities in aquatic life.

Duke University environmental scientist Ty Lindberg and his team found dramatic increases in salinity and trace metal concentrations in the water immediately downstream of mountaintop mining sites in central Appalachia. Most striking about their study was just how significant the linear relationship was between upstream surface mining disturbance and downstream water contamination – the team calculated some pretty mouthwatering p-values⁹, and their statistical analyses showed that over 85% of the increased pollutant concentration in the sampling sites could be blamed on the extent of mining disturbance in the watershed.

“The strength of these correlations is actually pretty astonishing,” Lindberg said. “You often don’t see it in these types of systems where there’s a lot of complexity.” Mountaintop mining, which is frequently conducted in the Appalachian region of the eastern United States, essentially blows the tops off of mountains using explosives so coal companies can extract the coal underneath. The unusable waste rock is then disposed of in the valleys and streams below, which creates fills that permanently bury streams under “tens to hundreds of meters of waste rock,” the researchers wrote. The EPA estimated that 1,944 km of headwater streams were buried between 1992 and 2002 with complete utilization of fill permits, and (predicted) that 2012 (would) see a doubling of buried stream length to nearly 4,000 km.

To assess the impacts of mountaintop debris on the adjacent watershed, the scientists collected samples from 23 sites in over 100 mining outlets that spanned about 28 square km of coal mines. After the sampling, which took place in West Virginia’s Upper Mud River between May and December 2010, the team measured concentrations of major and trace elements as well as the electrical conductivity of the water, a measure of salinity. Their results were telling: downstream of the mine discharge outlets, dissolved rock- and coal-weathering constituents and the resulting increased conductivity of the water significantly exceeded levels that the EPA has deemed harmful to aquatic life. Meanwhile, the two sampling sites upstream of the mountaintop mines demonstrated conductivity levels within an acceptable range. (Thean, 2011)

All fossil fuels emit carbon dioxide when burned, but coal is a uniquely dense source of greenhouse gas. Bituminous coal, the most common type of coal used for power generation, release 205.7 pounds of carbon dioxide per million BTU of energy; natural gas releases 117 pounds per million BTU...Coal burning is the single largest source of carbon emission in the world today, accounting for more than 44 percent of global carbon dioxide emissions...Our modern technological society would be inconceivable without cheap energy from coal. And that society will not survive unless we wean ourselves from coal. To limit catastrophic climate change, we must find a way to power our cities with less polluting energy sources, and we must do it in the next couple of decades. For the last century and

⁹ In statistical hypothesis testing, the p-value or probability value or asymptotic significance is the probability for a given statistical model that, when the null hypothesis is true, the statistical summary (such as the sample mean difference between two compared groups) would be the same as or of greater magnitude than the actual observed results.

a half, we have made a devil's bargain with coal, and now the payment has come due. If coal consumption is not drastically reduced in the next 20 years, ..., "it's game over." In other words, it doesn't matter how many roofs we cover with solar panels, how many windfarms we build, or how many electric vehicles we sell; if we don't shut down Big Coal, the fight against global warming is lost. (Martin, 2015)

2. Petroleum

Petroleum consists of a whole set of organic molecules made up of hydrogen and carbon atoms, and they are understandably referred to as hydrocarbons, which have extremely high energy densities. That characteristic makes them excellent sources of energy. We primarily burn them for heat to power motors and engines and to make steam for electricity. But hydrocarbons have a wide spectrum of use, including chemicals, fertilizers, pharmaceuticals, plastics, fabrics, among many other things.

Larger hydrocarbons such as heptane, octane, and nonane with respectively 7, 8, and 9 carbon atoms aren't liquid at surface temperature. They're the primary constituents of gasoline. 90% of transportation is powered by petroleum in liquid form that can be pumped directly into the tank of your car or truck. Larger hydrocarbons are thicker and more viscous and are good as lubricating oils and waxes. Even larger hydrocarbons are used as tars in road construction. Like coal, petroleum is a fossil fuel. It forms from living ocean organisms that tens of millions of years ago that died and filled the ocean sea floor, mostly one-cell planktons. Over time, two things happen: the pressure on these organisms increase and it got hot. The pressure and temperature turned the sediments into sedimentary rocks such as sandstone, shells, and limestones. In this process, the heat and pressure take down the planktons, break down their organic molecules into simpler organic molecules and eventually into hydrocarbons, which are, at first, stiff and tarry. But with more pressure, they will turn into liquid petroleum. With even more heat and pressure, petroleum will turn into natural gas. The oil refinery emulates this process while the Earth does it naturally.

The above points beg the question: why can't we find oil everywhere, especially if most of the continents were once covered with water? The answer is it takes just the right geologic conditions. If you compare the countries which have the largest coal reserves to the ones which have the largest oil reserves, you will notice that the former are big countries whereas the latter tend to be smaller countries. Now, to understand what petroleum involves, it's important to ask the following questions: how does it form? How do we find it? How do we remove it? How do we process, transport, and use it?

Formation of Petroleum

How does petroleum form? "Almost all geochemists believe petroleum results from a few million years of decay of once-living organisms. 'We can tell that by looking at biomarkers in the oils,' Kenneth Peters, an organic geochemist at Stanford University, told Life's Little Mysteries.

‘Molecules in oil have the same backbone structures that we find in living organisms.’ So what process turns the latter into the former? It mostly happens in sediment deposits that collect in depressions at the bottom of the ocean. When phytoplankton, algae and other marine organisms die, they drift to the seafloor, collectively forming sedimentary drifts of decaying organic matter. These get lodged in places where tectonic plates are subsiding. Proteins, lignin and cellulose break down very quickly into amino acids and sugars; they turn into sludge. ‘There is one fraction of organic matter that is preserved in sediments, and that’s the lipid fraction. That contains the precursors we find in crude oil,’ said Peters. Fats last forever. As more and more sediment layers accumulate, the bottom layers get compacted by the increasing pressure bearing down on them. This in turn ramps up their temperature. Over geologic time, turning up the heat catalyzes the chemical processes that cause extremely heavy and complex molecules called kerogens to assemble from the dismantled components of organic molecules. These kerogens, along with long-lasting lipids and scant leftover bits of cell wall, make up the raw material that will turn into petroleum.

When a kerogen layer gets buried one to three miles deep, the temperature climbs to the 120 to 300 degree-Fahrenheit range, and the pressure escalates. Over the course of several or tens of millions of years, the carbon bonds in kerogen and the other molecules break apart. This process, called ‘cracking,’ produces the simple hydrocarbon molecules that we call petroleum. Methane, propane, asphaltene and propylene are all examples of petroleum hydrocarbons, which differ from each other in the way the hydrogen and carbon atoms that compose them are arranged. Some hydrocarbons exist as liquids while others are gaseous, and they are thus known as oil and natural gas, respectively. ‘The expansion that occurs when the kerogen becomes a gas or liquid makes it like a pressure cooker,’ said Peters. ‘Eventually the surrounding rock fractures and that’s when we get expulsion. The oil migrates out of the source rocks to places where the pressure is lower.’ It usually moves upwards through permeable rock, such as sandstone (which has been piling up on top of it for eons), until it encounters what scientists refer to as a seal, or trap. ‘This could be a salt or stone structure that traps oil or gas below it,’ Peters said. ‘To find petroleum reserves, geophysicists look for inverted bowls or other landforms that act as structural traps,’ he explained. These may be deep under the seafloor, or, since tectonic plates shift, below land. (Wolchover, 2011)

A “petroleum play” is full of drama! A petroleum play is a group of oil fields in a single geographic region, created by the same geologic forces or during the same time period. A petroleum play may be defined by a time period (Paleozoic play), rock type (shale play), or a combination of both. In Los Angeles, California, bitumen has been seeping to the Earth’s surface for thousands of years at what is now called the La Brea Tar Pits. The pits have preserved fossils of saber-toothed cats, mastodons, turtles, dire wolves, horses, and other plants and animals that were trapped in the sticky substance 40,000 years ago. Bitumen continues to bubble up through the ground today. Crude oil

is usually black or dark brown, but can also be yellowish, reddish, tan, or even greenish. Variations in color indicate the distinct chemical compositions of different supplies of crude oil. Petroleum that has few metals or sulfur, for instance, tends to be lighter (sometimes nearly clear). (National Geographic, 2018)

Discovery of Petroleum

How do we find petroleum? Back in the day, they had to drill the ground at regular intervals to find oil. And most of the wells would be dry. So, it was a hit or miss operation. Today's state-of-the-art techniques have changed that. According to the Department of natural resources of the State of Louisiana, deciding where to drill may be as much of an art as it is a science. The primary search for hydrocarbons frequently begins with observation of surface terrain. Location of faults at the surface are very important because they indicated where potential structural traps may lie beneath the surface in reservoir rocks. The observation of anticlines, another type of structural trap, also indicate potential traps at depth. Naturally existing crude oil seeps blacken the ground and spread rainbow films on streams. Such direct evidence is useful, but most such places have long ago been identified and explored. So, the modern exploration geologist (a person who explores for petroleum) must rely on other techniques. There are three primary methodologies used to find hydrocarbons in the subsurface: geophysical, remote sensing, and wildcatting.

1. Geophysical Surveys

Geophysical techniques used for petroleum exploration utilize equipment to measure such things as: electrical currents, gravitational and magnetic anomalies, heat flow, geochemical relationships, and density variations from deep within the earth. Each technique records a different set of characteristics which can be used to locate hydrocarbons beneath the surface of the earth. Seismic surveys use vibration (induced by an explosive charge or sound generating equipment) to provide a picture of subterranean rock formations at depth, often as deep as 30,000 feet below ground level (BGL). This is accomplished by generating sound waves downward into the earth's crust which reflect off various boundaries between different rock strata. On land, the sound waves are generated by small explosive charges embedded in the ground or by vibrator trucks, sometimes referred to as thumpers which shake the ground with hydraulically driven metal pads. The human ear can barely hear the thump, but the frequency generated penetrates the earth's crust. The echoes are detected by electronic devices called geophones which receive the reflected sound waves and the data are recorded on magnetic tape which is printed to produce a two-dimensional graphic illustrating the subsurface geology.

Offshore surveys are conducted in a slightly different manner. Boats tow cables containing hydrophones in the water, which is similar to geophones on land. Sound waves use to be created by dynamite, but this method killed a variety of sea life. The most acceptable method today is to generate sound waves using pulses of compressed air which creates large bubbles that burst beneath the water surface creating sound. The sound waves travel down to the sea floor, penetrate the rocks beneath, and return to the surface where they are intercepted by the hydrophones. Processing and illustration is the same as the dry land method. In this type of survey, sound waves are sent into the earth where they are reflected by the different layers of rock. The time taken for them to return to the surface is measured as a function of time. This measurement reveals how deep the reflecting layers are; the greater the time interval, the deeper the rock layer. Moreover, this technique also can determine what type of rock is present because different rocks transmit sound waves differently.

The most sophisticated seismic surveys are three-dimensional (3-D). The recorded data is processed by computer and the results are a detailed, 3-D picture of the formations and structures below the surface. The process is expensive, on the order of \$30,000 per mile (Satterwhite, pers comm). But drilling a well can cost multiple millions of dollars, so time and money spent on accurate seismic surveys can be a good investment since it helps locate prospects and minimize dry holes. In general, seismic surveys can be carried out without disturbing people or damaging the environment, whether they are being conducted on land or water. It is a primary tool used by exploration geologists to locate [hydrocarbon] prospects. There are a number of other geophysical techniques such as magnetometers and gravimeters, and geochemical prospecting, a relatively new technique. A magnetometer is a device that is pulled behind an airplane on a long cable that detects variations in the earth's magnetic field. Sedimentary rocks generally have low magnetic properties compared to other rock types. A gravimeter measures minute differences in the pull of gravity at the earth's surface. Mapping these differences reveals large masses of dense subsurface rock which allows geologists to have a better idea of the structures below ground. Geochemical prospecting uses sensitive instruments to detect minute quantities of gases that seep upward from petroleum deposits. This is a relatively new technique but is one that is gaining wider acceptance.

2. Remote Sensing

Remote Sensing (RS) is the use of aerial photographs to locate and map surface features. Increasing use of satellite imagery is being made because it shows large areas on the surface of the earth. Even though the photographs are taken from several hundred miles up in space, they are able to show features only a few feet in size. And satellite imagery not only indicates what the human eye can see, but they can also reveal subtle variations in soil moisture, mineral and vegetation distribution, and soil type, all of which are import pieces to the exploration puzzle. Once an area

is selected and the satellite imagery obtained, the exploration geologist utilizes mapping techniques to produce a geologic map (a map that indicates geological structures by using conventional symbols) for the area. The series of lines and arrows indicate the type of structure that exists at the surface. For example, a photograph taken in November 1972 by a NASA satellite orbiting over 500 miles out in space, shows the surface topography very clearly for an area in Southeastern Oklahoma known as the Ouachita Mountains. These mountains are comprised of folded and faulted Paleozoic strata which are buried beneath younger sediments toward the south. These mountains are made of a combination of structures called anticlines, synclines, and faults, all of which form various types of hydrocarbon traps.



Another type of RS technique uses imagery that was created from a radar looking at the ground called Side Looking Airborne Radar (SLAR). Some of this imagery is flown with an aircraft while some of it is onboard satellites or the US

Space Shuttle. It produces an image much like a photograph that also shows earth structure at the surface. This figure is an area in South America that has never been explored. Until this SLAR image was made, there were no accurate maps of the region because the area is usually covered by clouds. But now, there are new opportunities based on this image. These types of maps allow geologists to determine where hydrocarbons might be located...Anticlines are ideal structural traps while synclines do not tend to trap hydrocarbons. The figure above shows anticlines that will aid in the development of new prospects.

3. Wildcat

A wildcat well is one that is drilled in a new area where no other wells exist and generally with scant information. It is drilled in an effort to locate undiscovered accumulation of hydrocarbons. About 1 in 10 wildcat wells strike oil or gas, but only one in perhaps 50 locate economically significant amounts. Many wildcat wells are drilled on a hunch, intuition, or a small amount of geology. Many times, they are based on photography and experience in a particular area. Wildcat wells are generally drilled at a smaller diameter than normal because this saves money (the average onshore well at present costs about 10 MM dollars to drill).

One of the earliest exploration tools was referred to as Creekolog. But recent technological advances have led to computer-enhanced capabilities using laptops that has had a major effect on the petroleum industry. New seismic techniques, for example, have created more mobile, less expensive, and easier to operate exploration tools that has created a wealth of information designed specifically for hydrocarbon exploration. Field equipment is smaller, lighter, more accurate and reliable and provides far greater detailed data. But the basic tool needed for the search for hydrocarbons still remains a knowledge of the Earth and earth processes of formation, lithology, and structure. But even with all of this, wildcat wells are still drilled, but their success rate is substantially lower than a well spudded in (to begin a new well) using all of the geological tools available. (Department of Natural Resources, Louisiana; 2018)

Terms for crude oil include:

- Light or low density
- Heavy or high density
- Sweet or low sulfur
- Sour or high sulfur

The petroleum industry is able to identify the likely places to find oil, which not only save us a lot of money but is much less disruptive of the surface. The Ghawar oil field in Saudi Arabia is just 30 KM x 280 KM but accounts for more than half of the Saudi petroleum. The petroleum that comes out of the ground isn't the same in any two places. It depends on the unique geologic history of that region, what sediments were there, how long they were heated and pressurized, what rocks the petroleum passed through picking up some other elements in the process. This all determines the composition of the petroleum. If it was subjected to higher temperature for longer time, it will contain lighter hydrocarbons. It could even be all gas. The West Texas Intermediate (WTI) oil is a very high-quality, sweet and light crude oil. Another high-quality oil is Brent crude, which comes from the north Atlantic.

Retrieval of Petroleum

Petroleum is remove from the ground in different ways than coal. "Extracting oil and natural gas from deposits deep underground isn't as simple as just drilling and completing a well. Any number of factors in the underground environment – including the porosity of the rock and the viscosity of the deposit -- can impede the free flow of product into the well. In the past, it was common to recover as little as 10 percent of the available oil in a reservoir, leaving the rest underground because the technology did not exist to bring the rest to the surface. Today, advanced technology allows production of about 60 percent of the available resources from a formation.

Primary recovery first relies on underground pressure to drive fluids to the surface. When the pressure falls, artificial lift technologies, such as pumps, are used help bring more fluids to the surface. In some situations, natural gas is pumped back down the well underneath the oil. The gas expands, pushing the oil to the surface. Gas lift technology is often used in offshore facilities. Primary recovery often taps only 10 percent of the oil in a deposit.

Secondary recovery is the most widely applied enhanced recovery technique. Water that is produced and separated from the oil in the initial phase of drilling is injected back into the oil-bearing formation to bring more oil to the surface. In addition to boosting oil recovery, it also disposes of the wastewater, putting it back where it came from. This can bring an additional 20 percent of the oil in place to the surface.

Enhanced recovery techniques are used to mobilize the remaining oil. There are three common approaches: thermal recovery, gas injection or chemical flooding:

- Thermal recovery entails injecting steam into the formation. The heat from the steam makes the oil flow more easily, and the increased pressure forces it to the surface.
- Gas injection uses either miscible or immiscible gases. Miscible gasses dissolve CO₂, propane, methane or other gasses in the oil to lower its viscosity and increase flow. Immiscible gasses do not mix with the oil but increase pressure in the “gas cap” in a reservoir to drive additional oil to the well bore.
- Chemical flooding involves mixing dense, water-soluble polymers with water and injecting the mixture into the field. The water pushes the oil out of the formation and into the well bore.

Enhanced recovery techniques are employed to bring as much as 60 percent of the reserve to the surface.” (Adventure in Energy, 2018)

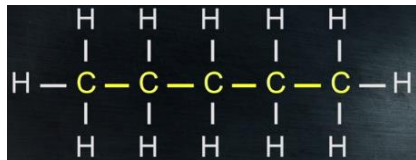
Arabian Production Vs. Rest of the World's

As shown in the table below, in 2000, Saudi Arabia, Iraq, UAE, Kuwait, and Iran accounted for two thirds of the world's oil reserve. The 2014 data are different.

2000 Estimated Global Reserves (~ 1 Trillion Barrels)		2014 Estimated Global Reserves (1.656 Trillion Barrels)	
Saudi Arabia	26%	Venezuela	18%
Iraq	11%	Saudi Arabia	16%
United Arab Emirates	10%	Canada	10%
Kuwait	10%	Iran	9%
Iran	10%	Iraq	11%
Venezuela	7%	Kuwait	6%
United States	2%	United Arab Emirates	6%
China	2%	Russia	4%
		United States	2%
		China	2%

This is a little bit upsetting for the US which has only 2% of the world's reserve but consumes 25% of the world's total oil production. The US use as much oil in a year as it had total in reserves. In 2014, according to the Energy Information Administration, estimated global reserves jumped to 60% increase compare to 2000. The five Middle-East countries now had less than half (46%) of the world's oil. Where did the reserves of countries such as Canada and Venezuela suddenly come from? More interestingly, most of those increases occurred in a single year. Most of Canada's reserves came about in 2003 and Venezuela's reserves were added in two years: 2011 and 2013. So, was all of this oil suddenly discovered all at once? No, efforts to discover oil is an ongoing process. The thing is unconventional or low-grade oil is hard to extract. If the overhead costs to tap into it are higher than the selling price, it's not worth to extract it. But, during the last 15 years, the price of oil has gone up. Then, it made sense to add those unconventional reserves to retrievable ones. In 2014, the US oil reserves jumped to 37 million barrels from 23 million barrels in 2000. It still had 2% of the world's total reserve. However, the US consumption actually decreased: 19 million barrels in 2014 from 20 million in 2000. Therefore, it used as much oil in two years as it had total in reserves compared to the use of as much oil in a year as it had total in reserves in 2000.

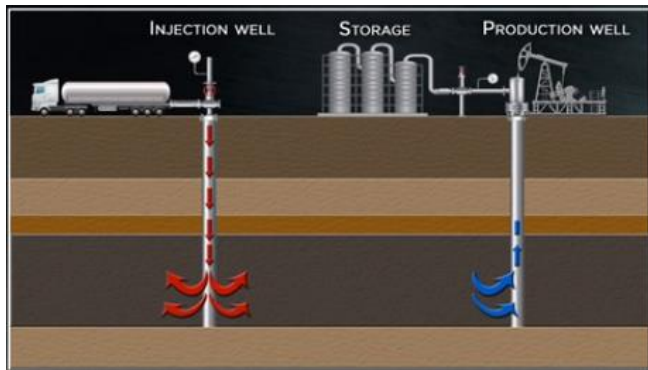
Characteristics of Venezuelan Petroleum Vs. Canadian Petroleum



Venezuelan oil's carbon configuration

Venezuelan's oil is actually very heavy and contains several carbon chains attached to the hydrogen atoms. Heavy oils also tend to be higher in sulfur and heavy metals, which all have to be removed during processing. The heaviest form of heavy oil is called bitumen or asphalt. It's so heavy that it doesn't flow. Bitumen is primarily used for paving roads. Bitumen is largely

found in areas called oil sands or tar sands, which are a mixture of bitumen, sand, clay, and water. Bitumen is found in Venezuela, but Canada's oil reserves are primarily tar sands located in the province of Alberta. These are low-grade, solid bitumen mixed with sand and clay. Out of Canada's oil reserve, maybe 10% is at most recoverable. Oil sands pose a real engineering challenge in terms of retrievability. The oil sands are dug up, heated with hot water and a caustic chemical (Sodium Hydroxide). Then, the mixture is piped through pipelines to facilities where the oil can be extracted.



Oil sands extraction: Thanks to novel technologies, the challenges of bitumen extraction may be overcome: one method consists in pumping hot water down a well to heat the bitumen to liquefy it and have it come out another well. This could potentially recover more than 50% of the bitumen. Other possible technologies might use microwaves by passing copper cables through the

bitumen in order to create electromagnetic fields. The advantage of these methods is that they are more likely to leave the surface much more intact. However, they also all take a lot of energy. So, they cost more. “Bitumen can be extracted using two methods depending on how deep the deposits are below the surface: in-situ production or open pit mining.

- *In-situ Production.* In-situ extraction methods are used to recover bitumen that lies too deep beneath the surface for mining (greater than 75 meters underground). Currently, 80% of oil sands reserves are accessible via in-situ techniques. Steam Assisted Gravity Drainage (SAGD) is currently the most widely used in-situ recovery method. This method requires the drilling of two horizontal wells, one slightly higher than the other, through the oil sands deposit. Steam is injected continuously into the top well and, as the temperature rises in what is termed the “steam chamber”, the bitumen becomes more fluid and flows to the lower well. The bitumen is then pumped to the surface.
- *Open Pit Mining.* Open-pit mining is similar to traditional mineral mining operations and largely employed where oil sands reserves are closer to the surface (less than 75 meters underground). Currently, 20% of oil sands reserves are accessible via mining techniques. Large shovels scoop the oil sand into trucks which then move it to crushers where the large clumps of earth are processed. Once the oil sand is crushed, hot water is added so it can be pumped to the extraction plant. At the extraction plant, more hot water is added to this mixture of sand, clay, bitumen, and water in a large separation vessel where settling time is provided to allow the various components to separate. During separation, bitumen froth rises to the surface, where it is removed, diluted, and refined further.

Upgrading

Bitumen recovered from open pit mines or from in situ extraction is a very thick, viscous substance that has to be upgraded or diluted in order to be pipelined and used as feedstock in refineries. The purpose of upgrading is to transform bitumen into synthetic crude oil (SCO) which can be refined and marketed as consumer products such as diesel and gasoline. Upgrading processes involve

either adding hydrogen or removing carbon from the bitumen to create SCO. Although the overall upgrading process flow diagram varies from company to company, generally the process is broken down into two broad types of upgrading, namely primary and secondary upgrading. Primary upgrading breaks down the heavy molecules of bitumen into lighter and less viscous molecules. Secondary upgrading is meant to further purify and distill the bitumen obtained from primary upgrading to remove unnecessary impurities such as nitrogen, Sulphur, and trace metals so that it could be used as feedstock for oil refineries.” (Natural Resources, Canada, 2018)

Other Form of Unconventional Oil Reserve

Another form of unconventional oil reserve is called oil shale or oil contained within a rock. This is a little bit of a mischaracterization because the oil isn’t really oil and the rock isn’t really shale. Oil shale refers to any number of organic-rich fine grain sedimentary rock that contains the organic material kerogen. The kerogen is a waxy material that contain complex organic compounds. However, if the kerogen is heated enough, it can produce shale oil. Sometimes called synthetic oil, shale oil is different in chemical composition than crude oil. But it can substitute for it in many applications especially when making mineral oil. Extracting shale oil requires a lot of energy and money. The largest known reserve is the Green River Basin in parts of Utah, Colorado, and Wyoming. To retrieve the reserves, much of Utah, Colorado and Wyoming would have to be dug up. But again, if the price of oil goes high enough, doing it will be worthwhile.

I will talk more about fracking or hydraulic fracturing in the next section (*Natural gas*). For now, keep in mind that “Hydraulic fracturing, or fracking, is a method of oil and natural gas extraction involving injection of a fluid under high pressures in order to crack the rock formation containing the hydrocarbon. The composition of the fluid varies with the type of formation being fractured, but generally consists of mostly (90-98 percent) water, a “proppant” such as sand to keep the fractures open, and a small percentage of chemical additives. Hydraulic fracturing was invented in the 1940s and is now used in more than 90 percent of U.S. drilling operations. Until recently, the technology has not been the focus of public concern. However, the widespread adoption of horizontal drilling technology, coupled with hydraulic fracturing for both oil and natural gas production, has broadened the scale and geographical scope of hydraulic fracturing significantly and aroused concern about the technology’s environmental impact.

Horizontal drilling and hydraulic fracturing have had a significant impact on natural gas and oil production in the United States. As the technologies are adopted worldwide, they will exert a major influence on energy economics. Already, the dramatically increased supply of natural gas and concomitant global reduction in natural gas prices have resulted in natural gas replacing coal in almost all new U.S. electricity generation. As a result, U.S. greenhouse gas (GHG) emissions from

burning fossil fuels have been reduced to levels not seen since the mid-1990s. The increased supply and reduced cost of crude oil and natural gas have also had a major impact on chemical production in the United States. Propagation of this resource through the chemical manufacturing supply chain may provide new opportunities for innovation leading to improved product portfolio and lifecycle impacts.” (ACS, 2016)

Transportation of Petroleum

Once the oil is out of the ground, we need to transport it and process it through a refinery. The United States imports half of its oil but also exports oils in the form of refined products. “Petroleum transport is the transportation of petroleum and derivatives such as gasoline (petrol). Petroleum is transported via rail cars, trucks, tanker vessels, and through pipelines. Which method is used to move this oil depends on the amount that is being moved and where it is being moved to. The biggest problems with moving this oil are pollution and the chance that the oil can spill. Petroleum oil is very hard to clean up and is very toxic to living animals.” (Wikipedia, 2018)

Marine vessels

Marine oil tanker and barges can transport petroleum all around the world. These vessels are used because they can carry a lot of fuel, so the amount it costs per barrel to move the oil from point A to point B is very cheap. These tankers are also really the only way to move crude oil across the oceans. Usually the larger tankers are used to transport this fuel on a global scale, taking fuel from one continent to the other. Barges are a lot like tankers, however barges are a lot smaller and do not have any method of propulsion to move them. Barges are often pushed or towed by tugs. This makes them very poor for transporting oil over long distances. Barges are very poor for traveling across rough seas, so they are used in calmer waters. However, they are usually used for transporting fuel over shorter distances.

Pipelines

Pipelines are used to transport oil from the wells to refineries and storage facilities. Pipelines are viewed as the most cost-efficient way to move oil on land. First the oil is collected at the wellhead, or some area where it is stored. From the wellhead it is pumped across the land through a pipe and is discharged at its destination which typically is a refinery. However, pipelines can be used the same way to deliver already refined fuels such as gasoline, diesel and even jet fuel from the refinery to distribution facilities or a consumer. These pipelines are not just a solid line of straight pipe but have various components on the pipeline. These pipelines will have booster pumps to keep the fuel moving along a long distance, inspection areas to make sure that the fuel is not getting any contaminants, and even other collection and delivery points along the way. Though it costs a lot of money and time to set up these pipelines, the operation cost is significantly less than using

any other type of transportation. Also, the amount of manpower needed to move this oil is not that much. Pipelines offer the most efficient mode of transporting this oil across a land mass. Even though these pipes are extremely cost effective there are some circumstances where this is not true, and it is more logical to use another method. An example of this is how it is cheaper and more logical to use a ship to move the oil across the Atlantic Ocean than a pipeline.

Rail cars

Tank cars are another way to move crude oil across a landmass. The oil is loaded into the tank cars and are moved by a diesel train across the rails to the refinery or the trains planned destination. Trains can carry a mass amount of this oil by using of multiple tank cars. Though each rail car holds a lot less oil than a large marine tanker vessel, when multiple are used a lot of oil can be transported. For example, the DOT-111 tank car is a very common tank car and can hold 34,500 US gallons (820 bbl; 131 m³). If ten tank cars were pulled the train would be carrying 345,000 US gallons (8,200 bbl; 1,310 m³) of oil, so the amount of volume increases rapidly. The locomotive used to pull these rail cars have a massive amount of horsepower and can be hooked up with other locomotives to increase the horsepower, making the rail car a fairly cost-effective way to move petroleum. These railcars just like the pipelines can be used to carry a refined fuel instead of crude oil from a refinery to a distributing plant. Railcars are a common way to move this fuel a long distance to areas where they do not have pipelines set up. (Wikipedia, 2018)

World's Major Pipelines

Blackman (2012) lists some of the longest pipelines – completed and under construction – in the world:

West-East Pipeline Project

West-East Gas Pipeline Project (WEPP) is one of the major natural gas transmission projects intended to connect the eastern markets of China, with western resources to allow mutual and sustainable development. The project involves the construction of four pipelines which will travel along varied terrains to link the 560,000 square kilometer Tarim Basin in Xinjiang Autonomous Region and Turkmenistan with the Yangtze Delta and Pearl Delta regions. The first west-east gas pipeline, measuring 4000km, opened in December 2004 and a section of the second west-east gas pipeline project was commissioned in June 2011. WEPP II will measure 8,704km once complete and travel through 15 provinces. A feasibility study for the third pipeline (WEPP III) has been initiated and the project [was expected to be completed by 2014]. WEPP IV [was still in the planning stage in 2014].

Yamal-Europe Pipeline

The Yamal-Europe pipeline is a natural gas distribution system running across Russia, Belarus, Poland and Germany. The 4,107km-long pipeline has a diameter of 1,420mm and can carry 33 billion cubic meters a year. Construction was carried out by dividing the length of the pipeline into different sections. The 402km Russian segment starts from the Torzhok gas transmission hub and receives gas from the Northern Tyumen Regions-Torzhok gas pipeline. The 575km Belarusian section runs across Belarus and includes five compression stations at Nesvizhskaya, Krupskaya, Slonimskaya, Minskaya and Orshanskaya. The Polish pipeline measures 683km-long and passes through 32 railway lines, 246 roads, 108 surface water streams and seven large rivers. The German section is connected to the YAGAL-Nord gas transmission system which is in turn connected to the STEGAL-MIDAL-Rehden UGS gas transmission system.

ESPO Pipeline

Once constructed, the Eastern Siberia-Pacific Ocean oil pipeline (ESPO) will export crude oil from Russia to the Asian Pacific markets of Japan, China and Korea over a length of 4,700km. The original project proposed to build a pipeline from Angarsk, Russia to Daqing in northern China. This was then combined with a pipeline project from Taishet in Irkutsk Oblast to the Far East port of Kozmino near Nakhodka in May 2003. In October 2008, the section between Taishet and Talakan was launched in a reverse to pump oil from Surgutneftegas-owned Alinsky deposit. This pipeline was completely laid in May 2009. The 1,963km section from Taishet to Kozmino will run 882km through the Amur region, 324km through the Jewish autonomous region, 247km through Khabarovsk territory and 570km through Primorye. Feasibility studies for this section have been completed and the pipeline [was expected to be fully laid by 2014]¹⁰.

Keystone XL

Keystone XL Pipeline is a new 1,897km-long crude oil pipeline being planned by TransCanada. The cross-border pipeline will run from Hardisty in Canada to Steele City in the US state of Nebraska and cost around \$7bn to construct. The pipeline, expected to help the US reduce its natural gas imports from the Middle East and Venezuela, will transport crude oil from the Western Canadian Sedimentary Basin (WCSB) and Bakken supply basin to the existing Keystone Pipeline at Steele City for further delivery to US refineries on the Gulf Coast. The project received approval from the National Energy Board (NEB) of Canada in March 2010. At the same time, the US Department of State extended the deadline for federal agencies to decide if the pipeline is in the national interest, and in November 2011, President Obama postponed the final decision on the proposed project until 2013.

Kazakhstan-China Crude Oil Pipeline

The 2,798km-long Kazakhstan-China pipeline transports crude oil from oil fields located in western Kazakhstan to the Dushanzi refinery in Xinjiang province of China. Construction of the

¹⁰ The pipeline is fully operational in 2018.

pipeline was divided into three segments and carried out in two phases. The first phase included a 448km-long first section which starts at Atyrau near the Caspian Sea and ends at Kenkiyak, Kazakhstan. This section became operational towards the end of 2003. The second phase included the construction of a 962km pipeline, which runs from Atasu in Kazakhstan to Alashankou in China, and a 761km section which runs from Kenkiyak to Kumkol in central Kazakhstan. In January 2011, the pipeline met its design capacity for the first time. It had transported more than 30mt of crude oil since the commissioning of the first section in 2006. The second phase was completed in July 2009.

Rockies Express Pipeline

The Rockies Express is a 1679km-long pipeline which runs between the Rocky Mountains in Colorado and Eastern Ohio. One of the largest pipelines ever constructed in the US, the Rockies Express cost \$5.6bn to complete and has the capacity to supply about 16.5 billion cubic meters of natural gas a year. The project was completed in three sections. The 528km REX Entrega section runs between the Meeker Hub in Rio Blanco County in Colorado and the Cheyenne Hub in Weld County, Colorado. The REX West section, which is divided into seven spreads, runs 1,147km in a 1,070mm pipe from Weld County to Audrain County in Missouri, near St Louis. There is also an eight kilometer, 610mm branch connecting to the Williams Energy-owned Echo Springs Processing Plant in Wyoming. The final section of the pipeline, REX East, is a 1,027km, 1,070mm pipeline running from Audrain County, Missouri, to Clarington in Monroe County, Ohio. This section was completed in November 2009.

Trans-Mediterranean Natural Gas Pipeline

The Trans-Mediterranean (Transmed) is a 2,475km-long natural gas pipeline built to transport natural gas from Algeria to Italy via Tunisia and Sicily. Built in 1983, it is one of the longest international gas pipeline systems and has the capacity to deliver 30.2bcm/y (billion cubic meters per annum) of natural gas. The Transmed pipeline begins in Algeria and runs 550km to Tunisian border. From Tunisia the line passes 370km to El Haouaria in the Cap Bon province and then crosses the 155km-wide Sicilian section. Passing through Mazara del Vallo in Sicily, the pipeline moves a further 155km from Sicily to the Strait of Messina and 1,055 kilometers in the Italian mainland to northern Italy with a branch to Slovenia. The pipeline consists of nine compressor stations, including one in the Algerian section, three in the Tunisian section, one in Sicily and four in the Italian section. (Blackman, 2012)

Use of Petroleum

How do we use petroleum? Ancient Egyptians used it for embalming. Ancient Chinese had even figured out how to use bamboo pole to pump petroleum out of the ground. “Small surface

occurrences of petroleum in the form of natural gas and oil seeps have been known from early times. The ancient Sumerians, Assyrians, and Babylonians used crude oil, bitumen, and asphalt (“pitch”) collected from large seeps at Tuttul (modern-day Hit) on the Euphrates for many purposes more than 5,000 years ago. Liquid oil was first used as a medicine by the ancient Egyptians, presumably as a wound dressing, liniment, and laxative. The Assyrians used bitumen as a means of punishment by pouring it over the heads of lawbreakers. Oil products were valued as weapons of war in the ancient world. The Persians used incendiary arrows wrapped in oil-soaked fibers at the siege of Athens in 480 BCE. Early in the Common Era the Arabs and Persians distilled crude oil to obtain flammable products for military purposes. Probably as a result of the Arab invasion of Spain, the industrial art of distillation into illuminants became available in western Europe by the 12th century. Several centuries later, Spanish explorers discovered oil seeps in present-day Cuba, Mexico, Bolivia, and Peru. Oil seeps were plentiful in North America and were also noted by early explorers in what are now New York and Pennsylvania, where American Indians were reported to have used the oil for medicinal purposes.

Until the beginning of the 19th century, illumination in the United States and in many other countries was little improved over that which was known during the times of the Mesopotamians, Greeks, and Romans. Greek and Roman lamps and light sources often relied on the oils produced by animals (such as fish and birds) and plants (such as olive, sesame, and nuts). Timber was also ignited to produce illumination. Since timber was scarce in Mesopotamia, “rock asphalt” (sandstone or limestone infused with bitumen or petroleum residue) was mined and combined with sand and fibers for use in supplementing building materials. The need for better illumination that accompanied the increasing development of urban centers made it necessary to search for new sources of oil, especially since whales, which had long provided fuel for lamps, were becoming harder and harder to find. By the mid-19th century kerosene, or coal oil, derived from coal was in common use in both North America and Europe.

The Industrial Revolution brought an ever-growing demand for a cheaper and more convenient source of lubricants as well as of illuminating oil. It also required better sources of energy. Energy had previously been provided by human and animal muscle and later by the combustion of such solid fuels as wood, peat, and coal. These were collected with considerable effort and laboriously transported to the site where the energy source was needed. Liquid petroleum, on the other hand, was a more easily transportable source of energy. Oil was a much more concentrated and flexible form of fuel than anything previously available. The stage was set for the first well specifically drilled for oil, a project undertaken by American entrepreneur Edwin L. Drake in northwestern Pennsylvania. The completion of the well in August 1859 established the groundwork for the petroleum industry and ushered in the closely associated modern industrial age. Within a short time, inexpensive oil from underground reservoirs was being processed at already existing coal oil refineries, and by the end of the century oil fields had been discovered in 14 states from New York

to California and from Wyoming to Texas. During the same period, oil fields were found in Europe and East Asia as well.

At the beginning of the 20th century, the Industrial Revolution had progressed to the extent that the use of refined oil for illuminants ceased to be of primary importance. The oil and gas industry became the major supplier of energy largely because of the advent of the internal-combustion engine, especially those in automobiles. Although oil constitutes a major petrochemical feedstock, its primary importance is as an energy source on which the world economy depends.

The significance of oil as a world energy source is difficult to overdramatize. The growth in energy production during the 20th century was unprecedented and increasing oil production has been by far the major contributor to that growth. By the 21st century an immense and intricate value chain was moving approximately 100 million barrels of oil per day from producers to consumers. The production and consumption of oil is of vital importance to international relations and has frequently been a decisive factor in the determination of foreign policy. The position of a country in this system depends on its production capacity as related to its consumption. The possession of oil deposits is sometimes the determining factor between a rich and a poor country. For any country, the presence or absence of oil has major economic consequences. On a timescale within the span of prospective human history, the utilization of oil as a major source of energy will be a transitory affair lasting only a few centuries. Nonetheless, it will have been an affair of profound importance to world industrialization.” (Riva et al., 2018)

According to the U.S. Energy Information Administration, crude oil and other liquids produced from fossil fuels are refined into petroleum products that people use for many different purposes. Biofuels, such as ethanol and biodiesel, are also used as petroleum products, mainly in mixtures with gasoline and diesel fuel. The United States consumes more energy from petroleum than from any other energy source. In 2016, total U.S. petroleum consumption was about 19.7 million barrels per day (b/d), the equivalent of about 37% of all the energy consumed in the United States. We use petroleum products to propel vehicles, to heat buildings, and to produce electricity. The petrochemical industry uses petroleum as a raw material to make products such as plastics, polyurethane, solvents, and hundreds of other intermediate and end-user goods.

What are the petroleum products people consume most? Gasoline is the most consumed petroleum product in the United States. In 2016, motor gasoline consumption averaged about 9.3 million b/d (391 million gallons per day), the largest amount recorded and equal to about 47% of total U.S. petroleum consumption. Distillate fuel oil is the second most-consumed petroleum product in the United States. Distillate fuel oil includes diesel fuel and heating oil. Diesel fuel is used in the diesel engines of heavy construction equipment, trucks, buses, tractors, boats, trains, some automobiles, and electricity generators. Heating oil, also called fuel oil, is used in boilers and furnaces for

heating homes and buildings, for industrial heating, and for producing electricity in power plants. Total distillate fuel oil consumption in 2016 was about 3.9 million b/d, or 20% of total U.S. petroleum consumption.

Hydrocarbon gas liquids (HGL), the third most-used category of petroleum in the United States, include propane, ethane, butane, and other hydrocarbon gas liquids that are produced at natural gas processing plants and oil refineries. HGL consumption in 2016 was about 2.5 million b/d. The petrochemical industry uses HGL as feedstock for making many products. Propane, a heavily consumed HGL, is also used in homes for space heating and water heating, for clothes drying, for cooking, for heating greenhouses and livestock housing, for drying crops, and as a transportation fuel. Jet fuel is the fourth most-used petroleum product in the United States. About 1.6 million b/d of jet fuel was consumed in 2016.

How much petroleum does the world consume? Total world consumption of petroleum in 2015 was about 93 million b/d. The five largest petroleum-consuming countries in 2015, and their shares of total world petroleum consumption:

United States—20.5%

China—12.6%

Japan—4.3%

India—4.3%

Russia—3.7% (EIA, 2018)

Petroleum's Outlook

The availability of cheap, plentiful oil has established itself as the very root and symbol of our civilization. But that oil will eventually begin to run out. And with China, India, Brazil and other countries coming on line as driving nations, the demand for oil will continue to grow exponentially even as the supply begins to diminish. (Goldstein & Intriligator, 2017)

What is the outlook for U.S. petroleum consumption? The U.S. Energy Information Administration projects that petroleum and other liquids will continue to contribute the largest share of total U.S. energy consumption through 2040, although the share will decline slightly. The Annual Energy Outlook 2017 Reference case projects U.S. consumption of petroleum and other liquids to average about 19 million to 20 million b/d through 2040. Petroleum continues as the main fuel for the transportation sector. Consumption of petroleum is projected to increase in the industrial sector, flatten in the commercial sector, and decrease in the residential and transportation sectors.

Short-term Oil Outlook (Courtesy: EIA)**Global Liquid Fuels**

North Sea Brent crude oil spot prices averaged \$65 per barrel (b) in February, a decrease of \$4/b from the January level and the first month-over-month average decrease since June 2017. EIA forecasts Brent spot prices will average about \$62/b in both 2018 and 2019 compared with an average of \$54/b in 2017.

EIA expects West Texas Intermediate (WTI) crude oil prices to average \$4/b lower than Brent prices in both 2018 and 2019. NYMEX WTI contract values for May 2018 delivery traded during the five-day period ending March 1, 2018, suggest a range of \$51/b to \$76/b encompasses the market expectation for June 2018 WTI prices at the 95% confidence level.

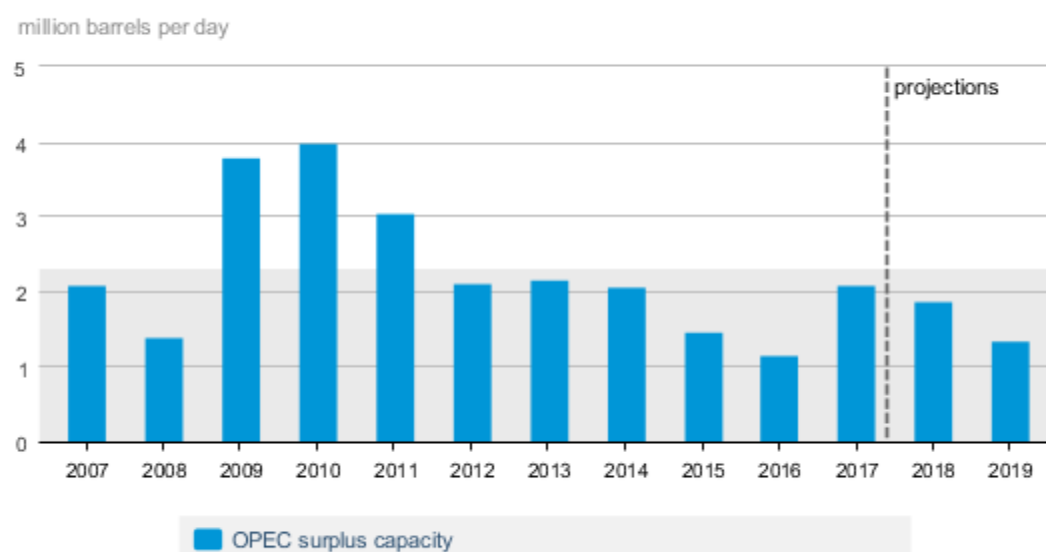
EIA estimates that U.S. crude oil production averaged 10.3 million barrels per day (b/d) in February, up 230,000 b/d from the January level, when there were some well freeze-offs in the Permian and Bakken. EIA has reported that total U.S. crude oil production averaged 9.3 million b/d in 2017, ending the year with production of 9.9 million b/d in December. EIA projects that U.S. crude oil production will average 10.7 million b/d in 2018, which would mark the highest annual average U.S. crude oil production level, surpassing the previous record of 9.6 million b/d set in 1970. EIA forecasts that 2019 crude oil production will average 11.3 million b/d.

EIA estimates that inventories of global petroleum and other liquid fuels declined by 0.6 million b/d in 2017. In this forecast, global inventories grow by about 0.4 million b/d in 2018 and by another 0.3 million b/d in 2019.

Global Petroleum and Other Liquids				
	2016	2017	2018	2019
^a Weighted by oil consumption. ^b Foreign currency per U.S. dollar.				
Supply & Consumption	(million barrels per day)			
Non-OPEC Production	57.97	58.67	61.18	62.37
OPEC Production	39.23	39.28	39.44	39.89
OPEC Crude Oil Portion	32.68	32.44	32.47	32.73
Total World Production	97.21	97.95	100.62	102.26
OECD Commercial Inventory (end-of-year)	2,968	2,859	2,925	3,009

Global Petroleum and Other Liquids				
	2016	2017	2018	2019
^a Weighted by oil consumption. ^b Foreign currency per U.S. dollar.				
Supply & Consumption	(million barrels per day)			
Total OPEC surplus crude oil production capacity	1.15	2.10	1.87	1.34
OECD Consumption	46.74	47.20	47.59	47.99
Non-OECD Consumption	50.12	51.30	52.61	53.94
Total World Consumption	96.87	98.50	100.20	101.92

OPEC surplus crude oil production capacity



Source: Short-Term Energy Outlook, March 2018

Note: Shaded area represents 2007-2017 average (2.3 million barrels per day)

Trends in U.S. oil production

Onshore

Uncertainty in onshore production forecasts for the United States comes primarily from upside supply risks. Recent EIA forecasts of U.S. oil production undershot actual production because the pace of improvement in onshore drilling productivity has surpassed expectations. Exploration and production companies are drilling many wells and constantly experimenting with new techniques to hydraulically fracture the tight formations. Technological innovation may cause a faster rise in

drilling productivity than currently forecast. Should this occur, EIA's current forecast for onshore Lower 48 states oil production could understate actual production growth.

Offshore

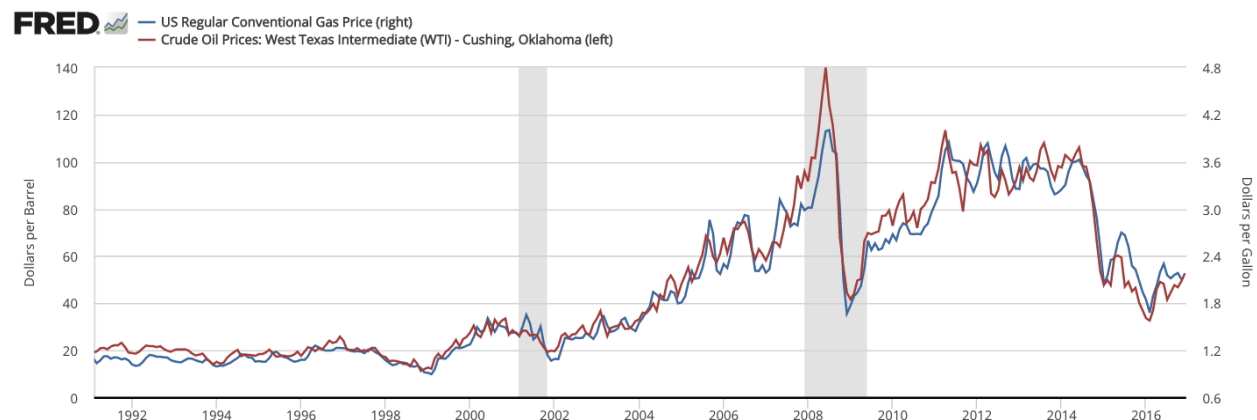
Oil production in the federal Gulf of Mexico (GOM) is forecast to grow...in 2018. While the GOM forecast is based on current and planned drilling projects, there is considerable uncertainty because of potential project delays and hurricane or maintenance outages. Large scale drilling projects in the Gulf of Mexico are extremely complex and progress can be easily delayed. Additionally, limited information is available about how productive new projects will be, and there is much uncertainty about how much production will come from offshore wells once they actually come on line. While EIA periodically tracks and updates project schedules, assumptions about production start dates and peak volumes are determined by publicly available information from the operating companies. As such, GOM production forecasts reflect current project schedules and production estimates. As projects are delayed the expected production volumes associated with those projects are pushed back as well.

Despite its drawbacks such as costs and environmental impacts, petroleum will be around for as long as we can tap into its vast recoverable reserves. This fact has pushed some to make the case for carbon. "The great quality and effectiveness of conventional internal combustion engines powerfully reinforces carbon's hegemony. We don't normally think much about our car's motor, and rightly we shouldn't. It functions so well that fretting about its inner workings is a fooling waste of time. But, it's actually a remarkable piece of machinery that takes up little space, delivers enormous power for its weight, and costs very little to make. It's admittedly a big hunk of metal, but this deceptive because metal is cheap and because the engine is delivering five hundred times the power for its weight that a horse does – or a human being. If we were willing to pay a little more money, we can get a gas turbine, which delivers five thousand times the power for its weight that a horse does. The cost and weight advantages of turbine are crucial to commercial aviation, which simply could not exist if the only available power sources were batteries or compressed air tanks. They're also important for the electric power industry, which uses gas turbine plants almost exclusively to cover its load peaks. But one doesn't have to be an expert on jets and electric power plants to see the benefits of internal combustion engines. Everyday experience with cars tells us that they're marvelous things, and that their low procurement and maintenance costs are central to the economic calculus of energy." (Laughlin, 2011)

The higher oil prices have made exploration more worthwhile. The ratio of energy return on investment for different types of energy resources are as follows:

- For conventional oil, the ratio of return to overhead costs is 25 to 1
- Oil sand (surface mining): 5 to 1
- Oil sands (steam injection): 3 to 1
- Corn ethanol: 13 to 1

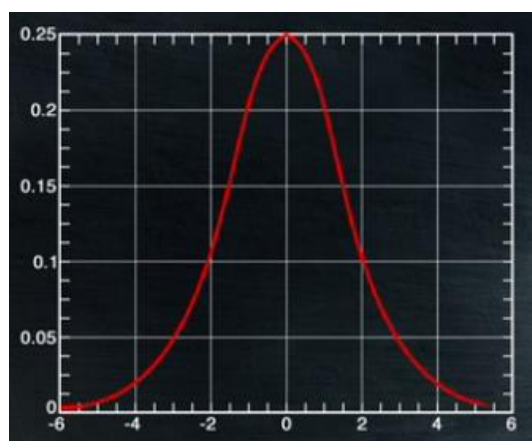
The price of a barrel of oil controls the entire energy market in the sense that when it goes up, tapping into unconventional oil reserves becomes relevant. “The price of oil, or the oil price, generally refers to the spot price of a barrel of benchmark crude oil—a reference price for buyers and sellers of crude oil such as West Texas Intermediate (WTI), Brent ICE, Dubai Crude, OPEC Reference Basket, Tapis Crude, Bonny Light, Urals oil, Isthmus and Western Canadian Select (WCS). There is a differential in the price of a barrel of oil based on its grade—determined by factors such as its specific gravity or API and its Sulphur content—and its location—for example, its proximity to tidewater and/or refineries. Heavier, sour crude oils lacking in tidewater access—such as Western Canadian Select—are less expensive than lighter, sweeter oil—such as WTI. From 1999 till mid-2008, the price of oil rose significantly. It was explained by the rising oil demand in countries like China and India. In the middle of the financial crisis of 2007–2008, the price of oil underwent a significant decrease after the record peak of US\$147.27 it reached on July 11, 2008. On December 23, 2008, WTI crude oil spot price fell to US\$30.28 a barrel, the lowest since the financial crisis of 2007–2010 began. The price sharply rebounded after the crisis and rose to US\$82 a barrel in 2009. In July 2008 oil reached a record peak of US\$147.27 but by February 2009 it sank beneath \$40 a barrel. On 31 January 2011, the Brent price hit \$100 a barrel for the first time since October 2008, on concerns about the political unrest in Egypt. For about three and half years the price largely remained in the \$90–\$120 range. In the middle of 2014, price started declining due to a significant increase in oil production in USA, and declining demand in the emerging countries. The oil glut—caused by multiple factors—spurred a sharp downward spiral in the price of oil that continued through February 2016.”



Crude oil prices to gas prices

By February 3, 2016 oil was below \$30— a drop of "almost 75 percent since mid-2014 as competing producers pumped 1-2 million barrels of crude daily exceeding demand, just as China's economy hit lowest growth in a generation." Some analysts speculate that it may continue to drop further, perhaps as low as \$18.

“According to a report released on February 15, 2016 by Deloitte LLP—the audit and consulting firm—with global crude oil at near ten-year low prices, 35% of listed E&P oil and gas companies are at a high risk of bankruptcy worldwide. Indeed, bankruptcies in the oil and gas industry could surpass levels seen in the Great Recession.” (Revolvy, 2018)



The Hubbert Curve

In the study of the history of the use and prices of petroleum, it is important to understand the *Hubbert Peak theory* and the *Hubbert curve* named for American geologist Marion King Hubbert. “Some 60 year ago, he predicted that the United States would start to run out of oil around 1970. Hubbert’ peak arrived right on schedule, but new, more perilous drilling techniques have deferred the inevitable. Nevertheless, other geologists started paying attention to Hubbert’s ideas. Collectively, they have predicted that the world will start running out of oil in the next century. Their predictions are subject to dispute, but they have made

one very important point: our real problems will arise, not when we have pumped the last drop of oil, but when we reach the half-way point and the available supply starts to diminish.” (Goldstein & Intriligator, 2017)

Anyway, the Hubbert’s Peak Theory is “a statistical theory of oil production that states that the rate of extraction from a particular region follows a bell-shaped curve. Initially, while there are minimum drilling operations the rate of production is limited. However, as infrastructure increases, and larger portion of land are explored, resource production approaches peak production. Eventually, as the oil becomes depleted, extraction rates begin to slow down. The Hubbert curve characterizes the life cycle of a drilling operation.” (Investopedia, 2018) “The Hubbert curve is an approximation of the production rate of a resource over time. It is a symmetric logistic distribution curve, often confused with the ‘normal’ gaussian function. ... It has gained a high degree of popularity in the scientific community for predicting the depletion of various natural resources.”

Explanation: at the start of one tail to the left, you have the discovery of a resource and then the gradual increase in production, so it looks to be exponentially increasing. But eventually, you start to run out, production slows, levels off and then it starts to decline. But it takes a long time to use

up all the remaining resources. So, the tail on the other end dies away into the future, looking like exponential decay. With the coming on board of unconventional sources, the curve might become more complicated with multiple peaks as the rising price of oil makes lower-grade of oil more recoverable. However, if you view the whole process like a geologist or a historian, you don't have a Hubbert curve. You have rather a *Hubbert blip*.

In conclusion, let's say that humans, for thousands of years, used biomass for energy, burning wood. Perhaps, we will eventually turn away from fossil energy to adopt renewable energy for an even longer time than the one we spent burning woods. It just happens that in between we spend a few centuries using unconventional or fossil fuel.

3. Natural Gas

Natural gas is composed almost entirely of methane although it does contain small amounts of other gases--ethane, propane, butane, and pentane. Methane is composed of a molecule of one carbon atom and four hydrogen atoms. Natural gas is colorless, non-toxic, invisible and odorless, although an odorant is added to all-natural gas that is transported in Connecticut. Known as mercaptan, this odorant is an important safety measure because it provides a distinct smell (much like the smell of rotten eggs) in the event of a gas leak. Natural gas is lighter than air and rapidly dissipates into the air when it is released. When natural gas burns, a high-temperature blue flame is produced, and complete combustion takes place producing only water vapor and carbon dioxide. It has a heating value of about 1000 BTUs per cubic foot. However, when it burns improperly, it can produce carbon monoxide – a deadly, poisonous gas. Natural gas has a flammability range of approximately 5 to 15 percent. That means that any mixture containing less than 5 percent or greater than 15 percent natural gas to air would not support combustion. Natural gas, when mixed with air and exposed to an ignition source, is combustible. Propane gas is similar to natural gas in many ways and is also used as a fuel. The most significant difference between propane and natural gas is that propane gas is heavier than air. If propane gas leaks, it does not tend to vent safely into the air. Rather, it settles in low areas, both inside a structure or outside. Liquid propane is stored in tanks and vaporizes when it is released from the tank because propane vaporizes at any temperature above -44°F. The flammability range of propane is approximately 2 – 10 percent propane in air.

Natural gas and crude oil are mixtures of different hydrocarbons. Hydrocarbons are molecules of carbon and hydrogen in various combinations. Hydrocarbon gas liquids (HGL) are hydrocarbons that occur as gases at atmospheric pressure and as liquids under higher pressures. HGL can also be liquefied by cooling. The specific pressures and temperatures at which the gases liquefy vary by the type of HGL. HGL may be described as being light or heavy according to the number of

carbon atoms and hydrogen atoms in an HGL molecule. HGL are found in raw natural gas and crude oil, and they are extracted when natural gas is processed at natural gas processing plants and when crude oil is refined into petroleum products. Natural gas plant liquids (NGPL), which account for most of HGL production in the United States, fall solely into the alkanes category. Refinery production accounts for the remainder of U.S. alkanes production, and it accounts for all of the olefins production data that are published by the U.S. Energy Information Administration (EIA). Greater volumes of olefins are produced at petrochemical plants from HGL and heavier feedstock. HGL were initially considered a nuisance product but are now high-value products. Shortly before World War I, a problem in a natural gas pipeline occurred. A section of a pipeline in a natural gas field ran under a cold stream, and the low temperature caused liquids to form and sometimes block the flow of natural gas in the pipeline. This experience led engineers to treat natural gas before it entered natural gas transmission pipelines. Natural gas processing facilities were built to cool and compress natural gas, which separated the hydrocarbon gases as liquids from the natural gas. The HGL then became marketable commodities as fuels and as feedstock for making other petroleum products and petrochemicals. (EIA, 2018)

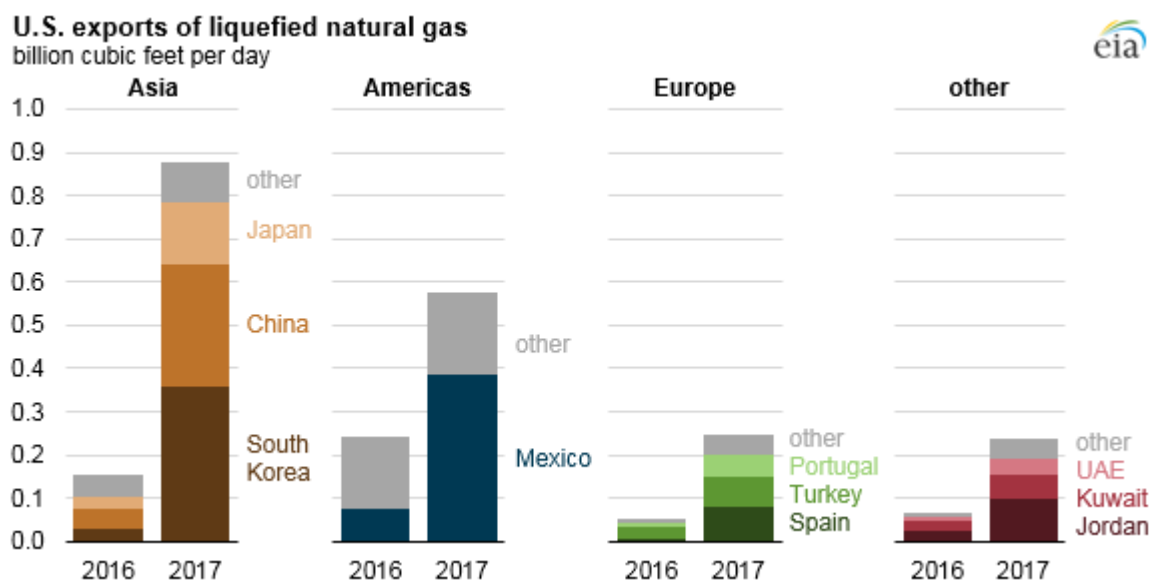
Part of the usefulness of hydrocarbons is that they have different properties depending upon how large the molecules are. The very simplest hydrocarbon, methane, which is the primary constituent of natural gas, consists of an atom of carbon bonded to four atoms of hydrogen. In Earth surface conditions, methane is a gas unless you compress under high pressure in which case you can force it into a liquid to make it easier to transport. Gases and liquids are easy to transport through pipelines. Natural gas is the fuel of choice for heating homes. It also increasingly being use for transportation and for generating electricity, currently replacing many coal-powered electricity plants.

Hydrocarbon gas liquids have many uses Because HGL straddle the gas/liquid boundary, their versatility and high energy density in liquid form make them useful for many purposes:

- Feedstock in petrochemical plants to make chemicals, plastics, and synthetic rubber
- Fuels for heating, cooking, and drying
- Fuels for transportation
- Additives for motor gasoline production
- Diluent (a diluting or thinning agent) for transportation of heavy crude oil

According to the US Energy Administration, U.S. exports of liquefied natural gas (LNG) reached 1.94 billion cubic feet per day (Bcf/d) in 2017, up from 0.5 Bcf/d in 2016. As LNG exports increased, shipments went to more destinations. U.S. LNG exports in 2017, all of which originated from Louisiana's Sabine Pass liquefaction terminal, reached 25 countries.

More than half (53%) of U.S. LNG exports in 2017 were shipped to three countries: Mexico, South Korea, and China. Mexico received the largest amount of U.S. LNG exports, at 20% of the 2017 total. Growing natural gas demand in Mexico, particularly from the power generation sector, and delays in the construction of domestic pipelines connecting to U.S. export pipelines led Mexico to rely on LNG imports to supplement imports of natural gas by pipeline.



Source: U.S. Energy Information Administration, Natural Gas Monthly

In Asia, the widening difference between the Henry Hub natural gas price—to which U.S. LNG contract prices are indexed—and crude oil—to which LNG prices are benchmarked in Asia—helped to drive increases in LNG imports from the United States. Exports to South Korea accounted for 18% of total U.S. LNG exports in 2017 and were part of long-term contracts between sellers Cheniere Energy and Shell and the Korean natural gas buyers—utilities KOGAS and KEPCO. Exports to China made up 15% of total U.S. LNG exports. These exports were sold mostly on a spot basis, with volumes in October, November, and December increasing as record-high LNG demand prompted China to seek additional LNG on the global spot market to supplement contracted volumes.

Almost 60% of U.S. LNG in 2017 was sold on a spot basis to more than 20 countries in Asia, North and South America, Europe, the Middle East and North Africa, and the Caribbean. Although liquefaction capacity at Sabine Pass is fully contracted under long-term contracts to various buyers, flexibility in those contracts' destination clauses allows U.S. LNG to be shipped to any market in the world.

After countries in Asia and North America (Mexico), countries in Europe collectively accounted for the third-largest share of U.S. LNG exports. LNG imports by several European countries increased in 2017, driven by increased demand primarily from the power generation sector. South American LNG imports declined in 2017. Demand for natural gas in that region is highly variable and is affected by the availability of competing lower-cost natural gas supply and hydro generation output.

Top 10 countries by proved reserves of natural gas (million m³)

Rank ⇅	Country/Region	Natural gas proven reserves ⇅ (million m ³)
1	 Russia	47,800,000
2	 Iran	34,020,000
3	 Qatar	24,530,000
4	 United States	9,659,000
5	 Saudi Arabia	8,489,000
6	 Turkmenistan	7,504,000
7	 United Arab Emirates	6,091,000
8	 Venezuela	5,617,000
9	 Nigeria	5,111,000
10	 Algeria	4,504,000

Source: Wikipedia (Date of information: 1 January 2016)

The increase in LNG exports over the past two years is the result of the continuing expansion of U.S. LNG export capacity. Two LNG projects—Sabine Pass in Louisiana and Cove Point in Maryland—have come online since 2016, increasing U.S. LNG export capacity to 3.6 Bcf/d.

Four more projects are scheduled to come online in the next two years: Elba Island LNG in Georgia and Cameron LNG in Louisiana in 2018, then Freeport LNG and Corpus Christi LNG in Texas in 2019. Once completed, U.S. LNG export capacity is expected to reach 9.6 Bcf/d by the end of 2019. As export capacity continues to increase, the United States is projected to become the third-largest LNG exporter in the world by 2020, surpassing Malaysia and remaining behind only Australia and Qatar.

Natural Gas Short-term Forecast

- The EIA estimates that U.S. dry natural gas production averaged 73.6 billion cubic feet per day (Bcf/d) in 2017. EIA forecasts that natural gas production will average 81.7 Bcf/d in 2018, establishing a new record. That level would be 8.1 Bcf/d higher than the 2017 level and the highest annual average growth on record. EIA expects natural gas production will also increase in 2019, with forecast growth of 1.0 Bcf/d.
- In February, the U.S. benchmark Henry Hub natural gas spot price averaged \$2.66 per million British thermal units (MMBtu), down \$1.03/MMBtu from January. Winter weather moderated in February after extremely cold temperatures in much of the country during the first half of January. U.S. heating degree days were an estimated 17% lower than the 10-year average for February, which contributed to lower consumption and prices.
- EIA expects natural gas prices to moderate in the coming months, based on a forecast of record natural gas production levels. EIA expects Henry Hub spot prices to average \$2.72/MMBtu in March and \$2.99/MMBtu for all of 2018. In 2019, EIA forecasts prices will average \$3.07/MMBtu. NYMEX contract values for June 2018 delivery that traded during the five-day period ending March 1, 2018, suggest that a range of \$2.16/MMBtu to \$3.49/MMBtu encompasses the market expectation for June Henry Hub natural gas prices at the 95% confidence level. (EIA, 2018)

Natural Gas Storage

Natural gas – a colorless, odorless, gaseous hydrocarbon—may be stored in a number of different ways. It is most commonly held in inventory underground under pressure in three types of facilities. These underground facilities are depleted reservoirs in oil and/or natural gas fields, aquifers, and salt cavern formations. Natural gas is also stored in liquid or gaseous form in above-ground tanks.

Each storage type has its own physical characteristics (porosity, permeability, retention capability) and economics (site preparation and maintenance costs, deliverability rates, and cycling capability), which govern its suitability for particular applications. Two important characteristics of an underground storage reservoir are its capacity to hold natural gas for future use and the rate

at which gas inventory can be withdrawn—called its deliverability rate (see Storage Measures, below, for definitions).

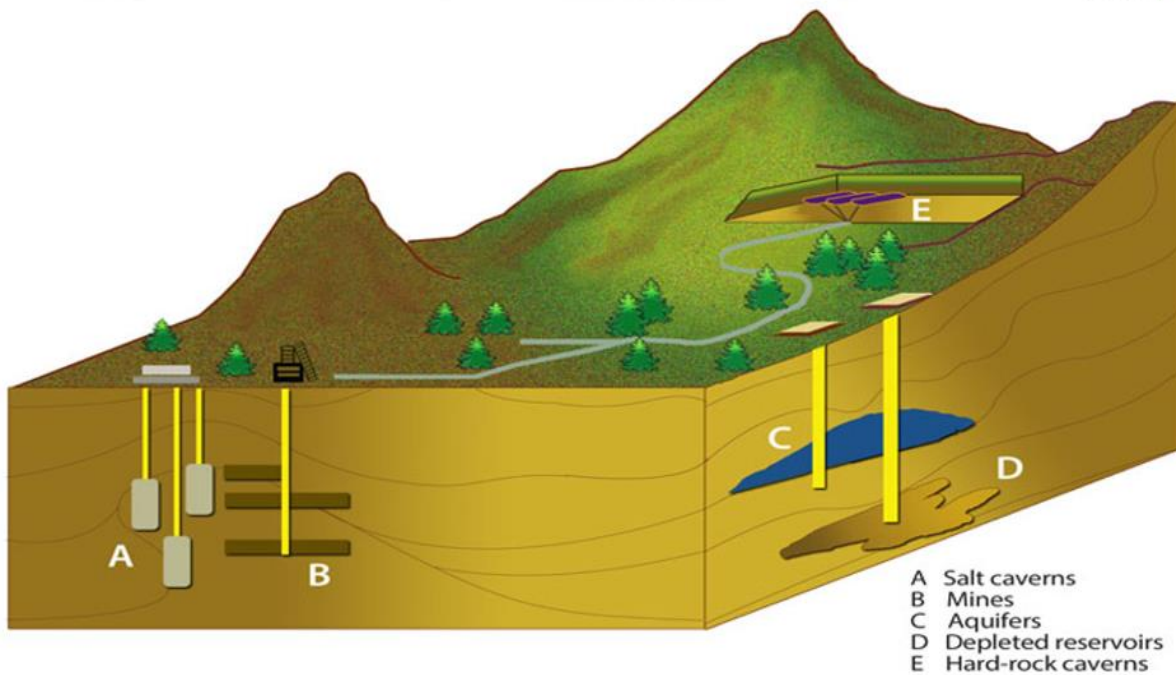
Most existing natural gas storage in the United States is in depleted natural gas or oil fields that are close to consumption centers. Conversion of a field from production to storage duty takes advantage of existing wells, gathering systems, and pipeline connections. Depleted oil and natural gas reservoirs are the most commonly used underground storage sites because of their wide availability.

In some areas, most notably the Midwestern United States, natural aquifers have been converted to natural gas storage reservoirs. An aquifer is suitable for gas storage if the water-bearing sedimentary rock formation is overlaid with an impermeable cap rock. Although the geology of aquifers is similar to depleted production fields, their use for natural gas storage usually requires more base (cushion) gas and allows less flexibility in injecting and withdrawing. Deliverability rates may be enhanced by the presence of an active water drive, which supports the reservoir pressure through the injection and production cycles.

Salt caverns provide very high withdrawal and injection rates relative to their working gas capacity. Base gas requirements are relatively low. Most salt cavern storage facilities have been developed in salt dome formations located in the Gulf Coast states. Salt caverns have also been made (by a process called leaching) in bedded salt formations in Northeastern, Midwestern, and Southwestern states. Cavern construction is more costly than depleted field conversions when measured on the basis of dollars per thousand cubic feet of working gas capacity, but the ability to perform several withdrawal and injection cycles each year reduces the per-unit cost of each thousand cubic feet of gas injected and withdrawn.

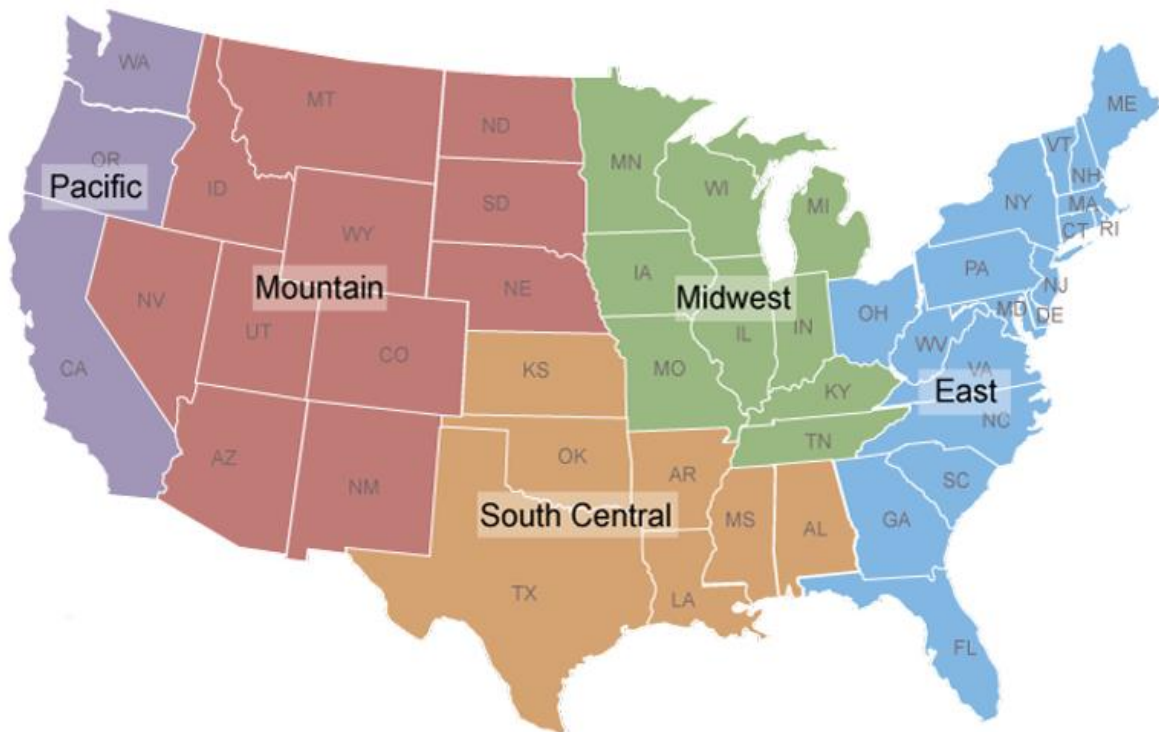
Figure 1 is a stylized representation of the various types of underground storage facilities. *Figure 2* shows the U.S. natural gas storage regions. (EIA, 2015)

Figure 1. Types of underground natural gas storage facilities



Source: PB-KBB, inc., enhanced by EIA.

Figure 2. Underground natural gas storage regions



Owners and Operators of Storage Facilities

The principal owners/operators of underground storage facilities are interstate pipeline companies, intrastate pipeline companies, *local distribution companies* (LDCs), and independent storage service providers. About 120 entities currently operate the nearly 400 active underground storage facilities in the Lower 48 states. If a storage facility serves interstate commerce, it is subject to the jurisdiction of the Federal Energy Regulatory Commission (FERC); otherwise, it is state-regulated.

Owners/operators of storage facilities are not necessarily the owners of the natural gas held in storage. In fact, most working gas held in storage facilities is held under lease with shippers, LDCs, or end users who own the gas. The type of entity that owns/operates the facility will determine to some extent how that facility's storage capacity is utilized.

For example, interstate pipeline companies rely heavily on underground storage to facilitate load balancing and system supply management on their long-haul transmission lines. FERC regulations allow interstate pipeline companies to reserve some portion of their storage capacity for this purpose. Nonetheless, the bulk of their storage capacity is leased to other industry participants. Intrastate pipeline companies also use storage capacity and inventories for similar purposes, in addition to serving customers.

In the past, LDCs have generally used underground storage exclusively to serve customer needs directly. However, some LDCs have recognized and have been able to pursue the opportunities for additional revenues available with the deregulation of underground storage (see "Open Access" to Storage Capacity, below). These LDCs, which tend to be the ones with large distribution systems and a number of storage facilities, have been able to manage their facilities so they can lease a portion of their storage capacity to third parties (often marketers) while still fully meeting their obligations to serve core customers. (Of course, these arrangements are subject to approval by the respective state-level regulators.)

The deregulation of underground storage combined with other factors such as the growth in the number of natural gas-fired electricity generating plants has placed a premium on high-deliverability storage facilities. Many salt formation and other high-deliverability sites, both existing and under development, have been initiated by independent storage service providers, often smaller, more focused companies started by entrepreneurs who recognized the potential profitability of these specialized facilities. These facilities are used almost exclusively to serve third-party customers who can most benefit from the characteristics of these facilities, such as marketers and electricity generators.

History of "Open Access" to Storage Capacity

Prior to 1994, interstate pipeline companies, which are subject to the jurisdiction of FERC, owned all of the natural gas flowing through their systems, including gas held in storage, and these companies had exclusive control over the capacity and utilization of their storage facilities. With the implementation of FERC Order 636, interstate pipeline companies were required to operate their storage facilities on an open-access basis. That is, the major portion of working gas capacity (beyond what may be reserved by the pipeline/operator to maintain system integrity and for load balancing) at each site must be made available for lease to third parties on a nondiscriminatory basis.

Today, in addition to the interstate storage sites, many storage facilities owned/operated by large LDCs, intrastate pipelines, and independent operators also operate on an open-access basis, especially those sites affiliated with natural gas market centers. Open access has allowed storage to be used other than simply as backup inventory or as a supplemental seasonal supply source. For example, marketers and other third parties may move natural gas into and out of storage (subject to the operational capabilities of the site or the tariff limitations) as changes in price levels present opportunities to buy and store natural gas when demand is relatively low and sell during periods of peak-demand when the price is elevated. Further, storage is used in conjunction with various financial instruments (e.g., futures and options contracts, swaps¹¹, etc.) in creative and complex ways in an attempt to profit from market conditions.

Reflecting this change in focus within the natural gas storage industry during recent years, the largest growth in daily withdrawal capability has been from high-deliverability storage sites, which include salt cavern storage reservoirs as well as some depleted oil or natural gas reservoirs. These facilities can cycle their inventories—i.e., completely withdraw and refill working gas (or vice versa)—more rapidly than can other types of storage, a feature more suitable to the flexible operational needs of today's storage users. Since 1993, daily withdrawal capability from high-deliverability salt cavern storage facilities has grown significantly. Nevertheless, conventional storage facilities continue to be very important to the industry.

Underground Natural Gas Storage Data

The U.S. Energy Information Administration (EIA) collects a variety of data on the storage measures discussed above, and EIA publishes selected data on a weekly, monthly, and annual basis. EIA uses Form EIA-912, Weekly Natural Gas Storage Report, to collect data on end-of-week working gas in storage at the company and regional level from a sample of all underground natural gas storage operators. The regions used for weekly reporting were formally the East, West and Producing regions. In October 2015, EIA increased the number of regions (Figure 2 above) and changed their names to better align the storage locations with the markets they serve and to provide more information to market observers and participants. Data from the EIA-912 survey are tabulated and published weekly at regional and national levels. The EIA-191, Monthly Underground Gas Storage Report, collects data on total capacity, base gas, working gas, injections, and withdrawals, by reservoir and by storage facility, from all underground natural gas storage operators. Data derived from the EIA-191 survey are published at a state level on a monthly basis in the Natural Gas Monthly, with select data available at the field level in the Natural Gas Respondent Query System. The data shown in the Natural Gas Monthly include tabulations of base gas, total inventories, total storage capacity, injections, and withdrawals at state and regional levels.

¹¹ A swap is a derivative contract where two parties exchange financial instruments. Most swaps are derivatives in which two counterparties exchange cash flows of one party's financial instrument for those of the other party's financial instrument.

Storage Measures

Several volumetric measures are used to quantify the fundamental characteristics of an underground storage facility and the gas contained within it. For some of these measures, it is important to distinguish between the characteristic of a facility, such as its capacity, and the characteristic of the natural gas within the facility such as the actual inventory level. These measures are as follows:

Total natural gas storage capacity is the maximum volume of natural gas that can be stored in an underground storage facility in accordance with its design, which comprises the physical characteristics of the reservoir, installed equipment, and operating procedures particular to the site.

Total gas in storage is the volume of natural gas in the underground facility at a particular time.

Base gas (or cushion gas) is the volume of natural gas intended as permanent inventory in a storage reservoir to maintain adequate pressure and deliverability rates throughout the withdrawal season.

Working gas capacity refers to total gas storage capacity minus base gas.

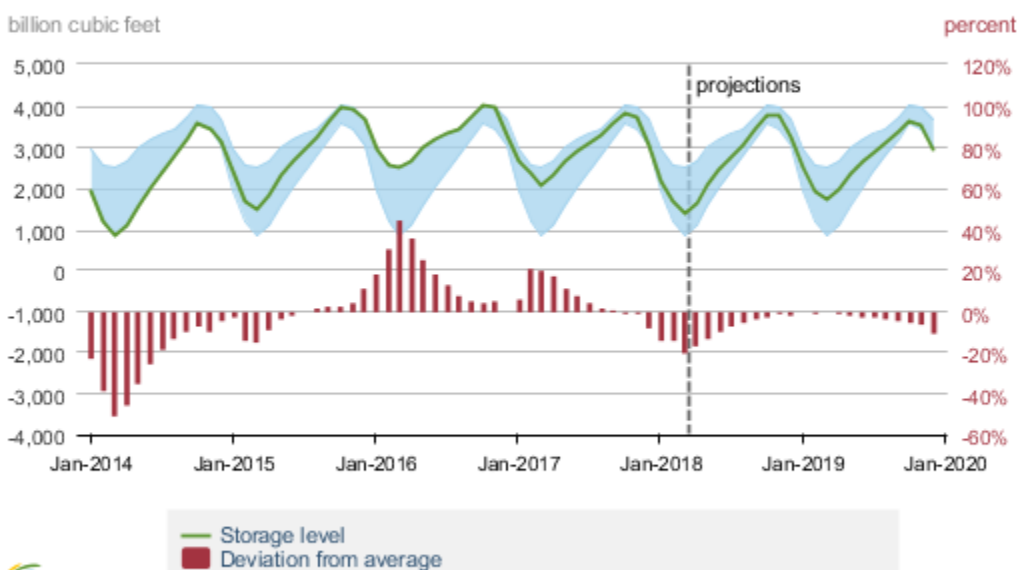
Working gas is the volume of gas in the reservoir above the level of base gas. Working gas is available to the marketplace.

Deliverability is most often expressed as a measure of the amount of gas that can be delivered (withdrawn) from a storage facility on a daily basis. Also referred to as the deliverability rate, withdrawal rate, or withdrawal capacity, deliverability is usually expressed in terms of million cubic feet per day (MMcf/d). Occasionally, deliverability is expressed in terms of equivalent heat content of the gas withdrawn from the facility, most often in dekatherms per day (a therm is 100,000 Btu, which is roughly equivalent to 100 cubic feet of natural gas; a dekatherm is the equivalent of about one thousand cubic feet (Mcf)). The deliverability of a given storage facility is variable, and it depends on factors such as the amount of natural gas in the reservoir at any particular time, the pressure within the reservoir, the compression capability available to the reservoir, the configuration and capabilities of surface facilities associated with the reservoir, and other factors. In general, a facility's deliverability rate varies directly with the total amount of natural gas in the reservoir: it is at its highest when the reservoir is most full and declines as working gas is withdrawn.

Injection capacity (or rate) is the complement of the deliverability or withdrawal rate—it is the amount of natural gas that can be injected into a storage facility on a daily basis. As with deliverability, injection capacity is usually expressed in MMcf/d, although dekatherms/day is also used. The injection capacity of a storage facility is also variable, and it is dependent on factors comparable to those that determine deliverability. By contrast, the injection rate varies inversely with the total amount of gas in storage: it is at its lowest when the reservoir is most full and increases as working gas is withdrawn.

None of these measures for any given storage facility are fixed or absolute. The rates of injection and withdrawal change as the level of natural gas varies within the facility. In practice, a storage facility may be able to exceed certificated total capacity in some circumstances by exceeding certain operational parameters. The facility's total capacity can also vary, temporarily or permanently, as its defining parameters vary. Measures of base gas, working gas, and working gas capacity also can also change from time to time. These changes occur, for example, when a storage operator reclassifies one category of natural gas to the other, often as a result of new wells, equipment, or operating practices (such a change generally requires approval by the appropriate regulatory authority). Finally, storage facilities can withdraw base gas for supply to market during times of particularly heavy demand, although by definition, this gas is not intended for that use. (EIA, 2015)

U.S. working natural gas in storage



Note: Colored band around storage levels represents the range between the minimum and maximum from Jan. 2013 - Dec. 2017.

Transportation of Natural Gas

The United States has an extensive and complex network of pipelines to transport natural gas from production areas to end users. One of the first major U.S. pipelines was built in 1891 to carry gas from central Indiana to Chicago. Little further construction happened until after World War II, but the 1950s and 1960s saw the rapid expansion of a national gas pipeline network that continues to grow today. The lower 48 states have over 300,000 miles of large transmission pipelines for shipping natural gas all over the country. More than two million additional miles of smaller, low-pressure distribution pipelines deliver the gas to individual homes and businesses. Today, pipelines supply more than 98 percent of the United States' natural gas needs from sources in North America. Natural gas is highly flammable, so the process of transporting it from wellhead to homes and businesses can be dangerous. The Pipeline and Hazardous Materials Safety Administration regulates natural gas pipelines and tracks injuries and fatalities associated with natural gas pipeline accidents in the U.S.

Between 2008 and 2012, there were 370 significant safety incidents at natural gas transmission pipelines, which were mostly caused by corrosion, equipment failure, and flooding. These incidents led to 10 fatalities and 85 injuries. During this same time period, there were 311 significant safety incidents at natural gas distribution pipelines, which were mostly caused by excavation damage. These incidents led to 41 deaths and 230 injuries. In addition to safety concerns, natural gas leaks from transmission and distribution pipelines are a significant source of global warming emissions. A 2012 study, which mapped urban pipeline leaks in Boston, found 3,356 separate leaks under the city streets. The study noted that Boston is not unique; other cities, like Boston, have aging natural gas distribution infrastructures, and similar methane leaks are likely widespread. Liquefied natural gas, or LNG, offers a means of transporting natural gas across long distances where pipelines are not available.

To produce LNG, natural gas is compressed and cooled to around minus 260 degrees Fahrenheit, a step that converts the gas to a liquid and reduces its volume by a factor of 600. LNG can then be shipped in specially-constructed tankers for overseas transport. Upon reaching its destination, the LNG is unloaded at a receiving terminal, returned to a gaseous state, and sent through local pipelines to end-users. LNG requires substantial infrastructure to cool and compress the natural gas to liquid, ship it overseas, and return the LNG to gaseous form at the receiving end. In addition, the production of LNG and subsequent refrigeration during transport is highly energy-intensive. For these reasons, recent decreases in natural gas prices in the U.S. have made LNG uncompetitive with domestic gas delivered through pipelines. In 2010, LNG accounted for 6 percent of the U.S. natural gas imports. Three-quarters of imported LNG came from Trinidad and Tobago, with the

remainder from Qatar, Yemen, Norway, and Egypt. LNG natural gas imports peaked in 2007 but declined sharply after U.S. natural gas prices fell in 2008. (Union of Concerned Scientists, 2018)

Impact of Natural Gas on the Environment

Natural gas is the cleanest of the fossil fuels and has the lowest greenhouse gas emissions per unit of energy (emitting about half of the CO₂ of coal when burned for electricity generation. The greatest threat that natural gas represents from its extraction which often involves hydraulic fracturing or fracking. Fracking involves getting natural gas out of a solid rock. The technology consists of drilling deep into the ground, run a pipeline through the shale layer up to 3 kilometers and have it make a 90° bend. The whole thing is known as horizontal drilling or fracking or hydraulic fracturing, which works for shale oil as well as shale gas. The technology was developed in the 1970s. it consists in fracturing the rock by forcing fluid under the ground with high enough pressure that the rock cracks open.

There is a lot of controversies over fracking. Fracking uses a lot of water (about 3 to 8 million gallons total per wells). The water gets contaminated and much of it gets pumped back into the ground permanently usually at a much greater depth where the fracking is done. There are environmental concerns. Sometimes, the wells' casing can crack, and the gas gets into the water table and is mixed with drinking water aquifers in layers that are above the shale. This happens rarely but it does happen. In 2014, a study of 133 water wells in Texas and Pennsylvania found that high levels of methane levels were found in these wells. Some States such as New York and Vermont have passed laws that banned fracking. The most risk associated with fracking isn't the leaks but the pumping of water into the ground. It causes earthquakes although very small on the Richter scale. One of the first places where this was documented was in Arkansas where the pumping of water into the Ozark aquifer caused 1200 earthquakes. The largest was a magnitude 4.7, which prompted the States to shut down the pumping.

“Beyond the methane leaks from drilling and venting associated with existing and abandoned wells, more methane is lost every day in processing, handling and transporting gas to its ultimate point of consumption. Pipeline losses occur in a more than 2-million-mile system that stretches from the production fields to residential customers. This gas transportation system has three main parts:

- gathering lines in production fields which are largely unregulated, and in many systems, unknown and unmapped (about 240,000 miles estimated);
- natural gas transmission pipelines to processing and storage locations (278,269 miles); and
- distribution lines to residential and business customers (about 1.8 million miles).

Leakage of methane from pipelines – a problem throughout the world – has been reported and studied for years. *New Scientist* noted in September 1990, that natural gas pipeline mains in Great Britain leaked so much methane that the leaks there contributed more to global warming than did the burned gas. As of 2006 the U.S. natural gas industry operated over 38,000 miles of natural gas pipelines that were made of cast iron, the most leak-prone type of gas piping. In 2012, a U.S. GAO¹² study on thousands of miles of ‘gathering lines’ that collect oil and gas from production sites revealed that these lines are not regulated by the federal government, meaning they are not regularly inspected for leaks or corrosion.” (Greenpeace, 2018)

Besides strictly environmental impacts, there are social ones too. The need for large volumes of water over short time periods for hydraulic fracking can cause stress at the coldest, driest, and most critical times of the year for communities surrounding fracking sites. There can also be spills associated with storing, mixing, and pumping slickwater, meaning there is a chance that chemicals involved in slickwater could infiltrate groundwater and the soil, causing potential health issues. Drilling rigs running all day and night create noise heard up to 4km away, and Volatile Organic Compounds which contribute to smog can leave odors up to 600m from a fracking platform. Shale gas also indirectly affects human social systems. For example, the province of Quebec could receive \$71 up to \$475 million over the next 25 years from shale gas revenues, but it is highly debated as some argue it could cost taxpayers up to four times the amount of revenue that will be brought in. This is an important point regarding the distribution of economic benefits. In Quebec, natural gas accounts for only 13% of the energy consumed, and over one third of that is from commercial sector consumption (MEI)¹³. Therefore, the main beneficiaries of exploiting shale gas in Quebec won’t be residential households, who rely predominantly on electricity, but instead provincial commercial and businesses. Depending on the profitability, productivity, and efficiency of natural gas production, the ability to export shale gas in the medium-long future would extend the beneficiaries nationwide - all which is unknown and subject to the Precautionary Principal. Another consideration socially, is the consequence of shale boom towns - local economies that would benefit but these booms in turn degrade local infrastructure, and inflationary pressures can make some regions unaffordable for residents. (Forbes, 2017)

¹² The Government Accountability Office (GAO) is a legislative branch government agency that provides auditing, evaluation, and investigative services for the United States Congress. It is the supreme audit institution of the federal government of the United States.

¹³ MEI : Montreal Economic Institute

III. NUCLEAR ENERGY

First and foremost, it's important to keep in mind that nuclear energy is not fossil fuel, which is doomed to be depleted. Nuclear energy cannot be said to be renewable energy either because, although the fuel rods may be recycled (see below) it has to be made (not created, as energy is never created) from radioactive elements instead of non-depletable sources like wind or solar rays. A nuclear reactor utilizes the strength of the force between nucleons while hydrocarbon burning relies on the chemical bonding between molecules.

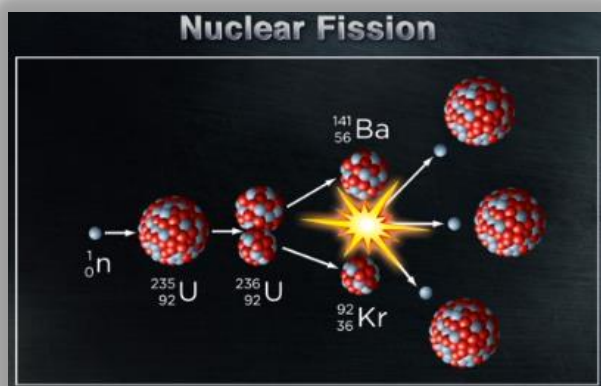
What is Nuclear Power? The Physics Behind It

In nuclear power, the energy is stored between strong nuclear forces. In terms of energy density, nothing comes close to nuclear power. Normally, when people talk about nuclear power, they always refer to nuclear fission or the splitting of large atoms such as Uranium to release energy. All commercial nuclear power plants that generate electricity use nuclear fission. There are experimental nuclear fusion reactors that are able to smash hydrogen atoms together to make helium and release energy. But we have not been able to sustain this at levels that are economically useful. "Nuclear reactors are often classified as 'fast' or 'thermal' reactors. This nomenclature refers to the energy of the neutrons that sustain the fission reaction. In fast nuclear reactors, the fission reaction is sustained by neutrons at higher energies ('fast' neutrons); in commonly deployed thermal reactors, such as light water reactors, the fission reaction is sustained by lower-energy ('thermal' neutrons). Fast and thermal reactors are distinguished by the presence or absence of a material known as a 'neutron moderator,' or simply 'moderator.' This material is present in thermal reactors but not in fast reactors. Collisions with the moderator slow the neutrons emitted by fissioning nuclei to thermal energies. In the next few decades, the majority of the new nuclear plants constructed in the United States will be based on evolutionary reactor designs. In most cases, alternative reactor designs will require significant development efforts before they can be ready for deployment." (NAS, 2009)

Uranium is the fuel most widely used by nuclear power plants for nuclear fission. In nuclear fission, energy is released when atoms are split apart to form smaller atoms. Nuclear power plants use the heat from nuclear fission to produce electricity. Uranium is a common metal, but it must be processed into a fuel. Uranium is a common metal found in rocks all over the world. Uranium occurs in combination with small amounts of other elements. Economically recoverable uranium deposits have been discovered primarily in the western United States, Australia, Canada, Central Asia, Africa, and South America. Nuclear power plants use a certain type of uranium, U-235, as fuel because its atoms are easily split apart. Although uranium is about 100 times more common than silver, U-235 is relatively rare. After uranium is mined, the U-235 must be extracted and processed before it can be used as a fuel. Mined uranium ore typically yields one to four pounds

of uranium concentrate (U_3O_8 or yellowcake) per ton, or 0.05% to 0.20% yellowcake (see below). (EIA, 2018)

What's going on at the subatomic level within the generation of nuclear electricity? The key to it is the binding energy that holds the nuclei together. During fission and fusion, small amounts of masses are converted into binding energy, some of which is released as radiation that we can use as a source of heat. The nucleus of the helium atom contains 2 protons and 2 neutrons. We know the masses of individual protons and neutrons. 1 proton is 1.00728 amu (atomic mass unit). A neutron is 1.00866 amu. 2 protons and 2 neutrons would yield to 4.01319 amu. When considering a helium atom, we don't get that number, however. Its mass is less. It's about 4.0015 amu. Which is less than the separate masses of protons and neutrons. This is strange because it is one case where the sum is actually less than the sum of the parts. When we put the protons and the neutrons together, we suddenly lose 1% of their mass. Where did that loss go? It went into the energy needed to bind the particles together. It is the energy needed during nuclear fission or fusion. Nuclear fusion is done with small atoms like hydrogen and nuclear fission is done with large atoms like Uranium. When an unstable nucleus like U^{235} is bombarded with neutrons, it breaks into two or more smaller pieces. This reaction is called nuclear fission.

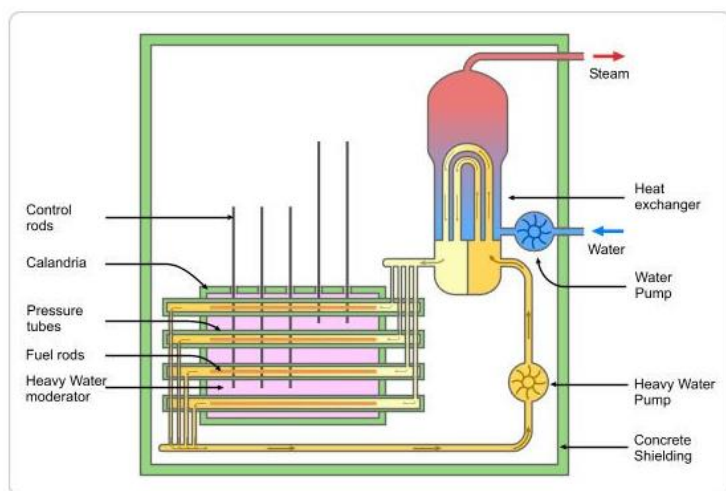


There is still a lot of U^{235} inside Earth from the time they were formed, which was during the last moments of the supernova explosion that created all the elements other than hydrogen and helium that came together under the pull of gravity to form our solar system 4.6 billion years ago. Nuclear fission is a chain reaction in which Uranium atoms, when bombarded, break apart, release energy and neutron and hit other atoms which do the same things. During nuclear fission, gamma

rays¹⁴ are also released. They go into cooling off the water inside the nuclear reactor, to generate steam, to run the turbines to generate electricity. 1 kg of U-235 releases 79 terajoules (79 trillion joules) of gamma rays. That's the energy equivalent of more than 13,000 barrels of oil.

¹⁴ Definition of Gamma Ray: penetrating electromagnetic radiation of a kind arising from the radioactive decay of atomic nuclei.

If the chain reaction is uncontrolled, you get a runaway temperature increase and can end up with



Pressurized Heavy Water Reactor (PHWR)

Source: NuclearStreet

a nuclear meltdown. This what happens with a nuclear bomb. However, if the chain reaction is controlled at a steady rate by absorbing most of those extra neutrons with some other sets of materials, you get a continuous stream of gamma rays. That's what goes on within a nuclear reactor. Nuclear power plants are simple in that the nuclear reactions are just used to heat water and drive a turbine just like coal or gas. But the plants are complicated in the technology needed to keep the reactions going in a continuous,

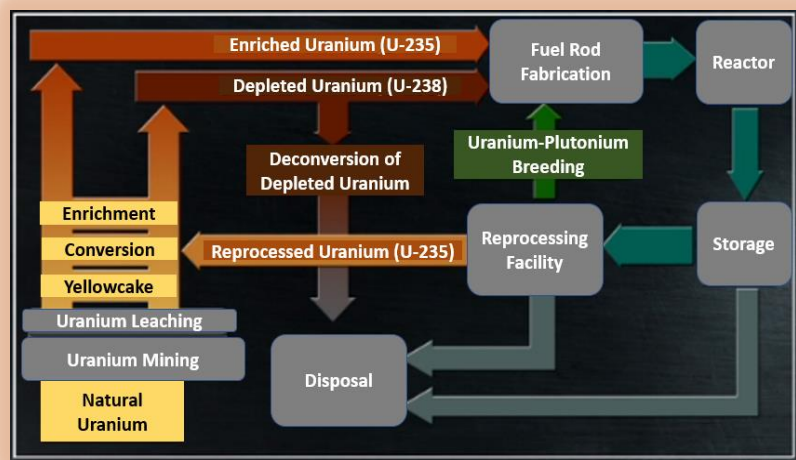
controlled, and safe manner. There several different kinds of reactors using different isotopes, though most use U-235. A light water reactor uses ordinary water; and that's either unpressurized (boiling water reactor: BWR) or pressurize (pressurized water reactor: PWR). There is another reactor called heavy water reactors, and these use water whose hydrogen atoms are in the form of deuterium isotopes. That's hydrogen nucleus with a neutron as well as a proton. This has several advantages. The heavy water helps to monitor the reaction and allows the reaction's temperature to be a little bit higher. And that's more efficient. So, a heavy water reactor can operate without having to enrich the Uranium. But heavy waters are expensive to make.

Now, unfortunately for the sake of energy generation, fission does not work for all large atoms. Only certain isotopes are fissile¹⁵. The most common of these isotopes are U-235, U-233, (Plutonium) Pu-241, and Pu-239. Other isotopes called fertile isotopes (that can be converted into fissile isotopes through "breeding" or neutron capture) are still useful. Breeding occurs through the bombardment of a fertile isotope with a fast neutron (a high-energy neutron) that controllably convert into a fissile isotope. Remember that when a fissile isotope is hit by a thermal neutron, it splits into two parts, and that's nuclear fission. Once you have your nuclear fuel, it's assembled into rods, which contain a variety of elements that are good at absorbing neutrons. This neutron absorption is necessary in order to maintain a controlled reaction. These are elements such as boron, silver, cadmium.

¹⁵ Isotopes that will split when hit by a thermal neutron, meaning a neutron that is at ambient temperature.

How Is Uranium Used to Make Electricity?

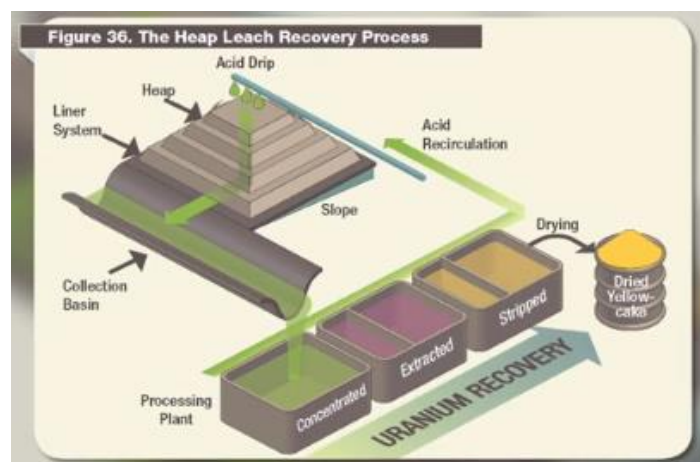
How do we start with a dull-looking rock, uranium ore, to end up producing electricity? currently all nuclear power start with uranium, which has to be mined like coal. In this sense, nuclear power is a non-renewable source of energy though the amount of available fuel might be extremely abundant, lasting tens to hundreds of thousands of years or more. But you can't just take this rock and put it into a reactor. There is a lot that has to be done to the uranium within the rock before it can be used to generate nuclear power. As in the case of fossil fuels, there are wastes that are left over after the reactions have occurred. The safe disposal of nuclear waste will always be the most significant drawback in the generation of nuclear power. They're toxic; they give high-energy gamma rays that are damaging to any living tissue and they generate a lot of heat, which makes them very difficult to handle and store.



Process of generating electricity from uranium ore

To explain the process of generating nuclear power, it's important to describe the nuclear fuel cycle, which is the step-by-step process starting with uranium-bearing rocks and ending up with a left-over product of nuclear fission: the nuclear waste. First of all, the uranium has to be found. Uranium, like most metals, is usually found in an oxidized state in the form of minerals such as uraninite, also called pitchblende, autunite, or torbernite. Different minerals result from different ratios of oxygen atoms. Pitchblende is usually uranium dioxide (UO_2) but can also take the form of U_3O_8 , three atoms of uranium and 8 atoms of oxygen. Given that the rocks-bearing uranium are constantly giving off gamma rays from the decaying uranium, they can be found thanks to a Geiger counter, which detects gamma rays and particles emitted from radioactive decay (alpha particles: helium nuclei or beta particles: electrons). Geiger counters usually have a speaker attached to them, so you can hear when you're closer to a radioactive source. Actually, the use of a Geiger counter was an old method used by geologists walking over the ground to find uranium ores. Today, you can fly over land in a plane equipped with a gamma ray spectrometer. It's like a digital camera but it records gamma rays instead of visible light rays. And you can map out regions of high uranium densities with it.

Unlike mining for coal, where what you find in a coal seam is mostly coal, uranium oxide minerals are usually found in rocks at very low concentration. Mining for uranium oxide is often done in large uranium open air mining pits, digging gradually downward and outward until all the minerals are removed.



Uranium ores can also be removed from underground through leaching. The next step is to concentrate the uranium ore into yellowcake. This is also done with leaching. The yellowcake is actually more brown or black color. It contains about 70 to 90% of the oxide U_3O_8 with the rest largely uranium dioxide and even some uranium trioxide. Because most naturally occurring uranium is in the form of uranium 238, which has very low

levels of radioactivity, as opposed to uranium 235, the yellowcake is quite safe to handle at this point. Next, the uranium oxide needs to be converted into forms that can be used within our nuclear reactors, depending upon the type of reactor. If a pressurized water reactor is used, then, the uranium oxide doesn't need to be concentrated into uranium 235. And the yellowcake is smelted at high temperatures into pure uranium dioxide pitchblende. However, for light water reactors, uranium oxide is combined with fluorine to make the gas uranium hexafluoride UF_6 . In this case, the uranium oxide also needs to have the uranium isotopes separated in order to enrich the fuel. This process is called enrichment. Uranium is usually found in the ground as 99.3% U-238 and 0.7% U-235. Remember, the U-235 is fissile, which means atoms will split apart when you bombard them with a neutron. This is what we need for nuclear fission to occur. Remember also that the U-238 is not fissile. That poses a problem because the latter is primarily the kind found in nature, the wrong kind. So, the uranium needs to be separated into rocks that have higher concentrations of uranium 235. That's the enriched uranium and the leftover rocks are mostly uranium 238, called depleted uranium.

There are several to separate the uranium isotopes to enrich the fuel in uranium 235. The most common method uses high speed centrifuges. You take the uranium hexafluoride gas (UF_6), put it in a centrifuge and spin it really fast at a rate of a hundred thousand times per minute. Even though U-238 is slightly heavier than U-235, over time, it moves to the outer edge of the centrifuge. If you siphon off the gas from the middle of the centrifuge, it has slightly more U-235, the stuff you want. It's a slow process, and you repeat it over and over but over time, the gas in the middle has more and more U-235.

It is possible that the U-235 might be easier to remove by using a laser tuned to just the right frequency. But this hasn't been scaled up to large production yet. Enrichments of less than 20% U-235 are called low-enriched uranium. For most reactors, enrichment of 3 to 4% is needed. Enrichments of more than 20% are called high-enriched uranium, which is needed for nuclear subs and boats. For nuclear weapons, enrichments of more than 90% U-235 are needed. This kind of enrichment can take a long time and a higher level of technological sophistication. Once the enrichment is done, the UF₆ is mixed with calcium, which makes a calcium fluoride salt leaving the uranium behind. The outcome of enrichment is pellets of U-235, which are very radioactive and have to be handled very carefully. The enriched uranium pellets are then assembled into fuel rods or often sealed into zirconium alloy tubes. In many reactors, the rods are lowered vertically down into the reactor's core. These fuel rods are what give off the heat in a controlled fission chain reaction. Each ton of these fuel rods will provide over 30 Megawatts of electricity for five years.

Once the rods are used up (they are called spent fuel at this stage), they have to be cooled down before being recycled. This process can take up to 20 years. Many US nuclear power plants are running out space to store their rods. The recycling process involves separating the plutonium from the U-238 which can then be used in a breeder reactor to make fissile fuel. This process involves bombarding the fissile isotopes with fast neutrons. It's important to note that no plutonium is left in the Earth's crust. It is a byproduct of nuclear reaction and can be bred from the abundant U-238.

Concerns about proliferation could discourage the United States from pursuing the commercialization of used fuel recycling at present. The current technology for the separation and plutonium and uranium extraction (PUREX), poses a proliferation risk, and modifications of PUREX to increase proliferation resistance do not greatly improve the situation. Some suggest that if the United States were to deploy recycle technologies (or, some argue, even pursue further R&D on them), it would become more difficult to stop other countries from doing the same. But others argue that the United States could positively influence recycling elsewhere by developing and deploying technologies that are more proliferation resistant than PUREX. Although future R&D may develop more proliferation resistant options, these options are highly unlikely to be *entirely* proliferation resistant. True proliferation control will require strong international arrangements to supplement technical advances and developing such arrangements will require considerable time and effort. It is the judgment of the committee that, at present, used fuel recycling does not appear to be a promising option for commercialization in the United States before 2035. However, the committee believes that a continuing R&D program on alternative fuel cycles is justified, as there may be a need for such technologies in the future. (NAS, 2009)

Other Known Uranium Resources

There are also other non-uranium resources that are not economical at current prices but easily could be if the price went up. These include:

- 8 million tons of conventional uranium ores
- 20 million tons of uranium in unconventional phosphate phosphorite deposits
- 5 million tons in unconventional black shales
- 4-5 billion tons of uranium in seawater

Uranium also exists in sea water at tiny but noticeable proportions (about 3 mg per cubic meter). The uranium gets dissolved out of mountains by rivers and carried to the ocean where there might be 4 to 5 billion tons of it. Let's say you will get 50% of it with a massive filtration effort. It will still be more than 2 billion tons, enough to last for 0 thousand years or so, longer if we use breeder reactor to reprocess the nuclear wastes and recycle them. Extracting uranium from sea water is currently too expensive to be worth the effort. But it's less expensive than you might think. It costs about \$300 a Kilogram. In 2015, mining uranium ore costed \$80/Kilogram. In fact, uranium ore had costed \$150 before 2011. But, following the Fukushima nuclear accident, the demand for uranium drops. Currently, there are no financial incentive to pursue sea water uranium or other non-conventional resources.

Applications of Nuclear Power

Uranium is used for datation purposes. For example, uranium-thorium is used to determine the ages of fossils that are 75,000 years old or less and uranium-lead is used to determine the ages of fossils that are older than 75,000 years old up to 4.6 billion years old. That's how we got to know the age of the solar system, 4.57 billion years old. That's the age of meteorites that formed at the birth of the early solar system and only recently fell to Earth. Archeologists use a different isotope, carbon 14, which has a much shorter half-life. It is used to find the ages of fossils that are 50,000 years old or less.

Another use of nuclear power is the nuclear bomb. This is an example where good thing can come out of bad thing. Although the nuclear bomb was created as a weapon of war, because of its deterrence functionality, it has assured peace between nuclear powers. It also became an efficient source of electricity. However, the genie is out of the bottle and you can't put him back in. there is always a threat that a country might be enriching uranium or breeding plutonium for building nuclear bombs and not just for nuclear power plants. That led the international community to be

concerned about Iran's nuclear intentions. Because once uranium is made or converted into plutonium, making a bomb becomes easy. Because of this, the US and other countries will always feel the need to maintain their nuclear arsenal. It's never going to go away.

According to the Nuclear Energy Institute, other applications may be identified. They include:

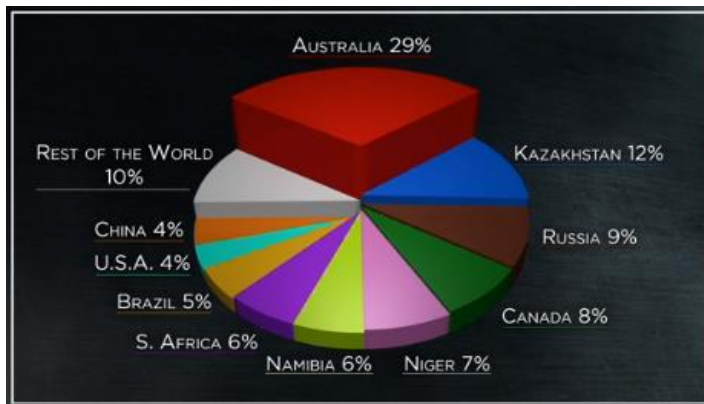
- Nuclear helps doctors diagnose and heal the sick. For example, cobalt-60, an isotope that commercial nuclear plants can be set up to produce, is used in medical imaging, specialized cancer treatments and medical equipment sterilization.
- Nuclear helps explore the depths of our oceans and propels the U.S. Navy around the globe, as nuclear reactors power submarines and aircraft carriers for national security, all without using a single tank of gas.
- The Cassini probe that studied Saturn travelled more than 1 billion miles through space using a special type of nuclear generator. Other spacecraft and probes such as the Mars rover Curiosity rely on nuclear energy to power their equipment too.
- According to the Centers for Disease Control and Prevention, more than 47 million Americans are affected by foodborne illness each year and more than 3,000 die. Nuclear radiation is used to treat food and kill bacteria, insects and parasites that cause illness.
- Consumer products that we come across everyday use small amounts of radiation or contain some radioactive material, like smoke detectors or photocopiers. For example, manufacturers sterilize cosmetics, medical bandages and some personal hygiene products using radiation.

Advanced reactors, including small modular reactors (SMRs), offer more applications beyond electricity.

- Readily available drinking water is out of reach for as much as a fifth of the world's population, a bar to human development. SMRs and advanced reactors can power desalination facilities in underdeveloped areas, turning seawater into potable water.
- Why should only electricity be carbon-free? Advanced reactors also will provide heat for processes such as chemical production and metal refining, allowing more industries to avoid carbon emissions. Heat generated by advanced reactors can even be used to keep houses warm in communities surrounding the plant.

- Innovative designers are working on advanced reactors that will recover and recycle elements in used nuclear fuel that can still produce energy, allowing for more efficient use of nuclear materials.
- Advanced nuclear technology can generate hydrogen, which could become an alternative engine fuel and play a major role in transportation as a substitute for fossil fuels. (Nuclear Energy Institute, 2018)

Major Producers of Uranium



First, let's start with the producers of Uranium ore which has a different geographic distribution than other energy fuels. The four countries with the largest uranium reserves are Australia, Kazakhstan, Russia, and Canada with 29%, 12%, 9%, and 8% respectively. That's a very different distribution compared to other resources. Coal was largely in the US and petroleum largely

in the Middle-East. Each year, more uranium is being discovered than is being consumed.

The United States imports most of the uranium it uses as fuel. Owners and operators of U.S. nuclear power reactors purchased the equivalent of 50.6 million pounds of uranium in 2016. About 11% of the uranium delivered to U.S. reactors in 2016 was produced in the United States and 89% came from other countries. The sources and shares of purchases of uranium produced in foreign countries in 2016 were as follows:

- Canada–25%
- Kazakhstan–24%
- Australia–20%
- Russia–14%
- Uzbekistan–4%
- Malawi, Namibia, Niger, and South Africa–10%
- Brazil, Bulgaria, China, Czech Republic, Germany, and Ukraine–2%

Summary Production Statistics of the U. S. Uranium Industry, 1993 - 2016

Year	Exploration and development surface drilling (million feet)	Exploration and development drilling expenditures ¹ (million dollars)	Mine production of uranium (million pounds U ₃ O ₈)	Uranium concentrate production (million pounds U ₃ O ₈)	Uranium concentrate shipments (million pounds U ₃ O ₈)	Employment (person-years)
1993	1.1	5.7	2.1	3.1	3.4	871
1994	0.7	1.1	2.5	3.4	6.3	980
1995	1.3	2.6	3.5	6.0	5.5	1,107
1996	3.0	7.2	4.7	6.3	6.0	1,118
1997	4.9	20.0	4.7	5.6	5.8	1,097
1998	4.6	18.1	4.8	4.7	4.9	1,120
1999	2.5	7.9	4.5	4.6	5.5	848
2000	1.0	5.6	3.1	4.0	3.2	627
2001	0.7	2.7	2.6	2.6	2.2	423
2002	W	W	2.4	2.3	3.8	426
E2003	W	W	2.2	2.0	1.6	321
2004	1.2	10.6	2.5	2.3	2.3	420
2005	1.7	18.1	3.0	2.7	2.7	648
2006	2.7	40.1	4.7	4.1	3.8	755
2007	5.1	67.5	4.5	4.5	4.0	1,231
2008	5.1	81.9	3.9	3.9	4.1	1,563
2009	3.7	35.4	4.1	3.7	3.6	1,096
2010	4.9	44.6	4.2	4.2	5.1	1,073
2011	6.3	53.6	4.1	4.0	4.0	1,191
2012	7.2	66.6	4.3	4.1	3.9	1,196
2013	3.8	49.9	4.6	4.7	4.7	1,156
2014	1.3	28.2	4.9	4.9	4.6	787
2015	0.9	28.7	3.7	3.3	4.0	625
2016	0.8	22.3	2.5	2.9	3.0	560

E = Estimated data, except for employment.

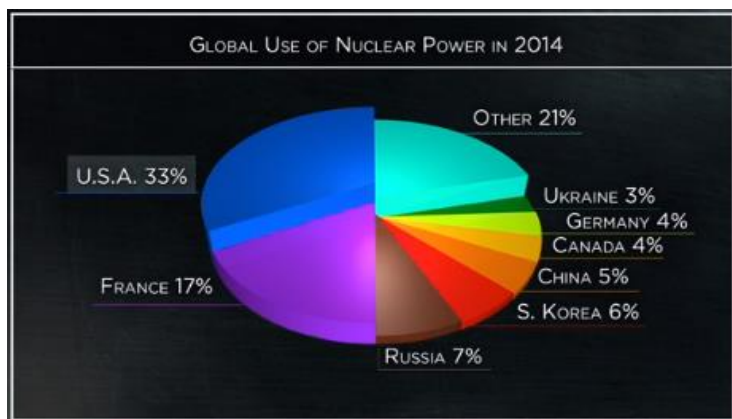
W = Data withheld to avoid disclosure of individual company data.

¹Expenditures are in nominal U.S. dollars.

Note: The 2003 annual production and shipment amounts were estimated by rounding to the nearest 200,000 pounds to avoid disclosure of individual company data.

Source: U.S. Energy Information Administration: 1993-2002-Uranium Industry Annual 2002 (May 2003), Table H1 and Table 2. 2003-15-Form EIA-851A, "Domestic Uranium Production Report" (2003-16).

The Energy Administration Information reported that at the end of 2016, estimated uranium reserves were 60 million pounds U₃O₈ at a maximum forward cost of up to \$30 per pound. At up to \$50 per pound, estimated reserves were 160 million pounds U₃O₈. At up to \$100 per pound, estimated reserves were 339 million pounds U₃O₈. The uranium reserve estimates presented here cannot be compared with the much larger historical data set of uranium reserves published in the July 2010 report U.S. Uranium Reserves Estimates. Those reserve estimates were made by EIA based on data collected by EIA and data developed by the National Uranium Resource Evaluation (NURE) program, operated out of Grand Junction, Colorado, by DOE¹⁶ and predecessor organizations. The EIA data covered approximately 200 uranium properties with reserve estimates, collected from 1984 through 2002. The NURE data covered approximately 800 uranium properties with reserve estimates, developed from 1974 through 1983. Although the data collected by the Form EIA-851A survey covers a much smaller set of properties than the earlier EIA data and NURE data, EIA believes that within its scope the EIA-851A data provides more reliable estimates of the uranium recoverable at the specified forward cost than estimates derived from 1974 through 2002. In particular, this is because the NURE data has not been comprehensively updated in many years and are no longer a current data source.



In terms of nuclear fission, the global distribution of nuclear power is more limited than the other resources. While anyone can burn coal, you have to have a high level of technological infrastructure to build and maintain a nuclear reactor. Currently, nuclear fission provides 11% of the world's electricity, which is about 300 GW. There are about 450 nuclear reactors worldwide and only 31 countries have

been able to generate electricity for commercial use, using nuclear fission. The US is the largest user of nuclear power, accounting for more than a third of it. And this provides 20% of all US electricity. France comes second. Its nuclear power provides 80% of all its electricity and accounts for 17% of world consumption. Therefore, nuclear power provides an important but modest contribution to world energy supplies, at least compared to the fossil fuels.

¹⁶ DOE: Department of Energy

Advantages of Nuclear Power

There are positive sides to nuclear power:

- It does not generate greenhouse gases.
- It doesn't contribute to global warming.
- It doesn't give off toxic air pollution¹⁷.

Disadvantages of Nuclear Power

- It's the fear that this reaction might become uncontrolled in what known as a core meltdown. That creates the greatest amount of pushback to nuclear power. The core reactor can melt down (its metals) if the temperature gets too high. Too much steam pressure can end up exploding the containment vessel and radioactive gases get released. Or the radioactive materials can fall to the bottom of the chamber by melting their way through the bottom, creating what is called a China syndrome. The China Syndrome refers to a scenario in which a molten nuclear reactor core could fission its way through its containment vessel, melt through the basement of the power plant and down into the earth. This was popularized by a 1979 movie of the same name *The China Syndrome*. Globally, there have been about 100 nuclear accidents, mostly in the US, though almost all of them were very minor. Something that can't be said for mining. Core reactor meltdowns have occurred twice: in 1986 in Chernobyl, Ukraine (number of deaths: 56 people died directly and another 4,000 died from radioactivity) and in 2011 in Fukushima, Japan (no death, but 37 physical injuries). These caused many people to be concerned about the safety of nuclear power. An earlier accident had occurred on Three-mile Island, Pennsylvania in March of 1979. Ironically, it happened 12 days after the release of *The China Syndrome* movie. The Fukushima nuclear plant was built to withstand a magnitude 8 earthquake. The one that resulted from the meltdown was 9. The wall that was built to withstand a tsunami was 19 feet tall. The one that resulted from the explosion was 40 feet high.

¹⁷ The U.S. Energy Policy Act signed by Congress in 2005 provided incentives for creation of technologies that don't generate greenhouse gases, including nuclear plants. The Energy Policy Act (EPA) addresses energy production in the United States, including: (1) energy efficiency; (2) renewable energy; (3) oil and gas; (4) coal; (5) Tribal energy; (6) nuclear matters and security; (7) vehicles and motor fuels, including ethanol; (8) hydrogen; (9) electricity; (10) energy tax incentives; (11) hydropower and geothermal energy; and (12) climate change technology. For example, the Act provides loan guarantees for entities that develop or use innovative technologies that avoid the by-production of greenhouse gases. Another provision of the Act increases the amount of biofuel that must be mixed with gasoline sold in the United States.

- The most perceived risk from nuclear power is what to do with the wastes, which are very radioactive because they give off gamma rays and high-energy alpha and beta particles. Radioactivity can be both short term and long term. Acute exposure can cause burns, tissue death, and organ damage leading to hair loss, internal bleeding, and even death. Exposure to radiation is often measured in rems. People are naturally exposed to a little more than 0.5 rem¹⁸ each year largely from cosmic rays from outer space. Trips taken on airplanes, chest X-Rays add to that amount. The breakdown of human exposure to radiation is as follows:
 - At 50 rems, the person feels nauseous within hours
 - At 75 rems, she loses all her hair within weeks
 - At 100 rems, he bleeds internally
 - At 400 rems, death follows within two months
 - At 2,000 rems, death follows in hours
- The other dangers from radiation, either low level or long-term exposure are less certain but more insidious. These include cancer, birth defect. These risks from low level radiations are generally hard to assessed and are generally done on a statistical basis such as correlating cancer rate with people's level of exposure to radiation. For example, implications of the US nuclear bombing of Nagasaki during WWII. 100,000 people were killed straight away mostly from burns. Over the years, a large number of the survivors developed leukemia, thyroid cancer, breast cancer, lung cancer, and for women who were pregnant, there were a high rate of newborn mortality. And 25% surviving newborns had some degree of mental retardation. The US has one place to store nuclear waste, a deep geological repository called the Waste Isolation Pilot Plant, east of Carlsbad, New Mexico built in a massive underground bedded salt deposit. By 2011, it had accepted more than 9,200 shipments from around the country. The problem with this site is that it only accepts wastes from the US military programs. All non-military nuclear wastes are stored onsite at nuclear power plants where barrels start to corrode and leak over time. Other countries use

¹⁸ Rem, is the unit of radiation dosage (such as from X rays) applied to humans. Derived from the phrase *Roentgen equivalent man*, the rem is now defined as the dosage in rads that will cause the same amount of biological injury as one rad of X rays or gamma rays. Formerly poorly defined, the rem was redefined in 1962 to clarify the usage of the term relative biological effectiveness (RBE) in both radiobiology and radiation protection. (Source: *Britannica*)

underground storage with different kinds of rocks. For example, Sweden and Finland use granite. Germany has been constructing a new site in sedimentary rock.

- There are other concerns to nuclear power. Plants are expensive to build. There is also the issue of mining uranium itself. “The primary impact of *mining*, in which natural uranium is extracted from the earth, and *milling*, in which natural uranium is chemically converted to a dry and purified uranium concentrate, is the production of slightly radioactive byproducts known as mill tailings, which are disposed of in ‘tailings piles.’ Radon emissions from mill tailings were previously an issue of public concern in the United States. At present, uranium milled in the United States is subject to comprehensive regulation for the control of environmental impacts, including radon emissions, under the Uranium Mill Tailings Radiation Control Act of 1978. The majority of uranium is imported from nations such as Canada and Australia, which have regulations equivalent to those of the United States. However, 17 percent is imported from nations that may not have equivalent regulations, primarily Namibia and Kazakhstan.” (NAS, 2009)

Nuclear Waste Transportation Methods

The Center for Nuclear Science and Technology Information suggests that transporting nuclear waste requires a sturdy container that can shield from radioactivity. A specially designed container called a cask is used. There are different cask types for different purposes, but they all have similar overall design to maximize the containment of radioactivity.

A cask is a strong, heavily-shielded, double-walled container. The outer structure is of several inches of high-strength steel. The inner structure is usually made of steel as well. Casks meant to transport used nuclear fuel assemblies have a rack of square openings in this inner structure to provide support for those assemblies. If the cask is being used for transporting used nuclear fuel assemblies, the rack may also contain neutron-absorbing materials to safeguard against the unlikely event of a nuclear chain reaction.

For transporting used nuclear fuel assemblies, the inner canister is dried and filled with an inert gas (usually helium) to prevent long-term corrosion of the fuel assemblies. The casks also usually feature several inches of lead or depleted uranium (which is not radioactive) between the inner and outer structures to provide gamma ray shielding. The inner canister is then sealed, preventing any release of radioactive material. Large honeycomb structures made of wood, foam, or aluminum are placed on the ends of the casks to absorb the force the cask would experience in the event of a drop.

Materials such as used nuclear reactor fuel assemblies, radioactive resins (such as those used to filter radioactive material from water), contaminated clothing or tools, and isotopes used in nuclear medicine are some examples of nuclear waste that may be transported in a cask. (Center for Nuclear Science and Technology Information, 2018)

According to the Canadian Nuclear Association, large amounts of radioactive materials have been transported in Canada since the 1930s. At that time, the Canadian government, military, and industry already had extensive experience in transporting hazardous materials such as munitions, chemicals, and petroleum products. Over 70 years later, Canadian organizations are still building on their experience in transporting, handling, and storing radioactive and other hazardous materials in Canada and internationally.

Some of the measures that contribute to safe management of both radioactive and other hazardous materials include:

- safe engineering of vehicles and containers;
- qualified personnel receiving sound procedures and training;
- inventory tracking and accountability;
- independent, professional regulatory bodies; and
- careful study and analysis of incidents.

Nuclear facilities depend on the safe, efficient, and reliable transportation of the full range of nuclear fuel cycle materials. This includes all operations, beginning with the mining of uranium, to the manufacturing of new fuel bundles, to the eventual shipment of spent fuel to reprocessing plants or storage facilities.

For security reasons, the Canadian nuclear industry accounts for all uranium from the moment it leaves the mine until its final storage. Still, the measures needed to handle uranium safely depend on where they are in the cycle. For example, the uranium ore brought from the mines and the uranium oxide concentrate (yellowcake) produced in mills are not soluble in water and can easily be recovered in the event of a spill – and, until uranium fuel is actually used in a reactor, the materials are not dangerously radioactive.

Many of the same principles apply to transporting nuclear isotopes for applications outside of the generation of power, such as food irradiation, crop improvements, industrial gauges and non-destructive testing, and medical diagnosis and therapy.

For packaging of nuclear materials, Canada has adopted the standards of the International Atomic Energy Agency (IAEA), which are based on the characteristics of nuclear material they contain, regardless of the mode of transportation:

- Ordinary industrial containers are sufficient for low-activity materials such as uranium ore and uranium oxide concentrate (yellowcake).
- Type A packages are designed to withstand minor accidents, and are used for medium-activity materials, such as medical or industrial radioisotopes.
- Type B packages are robust and very secure casks used for used fuel and highly radioactive waste. These packages have shielding for gamma and neutron radiation, even under extreme accident conditions. Type B packages are required to undergo stringent testing, which can include free-drop testing, puncture testing, thermal testing, immersion testing, and simulated aircraft accidents:
 - a 9-metre (30-foot) free-fall onto an unyielding surface;
 - a 1-metre (40-inches) free-fall onto a steel rod;
 - a 30-minute, fully-engulfing fire at 800°C (1475°F); and
 - an 8-hour immersion under water. (Canadian Nuclear Association, 2018)

Stages of Nuclear Transport			
From:	To:	Material	Notes
Mining	Milling	Ore	Rare: usually on the same site
Milling	Conversion	Uranium oxide concentrate ('yellowcake')	Usually 200-litre drums holding 400 kg, in standard six-meter transport containers
Conversion	Enrichment	Natural uranium hexafluoride (UF ₆)	Special UF ₆ containers, Type 48Y
Enrichment	Fuel fabrication	Enriched UF ₆	Special UF ₆ containers, Type 30B
Fuel fabrication	Power generation	Fresh (unused) fuel	Type A casks unless MOX fuel (Type B)
Power generation	Used fuel storage	Used fuel	After onsite storage, large Type B casks
Used fuel storage	Disposal*	Used fuel	Large Type B casks
Used fuel storage	Reprocessing	Used fuel	Large Type B casks
Reprocessing	Conversion	Uranium oxide	Called reprocessed uranium (RepU)
Reprocessing	Fuel fabrication	Plutonium oxide	
Reprocessing	Disposal*	Fission products	Vitrified (incorporated into glass)
All facilities	Storage/disposal	Waste materials	Sometimes on the same site
*Not yet taking place			
Source: World Nuclear Association (2018)			

According to the National Academy of Sciences, “when comparing the methodologies used to determine costs of new nuclear and fossil-fuel power plants, nuclear and fossil-fuel-fired power plants provide baseload electricity supply, and a comparison of their potential cost ranges is likely to be helpful in guiding decision making. However, when making these comparisons..., it should be noted that slightly different (but comparable) methodologies and assumptions have been used to estimate the ranges of potential LCOE¹⁹ from new fossil-fuel-fired power plants (with and without carbon capture and storage [CCS]) and from new nuclear power plants. The methodologies for estimating the LCOE for nuclear plants and fossil-fuel plants differ, at least in part because different consultants assisted the committee in developing the LCOE estimates.

Although both nuclear and fossil-fuel plants provide baseload electricity and both of them are capital intensive, several of the underlying assumptions needed to calculate the LCOE are not identical. For example, a 20-year financing period was used to estimate the LCOE for new coal plants with CCS, while a 40-year financing period was used for new nuclear plants. A 20-year financing life is appropriate for a new technology such as CCS (whereby the first few plants may not operate for as long as later versions), while evolutionary light-water reactors are a more mature technology and thus more likely to operate for 40 to 60 years or beyond. In addition, the LCOE for coal plants with CCS drops between 2020 and 2035 as more experience is gained in building plants in the United States. The same reasoning has not been applied to nuclear plants, although some vendors expect that construction costs will be reduced over time, as there is more experience in constructing them. The LCOE for new nuclear plants does not change in current-year dollars between 2020 and 2035.”

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¹⁹ Levelized cost of electricity (See Section I: *Background and General Remarks*)

IV. ALTERNATIVE TO FOSSIL FUELS: GREEN ENERGY

Green energy is another name for renewable energy also called environmentally friendly energy because it has no harmful effect on the environment. While renewable sources of energy constitute the single most important alternative to our energy crisis and a panacea to global warming, we should cautiously optimistic. According to Chris Martenson, “when people think of alternative energy, they are primarily talking about means of getting electricity from the sun, wind, and waves. While we still don’t have a means of running our transportation network on electricity, perhaps we could someday, and that’s the hope (dream?) of some. The reality is that alternative energy sources are generating such a low percentage of current electricity, even if they grew at astonishing compounding rates, it would be a very long time before they made a majority contribution to the global energy outlook. In 2006, Simmons & Company International, an investment banking firm focused on energy, estimated that if solar power capacity grew at the incredibly high rate of 25 percent per year over the next 14 years (from 2006 to 2020), it would provide roughly 1 percent of global electricity demand.” (Martenson, 2011) Normally, the term green energy includes five types of energy: solar power, wind power, hydropower, biofuels, and geothermal power.

1. Solar Power

I will talk more about the nature of sunlight (see below *Important Characteristics of Sunlight*), but for now I would like to emphasize the fact that “we consume energy in dozens of forms yet virtually all of the energy we use originates in the power of the atom. Nuclear reactions energize stars, including our sun. The energy we capture for use on Earth comes largely from the sun or from nuclear forces, local to our own planet. Sunlight is by far the predominant source, and it contains a surprisingly large amount of energy. On average, even after passing through hundreds of kilometers of air on a clear day, solar radiation reaches Earth with more than enough energy in a single square meter to illuminate five 60-watt lightbulbs...The sun’s energy warms the planet’s surface, powering titanic transfers of heat and pressure in weather patterns and ocean currents. The resulting air currents drive wind turbines. Solar energy also evaporates water that falls as rain and builds up behind dams, where its motion is used to generate electricity via hydropower. Most Americans, however, use solar energy in its secondhand form: fossil fuels. When sunlight strikes a plant, some of the energy is trapped through photosynthesis and is stored in chemical bonds as the plant grows. We can recover that energy months or years later by burning wood, which breaks the bonds and releases energy as heat and light. More often, though, we use the stored energy in the much more concentrated forms that result when organic matter, after millions of years of geological and chemical activity underground, turns into fossil fuels, such as coal, oil, or natural gas. Either way, we’re reclaiming the power of sunlight.” (National Academies Press, 2008)

The biggest area of growth for solar energy is the transformation of sunlight into electricity with the aid of solar panels. That electricity can be used for about everything. There are other ways to get electricity from sunlight. You can concentrate sunlight and use the heat to boil water and run a steam turbine. You can use it as a heat pump to generate electricity, using something called the Stirling engine²⁰. Photovoltaics or solar panels convert sunlight directly into energy using semi-conducting materials that exhibit the photoelectric effect.

How Do Photovoltaic Panels Work?

According to Dhar (2017), touted as a promising alternative energy source for decades, solar panels crown rooftops and roadside signs, and help keep spacecraft powered. But how do they work?

Simply put, a solar panel works by allowing photons, or particles of light, to knock electrons free from atoms, generating a flow of electricity. Solar panels actually comprise many, smaller units called photovoltaic cells. (Photovoltaic simply means they convert sunlight into electricity.) Many cells linked together make up a solar panel.

Each photovoltaic cell is basically a sandwich made up of two slices of semi-conducting material, usually silicon — the same stuff used in microelectronics.

To work, photovoltaic cells need to establish an electric field. Much like a magnetic field, which occurs due to opposite poles, an electric field occurs when opposite charges are separated. To get this field, manufacturers ‘dope’ silicon with other materials, giving each slice of the sandwich a positive or negative electrical charge. Specifically, they seed phosphorous into the top layer of silicon, which adds extra electrons, with a negative charge, to that layer. Meanwhile, the bottom layer gets a dose of boron, which results in fewer electrons, or a positive charge. This all adds up to an electric field at the junction between the silicon layers. Then, when a photon of sunlight knocks an electron free, the electric field will push that electron out of the silicon junction. A couple of other components of the cell turn these electrons into usable power. Metal conductive plates on the sides of the cell collect the electrons and transfer them to wires. At that point, the electrons can flow like any other source of electricity.

Recently, researchers have produced ultrathin, flexible solar cells that are only 1.3 microns thick — about 1/100th the width of a human hair — and are 20 times lighter than a sheet of office paper. In fact, the cells are so light that they can sit on top of a soap bubble, and yet they produce energy

²⁰ A Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas at different temperatures, such that there is a net conversion of heat energy to mechanical work. The engine runs on a thermodynamic cycle, but of air not of water. Unlike photovoltaics, Stirling engines have moving part which wear over time. It does not any storage capacity either and is more expensive to build than photovoltaics.

with about as much efficiency as glass-based solar cells, scientists reported in a study published in 2016 in the journal *Organic Electronics*. Lighter, more flexible solar cells such as these could be integrated into architecture, aerospace technology, or even wearable electronics. (Dhar, 2017)

Photovoltaic panels rely upon a principle of physics called the photoelectric effect which was first observed in 1887 by Heinrich Hertz (1857 – 1894) but the process was first explained in 1905 by Albert Einstein. It is a “phenomenon in which electrically charged particles are released from or within a material when it absorbs electromagnetic radiation. The effect is often defined as the ejection of electrons from a metal plate when light falls on it. In a broader definition, the radiant energy may be infrared, visible, or ultraviolet light, X rays, or gamma rays; the material may be a solid, liquid, or gas; and the released particles may be ions (electrically charged atoms or molecules) as well as electrons. The phenomenon was fundamentally significant in the development of modern physics because of the puzzling questions it raised about the nature of light – particle versus wavelike behavior – that were finally resolved by Albert Einstein in 1905. The effect remains important for research in areas from materials science to astrophysics, as well as forming the basis for a variety of useful devices.” (Britannica, 2018) Einstein showed that due to the photoelectric effect, light can behave as both particles, called photons, and waves. When sunlight heats a solar panel, most of the energy does not go into freeing electrons or generating electricity. Some of them get reflected. Most of them go into heat.

Solar panels generate direct current (DC). But this direct current needs to be converted into alternating current (AC). How do solar panels convert DC to AC.?

A solar inverter, or converter or PV inverter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. “When the sun shines on your solar photovoltaic (PV) system, electrons within the solar cells start to move around, which produces direct current (DC) energy. Circuits within the cells collect that energy for you to use in your home. This is where your inverter comes in. Most homes use alternating current (AC) energy, not DC, so the energy produced by your solar panels isn’t useful on its own. When your solar panels collect sunlight and turn it into energy, it gets sent to the inverter, which takes the DC energy and turns it into AC energy. At that point, your solar electricity can power your appliances and electronics or, if you’re producing more electricity than you need, it can feed back into the grid.” (Energy Sage, 2018)

There are other types of solar power technology — including solar thermal and concentrated solar power (CSP) — that operate in a different fashion than photovoltaic solar panels, but all harness

the power of sunlight to either create electricity or to heat water or air. (Dhar, 2017) Concentrated solar power works by focusing the heat from sunlight to boil water and run a steam-powered generator.

What Are Photovoltaic Panels Made Of?

Solar panels are primarily made of silicon. “The silicon that you'll now find in a solar cell is highly processed. The material is sourced in silica mines, which are often found in regions with heavy quartz concentrations. The silica is refined to reach metallurgical grade. This process takes place in an electric arc furnace, where carbon is used to release the oxygen in the silica quartzite, resulting in a more consistent silica makeup. However, metallurgical purity doesn't cut it for a photovoltaic cell.

High efficiency rates will boost the amount of energy released by the cell, so the purity of the photovoltaic-capable material is of utmost importance. The metallurgical grade silicon is exposed to hydrochloric acid and copper, which produce trichlorosilane gas. Hydrogen is then used to reduce this gas to silane gas, which is in turn heated to make molten silicon.

Pure silicon is crystalline - a structure necessary for photovoltaic cells. The purity level of silicon at this state is anywhere from 99.99999% to 99.9999999% pure. Silicon can be arranged into either a monocrystalline structure, which boasts the highest efficiency rates as well as the highest cost, or a polycrystalline shell.” (De Gree, 2015)

How Much Does It Cost to Produce Solar Energy?

It is not an easy task. As Maggie Koerth-Baker put it, “the truth: Capturing that power and putting it to work in the form of electricity, is relatively expensive. It’s true that the cost of solar electricity has declined over the past ten years. Along the way, the popularity of solar electricity has risen. A decade ago, fewer than 25,000 solar cells and modules were shipped in the United States every year. In 2008, that number had skyrocketed to more than 500,000. But that is still a drop in the bucket. Only about one-tenth of 1 percent of the energy consumed in the United States came from solar sources in 2008. In Germany, a country with a much more robust government incentive program, solar’s share is much larger, but still only 1.1 percent of that nation’s electricity. And, while most scientists agree solar power will be an important part of the future energy mix, there’s no clear consensus on when it will be able to compete on a large scale. In fact, the experts don’t even agree on how much solar electricity costs today.

The problem: Solar electricity isn't just one thing. Think about any simple item, like a shirt. A shopper may know how much he or she paid for it, but that doesn't mean the consumer knows how much a shirt, in general, costs. That number can vary quite a bit, depending on the type of shirt and where it is purchased. Solar electricity is similar. The cost varies based on the technology being used, and on where it is being installed. The situation looks much different in Phoenix, Arizona than it does in Albany, New York, and looks much different in Seville, Spain than in Leipzig, Germany.

Figuring out the levelized cost requires a number of guesses: How well the solar energy system will perform, how long it will last, and even how much sunshine it will get over the next 30 years. It's possible to make good guesses. But, right now, everybody makes different ones and it's hard to say who's right.

That said, there's wide agreement that solar electricity is pricey. The U.S. DOE's Energy Information Administration (EIA) estimates that it's the most expensive form of electricity among current technologies for new electricity generation, about \$396 per megawatt hour for PV. That's more than double EIA's estimate of the total system levelized cost of wind, and almost four times the cost of conventional coal.

It's All in the Material. So why is solar so expensive? Converting light into electricity with no moving parts is a profoundly different enterprise than turning a turbine to make power—the technology that is at work in coal, natural gas, nuclear, hydropower plants and, most visibly to the public, at wind farms.” (Koerth-Baker, 2010)

Solar Power Applications

The energy obtained through photovoltaic generators and their applications is greatly diverse. in terms of a general classification, it can be said that it is divided into two large sections: isolated systems and grid connection.

Applications of Solar Power	
1. Isolated Systems	
Telecommunications	
• Mobile phone	
• Radio and television repeaters	
• Roadside S.O.S. posts	
• Remote control	
• Remote control for irrigation systems	
• Telemetry	
• Radars	
• Radiotelephony in general and for militaries or forest surveillance posts	
• Rural telephones via satellite	
• Microwave	

Applications of Solar Power

1. Isolated Systems

- Public telephone booths
- Communication stations
- Radio links
- TRUNKING systems
- Radio and communication coverage in railway tunnels

There are two kinds of stations for mobile phones, BTS²¹ calls, made up of a photovoltaic-diesel hybrid system, with a photovoltaic peak power of 6 Kw²², in which the function of the generator is only for support. The second kind of installations are called RF calls, which only function with rotating photovoltaic panels and an installed peak power between 0.6 Kw and 1.8 Kw. The remote controls and telecommands with radio transmission are often used in applications related to water, tanks, risks, flowmeters and, in general, for collecting and controlling any kind of data.

Rural Electrification

- Temporary housing
- Permanent housing
- Centralized electrification with individual consumption control per house, in rural areas
- Refuge and mountain lodge electrification
- Aid stations. (lighting, medication and vaccine preservation with refrigerators)
- Schools and community centers
- Police stations and borders
- Religious facilities (chapels, missions, etc.)

Rural electrification currently has all of the commodities that a conventional electrification system can have since the incorporation of new sine wave inverters, allowing for the use of any appliance. One of the most important applications is currently the electrification of small rural areas with centralized systems. The advantages with respect to one installation per house are the following: lower installation cost, lower maintenance costs, higher level of user friendliness, higher security of the facility, and greater total return. To manage the energy, an energy limiting electronic device is installed in each of the houses that is programmed to be able to supply energy to the user every day. That being said, the device has to be intelligent enough to be able to increase the assigned energy, if the battery status is good or bad. To simplify and not perform complicated electrical wiring, the communication between the energy limiting device and the inverters is made along the same 220 Vac line, with small changes in frequency that do not affect the operation of the system in any way. The second greatest inconvenience is the power of the inverter and its efficiency against small charges. This was resolved with the installation of several inverters in parallel, with one of them (the master) being that which acts on the control of the rest (the slaves), so that if the power consumed is less than the sum of the power of all the inverters, it orders some of them to stop until they adapt to the consumed power. Another great advantage is that all of the inverters have the capacity to act as masters and as slaves. With this, the electrical supply is secured against possible failures in some of them.

²¹ A base transceiver station (BTS) is a piece of equipment that facilitates wireless communication between user equipment (UE) and a network. UEs are devices like mobile phones (handsets), WLL phones, computers with wireless Internet connectivity. The network can be that of any of the wireless communication technologies like GSM, CDMA, wireless local loop, Wi-Fi, WiMAX or other wide area network (WAN) technology.

²² KWp: In Photovoltaics, the maximum possible output of a solar generator operating under standard conditions is defined as its peak output, which is measured in watts or kilowatts and stated as either Wp (watt, peak) or kWp, respectively.

Applications of Solar Power

1. Isolated Systems

Agricultural

- Water pumps both in DC and AC (with battery)
- Direct drive water pumps (without battery)
- Warehouse electrification
- Risk controls
- Greenhouses (automation of windows and lighting)

One of the most important applications in agriculture, for its simple installation and above all for its zero maintenance and complete automation, are the direct drive water pumps, made up of a field of photovoltaic panels, an electronic device and the entire system of controls and pump sensors. The aforementioned electronic device has the capacity to obtain the maximum performance of the panel in low flow pumps. In high flow pumps, it has a second function, which is to convert the continuous current of the photovoltaic panel into alternating current. The main advantage of the direct drive pumps is that they coincide with the radiation curve and the water demand curve. They allow for water extraction in rural environments, where the possibility to install a conventional line does not exist due to its high cost. A second application in the agricultural sector has been the electrification of risk controls and solenoid valves, which has allowed for a better distribution and saving of water. They are mostly systems based on the risk of leaks or low pressure.

Used with Livestock / Cattle

- Water pumps to provide water to the livestock/cattle
- Farm electrification. (lighting, motors, shearing machines, etc.)
- Milking systems and milk refrigeration
- Fence electrification

The direct drive pumps, detailed under farmland applications, are at the cattle farms, a highly important location. The manufacture of high power inverters has made it possible to undertake works at the cattle farm, supply electrical energy to milking systems, preserve milk (cold tanks) and clean pumps, as well as to light up warehouses, power motors for the distribution of animal feed, fans, automation of shutters for cattle warehouses and greenhouses. The motors of the aforementioned equipment, originally and to achieve a higher performance at the facility, were installed in DC. Then, thanks to the new high-performance inverters, the motors are now in AC, obtaining a greater operational safety in the event of failure since an alternating motor is easy to obtain, while a continuous one is specially produced. The installed inverter, to provide more safety to the system, is modular with several power stages so that they can be repaired without the system running out of power.

Street Lighting

- Billboards
- Public streetlights
- Bus stops
- Tunnel, cave, etc. lighting

Public lighting, through photovoltaic systems, is presented as one of the most economic solutions to light the entrances of the towns, road junctions, rest areas, etc. A new type of street light is currently being installed, which

Applications of Solar Power

1. Isolated Systems

does not require any maintenance, by integrating long life stationary batteries with gelled electrolytes (over 300 streetlights in the Canary Islands).

Signage

- Lighthouses and marine buoys
- Air beacons and radio beacons
- Road signs to indicate curves, obstacles, roundabouts, etc. in cities and on roadways using LEDs
- Time and temperature indicators on public roads
- Railway crossings
- Oil rigs

The use of the ESF²³ has allowed for the automation of lighthouses, as well as an increase in buoy safety, where acetylene gel was previously used, significantly reducing maintenance. For aviation use, panels to supply the beacons and road signs on the runways are being used. The Madrid and Balearic airports stand out for their easy identification of facilities. Another wide application, which has recently been added to road safety with a great importance, is the labelling of roundabouts, curves, traffic signs, obstacles, etc. through the use of high luminosity LEDs, which, because of their low consumption, makes it possible to make a small photovoltaic installation.

Control

- Flowmeters and anemometers
- Activation of valves (solenoid valves)
- Controls, weather stations and earthquakes
- TV cameras to control and measure traffic
- Monitoring and automation of gates
- Fiber optic signal repeaters
- Environment metering stations
- Gas and oil pipeline control
- Data collection
- Control and remote operation of reservoirs
- Cathodic protection

In this section, it is currently worth mentioning that works are being performed on the river basins to control the flow and quality of the water, where the photovoltaic systems are found, as well as those that are more economic and secure for these types of applications. The photovoltaic installations have shown high reliability in greatly important applications and large projects, such as the gas and oil pipelines, where they are responsible for providing electrical energy to the control, communication, valve activation and cathodic protection systems. This previous application is also used on bridges.

Other Applications

- Chlorination through dosing pumps
- Purification through lagooning by supplying clean-grille motors and flowmeters

²³ ESF: Emergency Support Function

Applications of Solar Power

1. Isolated Systems

- Oxygenators for the water through compressors
- Salt water desalination (reverse osmosis)
- Scales to weigh lorries. (landfills, industrial centers, etc.)
- Systems to detect fires by means of infrared cameras
- Infrared perimeter security systems
- Surveillance and access control (video intercom, opening and closing of gates, remote control)
- Ionization for lightning rods
- Power supply for didactical uses at universities, professional colleges, etc.
- Sailing vessels and motor homes
- Recreational area equipment

2. Grid Connections

It is one of the latest and most innovative applications of the photovoltaic systems, consisting of the installation of a photovoltaic field and inverter capable of transforming the energy supplied by the panels and pumping it into the electricity grid. The inverter in this type of installation is the central nucleus inverter and must provide certain protections against situations that may occur in the electricity grid, such as:

- Out-of-range voltage
- Grid cut
- Discrepancy in the grid

To obtain economic viability of these systems, the country must provide a legal standard and economic aid lines, which compensate the increased cost per Kwh generated.

Source: Atersa Group Elecnor, 2018

The aviation industry is also considering using solar power. For example, the Swiss plane Solar Impulse flew from Abu Dhabi to Hawaii. Solar Impulse is a Swiss long-range experimental solar-powered aircraft project, and also the name of the project's two operational aircraft. Important facts about the aircraft include:

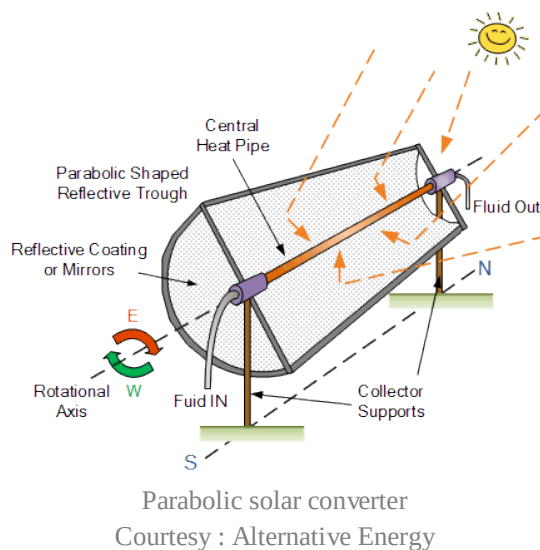
- Top speed: 87 mph
- Weight: 3,527 lbs
- Length: 72'
- Introduced: June 26, 2009
- Manufacturer: École Polytechnique Fédérale de Lausanne
- First flight: December 3, 2009
- Engine type: Electrical Motors

“Solar Impulse 2 has completed the first round-the-world flight by a solar-powered aeroplane, after touching down in Abu Dhabi early on Tuesday. The final leg of the feat, aimed at showcasing the potential of renewable energy, was a bumpy one, with turbulence driven by hot desert air leaving the solo pilot, Bertrand Piccard, fighting with the controls.

The plane, which has a wingspan wider than a Boeing 747 and carries more than 17,000 solar cells on its wings, began the circumnavigation in March 2015 in Abu Dhabi. It has since crossed both the Pacific and Atlantic Oceans using no fossil fuel and has spent more than 23 days in the air. Speaking to the Guardian from the cockpit shortly before landing, Piccard said he was feeling emotional as he neared the end of the journey: “It is a very, very special moment – it has been 15 years that I am working on this goal. ‘I hope people will understand that it is not just a first in the history of aviation, but also a first in the history of energy,’ he said.” (The Guardian, 2016)

Important Characteristic of Sunlight: Inexhaustible Energy Source

Sunlight is a literally inexhaustible source of energy. With the exception of geothermal and tidal energy, all other forms of energy ultimately come from the Sun. We saw that with photosynthesis, which was the basis for biomass energy, coal, oil, and gas. We will also see this with solar power,



wind power, and hydroelectric power. Sunlight carries an enormous amount of energy and we can use it in a lot of different ways. Sunlight is often referred to as an inexhaustible source of energy as opposed to renewable. Hydroelectric power is renewable. You can drain out the water behind the dam, but it will fill up again. It will renew. But the sunlight is always there. We can use it or not, it will shine. Humans have long used the Sun's heat in the construction of their homes. For example, if you go to Bandelier Canyon in New Mexico, you can even still see the cliff dwellings carved by the ancient Anasazi native into the north faces of volcanic tough cliffs. This was to get free thermal insulation. And it still worked at night. The

heat of the Sun would heat up the cliff during the day and the rock would still retain some of that heat over the course of the night. However, starting in the time of the Greeks, people started using sunlight in more direct ways. Archimedes supposedly defended the city of Syracuse from the attacking Romans in the year 214 BCE by using a parabolic reflecting mirror to burn attacking ships. The first application of using sunlight to create a solar furnace dates back to 1774. Antoine Lavoisier in France built a solar furnace also using a parabolic mirror that could reach temperatures of 1700° C that could melt rock. By 1878, Augustin Mouchot used a parabolic solar furnace to run a small printing press. By the way, what's so special about parabola? Well, one definition of a parabola is that if there is a source of light rays placed at a particular point called the focus of the

parabola, the rays will reflect off the inside of the parabola in such a way that they will all be traveling in the same direction. They'll all travel parallel away from the parabola. This is how a flashlight works. The light bulb is simply situated at the focus and the parabolic mirror reflects the light as a tight beam of light. A parabolic solar collector works just the opposite. You have sunbeams coming from the Sun all parallel, and the parabolic reflector focuses them all to one point, concentrating the energy at one point, thus, reaching very high temperatures. Around the world, people use this simple process of focusing sunlight for a variety of purposes. Low-tech solar cookers use the principle of the parabola to focus sunlight to boil water, desalinate water, cook or pasteurize food, kill parasites, etc.

The composition of the Milky Way is as follows:

- 74% Hydrogen
- 24% Helium
- 1% Oxygen
- 1% Everything else

“Why does the Sun give off light in the first place? Many people think that the Sun is on fire, but this is a misconception. The Sun does not burn, giving off smoke and leaving burnt charcoal behind, like a candle or campfire does. It is more like a light bulb or a burner on an electric stove -- it gets hot, and shines brightly, but it does not burn up. Unlike a light bulb, the Sun does not use electricity, but creates energy with a reaction called nuclear fusion. In nuclear fusion, two small atoms of hydrogen are pushed together to form a bigger atom, helium. Every time this happens, energy is given off as heat and light. The Sun is not the same all the way through. Nuclear fusion happens in the core of the Sun, and the resulting heat and light flow up through the Sun to the photosphere, the part of the Sun that we see. The chromosphere is a thin layer above the photosphere. Above that, the corona, or solar atmosphere, extends far into space. We do not usually see these parts of the Sun because they are not as bright as the photosphere, but during a total eclipse they are visible because the Moon blocks the light from the photosphere.” (University of North Carolina, 2001)

If the Sun's aspect is not the same all the way through, its composition is about the same. The Sun's temperatures – surface and core – are so high that fusion occurs spontaneously, which is very difficult and expensive to produce on Earth. The energy emitted by the Sun is done primarily by stellar nucleosynthesis which is the collective term for the nuclear reactions taking place in stars to build the nuclei of the heavier elements. The processes involved began to be understood early in the twentieth

century, when it was first realized that the energy released from nuclear reactions accounted for the longevity of the Sun as a source of heat and light.

The prime energy producer in the sun is the fusion of hydrogen to helium, which occurs at a minimum temperature of 3 million kelvin. Note that the fusion does not occur everywhere in the Sun. It happens just within its core where pressures and temperatures are higher.

How much of insolation does Earth receive? 1366 W/m^2 or 174,000 TW. As the Earth rotates, the energy gets distributed evenly across the planet. Earth gets more sunlight in an hour than most humans use in a year. So, how do we capture and use that energy? Sunlight may be used by photosynthesis in the case of plants converting it into chemicals that they can use as energy. The light can also be used directly as electricity in the case of solar panels. Is meeting all of our energy need thanks to sunlight doable? If we took the deserts of half of New Mexico and covered them with solar panels, we can generate 10 KW / person needed in the US. The thing is concentrating all the panels in one place wouldn't be efficient. They would have to be distributed. Solar energy, like all renewable energy, takes a lot of lands. Say we have 10 billion people who use 10 KW / person. That's 20 W / m^2 , which is the equivalent of 5 million Km^2 of solar panels or 3.3% of the world's land area. So, it's doable. However, the biggest issue with sunlight is that it doesn't shine at night.

Types of Solar Collectors

There exist several types of solar collectors. They include:

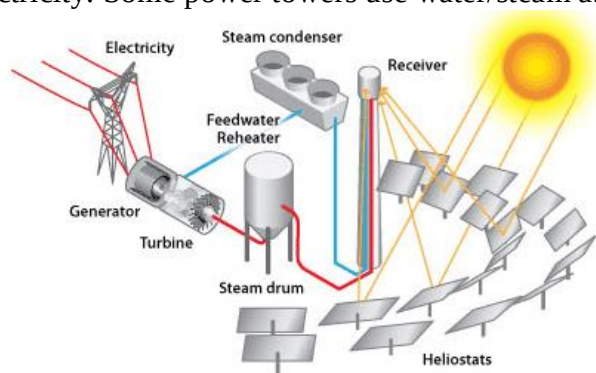
Parabolic trough. “A parabolic trough is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two, lined with a polished metal mirror. The sunlight which enters the mirror parallel to its plane of symmetry is focused along the focal line, where objects are positioned that are intended to be heated. For example, food may be placed at the focal line of a trough, which causes the food to be cooked when the trough is aimed so the Sun is in its plane of symmetry. For other purposes, there is often a tube, frequently a Dewar tube, which runs the length of the trough at its focal line. The mirror is oriented so that sunlight which it reflects is concentrated on the tube, which contains a fluid which is heated to a high temperature by the energy of the sunlight. The hot fluid can be used



Parabolic trough at a plant near Harper Lake, California

for many purposes. Often, it is piped to a heat engine, which uses the heat energy to drive machinery or to generate electricity. This solar energy collector is the most common and best-known type of parabolic trough. The paragraphs below therefore concentrate on this type.”

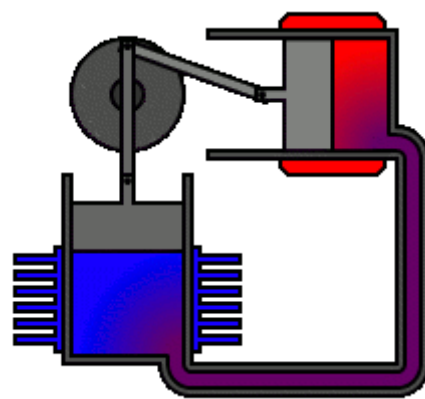
Solar towers. “Known as heliostats, they focus sunlight onto a receiver at the top of a tall tower. A heat-transfer fluid heated in the receiver is used to heat a working fluid, which, in turn, is used in a conventional turbine generator to produce electricity. Some power towers use water/steam as the heat-transfer fluid. Other advanced designs are experimenting with high temperature molten salts or sand-like particles to maximize the power cycle temperature. Two large-scale power tower projects are currently operating in the U.S. The Ivanpah Solar Electric Generating System is the largest concentrated solar thermal plant in the country. Located in California's Mojave Desert, the plant is capable of producing 392 megawatts of electricity using 173,500 heliostats, each with two mirrors that focus sunlight onto three solar power towers. Crescent Dunes Solar Energy Project is a 110-megawatt solar thermal power plant located in southwestern Nevada. The project includes 10,347 heliostats and is the largest power tower system with direct thermal energy storage, which means the heat transfer fluid is also the storage material. Aside from the U.S., Spain has several power tower systems. Planta Solar 10 and Planta Solar 20 are water/steam systems with capacities of 11 and 20 megawatts, respectively. Gemasolar, previously known as Solar Tres, produces nearly 20 megawatts of electricity and utilizes molten-salt thermal storage.” (Office of Energy Efficiency and Renewable Energy, 2013)



A Power Tower Plant
 Courtesy: U.S. Office of Energy Efficiency and
 Renewable Energy

Stirling engine. As noted above, a Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas at different temperatures, such that there is a net conversion of heat energy to mechanical work. The engine runs on a thermodynamic cycle, but of air not of water. Unlike photovoltaics, Stirling engines have moving part which wear over time. It does not any storage capacity either and is more expensive to build than photovoltaics.

“Invented by Robert Stirling in 1816, the Stirling engine has the potential to be much more efficient than a gasoline or



A Stirling engine

diesel engine. But today, Stirling engines are used only in some very specialized applications, like in submarines or auxiliary power generators for yachts, where quiet operation is important. Although there hasn't been a successful mass-market application for the Stirling engine, some very high-power inventors are working on it. A Stirling engine uses the Stirling cycle, which is unlike the cycles used in internal-combustion engines. The gasses used inside a Stirling engine never leave the engine. There are no exhaust valves that vent high-pressure gasses, as in a gasoline or diesel engine, and there are no explosions taking place. Because of this, Stirling engines are very quiet. The Stirling cycle uses an external heat source, which could be anything from gasoline to solar energy to the heat produced by decaying plants. No combustion takes place inside the cylinders of the engine.” (Nice, 2018)

Solar farm. A solar farm is a photovoltaic power station, also known as a solar park. It is a large-scale photovoltaic system designed for the supply of merchant power into the electricity grid. According to Katie Fehrenbacher, Solar panels on the rooftops of homes might be the most visible, and emblematic, form of solar energy. But it's the solar panels that make up the sprawling farms built on the ground in remote regions of the U.S., selling energy to utilities and big companies that are driving the boom in the solar industry... According to the analysts at GTM Research, almost 14 gigawatts of solar panels [were] installed in the U.S. by the end of 2016, and over 70% of that [came] from what they call “utility-scale” solar farms. These solar farms generate energy using thousands—or even—millions of panels, often piping energy long distances to residents and companies to use to power homes and offices. Approximately 14 gigawatts are enough solar energy to power 2.3 million homes and is the equivalent of about 14 large natural gas or coal plants. That figure is also 85% more than the number of solar panels installed in all types of systems in the U.S. in 2015.

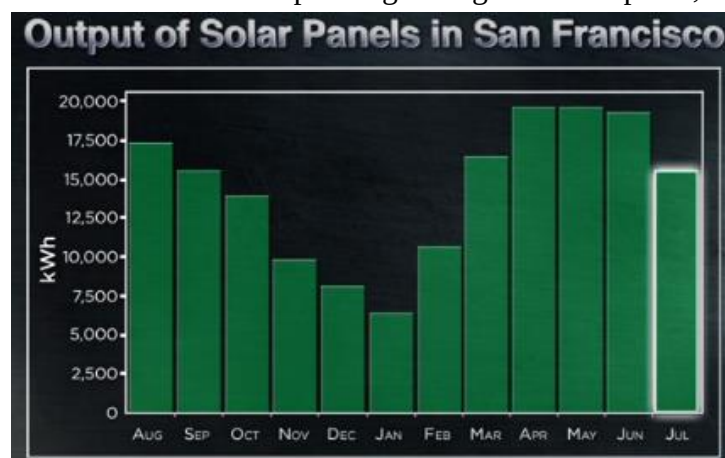


A solar farm

Of course, big solar farms are much larger than rooftop solar on a per-system basis, so it's not all that surprising that they'd collectively supply more power. One rooftop solar system could generate several thousand kilowatts, while a solar farm could generate tens or hundreds of

megawatts. That said, these big solar farms are attractive for a variety of reasons to utilities and power companies across the United States. They also seem to be an easier sell, at least at this point, compared to homeowners buying solar panels for their roofs. The solar companies building these large farms are often able to obtain the lowest price of solar energy available. Some have gotten record-low prices, like four cents per kilowatt-hour, making solar energy cheaper than fossil fuels in some regions. The prices for utility-scale solar farms has become so cheap that even some non-utility companies are joining in, including Apple (AAPL, +0.82%), which is buying tons of solar to power its operations, stores, and data centers. (Fehrenbacher, 2016)

The current and power output of photovoltaic panels are approximately proportional to the sun's intensity. At a given intensity, a solar panel's output current and operating voltage are determined by the characteristics of the load. If that load is a battery, the battery's internal resistance will dictate the module's operating voltage. A solar panel, which is rated at 17 volts will put out less



than its rated power when used in a battery system. That's because the working voltage will be between 12 and 15 volts. Because wattage (or power) is the product of volts multiplied by the amps, the module output will be reduced. For example, a 50-watt solar panel working at 13.0 volts will produce 39.0 watts (13.0 volts x 3.0 amps = 39.0 watts). This is important to remember when sizing a PV system. An

I-V curve is simply all of a solar panel's possible operating points (voltage/current combinations) at a given cell temperature and light intensity. Increases in cell temperature increase a solar panel's current slightly, but significantly decrease voltage output. (Wholesale Solar, 2018)

In many areas like California and Nevada, utilities need to make sure a large percentage of their energy is clean, and they're commonly turning to big solar farms (and wind farms) as the quickest and cheapest ways to get there. For the first time, California accounted for 42% of all rooftop solar panel installations in the second quarter of 2016, which is its lowest share in years. At the same time, other less traditional markets, like Texas and Utah, are growing their share of rooftop solar customers. During the first half of 2016, 11 states added more than 25 megawatts of rooftop solar, while only seven added that amount in the same period in 2015, according to GTM Research. Solar in the U.S. is growing rapidly on both rooftops and on the ground in large sprawling farms. But at this stage of the solar industry, it's the big solar farms that are dominating. Yet some day down the road, that could flip. Solar companies building large solar farms are also aggressively

taking advantage of the important U.S. incentive that gives solar companies a 30% tax credit on the price of a solar system. While home rooftop solar systems can also tap into this tax credit, the percentage incentive is large enough that it is making these really big solar farms—which can cost tens or hundreds of millions of dollars—far more economical. (Fehrenbacher, 2016)

World's Largest Solar Farms

According to Scott (2017), massive solar farms, made from millions of solar panels that harness the sun's energy, have started sprouting up all over the world. And they look incredible from an aerial view. Here are some of the biggest solar farms across the globe:

Longyangxia Dam Solar Park, China

The 850 megawatt-capacity Longyangxia Dam Solar Park is located on the Tibetan Plateau in eastern China. It's one of the largest solar farms in the world, stretching over ten square miles. The site is harnessing solar power from a whopping four million solar panels, amassing enough energy to power 140,000 homes.

Topaz Solar Farm, California

In the Carrizo Plain, the 550-megawatt Topaz Solar Farm is soaking up a lot of Southern California sun. According to NASA, at 9.5 square miles, the farm is roughly one-third of the size of the island of Manhattan — or 4,600 football fields. The plant utilized 9 million cadmium telluride solar modules. Operated by BHE Renewable, Topaz has been turned on since 2014, and it's capable of powering around 180,000 homes.

Desert Sunlight Solar Farm, California

Nestled in the Mohave Desert, the Desert Sunlight Solar Farm is pretty much on par with Topaz, utilizing 8.8 million cadmium telluride solar modules to harness 550 megawatts of energy. Co-owned by NextEra Energy Resources, GE Energy Financial Services, and Sumitomo Corporation of America, the farm began producing energy in 2015. At 6 square miles, the project has enough power to serve 160,000 California homes. According to First Solar, who developed Desert Sunlight, each year the alternative energy source displaces about 300,000 metric tons of CO₂ — the equivalent of removing 60,000 cars from the road.

Kamuthi Solar Power Project, India

Going online in November of 2016, Kamuthi Solar Power Project in the state of Tamil Nadu contains 2.5 million solar panels. Covering four square miles, it has a capacity of 648 megawatts. The solar farm is cleaned each day by a robotic system that's charged by the project's own solar panels. India, like China, has made a huge push in recent years to invest in the solar power industry.

Huainan's Floating Solar Farm, China

The Chinese city of Huainan is home to the largest floating solar power farm on Earth. The farm, which according to Quartz encompasses an area larger than 160 American football fields, was built on a lake that covers a collapsed coal mine. It's capable of producing 40 megawatts of power — comparatively small to the others listed here, but remember this plant is floating on water. According to Sungrow, the supplier of the solar panels used, the water that now resides on top of the former coal mine is so mineralized that the area would be valueless otherwise. It's one attempt to find alternatives for the region's reliance on coal-based energy. The solar farm produces enough energy to power 15,000 homes.

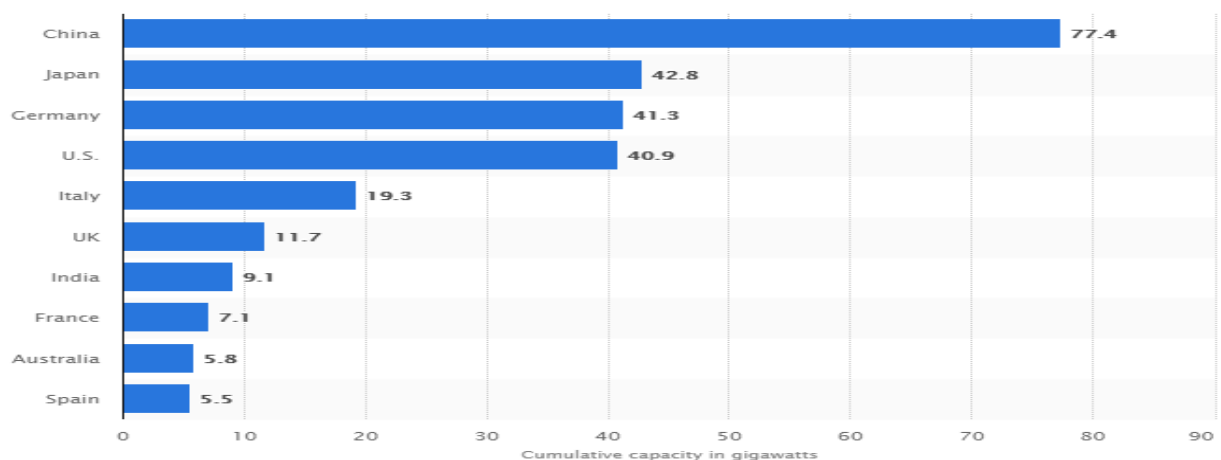
Kurnool Ultra Mega Solar Park, India

The Kurnool Ultra Mega Solar Park, located in the Indian state of Andhra Pradesh, has a whopping 1000-megawatt capacity. A joint development project that's being overseen by the Solar Park Implementation Agency and Andhra Pradesh Solar Power Corporation Limited, the Kurnool park is 9 square miles in size, according to the Press Trust of India. According to PV Magazine the park was slated to fully connect to the grid in mid-July. (Scott, 2017)

Global Photovoltaic Power

Global solar photovoltaic capacity has grown from around five gigawatts in 2005 to an approximately 306.5 gigawatts in 2016. In that year, cumulative solar PV installations reached some 41.3 gigawatts in Germany alone. By 2016, the residential solar PV market in the United States is projected to be worth around 4.7 billion U.S. dollars. Solar energy technologies remain one of the most heavily funded renewable sources.

Cumulative solar photovoltaic capacity globally as of 2016, by select country (in gigawatts)

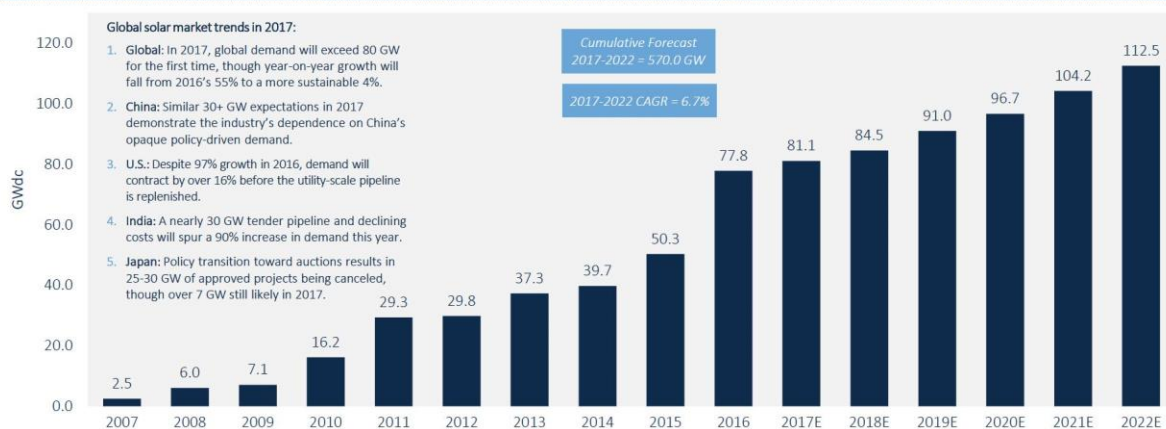


The capacity of newly installed solar PV has continued to steadily grow over the last decades, with China being one of the largest market for solar cells and modules. China was home to seven of the world's ten leading solar module manufacturers in 2015. The country's share of the global installed photovoltaic capacity reached 25.5 percent in recent years. At this time, solar PV capacity only accounts for about one percent of the country's energy output. However, China continues to place a larger focus towards moving to clean energy sources and is expected to continue adding solar capacity. Since the industry's beginnings in the country, China has moved from a small, rural-oriented solar program to one of the largest markets in the world. The market may have largely emerged in the late 1990s when demand for solar panels in Germany began to rise.

Despite its quick rise globally, the number of solar installations in China has decreased largely due to a reduction in feed-in tariffs. The cost of solar PV modules continues to decrease in international markets. Thus, weaker demand and prices may put heavy pressure on some solar companies. The election of Donald Trump will likely alter the regulatory environment of the solar energy industry which may cause repercussions across the world. (Statista, 2018)

Global Demand Growth Slows in 2017, But We'll Still See More Than 80 GW Installed

Global PV Demand, 2007-2022E



Source: GTM Research Global Solar Demand Monitor Q2 2017

By the end of 2017, solar PV capacity [rivalled] nuclear. By 2022, it could more than double nuclear capacity. The global solar market has been downgraded for 2017. A worrying sign? Hardly. Even with a 4-gigawatt downward adjustment in projected installations, it's still going to be a record-breaking year for new solar capacity additions -- yet again. The 81 gigawatts expected this year are more than double the amount of solar capacity installed in 2014. And it's 32 times more solar deployed a decade ago. (In the year 2000, global installations totaled 150 megawatts.)

Those numbers come from GTM Research's latest edition of the Global Solar Demand Monitor, which closely tracks market-moving and market-dooming developments in countries around the world. One of the most telling statistics: By 2022, global capacity will likely reach 871 gigawatts. That's about 43 gigawatts more than expected cumulative wind installs by that date. And it's more than double today's nuclear capacity...a major milestone. According to the Nuclear Energy Institute, there are 391.5 gigawatts of nuclear plants operating around the world...There will be roughly 390 gigawatts of solar PV plants spread across the globe, according to estimates from GTM Research. (The final numbers could be larger, since the outlook for China is growing stronger.) For the first time ever, solar power plants and nuclear power plants will be on equal footing -- at least when it comes to raw capacity. Of course, capacity only tells us part of the story. It's all about electrons. And in that regard, nuclear still dominates. Nuclear generates 2,476,671 gigawatt-hours of electricity every year, accounting for roughly 11 percent of global generation. Solar, on the other hand, only accounts for 375,000 gigawatt-hours of electricity yearly, or about 1.8 percent of global generation. (Lacey, 2017)

Role of Economics in the Development of Solar Technologies

Solar energy is becoming more economically attractive as technologies improve and the cost of electricity generated by fossil fuels rises. By 2020, hundreds of billions of dollars of investment capital will probably boost global solar-generating capacity 20 to 40 times higher than its current level. As the new sector takes shape, producers of solar components must drive their costs down, utilities must place big bets despite enormous technological uncertainty, and regulators must phase out subsidies with care. The actions these players take will determine the solar sector's scale, structure, and performance for years to come. (Lorenz et al., 2008) Cost of solar energy vary according to the time of the year. By and large, electricity is most expensive during the summer days when businesses are open, air conditioners are running at full blast. Households could offset some these costs by installing solar panels. "Cost reductions and the resulting increases in installed capacity are enabling solar to become a competitive source of electricity on the US grid. The ITC has contributed significantly to the increase in capacity and allowed cost parity with fossil fuel sources in some markets. Extending the ITC for five years at the end of 2015 has given the market near term policy certainty and is expected to contribute to the continued robust pace of solar development. If history is any guide, prices will continue to fall as capacity increases. As the Sunshot studies indicate, cost parity on an unsubsidized basis is achievable by the end of the decade." (McGarry, 2016)

Darvin Tocmo identifies three main economic benefits of using solar energy:

1. *Everybody is Saving Money.* The average household, depending on where it is located, can drastically cut its energy savings from \$20,000 to over \$60,000 in two decades use of solar energy. Not just for individual households, but commercial entities are also seeing the green in switching green. Walmart, the biggest retailer of the world for example is now as the largest commercial solar power in the U.S. With their ongoing investments, a whopping \$1 billion energy savings a year is predicted by 2020.
2. *Job Opportunities.* Employment in solar energy industry added a whopping 20% between 2013 and 2014. Solar energy jobs keep popping up that it grew 12 times as fast as the US economy. Solar distributors also play an important role in solar industry as it helps manufacturers to do business with professional & capable solar installers that makes more jobs for people. Optimus Energy, a leading whole sale solar distributor in Australia for example, doesn't only assist solar companies in Australia to do business better, but also assists those in need to access solar technology, so while helping people get their jobs, they are also educating individual households on how solar energy helps them, a win-win for them.
3. *Environmental Value.* The main reason why solar energy was built is not to cut our energy bills but to cut the global carbon emissions. Solar power's low carbon footprint, low emissions and long-term sustainability make for healthier people, waterways, soil, animals and beyond. It's a benefit that's clearly invaluable, but it makes good financial sense, too. (Tocmo, 2017)

"We forecast global solar demand by estimating the payback period for customers in different countries and regions. (Payback estimates rest on projected system costs and power prices, as well as local sunlight and incentive schemes.) Our analysis suggests that by 2020 at least ten regions with strong sunlight will have reached grid parity, with the price of solar electricity falling from upward of 30 cents per kilowatt hour to 12, or even less than 10, cents. From now until 2020, installed global solar capacity will grow by roughly 30 to 35 percent a year, from 10 gigawatts today to about 200 to 400 gigawatts requiring capital investments of more than \$500 billion. exactly where within this range actual installed capacity falls will depend upon the evolution of solar costs, carbon costs, and power prices (which in turn are heavily influenced by natural gas prices). Even though this volume represents only 1.5 to 3 percent of global electricity output, the roughly 20 to 40 new gigawatts a year of installed solar capacity would provide about 10 to 20 percent of annual new power capacity over that period. This level of installed solar capacity would abate some 125 to 250 megatons of carbon dioxide—roughly 0.3 to 0.6 percent of global emissions in 2020. Our demand and capacity forecasts assume continued improvement in solar-cell designs

and materials but neither a radical breakthrough nor the emergence of a dominant technology. At present, three technologies—silicon-wafer-based and thin-film photovoltaics and concentrated solar thermal power—are competing for cost leadership. Each has its advantages for certain applications, but none holds the overall crown. Major innovations and shifts in the relative cost competitiveness of these technologies could occur.” (Lorenz et al., 2008)

Living totally or partially off the electric company’s grid can turn out to be financially sound for the users. However, if everyone starts doing it, electric companies will start losing money. As a solar power user, you would benefit from low monthly rates, flexible living, and your decision would have a positive environmental impact. But, you could, at the same time, incur significant costs such as logistical challenges, the hassle of initial setup and maintenance, and limited power supply. In light of the above, “Living off the grid sounds daunting. The phrase conjures mental images of freezing winters, grueling treks carrying firewood through blizzards, and punishingly distant access to the perks of civilization. While there are certainly many people who love to live like that, being off the grid really just means that you’re producing your own power to some degree, either entirely or in part — less Jack London or Henry David Thoreau, more tax credits and solar panels...Despite the initial cost, installing renewable energy will save you plenty on your monthly power bill. The amount you save will differ depending on the state you live in and the systems you use, but the average monthly savings from solar panels alone is around \$84. Most solar panels have a projected lifespan of over 20 years, so the savings can add up to over \$20,000 in most states...If you prefer wide open spaces, refreshing views of nature, or the peace of rural life to noisy, rude neighbors or overbearing homeowner associations, you can benefit from renewable energy. Producing your own power will give you the freedom to live just about anywhere...Global warming has been a major topic of global political discussion, and with good reason — climate change is projected to significantly alter the way we live over the next century. Switching to renewable energy and staying off the grid can lessen global emission rates...

Renewable energy requires a significant financial investment upfront. A 5 kW home solar panel array costs between \$25,000 to \$35,000, and a 10 kW wind turbine costs around \$48,000 to \$65,000. Even though you’ll recoup those expenses over time, the initial price can be a major obstacle to living off the grid...Taking control of your own energy production is complicated and requires a lot of research. You will need to determine which system will benefit you the most, and once you’ve settled on a setup, you’ll then have to figure out which parts of your property receive the most exposure to your chosen renewable energy sources...Americans use more power than almost anyone else in the world. Depending on your usage habits and the size of your family, renewable energy systems might not meet your electricity needs by themselves. Users with larger power demands, urban users, and those in less sunny or windy climates may need to stay connected to the grid to supplement their renewable energy with power from their local providers.” (Baker, 2016)

Pros and Cons of Solar Power

Pros	Cons
• Inexhaustible and sustainable • Abundant • Environmentally friendly • Equitable • Flexible • Scalable • Silent • Low maintenance • Rapidly improving • Cost is decreasing	• High investment costs • Pollution from manufacturing • Uses rare and expensive materials • Intermittent • Doesn't work well at high altitudes • Requires a lot of land

“Nedal Nassar, chief of the Materials Flow Section at the USGS National Minerals Information Center, described the minor metals required to increase production of wind and solar power, including silver, cadmium, tellurium, indium, gallium, selenium, and germanium. Many are produced as by-products of other commodities and needed only in small quantities but are nevertheless essential.

On the solar side, different technologies require different minor metals. Globally, crystalline silicon has been the predominant solar PV technology. Until recently, cadmium telluride was gaining market share in the United States. Nassar noted that it is uncertain which technology will dominate in the future, and it will have implications for which by-product metals will be needed. Likewise, different wind turbines, and whether the turbines are on- or off-shore, also will result in different minor metal requirements.

Minor metal requirements depend on three key uncertainties that will produce a range of possible futures:

- Amount: How much new capacity will be required?
- Market share: Which renewable energy technology will dominate?
- Material intensity: How will the number of kilograms of material per kilowatt of capacity change over time and under different scenarios?” (NAP, 2017)

2. Wind Power

Since early recorded history, people have harnessed the energy of the wind. Wind energy propelled boats along the Nile River as early as 5000 B.C. By 200 B.C., simple windmills in China were

pumping water, while vertical-axis windmills with woven reed sails were grinding grain in Persia and the Middle East. New ways of using the energy of the wind eventually spread around the world. By the 11th century, people in the Middle East used windmills extensively for food production. Returning merchants and crusaders carried this idea back to Europe. The Dutch refined the windmill and adapted it for draining lakes and marshes in the Rhine River Delta. When settlers took this technology to the New World in the late 19th century, they began using windmills to pump water for farms and ranches and later to generate electricity for homes and industry. American colonists used windmills to grind wheat and corn, to pump water and to cut wood at sawmills. With the development of electric power, wind power found new applications in lighting buildings remotely from centrally generated power. Throughout the 20th century, small wind plants, suitable for farms and residences, and larger utility-scale wind farms that could be connected to electricity grids were developed.

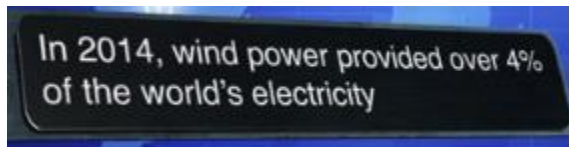
During World War II, the largest wind turbine known in the 1940s, a 1.25-megawatt turbine that sat on a Vermont hilltop known as Grandpa's Knob, fed electric power to the local utility network. Wind electric turbines persisted in Denmark into the 1950s but were ultimately sidelined due to the availability of cheap oil and low energy prices. The oil shortages of the 1970s changed the energy picture for the U.S. and the world. They created an interest in alternative energy sources, paving the way for the re-entry of the wind turbine to generate electricity. From 1974 through the mid-1980s, the U.S. government worked with industry to advance the technology and enable development and deployment of large commercial wind turbines. Large-scale research wind turbines were developed under a program overseen by the National Aeronautics and Space Administration to create a utility-scale wind turbine industry in the United States. With funding from the National Science Foundation and later the U.S. Department of Energy, 13 experimental turbines were put into operation using four major wind turbine designs. This research and development program pioneered many of the multi-megawatt turbine technologies in use today. The large wind turbines developed under this program set several world records for diameter and power output.

In the 1980s and early 1990s, low oil prices threatened to make electricity from wind power uneconomical. But in the 1980s wind energy flourished in California partly because of federal and state tax incentives that encouraged renewable energy sources. These incentives funded the first major use of wind power for utility electricity. The turbines, clustered in large wind resource areas such as Altamont Pass, would be considered small and uneconomical by modern wind farm development standards. While wind energy's growth in the U.S. slowed dramatically after-tax incentives ended in the late 1980s, wind energy continued to grow in Europe, in part due to a renewed concern for the environment in response to scientific studies indicating potential changes to the global climate if the use of fossil fuels continues to increase. Today, wind-powered generators operate in every size range, from small turbines for battery charging at isolated

residences to large, near-gigawatt-size offshore wind farms that provide electricity to national electric transmission systems. (Wind Energy Foundation, 2018)

Rise of Wind Power In the 21st Century

The wind is primarily ultimately driven by sunlight, heating up some areas of the land more than others, creating changes in air pressure and in this way, driving the winds. If the wind seems like



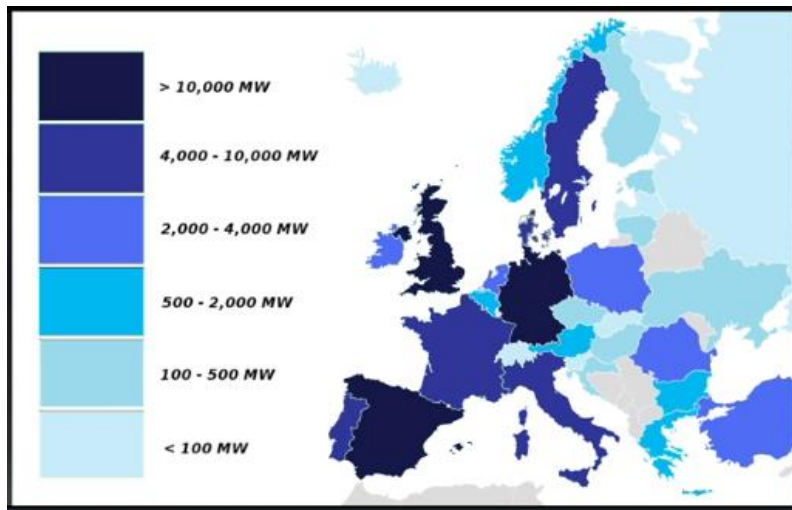
a poor substitute for sunlight, well, you can get windburn as well. Mount Washington²⁴, in New Hampshire, held the world's record for the highest recorded wind speed (231 Mph). There can be a lot

of power in wind. In terms of a human energy source, wind power has had a rapid growth rate, much like that of solar power. Technology is making the use of wind power increasing popular and affordable. By the end of 2014, the world had a power capacity of 370 GW from installed wind turbines. The capacity factors for wind turbines tend to be the same as new solar installations, about 30%. Over the past 10 years, there have been a capacity growth of 23%. That's doubling a little more than every three years. In 2014, wind power provided over 4% of the world's electricity. That figure was about the same, 4.4% for the United States. By the end of 2014, the U.S. had a capacity of 66 GW. The average power was about 21 GW. In comparison, in 2014 solar power provided about 0.45% of U.S. electricity. so, wind provided 10 times as much. Both are increasing rapidly.

In 2014, wind provided more than 25% of electricity in two States: Iowa and South Dakota, and more than 10% in seven others: Kansas, Idaho, Minnesota, North Dakota, Oklahoma, Colorado, and Oregon. Importantly, these are not the same States as the top solar users as a percentage of their total electricity. those were Arizona, Hawaii, Nevada, New Jersey, New Mexico, and California. There is a distribution of renewable energy sources here. The regions with the best solar resources are usually not the same ones with the best wind resources.

²⁴ Mount Washington, called Agiocochook by some Native American tribes, is the highest peak in the Northeastern United States at 6,288.2 ft (1,916.6 m) and the most prominent mountain east of the Mississippi River. The mountain is notorious for its erratic weather.

Source: Wikipedia: [https://en.wikipedia.org/wiki/Mount_Washington_\(New_Hampshire\)](https://en.wikipedia.org/wiki/Mount_Washington_(New_Hampshire))



Wind power reached grid parity in parts of Europe

In 2014, many European countries were also getting a large percentage of their electricity from wind power, which is referred to as a penetration. As in the case of solar power, the more wind turbines that get installed, the cheaper the costs get. Wind power already reached grid parity in parts of Europe and the U.S. by 2014. Wind power now costs under 2.5 cents per KWh. In some parts of the country, just about

cheaper than any other source of energy except for natural gas combined cycle plants. (Wysession, 2015).

According to Annie Sneed for Scientific American, Wind energy is soaring in the U.S.; the nation's renewable energy capacity has more than tripled in the past nine years, and wind and solar power are largely responsible. Now businesses want to harness even more wind energy, at a cheaper price—and one of the best ways to lower cost is to build bigger turbines. That's why an alliance of six institutions led by researchers at the University of Virginia are designing the world's largest wind turbine at 500 meters tall—almost a third of a mile high, and about 57 meters taller than the Empire State Building.

Turbines are already noticeably larger than they were 15 or 20 years ago. Size varies, but today's typical wind farm towers stand around 70 meters tall, with blades about 50 meters long. Their power output depends on size and height, but it generally ranges between one and five megawatts—on the upper end, that's enough to power about 1,100 homes. "There's this motivation to go to larger wind turbines, and the reason is pretty much economics," explains John Hall, an assistant professor of mechanical and aerospace engineering at the University at Buffalo, S.U.N.Y. One reason giant turbines are more cost-effective is that wind blows stronger and more steadily at greater altitudes. Thus, "you capture more energy" with a taller structure, says Eric Loth, project leader of the massive turbine project, which is funded by the U.S. Department of Energy's Advanced Research Projects Agency–Energy (ARPA–E).

Another reason wind experts say bigger is better: longer turbine blades also catch the wind more efficiently, and taller towers enable lengthier blades. A turbine's power is directly related to its

“swept area”—the circular area covered by the blades’ rotation—explains Christopher Niezrecki, a professor of mechanical engineering and director of the Center for Wind Energy at the University of Massachusetts Lowell. And this relationship is not linear—if blade length doubles, a system can produce four times as much energy, Niezrecki explains. He notes that bigger turbines also have a lower “cut-in” speed, the wind speed at which they can start generating energy.

Loth’s team wants to design a 50-megawatt system with blades 200 meters long, much larger than today’s wind turbines. If the researchers succeed, they believe the turbine would be 10 times more powerful than existing equipment. But the scientists do not intend to simply supersize conventional designs; they are fundamentally changing the turbine structure. The ultra large machine will have two blades instead of the usual three, lowering the weight of the structure and cutting costs. Loth says that reducing the number of blades would ordinarily make a turbine less efficient, but his team is using an advanced aerodynamic design that he says largely makes up for those losses. (Sneed, 2017)

So, how do we get energy from wind turbines? A wind turbine is like a plane propeller but in reverse. Instead of an engine turning a rotor and generating a wind force that pulls the plane forward, the natural wind force blows through the rotors, generating a force that powers the engine. But, the principles are pretty much the same. The physics of the process is actually fairly complicated. Both the wind turbine and the plane propeller work because of the Bernoulli principle, which describes the relationship between the pressure and the velocity of a moving fluid (i.e., air or water). Bernoulli’s principle states that as the velocity of fluid flow increases, the pressure exerted by that fluid decreases. Wind turbines pick up some of their kinetic energy from the deflection of air as it hits the blades. Air blowing onto the turbines blades is forced to change its velocity (speed and/or direction) at constant pressure. ... Air moving over the blades changes its local pressure due to the Bernoulli effect. A wind turbine is just like any other machine powered by either coal, oil, or gas with the exception that the fuel is free: it’s wind.

Types of Wind Turbines

There are two basic types of wind turbines: horizontal-axis turbines and vertical-axis turbines. The size of wind turbines varies widely. The length of the blades is the biggest factor in determining the amount of electricity a wind turbine can generate. Small wind turbines that can power a single home may have an electricity generating capacity of 10 kilowatts (kW). The largest turbines have generating capacities of 5,000 kW to 8,000 kW. Large turbines are often grouped together to create wind power plants, or wind farms, that provide power to electricity grids.

Horizontal-axis turbines are similar to propeller airplane engines. Horizontal-axis turbines have blades like airplane propellers, and they commonly have three blades. The largest horizontal-axis turbines are as tall as 20-story buildings and have blades more than 100 feet long. Taller turbines with longer blades generate more electricity. Nearly all of the wind turbines currently in use are horizontal-axis turbines.

Vertical-axis turbines look like egg beaters. Vertical-axis turbines have blades that are attached to the top and the bottom of a vertical rotor. The most common type of vertical-axis turbine—the Darrieus wind turbine, named after the French engineer Georges Darrieus who patented the design in 1931—looks like a giant, two-bladed egg beater. Some versions of the vertical-axis turbine are 100 feet tall and 50 feet wide. Very few vertical-axis wind turbines are in use today because they do not perform as well as horizontal-axis turbines.

Wind power plants, or wind farms, produce electricity. Wind power plants, or wind farms, are clusters of wind turbines that produce large amounts of electricity. A wind farm usually has many turbines scattered over a large area. One of the world's largest wind farms, the Horse Hollow Wind Energy Center in Texas, has about 420 wind turbines spread over about 47,000 acres. The project has a combined electricity generating capacity of about 735 megawatts (or 735,000 kW). (Energy Information Administration) The largest turbine gets over 8 MW, which can power about 3,000 homes.

Storage of Wind Power

How do you store wind power? According to Ben Arnold, through several different storage processes, excess energy can be stored to be used during periods of lower wind or higher demand.

- *Battery Storage.* Electrical batteries are commonly used in solar energy applications and can be used to store wind generated power. Lead acid batteries are a suitable choice as they are well suited to trickle charging and have a high electrical output charging efficiency.
- *Compressed Air Storage.* Wind turbines can use excess power to compress air, this is usually stored in large above-ground tanks or in underground caverns. When required the compressed air can be used through direct expansion into a compressed air motor. It can also be injected in an internal combustion turbine, where it is burnt with fuel to provide mechanical energy which then powers a generator.
- *Hydrogen Fuel Cells.* Hydrogen fuel cells can also be used to store excess energy. A hydrogen generator is used to electrolyze water using power generated from the wind turbine, storing the resulting hydrogen and converting it back to electricity using a fuel cell power system when needed.

- *Pumped Storage.* Pumped storage is associated with hydroelectric power generation but is yet to be used with wind power generation. Water could theoretically be pumped up to an elevated reservoir utilizing excess generated power and then be used to drive a water turbine when required. The technology is proven and has been used for centuries, giving a relatively high overall efficiency of 70%. Existing hydroelectric power plants could be utilized if they are in an area suitable for a wind farm. (Arnold, 2018)

Distribution of Wind Power

How does wind power get distributed? The Wind Energy Technologies Office of the Department of Energy defines distributed wind in terms of technology application, based on a wind plant's location relative to end-use and power distribution infrastructure, rather than technology or project size. The following wind system attributes are used by the office to characterize them as distributed:

- **Proximity to End-Use:** Wind turbines that are installed at or near the point of end-use for the purposes of meeting onsite energy demand or supporting the operation of the existing distribution grid.
- **Point of Interconnection:** Wind turbines that are connected on the customer side of the meter (also known as behind-the-meter), directly to the distribution grid, or are off-grid in a remote location.

Distributed wind energy systems are commonly installed on, but are not limited to, residential, agricultural, commercial, industrial, and community sites, and can range in size from a 5-kilowatt turbine at a home to multi-megawatt turbines at a manufacturing facility or connected to a local distribution system.

An analysis of behind-the-meter distributed wind potential in the United States found that distributed wind systems are technically feasible for approximately 49.5 million residential, commercial, or industrial sites, or about 44% of all U.S. buildings. This analysis shows that the distributed wind market opportunity is significant, and distributed wind has potential to play an increasing role in the U.S. electricity sector. In order for distributed wind to realize these opportunities, technology cost reduction—including reductions in turbine costs, balance of system costs, and soft costs, as well as performance improvement—is necessary but not sufficient.

Increasing access to low-cost capital, and standardizing site assessment, project development and installation processes will also be important drivers.

Small wind turbine technology, which includes turbines that have a rated capacity of less than or equal to 100 kilowatts, is the primary technology type used in distributed wind energy applications and is the focus of the office's technology R&D efforts for distributed applications. (U.S. Department of Energy, 2018)

Potential of Wind Power

Ultimately how much energy could we get from wind? The sky is the limit for wind power. The amount of power to be reaped from tapping low- and high-altitude winds dwarfs global demand. Wind turbines on land and offshore could readily provide more than four times the power that the world as a whole currently uses. Throw in kites or robot aircraft generating electricity from sky-high winds and the world could physically extract roughly 100 times more power than presently employed—and the climatic consequences remain minimal. Two new computer-model analyses suggest there are few limits to the wind's potential. Although “there are physical limits to the amount of power that can be harvested from winds, these limits are well above total global energy demand,” explains climate-modeler Kate Marvel of Lawrence Livermore National Laboratory, who led the analysis published September 9 in *Nature Climate Change*...Current global demand is roughly 18 terawatts. (A terawatt is one trillion watts.) Given the desire to reduce greenhouse gas emissions from electric generation, a growing number of wind farms are cropping up from the U.S. to China—more than 239 gigawatts worth of wind turbines have been installed globally. But the ultimate limits of wind power's potential contribution remained unclear. One complication, for example, is that any effort to harvest wind power ends up having an impact on the wind itself, reducing its speed—as well as influencing both local weather and global climate. (Biello, 2012)

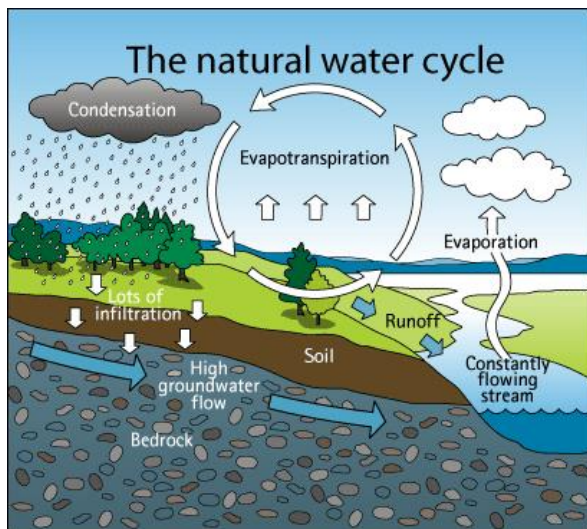
Pros and Cons of Wind Power

Pros	Cons
• Wind is a clean fuel source. • It doesn't generate pollution or greenhouse gases. • Wind is sustainable and domestic. No country has to buy wind from anyone else. • Wind power is now one of the lowest priced form of electricity. • New technologies such as offshore winds and vertical axis arrays show a lot of promise for the future. • Wind turbines can be put on existing lands, particularly farms and ranches. • Wind power is now providing a stable income for many farmers and ranchers.	• It requires a large capital investment. • Wind farms are located far from urban areas, making its distribution challenging • The turbines can be noisy (the largest can be heard sometimes up to a mile away). • Because they are visible, some people object to them on esthetic ground. • Repair costs can be high. • Power grids aren't advanced enough to fully capitalize on power potential. • The rotors can be dangerous to birds and migratory bats. Thousands of birds are killed each year, which represents a significant environmental impact.

But, as for solar power, the market has decided that for wind power, pros outweigh the cons and there continues to be a rapid increase in the installation of wind turbines. And, research continues into improving those technologies.

3. *Hydroelectric Power*

Currently, the largest renewable source of electricity isn't sun power. It isn't wind power. It is water power. Hydroelectric power has been for a long time and still is the largest renewable source of electricity. This is in the form of river water flowing downhill to the sea. Hydroelectric power has many benefits that make it desirable. It doesn't produce carbon dioxide except in the curing of the concrete for the dams and its fuel is free. It's just rain water. However there are also several significant drawbacks with hydropower. Because of strict limitations on efficiency, hydropower is not expected to grow all that much for most of the world, at least compared to wind and solar. Hydroelectricity is ultimately a form of solar power. It's the sun that drives the water cycle. But, directly, it's the force of gravity that is responsible for converting the gravitational potential energy of water into electricity. Water falls down through the hydroelectric plant, spinning the turbines of the generator as it falls.



History of Hydropower

Water power has a very long history. According to the Office of Energy Efficiency & Renewable Energy of The U.S. Department of Energy, humans have been harnessing water to perform work for thousands of years. The Greeks used water wheels for grinding wheat into flour more than 2,000 years ago. The evolution of the modern hydropower turbine began in the mid-1700s when a French hydraulic and military engineer, Bernard Forest de Bélidor wrote *Architecture Hydraulique*.

In 1880, a dynamo driven by a water turbine was used to provide arc lighting—a technique where an electric spark in the air between two conductors produces a light—to a theatre and storefront in Grand Rapids, Michigan, and in 1881, a dynamo connected to a turbine in a flour mill provided street lighting at Niagara Falls, New York; both of which used direct current technology. The

breakthrough of alternating current, the method used today, allowed power to be transmitted longer distances and ushered in the first U.S. commercial installation of an alternating current hydropower plant at the Redlands Power Plant in California in 1893. The Redlands Power Plant utilized Pelton waterwheels driven by water taken from the nearby Mill Creek and a 3-phase generator which ensured consistent power delivery. (Office of Energy Efficiency & Renewable Energy, 2018)

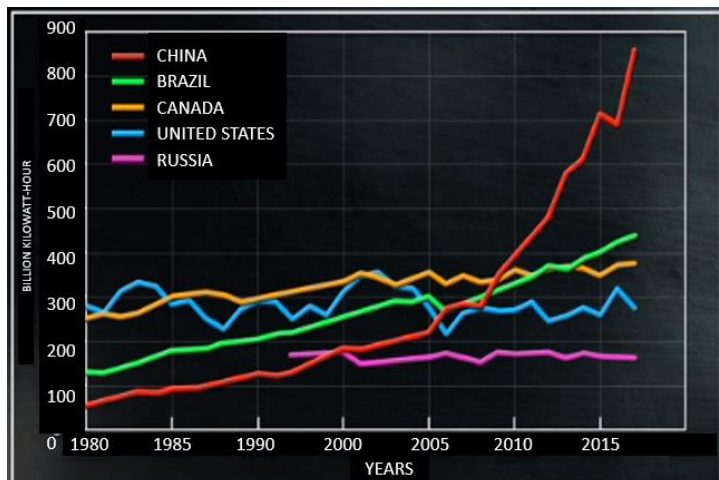
The International Hydropower Association (IHA, 2018) reported that by the turn of the 20th century the technology was spreading round the globe, with Germany producing the first three-phase hydro-electric system in 1891, and Australia launching the first publicly owned plant in the Southern Hemisphere in 1895. In 1895, the world's largest hydroelectric development of the time, the Edward Dean Adams Power Plant, was created at Niagara Falls. In 1905, a hydroelectric station was built on the Xindian creek near Taipei, with an installed capacity of 500 kW. This was quickly followed by the first station in mainland China, the Shilongba plan in the Yunnan province, which was built in 1910 and put into operation in 1912. Upon completion Shilongba had an installed capacity of 480 kW – today it is still in operation with an installed capacity of 6 MW.

In the first half of the 20th century, the USA and Canada led the way in hydropower engineering. At 1,345 MW, the Hoover Dam on the Colorado River became the world's largest hydro-electric plant in 1936, surpassed by the Grand Coulee Dam (1,974 MW at the time, 6,809 MW today) in Washington in 1942. From the 1960s through to the 1980s, large hydropower developments were carried out in Canada, the USSR, and Latin America. Over the last few decades, Brazil and China have become world leaders in hydropower. The Itaipu Dam, straddling Brazil and Paraguay, opened in 1984 at 12,600 MW (it has since been enlarged and uprated to 14,000 MW), and is today only eclipsed in size by the 22,500 MW China Three Gorges Dam, which opened in 2008.

Into the 21st century, hydropower continues to catalyze growth around the world. For example, it has played a key role in transforming Brazil into the seventh largest country by GDP in 2012; not least through a period of very rapid economic growth between 2000 and 2010, which saw its increase in (nominal GDP) value only outpaced by the USA and China. This was only possible with the massive increases in electricity output that have been delivered by its investment in hydropower. In 2010, Brazil produced 349,000 GWh of electricity, and by 2011 this had increased by 40 per cent to 489,000 GWh. Remarkably, just 2 per cent of this energy came from imports, and around 80 per cent from hydropower. The result is a very modern fleet of very large hydropower stations – of which at least 24 are rated at 500 MW or above. Brazil has made the most of its rich hydrological resource to transform itself into a leader on the world stage, keep costs down and maintain its energy independence from the rest of the world. This is just one example of the massive stimulus to economic growth that hydropower can provide; As we look towards the future the technology has a huge role to play in bringing growth and prosperity to the developing world. (IHA, 2018)

Current Use of Hydropower

Currently, hydropower generates about 16% of the world's total electricity. In 2014, the global hydropower totaled about 1 TW, with the total average power at about 450 GW. China had the



Current use of hydropower
China had the largest capacity of hydropower

largest capacity, about a ¼ of the world total. But, it's the process of building many more hydropower plants. So, their share is rapidly going up. As with solar and wind, the percentage of hydro capacity that is actually converted into usage energy is always less than 100 percent. One factor in this for hydropower is rainfall. Rainfall changes over the course of the years. So, rivers carry water sometimes less than others. Sometimes, the yield of the capacity of the power plants might also be more than the demand. In that case,

they just let the water flow through the dam. For China, in terms of capacity factor, the amount of usable hydropower produced is about 40%. For Canada, it's a bit higher, about 60%. The capacity factor differs by regions, sometimes even within countries.

Some countries get all or nearly all of their electricity from hydropower. For example, Norway gets 98% of its electricity from hydropower. Paraguay gets 100%²⁵ of its electricity from hydropower. The U.S. gets a lot of electricity from hydro but it's not a growing industry. Across the world, hydropower has been growing slowly but steadily in about 3% a year. However, there hasn't been any recent growth in the U.S. For example, in 2004, hydropower generated about 30 GW of average electrical power in the U.S. All other renewable resources were less than 10 GW. Ten years later, in 2014, was the first year that the U.S. generated more electricity from renewable sources other than hydropower. And hydro was still around 30 GW. "The largest U.S. hydroelectric power plant is Grand Coulee Dam on the Columbia River in Washington State. Built between 1933 and 1941, it is the fourth largest hydroelectric plant in the world, generating more than 6,800 MW of electricity. It took nearly 12 million cubic yards of concrete to build the dam. With that much concrete, you could build sidewalk 4-feet wide (1.2 m) and 4-inches thick (10 cm) and wrap it twice around the Earth at the equator!" (Heinrichs, 2011)

²⁵ Paraguay has such a surplus that it exports 90% of the power produced to Brazil and Argentina and still has enough to meet its national demand.

Rainfall is seminal to hydropower. According to World Atlas, precipitation can be defined as various forms of water (solid or liquid) that form in the atmosphere and fall upon an area's surface. Precipitation is influenced by a number of factors including the presence of landforms, proximity to water bodies, elevation, latitude, and water currents. Landforms such as mountains prevent heavy rain clouds from traveling out of a region thus causing rainfall concentration on that particular area. Wind currents from water-bodies and high elevations from sea level also influence precipitation patterns. Some of the wettest places in the world are:

Mawsynram, India

Mawsynram, located in the Meghalaya State in India, is the wettest place in the world, with an annual rainfall of 11,871 millimeters. The large volume of rain is caused by the Himalayas Ranges blocking heavy clouds' escape to the North. The region's rainfall rises to 12 meters, making the area home to rivers and waterfalls. The dwellers of Mawsynram have adapted to the wet conditions and never leave the house without an umbrella. The residents make basket-like covers with reeds, to block out the rain as they work in the fields. The villagers make use of grass as soundproof for their huts. The drier periods in the region are considered to be between December and January when the rainfall can amount to a mere 60 millimeters.

Cherrapunji, India

15 kilometers from Mawsynram is the second wettest place in the world. Cherrapunji receives an annual rainfall of 11,777 millimeters and is also located in India's Meghalaya State. The region stands at 4500 feet above sea level on the Khasi Hills and receives its rainfall from the Monsoon winds traveling from the Bay of Bengal. The region is characterized by the monsoon season with varying amounts of rainfall per month. During the summer season, temperatures get as high as 23 Degrees Celsius and as low as seven degrees Celsius in the winter months. Perhaps Cherrapunji is mostly famed for its live Root Bridges, strong enough to hold about 50 people at once and the products of villager's bioengineering efforts.

Tutendo, Colombia

Tutendo is found in the nation of Colombia in South America and receives an annual rainfall of 11,770 millimeters. Tutendo has two rainy seasons and has a small population, less than 1,000 people. The small number of inhabitants in the region erect houses roofed with water-proof sheets to prevent leakages. The city of Quibdo lies nearby and is one of the wettest cities in the world.

Cropp River, New Zealand

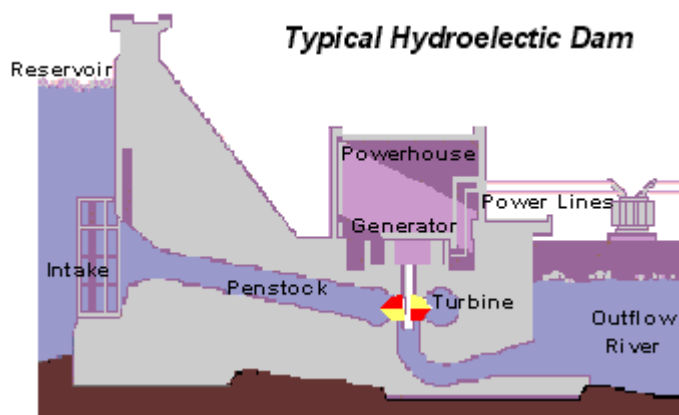
Cropp River is found in New Zealand and receives an annual rainfall of 11,516 millimeters. The Cropp River is 9 kilometers in length. Its climate is a stark contrast to the mostly arid climate, which characterizes the rest of New Zealand. Cropp River recorded 1,049 millimeters of rainfall on December 12th-13th, 1995, the highest ever registered in New Zealand in a 48-hour period.

Other Extremely Wet Destinations

Other wet places in the world in regard to the amount of rainfall they receive are San Antonio de Ureca, Bioko Island in Equatorial Guinea, which receives 10,450 millimeters of rainfall annually; Debundscha, Cameroon, Africa (10,299 millimeters); Big Bog, Maui, Hawaii (10,272 millimeters); Mt. Waialeale Kauai, Hawaii (9,763 millimeters); Kukui, Maui, Hawaii (9,293 millimeters) and Sichuan Province, China (8,169 millimeters). Cherrapunji is a major tourist attraction. The Umshiang Double-Decker Live Root Bridge and other bridges of the same nature offer spectacular attractions. Cherrapunji and Mawsynram are home to the waterfalls, caves, stone gorges, lush green plains, and ideal trekking terrain which make them tourism hot spots. (WorldAtlas, 2018)

How Does Hydrogeneration of Electricity Work?

So just how do we get electricity from water? The U.S. Geological Survey explains it saying that, hydroelectric and coal-fired power plants produce electricity in a similar way. In both cases a power source is used to turn a propeller-like piece called a turbine, which then turns a metal shaft in an electric generator, which is the motor that produces electricity. A coal-fired power plant uses steam to turn the turbine blades; whereas a hydroelectric plant uses falling water to turn the turbine. The results are the same.

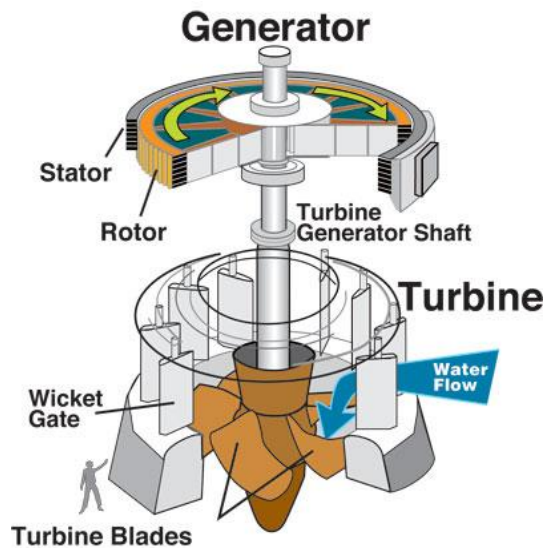


Source : United States Geological Survey

The theory is to build a dam on a large river that has a large drop in elevation (there are not many hydroelectric plants in Kansas or Florida). The dam stores lots of water behind it in the reservoir. Near the bottom of the dam wall there is the water intake. Gravity causes it to fall through the penstock inside the dam. At the end of the penstock there is a turbine propeller, which is turned by the moving water. The shaft from the turbine goes up

into the generator, which produces the power. Power lines are connected to the generator that carry electricity to your home and mine. The water continues past the propeller through the

tailrace into the river past the dam. By the way, it is not a good idea to be playing in the water right below a dam when water is released!



Courtesy of U.S. Army Corps of Engineers

As to how this generator works, the Corps of Engineers explains it this way: "A hydraulic turbine converts the energy of flowing water into mechanical energy. A hydroelectric generator converts this mechanical energy into electricity. The operation of a generator is based on the principles discovered by Faraday. He found that when a magnet is moved past a conductor, it causes electricity to flow. In a large generator, electromagnets are made by circulating direct current through loops of wire wound around stacks of magnetic steel laminations. These are called field poles and are mounted on the perimeter of the rotor. The rotor is attached to the turbine shaft and rotates at a fixed speed. When the rotor turns, it causes the

field poles (the electromagnets) to move past the conductors mounted in the stator. This, in turn, causes electricity to flow and a voltage to develop at the generator output terminals." (USGS Water Science School, 2018)

Storage of Hydropower

Demand for electricity is not "flat" and constant. Demand goes up and down during the day, and overnight there is less need for electricity in homes, businesses, and other facilities. For example, in Atlanta, Georgia at 5:00 PM on a hot August weekend day, you can bet there is a huge demand for electricity to run millions of air conditioners! But, 12 hours later at 5:00 AM not so much. Hydroelectric plants are more efficient at providing for peak power demands during short periods than are fossil-fuel and nuclear power plants, and one way of doing that is by using "pumped storage", which reuses the same water more than once.

Pumped storage (as seen above) is a method of keeping water in reserve for peak period power demands by pumping water that has already flowed through the turbines back up a storage pool above the

powerplant at a time when customer demand for energy is low, such as during the middle of the night. The water is then allowed to flow back through the turbine-generators at times when demand is high, and a heavy load is placed on the system.

The reservoir acts much like a battery, storing power in the form of water when demands are low and producing maximum power during daily and seasonal peak periods. An advantage of pumped storage is that hydroelectric generating units are able to start up quickly and make rapid adjustments in output. They operate efficiently when used for one hour or several hours. Because pumped storage reservoirs are relatively small, construction costs are generally low compared with conventional hydropower facilities. (United States Geological Survey, 2018)

Hydroelectric plants range in size from micro to huge:

- Pico-hydro plants produce under 5 kW of power. They're used in remote areas to power a home or a few homes. They can operate with only 1 meter high of water drop.
- Micro-hydro plants can produce up to 100 kW of power. There are many of many all around the world. They're usually inexpensive.
- Small hydro power plants, which produce up to about 10 MW. They're found in small communities or industrial plants. In 2013, the total capacity of these plants was about 75 GW, mostly in Asia.
- Major power plants. They are located in huge dams.

“The Three Gorges Dam in Hubei Province, China, can hold back more than five trillion gallons (19 billion cubic meters) of water, according to NASA. At 1.4 miles wide (2.3 kilometers) and 630 feet (192 meters) high, Three Gorges Dam is the largest hydroelectric dam in the world, according to International Water Power & Dam Construction magazine. Three Gorges impounds the Yangtze River about 1,000 miles (1,610 km) west of Shanghai. It's named for its location near the three gorges at the foot of the western Wu Shan Mountains, according to PBS. Until the Three Gorges Dam's near-completion in 2009, the Guri dam in Venezuela held the title of the world's largest, followed by the Itaipu dam on the border between Brazil and Paraguay, according to International Water Power & Dam Construction magazine.” (Cox, 2010)

Distribution of Hydroelectric Power

According to Hydro Québec, inside a generating station, turbines use the driving force of water to set electrons in motion and generate alternating current. Electricity from the power station has a long way to go before reaching your home.

- 1 – The voltage of the current produced by a generating station can reach 13,800 volts, like at the Robert-Bourassa generating facility.
- 2 – Thanks to the voltage step-up transformer located in the generating station's switchyard, the electricity is transmitted at much higher voltages, from 44,000 to 765,000 volts.
- 3 – Once in the transmission system, electricity from each generating station is combined with electricity produced elsewhere.
- 4 – The electricity passes through cables which are suspended from towers. These towers are arranged in a series from the generating stations to source substations—which lower the voltage—and then reach the satellite substations, which further reduce the voltage.
- 5 – Leaving the satellite substations, electricity travels through underground lines. At some distance from the substations, the distribution system goes from underground to overhead, and transformers attached to poles lower the voltage one last time. Inside our homes, we use either 120 volts to power our televisions, radios and other regular electrical appliances, or 240 volts for the appliances that require a strong current like the dryer or stove.
- 6 – Electricity is consumed as soon as it is produced. It is transmitted at a very high speed, close to the speed of light (300,000 km/s). (Hydro Québec, 2018)

Pros and Cons of Hydroelectric Power	
Pros	Cons
• The fuel is free. • The average cost of hydroelectricity for a large facility is about \$0.03 - \$0.05 kW/h or about \$14 per Giga joule. • Flexible. The plant can ramp power up or down in a matter of minutes in response to energy demand. • Very low CO₂ emissions. • Useful for storing water year-round for a variety of purposes such agriculture, flood control, and human leisure such boating and swimming.	• Initial costs are significantly high (manpower, technology, specific material, etc.). • Significant geographic limitations to hydropower. A river is needed, and a lot of water are needed to have a large drop. Places that have both are not numerous. Not every river can support a dam. • Surrounding topography. if the region is flat, a significant amount of land needs to be flooded to provide enough height on the dam to make the plant economically worthwhile, which displaces people and destroy ecosystems. for example, the Churchill Falls Dam in Canada required flooding 7,000 Km² of land. That's larger than the size of the State of Delaware. In South America, thousands of kilometers of land in the rain forest have been flooded to make dams. • Negative impacts on fish and birds²⁶. Many fish migrate up rivers. The dams block their natural migration routes, although that can be mitigated by providing fish with fish ladders, which allow them to bypass the dams. • Increase of mosquito population in many parts of the world due to the presence of large bodies of standing water that dams represent. This creates a significant health hazard at very great costs. • Safety concerns. Dam failures can flood downstream communities and cause both fatalities and property damages²⁷.

²⁶ Environmentalists are concerned about the dam's impact on wildlife. Most of the world's population of critically endangered Siberian cranes spend their winters in wet lands that have been covered by the reservoir. The Yangtse River dolphin, found only in the Yangtse, has become virtually extinct since dam construction began. Hundreds of

Hydroelectric power will continue to play an important role in generating electricity. There are many advantages to hydropower particularly for smaller scale projects that are less destructive to the surrounding environment. But, these disruptions can be significant for larger projects. It's estimated by several studies that the total global hydroelectric potential may be as large as 4 to 6 TW, but it will take a lot of land and the environmental impacts would be severe. There are new forms of hydropower on a smaller scale that would be less disruptive. One experimental form is to have turbines on river barges with small amount of power wired to homes and villages. But, in terms of hydropower as the main source of electricity – at a level similar to that of petroleum – on a global scale, that is just not feasible right now.

4. Biofuels

Biofuels are also called biomass energy. The most notable ones are Biodiesel and Ethanol which are liquid biofuels. Turning plants into fuel is complex. Liquid biofuels can help reduce the need to buy petroleum from oil-producing countries. Biofuels offer plant-based solutions to the Earth's growing energy problems.

What Is Biofuel and How Is It made?

According to National Geographic, Biofuels have been around as long as cars have. At the start of the 20th century, Henry Ford planned to fuel his Model Ts with ethanol, and early diesel engines were shown to run on peanut oil. But discoveries of huge petroleum deposits kept gasoline and diesel cheap for decades, and biofuels were largely forgotten. However, with the recent rise in oil prices, along with growing concern about global warming caused by carbon dioxide emissions, biofuels have been regaining popularity. Gasoline and diesel are actually ancient biofuels. But they are known as fossil fuels because they are made from decomposed plants and animals that have been buried in the ground for millions of years. Biofuels are similar, except that they're made from plants grown today. Much of the gasoline in the United States is blended with a biofuel—ethanol. This is the same stuff as in alcoholic drinks, except that it's made from corn that has been heavily processed. There are various ways of making biofuels, but they generally use chemical reactions, fermentation, and heat to break down the starches, sugars, and other molecules in plants. The leftover products are then refined to produce a fuel that cars can use.

ancient archeological sites have been submerged as well, including hanging coffins where ancient people buried their dead in caves high on the cliff sides. (Heinrichs, 2011)

²⁷ Typhoon Nina, known in the Philippines as Typhoon Bebang, was the fourth-deadliest tropical cyclone on record. Approximately 229,000 people died after the Banqiao Dam collapsed and devastated areas downstream. (Source: Wikipedia)

Countries around the world are using various kinds of biofuels. For decades, Brazil has turned sugarcane into ethanol, and some cars there can run on pure ethanol rather than as additive to fossil fuels. And biodiesel—a diesel-like fuel commonly made from palm oil—is generally available in Europe. On the face of it, biofuels look like a great solution. Cars are a major source of atmospheric carbon dioxide, the main greenhouse gas that causes global warming. But since plants absorb carbon dioxide as they grow, crops grown for biofuels should suck up about as much carbon dioxide as comes out of the tailpipes of cars that burn these fuels. And unlike underground oil reserves, biofuels are a renewable resource since we can always grow more crops to turn into fuel. Using biofuels as jet fuel also offers a solution to carbon emissions from air travel. In 2016, United Airlines announced a new initiative to integrate biofuel into its energy supply with the hopes of reducing greenhouse gas emissions by 60 percent. Because commercial air travel comprises a significant amount of all carbon dioxide emissions, airlines and environmental advocates readily seek alternative fuel sources. (National Geographic, 2018)

Biofuel Blends

- **B2: 2% biodiesel**
- **B5: 5% biodiesel**
- **B20: 20% biodiesel**

In 2014, biodiesel had only replaced about 4% of total diesel fuel in the U.S., but, it's rapidly increasing. At the pump, it's purchased as blend. The most common blend is B5, which contains 5% biodiesel.

Currently, the most significant biofuel is ethanol. It's generally purchased at the gas pump in the form of E10 blend which contains 90% gasoline and 10% ethanol. There are other blends such as E15, but they aren't so popular. Ethanol can be made from any kind of plant. But, currently, it's primarily made from corn. In the United States,

corn is primarily grown in the upper mid-west in States like Iowa, Nebraska, Minnesota, South Dakota, Illinois, and Indiana where the soils are extremely rich because of the accumulation of vast quantities of rocks that were ripped off, pulverized, and dragged south from Canada by giant glaciers during the last ice age. This rich soil, called loess, is more than 100 feet thick in the northern mid-west. And the U.S. grows about one third of all the world's corn. 13% of the corn produced are exported, largely to Japan and Mexico, and other countries. 6.5% were used for corn syrup and other sweeteners, mostly high-fructose corn syrup. Less than 2% was for cereal, popcorn, and other human food. Another 1% went to alcohol. So, the bulk of the corn (45%) went to feed animals and to gasoline additives. While in the U.S. gasoline for cars may contain 10% ethanol, in Brazil it's 25%.

2014 U.S. Corn

- **172 bushels/acre**
- **14,2 billion bushels total**
- **Exported 13%**

Implications of Growing Biomass for Fuel

First of all, water is the magic word! Corn takes a lot of water to grow. For example, one acre of corn takes a third of a million of gallon of water to grow. It's not just corn. It's any form of biomass used to make biofuel. For a tree, each pound of it requires 120 gallons of water. For comparison, if you were a tree, scaled to your size, you would need to drink 20 gallons of water every day. For much of the world, there just isn't that much rain. In the U.S., we're increasingly relying upon pumping water out of the ground. As a result, ground water levels are dropping globally. In the midwestern U.S. the crops are being grown with water from large underground aquifers such as the Ogallala which stretches from Texas all the way to South Dakota. It's important to note that the Ogallala water is ancient water from ancient glacier. It's prone to depletion. That is what happened in California.

What happens when the Ogallala is gone? Before we make big commitments to rely upon biomass for energy, we would need to make sure we have a continuous supply of water. In the long-term, the only real way to make this happen is to desalinate ocean water on large scale and pipe it inland. However, this would be expensive and would take energy. The bottom line is we need water to make energy. The largest single use of water in the United States is to cool nuclear power plants. On the other hand, we need energy to make water. Then, we would better have one of them or we'll have neither. So, it's a dilemma. Desalination, which is a workable idea, takes a lot of energy. You would have to use a Gigawatt of power for 4 billion gallons a day of fresh water produced. You would also energy to pump the water up from the ocean to wherever you'd need it for farming, essentially giving gravitational potential energy, and, of course, you would first need to build a pipelines system to transport the water. The whole process would take time and money.

Using Ethanol to Replace Gasoline

- 137 billion gallons gasoline/year
- 13.5 billion gallons ethanol/year
- Ethanol has 2/3 the energy density of gasoline
- Need 219 billion gallons of ethanol to replace 146 billion gallons of gasoline

Second, the chemical conversion, from corn to ethanol is just not very efficient. Most energy gets lost to heat. By and large, you get on average a 1.5-to-1 return on energy from ethanol. That's 1.5 joules for every 1 joule you put in. even that is variable depending on year and the processing steps. Sometimes you even lose energy in the process of making the ethanol. In other words, you might end up spending more energy than you actually get back from the ethanol. A big part of the issue surrounding corn-based ethanol is that about 40% of corn is used to make ethanol, and that means 40% of corn is not available for food. Between 2005 and 2012, the cost of

corn in the United States almost quadrupled. This has created some supply problems with food shortage in Mexico which has traditionally imported a lot of corn from the U.S. for food – Mexican cuisine is largely based on corn. But they can't afford it now.

Ethanol Source Crops and Energy Yield		
Source Crop	Gallons of Ethanol Per Year from 1 Acre of Crop	Net Energy Yield (units of energy generated for every 1 unit of energy spent to make the fuel)
Corn	354	1.5
Sugarcane	662	8+
Sugar beets	714	1.9
Switchgrass	1,150	4
Source: Lester R. Brown, <i>Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble</i> (NY: W.W. Norton & Co., 2006), pp. 34 – 35. Quoted in <i>Sustaining Earth's Energy Resources</i> , p. 76. (Heinrichs, 2011)		

Third, biomass energy, just like solar power, takes up lands. If you think about it, how much land would be required for the U.S. to meet its annual need of gasoline from corn-based ethanol? To get 219 gallons of ethanol would take 450 million acres or 1,350 Km on the side. That's 840 miles on the side, which represents $\frac{1}{4}$ of the entire continental U.S. it's also 10 percent more of the total farm land in the continental U.S. That's assuming that everywhere the soil is rich and that our need for gasoline doesn't go up. In that case, yes, the U.S. could possibly replace all of its need for gasoline with corn bioethanol, but we would have to import

all of our food or start finding other lands on which to grow food. There are other crops that would be much more energy efficient than corn is in making ethanol. Sugar cane and sugar beet could be good alternatives. So could fast-growing trees such as willow or hybrid poplar. Compared to solar power and wind power, biomass is not a better alternative. Solar power takes up land but the return on energy is higher. Wind power takes up less land and also has a higher return.

Pros and Cons of Using Biomass to Generate Biofuels

Pros	Cons
• Biomass is globally available. Almost everybody has the ability to harness crops of some type or other – may be not so much in Greenland. • Biofuels involve both low and high technologies. Everyone can burn wood. • Pyrolysis and gasification can be used to make fuel. • In the tropics, where there is no winter, photosynthesis can be very land efficient. You grow your crops year-round. • Biofuels can be a great option for recycling the carbon content of solid and liquid wastes, turning trash into electricity or human waste into fertilizer. • Ideally, biomass wouldn't add to the carbon dioxide content of the atmosphere. • From the generation of syngas from gasification, you could also have an easy means of removing carbon dioxide from the atmosphere. • Ethanol can reduce the dependence upon foreign oil. For the U.S., this has provided a new source of income from export to other countries. • Biofuel can be made from algae²⁸ which can grow from briny water and can be used to make a very rich biofuel.	• Photosynthesis is an inefficient way of capturing solar energy. • When compared to solar and wind energies, biofuels remove nutrients from the soils. So, soil fertility, along with the efficiency of the biofuel, decreases over time. The solution to this is the use of fertilizers which are currently very expensive and have had very significant environmental impacts in the form of pollution of ground waters, streams, lakes, and the ocean leading to algae blooms and the formation of dead zones in the ocean. • Crops require a lot of water which is becoming in short supply in many parts of the world. • Crops for biofuel could take up a lot of lands we now use for food.

In the United States, the average lifetime of a car is about 12 years. That's also how long it would take for the world population to increase by another billion people. So, if you get a car, by the time

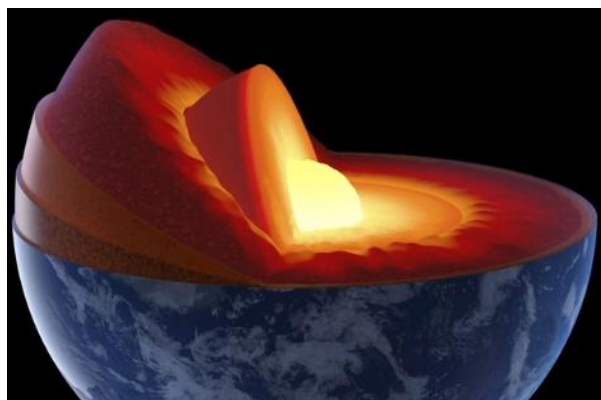
²⁸ Algae are easy to farm because all we need to do is overfertilize them. This induces a population runaway called a bloom, a kind of plant version of a nuclear explosion. The growth rates we get are blistering – in some cases four times the seasonal average of the best corn fields. The artificial blooms emulate natural ones caused by nutrient upwellings in all the world's oceans. Natural blooms are often hundreds of kilometers in size and can be seen from space by satellites. (Laughlin, 2011)

you get another new car, there will be an additional billion human mouths to feed. Can we afford to grow crops to feed the cars instead? It is important we keep in mind that there will be some difficult energy questions that we as humans will need to address and choices that we'll need to make.

5. Geothermal Energy

Definition and Origin of Geothermal Energy

Now, it is time to turn downward and consider geothermal energy or energy from inside our planet. Let me say right now that geothermal energy does not play a role as big as the elemental energies such as fire, wind, and water nor is it likely to in the future. However, for some parts of the world, particularly those near volcanic activities, geothermal will provide a steady supply of electricity



Geothermal energy taps into the heat that's constantly flowing out of Earth's interior towards its surface.

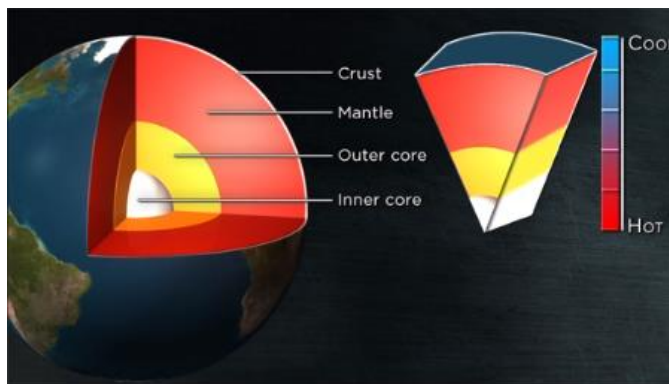
for some time to come. Geothermal energy taps into the heat that's constantly flowing out of Earth's interior towards its surface. The temperature gets hotter as you go down inside the Earth and this heat is constantly slowly walking its way back up toward the surface. Sometimes, we see this dramatically with volcanic eruptions. But for most of our surface, it occurs imperceptibly. It takes hundreds of millions of years for heat inside the Earth to slowly walk its way to the surface. This is because rocks are not good conductors of heat.

What's the origin of Earth core's heat? "A gravitational source of heat is added to secular cooling and the heat from the decay of radioactive elements to close the gap between heat loss and heat production for whole mantle convection. This unrecognized source of heat comes from viscous friction in sheet-like mantle plumes rising from the core-mantle boundary to create oceanic plates, cause earthquakes and raise mountains and volcanoes. The frictional heat generated in the plumes is equal to the gravitational potential energy lost because their heavy fraction, FeO, was absorbed by the molten iron at the top of the core. When mantle material is subjected to the temperature and pressure prevailing at the 670 km seismic discontinuity in the laser-heated diamond cell, it is transformed into a magnesium iron silicate perovskite and magnesiowuestite that remain stable to the temperature and pressure of the core-mantle boundary, where they lose their FeO to the core. The energy that had been expended by this process during the life of the Earth, has come from the composition Fe_2O of the outer core, as required by the seismic speeds and the moment of inertia of the Earth. This energy is 7.07×10^{30} J, 2.3 times what would have been expended by plate

creation at the present rate. Secular cooling does not originate from the primordial high temperature, but from the decay of the radioactivity and the decrease of the amount of FeO in the mantle. (Schubert et al., 1980)...

...At present plate creation by mantle plumes provides 47.5% of the heat of 44.2 TW. The larger part of this heat comes from viscous friction in the plumes, the remainder coming from the cooling of the core. Radioactivity gives 41%, and 11% comes from secular cooling that takes no part in plate creation. In apportioning the heat from these sources between land and sea, it is assumed that in very old oceans only 15% of the heat comes from plate creation and that the remaining 85% comes from radioactive elements uniformly disseminated in the mantle and secular cooling. The last two sources being world-wide, we extend this heat of 32.0 mW/m² over the 510×10^6 km² of the Earth's surface, 16.3 TW in all. At sea, where the heat flow is greater than 32.0 mW/m², the additional heat comes from plate creation, while on land the extra amount is from radionuclides concentrated in the crust. The measured losses on land and sea are 30% and 70% of 44.2 TW, respectively. On land, the total measured loss is 13.26 TW, 86% of it is radiogenic, and 14% is from cooling. At sea, the heat loss is 30.9 TW, 22% of it is radiogenic, 10% from cooling and 68% from plate creation.” (Vacquier, 1998)

“Geothermal energy is heat that is generated within the Earth. (Geo means “earth,” and thermal means “heat” in Greek.) It is a renewable resource that can be harvested for human use. About 2,900 kilometers (1,800 miles) below the Earth’s crust, or surface, is the hottest part of our planet: the core. A small portion of the core’s heat comes from the friction and gravitational pull formed



About 2,900 kilometers (1,800 miles) below the Earth’s crust, or surface, is the hottest part of our planet

when Earth was created more than 4 billion years ago. However, the vast majority of Earth’s heat is constantly generated by the decay of radioactive isotopes, such as potassium-40 and thorium-232. Isotopes are forms of an element that have a different number of neutrons than regular versions of the element’s atom. Potassium, for instance, has 20 neutrons in its nucleus. Potassium-40, however, has 21 neutrons. As potassium-40 decays, its nucleus changes, emitting enormous amounts of

energy (radiation). Potassium-40 most often decays to isotopes of calcium (calcium-40) and argon (argon-40). Radioactive decay is a continual process in the core. Temperatures there rise to more than 5,000° Celsius (about 9,000° Fahrenheit). Heat from the core is constantly radiating outward and warming rocks, water, gas, and other geological material.

Earth's temperature rises with depth from the surface to the core. This gradual change in temperature is known as the geothermal gradient. In most parts of the world, the geothermal gradient is about 25° C per 1 kilometer of depth (1° F per 77 feet of depth). If underground rock formations are heated to about 700-1,300° C (1,300-2,400° F), they can become magma. Magma is molten (partly melted) rock permeated by gas and gas bubbles. Magma exists in the mantle and lower crust, and sometimes bubbles to the surface as lava. Magma heats nearby rocks and underground aquifers. Hot water can be released through geysers, hot springs, steam vents, underwater hydrothermal vents, and mud pots. These are all sources of geothermal energy. Their heat can be captured and used directly for heat, or their steam can be used to generate electricity. Geothermal energy can be used to heat structures such as buildings, parking lots, and sidewalks. Most of the Earth's geothermal energy does not bubble out as magma, water, or steam. It remains in the mantle, emanating outward at a slow pace and collecting as pockets of high heat. This dry geothermal heat can be accessed by drilling and enhanced with injected water to create steam." (National Geographic, 2018)

Use of Geothermal Energy

"People began harnessing geothermal energy thousands of years before they had the technology to dig down into geothermal reservoirs. The ancient Romans used hot springs to heat their homes, bathe and cook. In 1892, the first modern district heating system was developed in Boise, Idaho. It used water piped from hot springs to heat buildings. The first geothermal energy plant was built in Larderello, Italy, in 1904. Today, geothermal energy is used in France, Turkey, New Zealand, the United States and Japan, among others. Iceland is one of the biggest users of geothermal energy -- virtually the entire city of Reykjavik is heated with water pumped in from hot springs and geothermal wells. Some cities -- like Klamath Falls, Ore. -- even pump hot water underneath their roads and sidewalks in the winter to melt snow and ice. Geothermal energy can be used in three ways:

- I. **Direct geothermal energy.** In areas where hot springs or geothermal reservoirs are near the Earth's surface, hot water can be piped in directly to heat homes or office buildings. Geothermal water is pumped through a heat exchanger, which transfers the heat from the water into the building's heating system. The used water is injected back down a well into the reservoir to be reheated and used again.
- II. **Geothermal heat pump.** A few feet under the ground, the soil or water remain a constant 50 to 60 degrees Fahrenheit (10-15 degrees Celsius) year-round. Just that little bit of warmth can be used to heat or cool homes and offices. Fluid circulates through a series of pipes (called a loop) under the ground or beneath the water of a pond or lake and into a building. An electric compressor and heat exchanger pull the heat from the pipes and send

it via a duct system throughout the building. In the summer the process is reversed. The pipes draw heat away from the house and carry it to the ground or water outside, where it is absorbed.

III. **Geothermal power plant.** Hot water and steam from deep underground can be piped up through underground wells and used to generate electricity in a power plant. Three different types of geothermal power plants exist:

- 1) *Dry steam plants.* Hot steam is piped directly from geothermal reservoirs into generators in the power plant. The steam spins turbines, which generate electricity.
- 2) *Flash steam plants.* Water that's between 300 and 700 degrees Fahrenheit (148 and 371 degrees Celsius) is brought up through a well. Some of the water turns to steam, which drives the turbines. When the steam cools it condenses back into water and is returned to the ground.
- 3) *Binary cycle plants.* Moderately hot geothermal water is passed through a heat exchanger, where its heat is transferred to a liquid (such as isobutene) that boils at a lower temperature than water. When that fluid is heated it turns to steam, which spins the turbines. (Watson, 2009)

According to the U.S. Energy Information Administration, the United States leads the world in the amount of electricity generated with geothermal energy. Geothermal electricity generation requires water or steam at high temperatures (300° to 700°F). Geothermal power plants are generally built where geothermal reservoirs are located, within a mile or two of the earth's surface. In 2016, U.S. geothermal power plants produced about 17.4 billion kilowatt-hours (kWh), or 0.4% of total U.S. electricity generation. In 2016, seven states had geothermal power plants.

Share of U.S. geothermal electricity produced by each state, 2016	
California	72%
Nevada	22%
Utah	3%
Hawaii	1%
Oregon	1%
Idaho	<1%
New Mexico	<1%
Source: EIA	

Most geothermal energy is not used for generating electricity but for a variety of other ways that people need heat. Geothermal Energy is used for:

- Residential heating
- Space heating
- Spas
- Industry
- Desalination
- Drying food

Geothermal Energy Leaders (2015)		Geothermal Energy Leaders (Percentage of total)	
• United States	3.5 GW	• Iceland	30%
• Philippines	1.9 GW	• Philippines	27%
• Indonesia	1.4 GW	• El Salvador	25%
• Mexico	1.0 GW	• New Zealand	14.5%
• New Zealand	1.0 GW	• Indonesia	3.7%
• Italy	0.9 GW	• Mexico	3%
• Iceland	0.7 GW	• Italy	1.5%
		• United States	0.3%

In the U.S., The Geysers is a geothermal field located in California's Mayacamas Mountains, approximately 115km north of San Francisco. It is the world's biggest single geothermal field, comprising of 22 geothermal power plants with an installed capacity of 1,517MW. The Geysers is also the area where the US's first geothermal power plant was put into

commercial operation. The number of geothermal power plants currently operating within the region is 18 and the present combined generation capacity of these plants is 900MW, enough to power 900,000 homes. The Geysers geothermal resource field is spread over 117 square kilometres in the counties of Sonoma, Lake and Mendocino.

More than 350 steam production wells have been drilled within The Geysers region to tap natural steam. Some of these wells are as deep as three kilometres. The steam which rises is brought overland through pipes and then supplied to a network of interconnected power plants. Here, the steam spins conventional steam turbines which, in turn, run generators to produce green electricity. Electricity generated from The Geysers field is supplied to Sonoma, Lake, Mendocino, Marin and Napa counties. The Geysers account for 20% of the green power generated in California and the area is considered as one of the most reliable sources for energy in the state. Steam for the power plants is harnessed from a greywacke sandstone reservoir located at the top of a heterogeneous mix of low permeability rocks. Heat for the steam reservoir comes from a large molten rock chamber, spanning over seven kilometers beneath the ground. The diameter of this chamber is about 14km. (Power Technology, 2018)

On the other hand, located in Iceland, the Svartsengi power plant is the first geothermal power plant in the world to combine generation of electricity and production of hot water for district heating. Today, the total production capacity of the Svartsengi Power Plant is 75 MWe²⁹ and 150 MWth³⁰. Waste heat from the plant is used for various purposes at the Blue Lagoon spa facilities located nearby. Verkís hf has provided consulting services at all stages during the Plant development, since the very beginning. The Power Plant in Svartsengi has been developed in 6 successive phases since 1978. The Power Plant produces electricity and hot water for district heating. Geothermal brine effluent, rich in minerals and silica algae, is lead to the Blue Lagoon, now a well-known bathing and healing resort. (Verkís, 2018)

How Does Geothermal Compare to Other Energy Sources?

Experts say geothermal energy is cleaner, more efficient, and more cost-effective than burning fossil fuels, and it can reduce our dependence on foreign oil. Geothermal energy is clean because it can be generated without burning fossil fuels. Geothermal plants release a fraction of the carbon dioxide produced by fossil fuel plants, and they create very little nitrous oxide or sulfur gases. Reykjavik, Iceland, which heats 95 percent of its buildings using geothermal energy, is considered one of the cleanest cities in the world.

Ground Source Heat Pumps (2014)

- 400,000 in the U.S.
- 15 GW of total yield
- Cost can be > 10 000 \$
- Energy-efficient and cost-efficient
- Payback period:- 12 years (natural gas), ~ 5 years (oil), or ~ 4 years (électric)

Because the energy is generated right near the plant, it saves on processing and transportation costs compared to other types of fuel. Geothermal plants are also considered to be more reliable than coal or nuclear plants because they can run consistently, 24 hours a day, 365 days a year.

The initial costs of geothermal energy are high -- wells can cost \$1 to \$4 million each to drill, and installation of a home geothermal pump system can run as much as \$30,000. However, a home geothermal energy pump can cut energy bills by 30 to 40 percent and will pay for itself within 5 to 10 years. Geothermal energy is considered renewable because the heat is continually replaced. The water that is

removed is put right back into the ground after its heat is used.

The world uses about 7,000 megawatts of geothermal energy, about 2,700 megawatts of which is produced in the United States (the equivalent of burning 60 million barrels of oil each year). Still, we're not using nearly as much geothermal energy as is available. That has to do with the limited geographic availability of geothermal energy, and the difficulty and expense of drilling down far enough to reach

²⁹ MWe = Megawatt electric

³⁰ MWth = Megawatt thermal

that energy. More advanced techniques being developed could allow for deeper drilling, potentially bringing geothermal energy to more people in more places. For right now, geothermal heat pumps are the most viable option. They can be used just about anywhere in the world because the temperature beneath the ground always remains constant. (Watson, 2009)

For thermal energy storage, one of the most common technologies installed today is domestic hot water tanks. Other technologies, such as ice and chilled water storage, play an important role in several countries, including Australia, the United States, China and Japan, as utilities seek to reduce peak loads and consumers seek to lower their electricity bills. Underground thermal energy storage (UTES) systems are frequently found in Canada, Germany, and many other European countries. Thermal energy storage (TES) technologies operate with a goal of storing energy for later use as heating or cooling capacity. Individual TES technologies operate in the generation and end-use steps of the energy system and can be grouped by storage temperature: low, medium, high. Thermal storage technologies are well suited for an array of applications including seasonal storage on the supply-side and demand management services on the demand-side portion of the energy system. (IEA-ETSAP, 2013). As heating and cooling requirements represent 45% of the total energy use in buildings, these demand-side services can represent significant value to the energy system. Some thermal energy storage technologies have already realized significant levels of deployment in electricity and heat networks, including UTES systems and ice storage systems for residential cooling. Further, some end-use technologies that have already been deployed to meet other societal requirements include TES capabilities, though this potential is not currently being fully realized (e.g. residential hot water heaters). Today's R&D in thermal energy storage is primarily focused on reducing the costs of high-density storage, including thermochemical process and phase-change material. (IEA, 2014)

Due to the higher energy storage densities seen with PCMs compared to sensible heat storage, the United States and Japan have already installed significant amounts of thermal storage that uses ice for cooling applications. In the United States, an estimated 1 GW of ice storage has been deployed to reduce peak energy consumption in areas with high numbers of cooling-degree days. (O'Donnell and Adamson, 2012)

Pros and Cons of Geothermal Energy

Pros	Cons
• Geothermal energy is local and does not require buying fuel from other countries • Relatively low cost • Useful minerals such as zinc and Sulphur can be extracted from the waters that are pumped up from underground • Online 90-100% of the time (whereas coal plant unit can only be online for about $\frac{3}{4}$ of the time and nuclear plant units can only be online for about $\frac{2}{3}$ of the time) • Creates very little air pollution • Does not require much land (just the land for the generators). All the action is underground	• Fluids from geothermal energy extraction can be very corrosive and mineral-rich which can both corrode pipes and clog them up with mineral deposits • Costs of geothermal are highly variable by site depending upon many cost factors but mostly upon the depth of the wells. Exploration costs in particular can be very high. Drilling is expensive, as with petroleum • Although the fuel is free, the pumping takes a lot of energy • High initial capital costs • Contamination of soil is possible • Risk of explosion because geothermal often operate at very high pressures • Correlation between the pumping of water and the occurrence of earthquake, as we saw with fracking for natural gas • Few places in the world where geothermal energy is economically efficient

By and large, although most people are inclined to welcome a complete transition from fossil fuels to renewable energy sources, it's important to keep in mind that "the fact that renewable-energy sources have smaller environmental 'footprints' than do fossil-fuel sources arguably provides the greatest impetus for making a transition. However, the use of renewables does not eliminate all environmental impacts, though the types and magnitudes differ substantially from those of fossil fuels and from one renewable technology to another. While most renewable technologies do not emit air pollutants during the generation of electricity, they do emit them during manufacture or installation. Thus, an accurate accounting of emissions and other impacts must embrace the whole life cycle of a given technology. The process of life-cycle analysis (LCA) aims to estimate the overall energy usage and environmental impacts of a given technology by considering all of its stages—from the extraction and refinement of raw materials to construction, use, and disposal. However, a major complication in comparing LCAs is that there is no set standard by which such analyses are carried out. While all LCAs attempt to cover technologies from 'cradle to grave' in a systematic way, there is significant variability in the assumptions, boundaries, and methodologies used in these assessments. Further, the data are for normal operations and do not consider emissions or other impacts that result from start-ups, shutdowns, or accidents. Comparisons of LCA should therefore be made with caution; each LCA is only an approximation of a technology's actual set of impacts. Not surprisingly, based on the range of estimates of carbon dioxide (CO₂)-equivalent (CO₂-eq) emissions that appear in the literature, renewables have significantly lower CO₂-equivalent emissions than do coal, oil, and gas. Estimates for solar, wind,

hydropower, and geothermal range from about 10 to 50 grams of CO₂ equivalent emissions per kilowatt-hour, similar to the numbers for nuclear power. Much higher values are found for fossil-fuel sources of electricity, upward of 500 g CO₂ eq per kilowatt-hour for natural gas and 1000 g CO₂ eq per kilowatt-hour for coal, though the relative advantage of renewables would be significantly reduced by adding carbon capture and storage (CCS) to coal and gas systems (if the commercial viability of CCS were demonstrated)...Renewable-electricity sources also have much lower emissions of other atmospheric pollutants, including sulfur oxides, nitrogen oxides, and lead.” (NAS, 2009)

On the other hand, because renewable-energy resources are more diffuse than fossil and nuclear energy resources, the land areas needed to collect renewable energy and convert it to electricity are, on an energy-equivalent basis, much larger than those of fossil and nuclear. Spitzley and Keoleian (2005) report land-use values of 9–14.3 m²/MWh per year for solar, 69–94 m²/MWh per year for wind, and 360–488 m²/MWh per year for biopower. Spitzley and Keoleian (2005) included one LCA example of hydroelectric power with a land-use value of 122 m²/MWh per year for a high capacity, large-reservoir facility in the United States. This compares with estimates for natural gas, coal, and nuclear technologies of 0.45 m²/MWh per year, 4.4–5.8 m²/MWh per year, and 6.5 m²/MWh per year, respectively. An exception to the statement that most renewable-electricity sources require large land areas is geothermal electricity, including both hydrothermal and EGS. Land requirements for geothermal energy are smaller than those for other renewables and are comparable, in fact, to those for nonrenewable sources of electricity (MIT, 2006). It should be noted, however, that in order to operate fossil-fuel and nuclear plants the fuel must first be extracted or mined. Most LCAs, including that of Spitzley and Keoleian (2005), do not account for that process in their assessment of land-use requirements.

Further, there is a wide spectrum of other environmental impacts of renewables that have not been addressed by LCA or analyzed in the studies cited previously. One impact often ascribed to wind power is bird and bat mortality. However, a recent NRC study concluded that although the impacts on bat populations were unclear, there was no evidence that bird fatalities caused by wind turbines had measurable effects on U.S. bird populations (NRC, 2007). Another consideration is that wind-farm deployments at levels needed to produce large amounts of power may extract a significant portion of the energy from the wind field. Continental-scale simulations indicate that high levels of wind power extraction could, to various degrees, affect regional weather as well as climate. In addition to limiting the efficiency of large-scale wind farms, model calculations suggest that the extraction of wind energy from very-large scale wind farms could have some measurable effect on weather and climate at the local or even continental and global scales. (Roy et al., 2004; Keith et al., 2004)

Other potential impacts from renewables include water diversion, water pollution, and land subsidence from geothermal drilling; ecosystem changes due to hydropower; and noise pollution and aesthetic degradation from wind power. In addition, CSP technologies, except for air-cooled dish-engine technologies, also require significant cooling water. While such impacts may not be widespread or overwhelming, they are often what raise the biggest concerns from local populations and regulators. This means that local and state authorities exercise significant authority over the siting and deployment of renewable-energy generating facilities.

While this situation is not unique to renewable sources of electricity generation, there is a long, evolved permitting process that has been applied across the country in the case of traditional generating facilities such as coal and gas. For renewable technologies, on the other hand, the regulatory process is still in the developmental stage. (NAS, 2009)

I would like to end this section by saying a final word on levelized cost of electricity, which I previously talked about (see *Energy Efficiency* above). I would like to add the fact that “levelized cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competitiveness of different generating technologies. It represents the per-megawatt hour cost (in discounted real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type. The importance of these factors varies among the technologies. For technologies such as solar and wind generation that have no fuel costs and relatively small variable O&M costs, LCOE changes in rough proportion to the estimated capital cost of generation capacity. For technologies with significant fuel cost, both fuel cost and overnight cost estimates significantly affect LCOE. The availability of various incentives, including state or federal tax credits can also affect the calculation of LCOE. As with any projection, there is uncertainty about all of these factors, and their values can vary regionally and temporally as technologies evolve and as fuel prices change. Note that actual plant investment decisions are affected by the specific technological and regional characteristics of a project, which involve many other factors not reflected in LCOE values. The projected utilization rate, which depends on the load shape and the existing resource mix in an area where additional capacity is needed, is one such factor. The existing resource mix in a region can directly affect the economic viability of a new investment through its effect on the economics surrounding the displacement of existing resources. For example, a wind resource that would primarily displace existing natural gas generation will usually have a different economic value than one that would displace existing coal generation. A related factor is the capacity value, which depends on both the existing capacity mix and load characteristics in a region. Because load must be balanced on a continuous basis, generating units with the capability to vary output to follow demand (dispatchable technologies) generally have more value to a system than less flexible units (non-dispatchable technologies), or than units using intermittent resource to operate. The direct comparison of LCOE across technologies is, therefore, often problematic and can be misleading as a method to assess the economic competitiveness of various generation alternatives because projected utilization rates, the existing resource mix, and capacity values can all vary dramatically across regions where new generation capacity may be needed.” (EIA, 2018)

The following tables show respectively the estimated levelized cost of electricity (capacity-weighted average) for new generation *resources* and the estimated levelized cost of electricity (unweighted average) for new generation resources entering service in 2022:

Table 1a. Estimated levelized cost of electricity (capacity-weighted average) for new generation resources entering service in 2022 (2017 \$/MWh)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit ²	Total LCOE including tax credit
Dispatchable technologies								
Coal with 30% CCS ³	NB	NB	NB	NB	NB	NB	NA	NB
Coal with 90% CCS ³	NB	NB	NB	NB	NB	NB	NA	NB
Conventional CC	87	13.0	1.5	32.8	1.0	48.3	NA	48.3
Advanced CC	87	15.5	1.3	30.3	1.1	48.1	NA	48.1
Advanced CC with CCS	NB	NB	NB	NB	NB	NB	NA	NB
Conventional CT	NB	NB	NB	NB	NB	NB	NA	NB
Advanced CT	30	22.7	2.6	51.3	2.9	79.5	NA	79.5
Advanced nuclear	90	67.0	12.9	9.3	0.9	90.1	NA	90.1
Geothermal	91	28.3	13.5	0.0	1.3	43.1	-2.8	40.3
Biomass	83	40.3	15.4	45.0	1.5	102.2	NA	102.2
Non-dispatchable technologies								
Wind, onshore	43	33.0	12.7	0.0	2.4	48.0	-11.1	37.0
Wind, offshore	45	102.6	20.0	0.0	2.0	124.6	-18.5	106.2
Solar PV ⁴	33	48.2	7.5	0.0	3.3	59.1	-12.5	46.5
Solar thermal	NB	NB	NB	NB	NB	NB	NB	NB
Hydroelectric ⁵	65	56.7	14.0	1.3	1.8	73.9	NA	73.9

Note: Costs are expressed in terms of net AC power available to the grid for the installed capacity. LCOE=levelized costs of energy. CCS=carbon capture and sequestration. CC=combined-cycle (natural gas). CT=combustion turbine. PV=photovoltaic. NA=not available. NB=not built. O&M=operation and maintenance. Source: EIA, 2018.

Table 1b. Estimated levelized cost of electricity (unweighted average) for new generation resources entering service in 2022 (2017 \$/MWh)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit ¹	Total LCOE including tax credit
Dispatchable technologies								
Coal with 30% CCS ²	85	84.0	9.5	35.6	1.1	130.1	NA	130.1
Coal with 90% CCS ²	85	68.5	11.0	38.5	1.1	119.1	NA	119.1
Conventional CC	87	12.6	1.5	34.9	1.1	50.1	NA	50.1
Advanced CC	87	14.4	1.3	32.2	1.1	49.0	NA	49.0
Advanced CC with CCS	87	26.9	4.4	42.5	1.1	74.9	NA	74.9
Conventional CT	30	37.2	6.7	51.6	3.2	98.7	NA	98.7
Advanced CT	30	23.6	2.6	55.7	3.2	85.1	NA	85.1
Advanced nuclear	90	69.4	12.9	9.3	1.0	92.6	NA	92.6
Geothermal	90	30.1	13.2	0.0	1.3	44.6	-3.0	41.6
Biomass	83	39.2	15.4	39.6	1.1	95.3	NA	95.3
Non-dispatchable technologies								
Wind, onshore	41	43.1	13.4	0.0	2.5	59.1	-11.1	48.0
Wind, offshore	45	115.8	19.9	0.0	2.3	138.0	-20.8	117.1
Solar PV ³	29	51.2	8.7	0.0	3.3	63.2	-13.3	49.9
Solar thermal	25	128.4	32.6	0.0	4.1	165.1	-38.5	126.6
Hydroelectric ⁴	64	48.2	9.8	1.8	1.9	61.7	NA	61.7

Note: Costs are expressed in terms of net AC power available to the grid for the installed capacity. LCOE=levelized costs of energy. CCS=carbon capture and sequestration. CC=combined-cycle (natural gas). CT=combustion turbine. PV=photovoltaic. NA=not available. NB=not built. Source: EIA, 2018. O&M=operation and maintenance. Source: EIA, 2018.

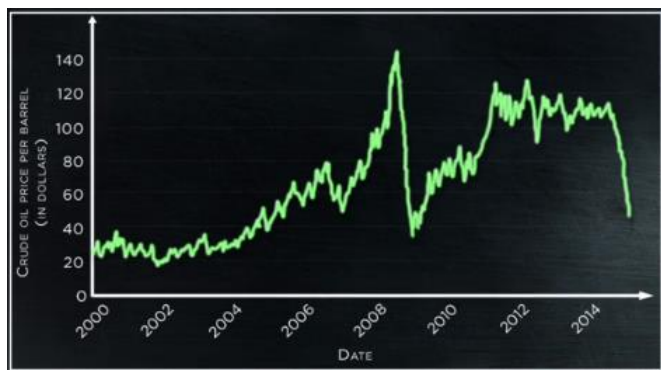
V. ENERGY AND POLITICS

Thus far, we've seen the available energy resources and the technologies used to explore, discover, retrieve, store, and distribute energy. The laws of thermodynamics and engineering are part of all aspects of energy production. If it was just that simple. As you have seen energy resources are not developed, used, produced, and distributed in a vacuum. They're made by people and for people. And once people get involved, things get a lot more complicated. All of the energy issues are ultimately tied to economic and political issues. People have thought that solar and wind powers were great ideas for a long time but the big push to develop those technologies as well as the need to develop less efficient oil sand and oil shales occurred when the price of the barrel of oil exceeded one hundred dollars. Suddenly, these energy resources became economically viable. Governments can play a huge role in economic viability. The steady improvement in car engine efficiency has been largely driven by standards in the State of California as well as national standards. Governments also provide huge subsidies to energy industries to help drive economic viability particularly to the fossil fuel industry to help guarantee a steady supply of energy. Governments and private industries both influence the economic viability through international trades and conflicts. For example, some of the oil shortages of the late 20th century was a result of OPEC's oil export policies and global oil prices spikes in 1991 following Iraq's invasion of Kuwait.

"Energy policies are the actions governments take to affect the demand for energy as well as the supply of it. These actions include the ways in which governments cope with energy supply disruptions and their efforts to influence energy consumption and economic growth. The energy policies of the United States government have often worked at cross purposes, both stimulating and suppressing demand. Taxes are perhaps the most important kind of energy policy, and energy taxes are much lower in the U. S. than in other countries. This is partially responsible for the fact that energy consumption per capita is higher than elsewhere, and there is less incentive to invest in conservation or alternative technologies. Following the 1973 Arab oil embargo, the federal government instituted price controls which kept energy prices lower than they would otherwise have been, thereby stimulating consumption. Yet the government also instituted policies at the same time, such as fuel-economy standards for automobiles, which were designed to increase conservation and lower energy use. Thus, policies in the period after the embargo were contradictory: what one set of policies encouraged, the other discouraged...

Energy policy issues have always been very political in nature. Different segments of the energy industry have often been differently affected by policy changes, and various groups have long proposed divergent solutions. The energy crisis, however, intensified these conflicts. Advocates of strong government action called for policies which would alter consumption habits, reducing dependence on foreign oil and the nation's vulnerability to an oil embargo. They have been opposed by proponents of free markets, some of whom considered the government itself responsible for the crisis. Few issues were subject to such intensive scrutiny and fundamental

conflicts over values as energy policies were during this period. Interest groups representing causes from energy conservation to nuclear power mobilized. Business interests also expanded their lobbying efforts.” (Marcus, 1992)



Oil prices fell below \$40 a barrel in 2015

Countries also use energy as a means of political leverage. For example, the petroleum embargo against Russia and Iran. Major economic and political forces have shaped the development of energy resources in the past and will continue to do so in the future. I stated in the beginning of this book how energy is affected by supply and demand. A huge economic factor for energy resources is the marginal cost of oil production. For any petroleum resource or

resource technology, the marginal cost of oil production is the point below which it becomes uneconomical to bring new oil projects to markets. Above the marginal cost of production, oil can be extracted and sold at a price that will return to investors an acceptable after-tax capital return adjusted for risks. The effect on the development of other technologies is huge. When oil goes over \$100 a barrel, the low-grade oil sand reserves of countries like Canada and Venezuela became economically retrievable. But in the same manner, when the price of oil fell below \$40 a barrel in 2015, those reserves were no longer profitable and associated industries were hit with large financial losses.

There is also a large effect on other commodities and industries but in just the opposite way. When the costs of oil go up, energy industries are booming, their stock values are high but everything else get hit hard. For example, the cost of business goes up, manufacturing becomes more expensive, commodity prices go up, travel – especially air travel – becomes much costlier. But when fuel prices go down, it's as if everyone get a rebate. Individuals have more money to spend. Industry can lower prices. Therefore, sales increases. However, the effects on consumer habit can be complicated. When oil prices go down and people pay less for gasoline, they end up driving more, using more gasoline, which drives up demand and, to some degree, the price of oil again. This is an example of the negative feedback process. If supply and demand play a major role in energy development in the short-term, governments can enact policies that have long-term effects on energy resources. However, energy policies are not and cannot be written in stone. Sometimes, like the market, they change and adapt to status quos. For example, coverage of policies targeting energy efficiency has been steadily increasing in recent years, and 31.5% of final energy consumption was subject to mandatory energy policy in 2016, up from only 14% in 2000. However, the rate of increase of coverage slowed in 2016 and early indications are that it slowed

again in 2017. Further, the increased coverage in 2017 appears to have come mostly from extensions to existing policies, rather than new policies in previously uncovered sectors and countries. (IEA, 2017)

In their article *Energy: Industry and Politics*, The Washington Post reported that in his 2011 State of the Union address, President Obama challenged Americans to reinvent themselves for a new economy, especially in the area of “clean-energy technology.”...Obama said the nation must confront a new “Sputnik moment,” referring to the 1957 surprise launch of a Soviet satellite into space, and to “turn sunlight and water into fuel for our cars.” He wants one million electric vehicles on the road by 2015 and 80 percent of U.S. electricity to come from clean-energy sources by 2035. He’d pay for it by cutting taxpayer subsidies to oil companies...But since then, a major green energy controversy has engulfed the White House as Solyndra, a solar panel maker, went bankrupt after receiving a \$528 million federal loan. Despite warnings from administration officials and some outside advisers, Obama did visit the company on May 25, 2010, calling it an “engine of economic growth.” Meanwhile, Congress is investigating how the company blew through the money...Before 2007, the last major energy action was the 2005 energy bill signed into law by President George W. Bush and supported by then-Sen. Obama (D-Ill.). Though environmentalists largely criticized the legislation as an \$85 billion boon in tax breaks and subsidies to all sectors of the energy industry, it did mandate that 7.5 billion gallons of biofuel (typically ethanol) be blended into the U.S. fuel supply...

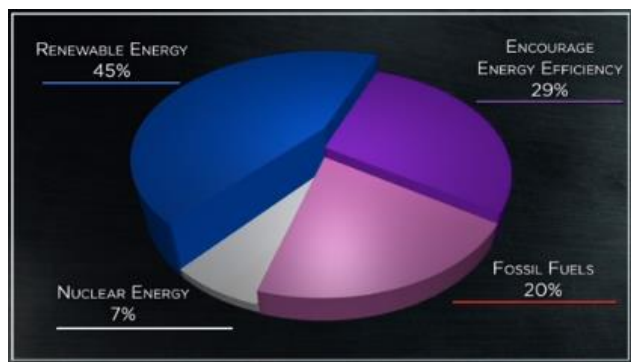
From a policy standpoint, climate change is effectively an energy issue, since reducing carbon emissions will require a nearly complete revamping of our energy systems. Energy is, by definition, humanity’s most basic source of power, and since politics is a contest over power (albeit social power), it should not be surprising that energy is politically contested. A politician’s most basic tools are power and persuasion, and the ability to frame issues. And the tactics of political argument inevitably range well beyond logic and critical thinking. Therefore, politicians can and often do make it harder for people to understand energy issues than would be the case if accurate, unbiased information were freely available. (Heinberg, 2014)

Trump’s energy plan reads like a wish list from the fossil fuel industry: it envisions unfettered oil, gas and coal development as a path to national prosperity and energy independence. Gone are Obama-era overtures to address climate change by modernizing fossil fuel use and development, and embracing ambitious renewable energy goals...Trump, who has vowed to pull the U.S. out of the Paris pact, has installed vehement climate denialist Myron Ebell as leader of the U.S. Environmental Protection Agency’s transition team and nominated fellow denialist and strident EPA foe Oklahoma Attorney General Scott Pruitt to lead the agency. Pruitt filed suit against the EPA to kill the Clean Power Plan, which is currently tied up in court and barred from taking effect until the Supreme Court makes a final ruling...The 24 states suing to stop the Clean Power Plan,

including Oklahoma, have asked Trump...to undo it even before a court ruling, which was expected sometime in 2017. (Magill 2016)

According to Burke & Stephens (2018), energy democracy and energy transitions are also fundamentally political. Given the seemingly pervasive grip that fossil fuel industries and their financial and political allies command over contemporary political life, energy democracy activists seek to make visible within the public sphere the hidden infrastructures, privatized decisions and distant consequences of modern energy systems. The instinct to politicize renewable energy transition reflects an implicit understanding that the transition from fossil-fuel dominant systems to those based on renewables offers an unprecedented yet potentially unrepeatable opportunity. As with new forms of media communications, new energy technologies present an opportunity to more deeply engage with questions of technological determinism. Through selection and construction of these large-scale infrastructural technologies, the world will again be re-ordered: decisions and investments will be made, groups of actors will be politically re-positioned, and material structures as well as social and ecological patterns will be established that may endure for generations. The form of politics used to steer renewable energy transitions will greatly influence the possibility for more democratic futures.

In other words, if governed largely to preserve existing power relations, the renewable energy political economy may replicate existing dynamics of power, continuing to strengthen the powerful and weaken the marginalized. Energy democracy sees renewable energy transitions as unavoidably political processes as well as key opportunities for advancing renewable energy and democracy together. This framing rejects the view of energy transition as simple technological substitution; rather renewable energy transitions cannot avoid the re-ordering of social and political relations. Energy democracy urges us to consider how, by whom and for whom renewable energy transitions proceed. In this way, energy democracy stands in sharp opposition to the strategy of “renewable energy by any means necessary”, and instead embraces energy as politics by other means.



A broad set of strategies including reducing fossil fuel investments and subsidies – 2013 U.S. Government Subsidies (\$16.4 billion)

Energy-politics also raises the question of the desirability of rapid energy transitions. The renewable energy transition is not simply a race against climate change nor primarily about substitution of fuel sources. The burning of fossil fuels must rapidly be put to an end, both to reduce the damages of the climate emergency and to reduce the power of incumbent energy interests. Climate change and climate justice require rapid decarbonization, and energy democracy

justifiably places resistance to fossil fuels and decarbonization at the top of a short-term agenda, which itself raises a host of issues of how to equitably and democratically end fossil fuel production and use. However, climate mitigation requires a broad set of strategies including reducing fossil fuel investments and subsidies, lowering of aggregate consumption levels, and changing land use practices, strategies that may yield greater short-term social and environmental benefit than rapidly deploying renewables.

The energy democracy movement represents a contemporary expression of ongoing struggles for social and environmental justice through engagement with technological systems. Energy democracy redefines individual energy consumers as energy citizens, energy commodities as public goods, and energy infrastructure not as a class of assets but rather as public works or common resources. Recognizing an opportunity in the renewable energy transition, the agenda for energy democracy calls for opposing fossil fuels and other centralized energy systems agenda, reclaiming the energy sector within the public sphere, and restructuring energy systems technologies and governance for greater democracy and inclusivity. Above all, energy democracy allows for a vision of renewable energy transitions as pathways for democratic development. (Burke & Stephens, 2018)

Under most existing forms of policy intervention, the benefits tend to accrue disproportionately to wealthier segments of society. One example of successful reform is the Kerosene to LPG Conversion Program in Indonesia, designed to facilitate a switch to the use of LPG for cooking purposes, thereby improving access to modern energy and reducing the financial burden for the state associated with the subsidies to kerosene. A similar program has reduced kerosene use in New Delhi and is currently being rolled out in several other Indian cities.

Energy efficiency policy also requires specific provision for the poorest. At a macro level, increasing energy efficiency reduces the need to build supply-side capacity in order to provide electricity access, usually allowing more people to be connected at the same level of investment. It can also reduce the adverse health effects of using kerosene lamps for lighting, or diesel generators for electricity during times of outage. At a micro level, improving energy efficiency may increase purchasing costs when the least-efficient appliances and light bulbs are banned. Where this is the case, careful design is required to ensure that additional market barriers do not preclude the poorest segments of society from being able to afford basic appliances. Measures to improve energy access may also, of course, increase overall efficiency, such as where inefficient cookstoves are replaced by more efficient ones.

Increasing investment for renewable energies generally has positive effects on increased electricity access, for as long as the investment is additional. Off-grid renewables solutions, such as solar home systems or small hydroelectric plants, can boost electricity access in regions with important

renewables potential, such as sub-Saharan Africa or India. In cases where a large-scale push is being made to increase on-grid renewables, the integration costs of renewables could increase electricity tariffs and put affordability at risk. Lower tariffs for a basic level of consumption in the residential sector may be a satisfactory means to mitigate the problem (while simultaneously incentivizing energy efficiency), but the system will need to be carefully monitored for unintended effects. (IEA, 2015)

Is there one-size-fits-all solution? Energy policy must fit the national context, but necessary ingredients are:

- Political consensus
- Clear long-term vision
- Stable institutions
- Leadership
- Stakeholders engagement

And the key points for designing energy policies are:

- Demand outlook: growing in non-OECD economies
- Objectives: transition to a low-carbon economy?
- Planning and implementation: should be based on long-term forecasts and accurate data
- Market/Framework: Need to develop flexible and responsive market and regulatory frameworks
- International cooperation and agreed actions are required

Role of Energy in Armed Conflicts

I think that the analysis of the relationship between energy and politics wouldn't be complete without a word on why countries fight over oil resources. As Michael Klare put it, global conflicts are increasingly fueled by the desire for oil and natural gas and the funds they generate. Iraq, Syria, Nigeria, South Sudan, Ukraine, the East and South China Seas: wherever you look, the world is aflame with new or intensifying conflicts. At first glance, these upheavals appear to be independent events, driven by their own unique and idiosyncratic circumstances. But look more closely and they share several key characteristics – notably, a witch's brew of ethnic, religious, and national antagonisms that have been stirred to the boiling point by a fixation on energy.

In each of these conflicts, the fighting is driven in large part by the eruption of long-standing historic antagonisms among neighboring (often intermingled) tribes, sects, and peoples. In Iraq and Syria, it is a clash among Sunnis, Shiites, Kurds, Turkmen, and others; in Nigeria, among Muslims, Christians, and assorted tribal groupings; in South Sudan, between the Dinka and Nuer; in Ukraine, between Ukrainian loyalists and Russian-speakers aligned with Moscow; in the East and South China Sea, among the Chinese, Japanese, Vietnamese, Filipinos, and others. It would be easy to attribute all this to age-old hatreds, as suggested by many analysts; but while such hostilities do help drive these conflicts, they are fueled by a most modern impulse as well: the desire to control valuable oil and natural gas assets. Make no mistake about it, these are twenty-first-century energy wars.

It should surprise no one that energy plays such a significant role in these conflicts. Oil and gas are, after all, the world's most important and valuable commodities and constitute a major source of income for the governments and corporations that control their production and distribution. Indeed, the governments of Iraq, Nigeria, Russia, South Sudan, and Syria derive the great bulk of their revenues from oil sales, while the major energy firms (many state-owned) exercise immense power in these and the other countries involved. Whoever controls these states, or the oil- and gas-producing areas within them, also controls the collection and allocation of crucial revenues. Despite the patina of historical enmities, many of these conflicts, then, are really struggles for control over the principal source of national income.

Moreover, we live in an energy-centric world where control over oil and gas resources (and their means of delivery) translates into geopolitical clout for some and economic vulnerability for others. Because so many countries are dependent on energy imports, nations with surpluses to export -- including Iraq, Nigeria, Russia, and South Sudan -- often exercise disproportionate influence on the world stage. What happens in these countries sometimes matters as much to the rest of us as to the people living in them, and so the risk of external involvement in their conflicts -- whether in the form of direct intervention, arms transfers, the sending in of military advisers, or economic assistance -- is greater than almost anywhere else.

The struggle over energy resources has been a conspicuous factor in many recent conflicts, including the Iran-Iraq War of 1980-1988, the Gulf War of 1990-1991, and the Sudanese Civil War of 1983-2005. On first glance, the fossil-fuel factor in the most recent outbreaks of tension and fighting may seem less evident. But look more closely and you'll see that each of these conflicts is, at heart, an energy war. As these conflicts and others like them suggest, fighting for control over key energy assets or the distribution of oil revenues is a critical factor in most contemporary warfare. While ethnic and religious divisions may provide the political and ideological fuel for these battles, it is the potential for mammoth oil profits that keeps the struggles alive. Without the promise of such resources, many of these conflicts would eventually die out for

lack of funds to buy arms and pay troops. So long as the oil keeps flowing, however, the belligerents have both the means and incentive to keep fighting. (Klare, 2014)

“Currently, it is believed that the South China Sea³¹ contains an oil reserve approaching 8 billion barrels; not an insignificant amount, but far less than the 147 billion barrels hidden beneath the Tarim Basin. This total for the South China Sea, however, excludes the potentially rich areas that are implicitly defined as by China as part of its continental self-jurisdiction, but that are not treated as such in the United Nations' Law of the Sea Treaty (November 1994). Other areas in the South China Sea claimed by China have also been excluded as a result of disputes over sea boundaries. Indeed, this dispute is of great concern to China. While experts disagree about the size of the potential oil reserves in the disputed territories surrounding the Spratly archipelago in the South China Sea, China is confident of the existence of a very large reserve. It was reported by the *China Geology Newspaper* in May 1989 that surveys by the Chinese Ministry of Geology and Mineral Resources indicated the presence of an estimated 130 billion barrels in the region, or 5.5 times China's current proven reserve. This compares with 112 billion barrels for Iraq, which is ranked second after Saudi Arabia in terms of proven reserves. Although this estimate has yet to be independently verified, it is not hard to see why China has begun to look with such hope to the South China Sea with such hope.

So then, this is the position that China is in: It possesses a very large and fast-growing economy. This size and high growth rate requires a prodigious amount of oil. The country's proven oil reserves are insufficient to keep pace with this high rate of growth. The Chinese government has identified two areas that may be able to augment the nation's oil reserves. One of them, however, (the Tarim Basin) is still somewhat inaccessible due to the huge cost of drilling in its tough terrain. Unfortunately for China, the other major source of oil it has identified (the South China Sea) is outside of the nation's recognized international authority. The situation could be ripe for conflict.” (Lillie & Lowenkroan, 2018)

In a fossil-fuel world, control over oil and gas reserves is an essential component of national power. ‘Oil fuels more than automobiles and airplanes,’ Robert Ebel of the Centre for Strategic and International Studies told a State Department audience in 2002. ‘Oil fuels military power, national treasuries, and international politics.’ Far more than an ordinary trade commodity, ‘it is a determinant of well-being, of national security, and international power for those who possess this vital resource, and the converse for those who do not.’ If anything, that's even truer today, and as energy wars expand, the truth of this will only become more evident. Someday, perhaps, the development of renewable sources of energy may invalidate this dictum. But in our present world, if you see a conflict developing, look for the energy. It'll be there somewhere on this fossil-fueled planet of ours. (Klare, 2014)

³¹ More can be found in my essay: *The South China Sea: A Look into China's Modern Times Maritime Silk Road and its Geopolitical Implications*.

VI. FUTURE OF ENERGY

Because we are aware that fossil fuels will eventually deplete and that we won't have any other choice than embrace new forms of energy, we already have an idea about the future of energy on our planet as we know it today. However, my guess is the world will not fully turn to renewable forms of energy until all the fossil fuels are fully depleted. Meanwhile, we can make them last and think about how to make the most of green energy when the need arises in the future. Making fossil fuels last is all about using them efficiently. I previously talked about energy efficiency in section I by showing what both policy makers and consumers alike could do to achieve it. The future of energy relies upon the future of energy efficiency which, itself, depends on such rationales as:

- “Defer construction of new, large, expensive, and polluting power plants;
- Reduce dependence on foreign oil;
- Compensate for distortions in electricity prices;
- Acquire a least- cost resource;
- Reduce the adverse environmental effects of electricity production and transmission; and
- Compensate for the absence of government programs and standards intended to improve the efficiency of electricity use.” (Eto & Hirst, 1996)

But I reckon that these goals are not easy to achieve because of barriers to energy efficiency especially in residential and commercial buildings where consumers are most likely to be found. In that regard, proponents to energy efficiency point to a wide range of market failures or barriers that inhibit greater investment in energy efficiency measures, which include the following:

- Limited supply and availability of some energy efficiency measures;
- Consumers lacking information or having incomplete information about energy efficiency opportunities, and the high transactions costs for obtaining such information;
- Users of energy lacking the capital to invest in energy efficiency measures;
- Fiscal or regulatory policies that discourage energy efficiency investments, often inadvertently;
- Decision making that does not consider or value energy efficiency;
- Perceived risk associated with the performance or relatively new energy efficiency measures;
- Split incentives whereby the party designing, constructing, or purchasing a building or piece of equipment does not pay the operating costs; and
- Energy prices that do not reflect the full costs imposed on society by energy production and use (externalities).

These barriers, including environmental externalities, are one of the most important and frequently cited examples of unpriced costs and benefits. Energy prices do include costs associated with meeting environmental standards, but other adverse environmental impacts, such as emissions of mercury or CO₂, land disruption, or legal water contamination, are not factored into energy prices. Likewise, the cost paid by society to protect and defend sources of oil and other energy imports is not included in energy prices. More fossil energy is consumed than is socially optimal. (Brown et al., 2007) The table below shows the market failures and market barriers inhibiting greater energy efficiency:

Market Failures and Market Barriers Inhibiting Greater Energy Efficiency	
Market Failures	Market Barriers
• Unpriced costs and benefits • Distortional fiscal and regulatory policies • Misplaced or split incentives • Insufficient and inaccurate information	• Low priority of energy issues • Incomplete market for energy efficiency • Lack of access to capital • Fear of not getting value from next buyer
<i>Source: Brown, 2001</i>	

But what are the net costs and benefits of energy savings? Analysts attempt to measure energy savings to consumers by means of various measures. They often use the net present value (NPV) of the energy savings, computed using a particular interest rate, minus the initial purchase price. A variation of this method is to calculate the return on investment or ROI. This method calculates the interest rate implicit in equating the higher initial cost to the stream of energy savings over time. For example, if an efficient air conditioner costs \$300 more than a less efficient model and saves \$30 per year in electricity, the ROI is approximately 10 percent. For the more efficient air conditioner, there is no net savings for someone who would have to pay a credit interest, but a large savings for someone taking the money from a checking account. The ROI and NPV depend both on the annual savings and on how long the air conditioner provides these savings – for example, if the building in which the air conditioner is installed will be torn down and the air conditioner destroyed in 3 years, that is the relevant period over which to calculate the return.

Furthermore, the future of energy also depends on changing consumer behavior for energy efficiency to be attained. The energy efficiency policies and programs should not only target energy efficiency of buildings, appliances, vehicles, and industrial operations but also consumer behavior which must change. For example, encouraging people to drive less or buy fewer and/or smaller vehicles, appliances, or homes. Consumer behavior can be influenced in a number of ways, including the following:

- Offering convenient alternatives such as practical and high-quality mass transit services;

- Using financial incentives such as taxing energy, taxing carbon dioxide pollutant emissions, or taxing inefficient devices more heavily; Increasing awareness, for example by educating people about the environmental consequences of their lifestyle choices; and
- Providing feedback on energy consumption – for example, by including easy-to-understand comparative information on energy use on monthly utility bills.

Projected Costs of Implementing Hydrogen Fuel-Cell Vehicles	
By 2023 (break-even year): • The government would have spent about \$55 billion, including: —\$40 billion for the incremental cost of HFCVs³², — \$8 billion for the initial deployment of hydrogen supply infrastructure, and —\$5 billion for research and development. • About 5.6 million HFCVs would be operating.	By 2050: • More than 200 million HFCVs would be operating, and there would be: —180,000 hydrogen stations, —210 central hydrogen-production plants, and —80,000 miles of pipeline. • Industry would have profitably spent about \$400 billion on hydrogen infrastructure.
Source: NAS, 2009	

It remains to be seen if changing behavior can play a larger role in energy efficiency efforts in the coming decades. Now, the question is: what else, in addition to changing consumers' behavior, can be done to face or eliminate the above barriers? Because the decisions about energy policies come from local, national, and international leaders, implementing a specific set of options may turn out to be difficult even impossible. Each society has its own economics in terms of energy, that is, its own policies and market affecting how energy and its byproducts are produced, distributed, and consumed. Therefore, the resolution of the energy crisis in the future will have to rely on something that every country uses instead of on intangible and hard to materialize goals. I think that a common ground can be found in technology since it is inescapable today, let alone in the future.

Costs and Benefits of Policies and Programs That Address Barriers

According to Sathaye & Phadke (2011), cost effective policies and programs can address some of the barriers and increase the energy efficiency potential that can be achieved. Hence understanding the cost, benefit, and potential for these cost-effective policies and programs is critical for accurately estimating/representing the role EE can play as a mitigation option. In the United States, utility programs address these barriers to capture some of the “negative-cost” potential, and expenditures on these programs provide an estimate of the cost of overcoming some of these barriers. Hence by adding these program costs to the cost of efficiency measures typically estimated by engineering economic studies, one can potentially estimate the societal cost of energy efficiency as a mitigation option. Many energy climate models, which focus on analyzing the role of various mitigation options in climate stabilization scenarios, can consider these program costs and model accelerated adoption of cost effective measures due to these programs.

³² Hydrogen fuel cell vehicles

Most energy-climate models do not undertake this exercise given the lack of empirical information on program costs especially at the measure level...We present the results of the analysis of efficiency programs implemented by California utilities during 2006-2008. California has long been a national leader in promoting energy efficiency: the state's policies, programs, and standards have served as a model for federal policies as well as initiatives in other states. California utilities undertake one of the largest ratepayer funded energy efficiency initiatives in the world. The state's utility energy efficiency programs are numerous, costing about one billion dollars per year. These programs are funded by resources collected from ratepayers and are overseen by the California Public Utilities Commission (CPUC), which regulates the investor owned utilities (IOUs) in the state. IOUs are required to file monthly, quarterly, and annual reports, which provide various details on the outcomes of their energy efficiency programs to the California Public Utilities Commission.

In terms of costs associated with policies and programs, Sathaye & Phadke (2011) go on to say that it has been demonstrated that policies and programs which address various barriers lead to increased adoption of energy efficiency. These policies and programs also incur some costs such as administrative, marketing, installation, and financial incentives (which are more of a transfer than actual cost). From a societal perspective, the desirability of these programs depends on whether the benefits of these policies and programs outweigh their costs and empirical evaluation of the same is warranted. Further, it is important to analyze the impact of policies and programs to estimate how the impact of energy efficiency gets adopted. We report the results of our empirical analysis of utility energy efficiency programs in California, which are one of the largest and most comprehensive energy efficiency programs in the world.

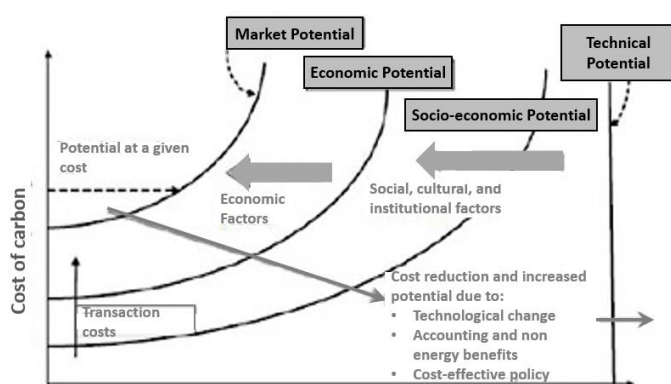
To come up with energy efficiency cost curves, the authors hypothesized that the energy sector comprises the major energy demand sectors (industry, residential and commercial, transport, and agriculture), and the energy supply sector, which consists of resource extraction, conversion, and delivery of energy products. Greenhouse gas emissions occur at various points in the sector, from resource extraction to end use, and accordingly, options for mitigation exist at any of these points.

The representation of the marginal cost curves of energy efficiency options is referred to as cost of conserved energy (CCE). CCE curves were developed about three decades ago to place energy-efficiency cost estimates at a level comparable to that for supply-side options (Meier, 1982). A CCE curve is made up of a combination of several options and can be sector-specific or economy-wide. The CCE is estimated for each mitigation option and plotted against its resulting energy or emissions savings. A combination of such calculations yields a curve of CCE for a suite of mitigation options. The CCE calculation is based on investment theory and it is expressed as:

$$CCE = \frac{1 \cdot q}{ES} \quad \text{and} \quad CCE = \frac{1 \cdot q}{ES}$$

One criticism that has been directed at the calculation of CCEs is that they may err by aggregating across the entire stock, without differentiating costs, and discount rates for various classes of consumers. One way to avoid this mistake is illustrated by Sathaye and Murtishaw (2004) in the clothes washer analysis by

disaggregating potential adopters by income class. Stoft (1995) offers an alternative expression that avoids the problem of double counting due to dependence among measures on a curve.



Penetration of mitigation technologies: A conceptual framework
Source: Sathaye & Phadke (2011)

Where:

CCE = Cost of conserved energy for an energy-efficiency measure (or mitigation option), in $\$/\text{GJ}^{33}$

I = Incremental Capital cost (\$)

q = Capital recovery factor (yr^{-1})

ES= Annual energy savings (GJ/yr)³⁴

d = Discount rate; and

n = Lifetime of the mitigation option (years)

These savings are estimated by comparing the electricity use of an efficient and an inefficient end-use technology, a compact fluorescent lamp (CFL) vs. an incandescent bulb for example. The comparable device has to be such that it offers the same service in terms of the lumen output, color rendering, and robustness to quality of electricity supply. The above expression can easily be converted to a cost of avoided greenhouse gases by applying emission factors to the affected energy source. Appropriate terms can be added to the equation above to take into account various other costs such as operating and transaction costs (such as search costs), and benefits such as material and labor savings and environmental benefits. (Sathaye & Phadke, 2011)

100W incandescent	23 W compact fluorescent
1,000 hours	10,000 hours
\$1.50 / light bulb	2.50 \$ / light bulb
\$0.125 / kWhr	0,125 / kWhr
\$123 / year	\$27.40 / year

2015 costs of incandescent Vs. compact fluorescent

³³ Dollars per gigajoule

³⁴ Gigajoule per year

Short-term Forecast for U.S. Electricity, Coal, Renewables, and Emissions

- EIA expects the share of U.S. total utility-scale electricity generation from natural gas-fired power plants to rise from 32% in 2017 to 34% in both 2018 and 2019. The forecast generation share from coal in both 2018 and 2019 averages 29%, down from 30% in 2017. The nuclear share of generation was 20% in 2017 and is forecast to average 20% in 2018 and 19% in 2019. Non-hydropower renewables provided slightly less than 10% of electricity generation in 2017 and are expected to provide 10% in 2018 and nearly 11% in 2019. The generation share of hydropower was over 7% in 2017 and is forecast to fall below 7% in both 2018 and 2019.
- EIA forecasts coal production to decline by almost 5% to 736 million short tons (MMst) in 2018 and then increase by 1% to 745 MMst in 2019. Lower expected global demand for U.S. coal exports (down 17% in 2018 and another 5% in 2019) and lower forecasts of coal use in the electric power sector (down 5% in 2018) contribute to the forecast of lower coal production.
- U.S. coal exports were 97 MMst in 2017, a 61% increase from the previous year, but they are expected to decrease in both 2018 and 2019. Exports of metallurgical coal, which are used in the steelmaking process, remain at 55 MMst in 2018 and decline to 54 MMst in 2019. Steam coal exports, which were an estimated 42 MMst in 2017, are expected to decline to 26 MMst and 23 MMst in 2018 and 2019, respectively.
- In 2017, EIA estimates that wind generated on average 697,000 megawatt hours per day (MWh/d). EIA projects that generation from wind will rise to 722,000 MWh/d in 2018 and to 778,000 MWh/d in 2019. If factors such as precipitation and snowpack remain as forecast, conventional hydropower is projected to generate 747,000 MWh/d in 2019, which would make it the first year that wind generation exceeds hydropower generation.
- Total solar electricity generation averaged an estimated 211,000 MWh/d in 2017. EIA projects that it will reach 246,000 MWh/d in 2018 and 294,000 MWh/d in 2019.
- After declining by 0.6% in 2017, EIA projects that energy-related carbon dioxide (CO₂) emissions will increase by 1.0% in 2018 and by another 0.8% in 2019. Energy-related CO₂ emissions are sensitive to changes in weather, economic growth, and energy prices. (*EIA, 2018*)

Price Summary				
	2016	2017	2018	2019
^a West Texas Intermediate. ^b Average regular pump price. ^c On-highway retail. ^d U.S. Residential average.				
WTI Crude Oil ^a (dollars per barrel)	43.33	50.79	58.17	57.51
Brent Crude Oil (dollars per barrel)	43.74	54.15	62.13	61.51
Gasoline ^b (dollars per gallon)	2.15	2.42	2.60	2.58
Diesel ^c (dollars per gallon)	2.31	2.65	2.90	2.86
Heating Oil ^d (dollars per gallon)	2.10	2.51	2.80	2.82
Natural Gas ^d (dollars per thousand cubic feet)	10.04	10.92	10.66	10.94
Electricity ^d (cents per kilowatt-hour)	12.55	12.90	13.17	13.57

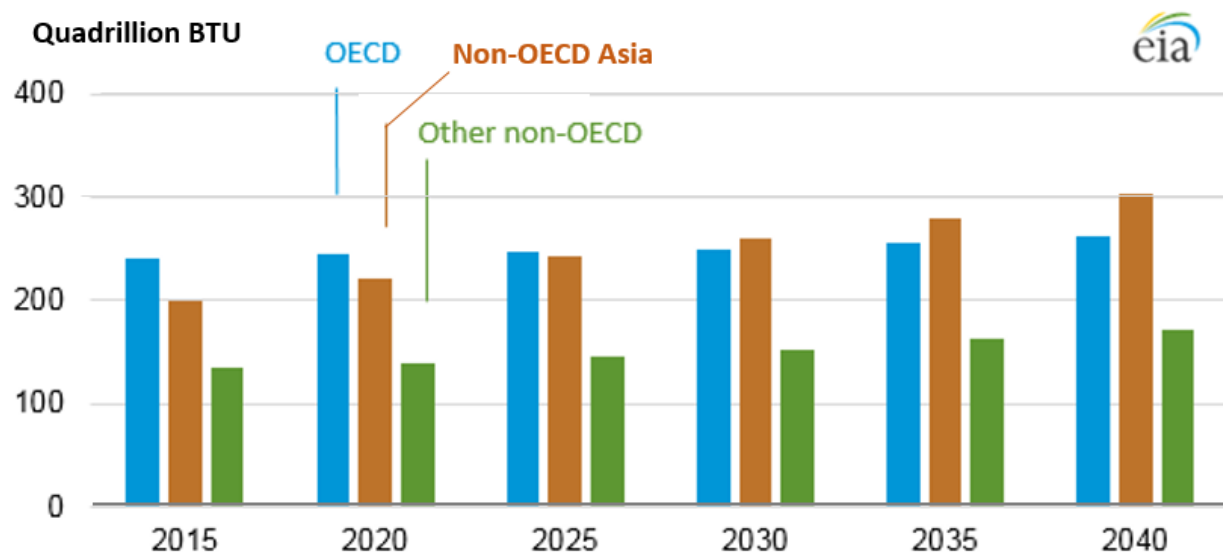
International Energy Outlook

The U.S. Energy Information Administration reported that “total world energy consumption rises from 575 quadrillion British thermal units (Btu) in 2015 to 736 quadrillion Btu in 2040, an increase of 28%. Most of the world’s energy growth will occur in countries outside of the Organization for Economic Cooperation and Development (OECD)³⁵, where strong, long-term economic growth drives increasing demand for energy. Non-OECD Asia (including China and India) alone accounts

³⁵ For consistency, OECD includes all members of the organization as of June 1, 2016, throughout all the time series included in this report. OECD member countries as of June 1, 2016, are Austria, Australia, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. For statistical reporting purposes, Israel is included in OECD Europe. Latvia became a member of the OECD on July 1, 2016, and its membership is not yet reflected in the IEO projections.

for more than half of the world's total increase in energy consumption over the 2015 to 2040 projection period. By 2040, energy use in non-OECD Asia exceeds that of the entire OECD by 41 quadrillion Btu in the IEO 2017 Reference case (Figure 1).” (International Energy Outlook, EIA, 2017)

Figure 1. World energy consumption by country grouping (2015 - 2040)



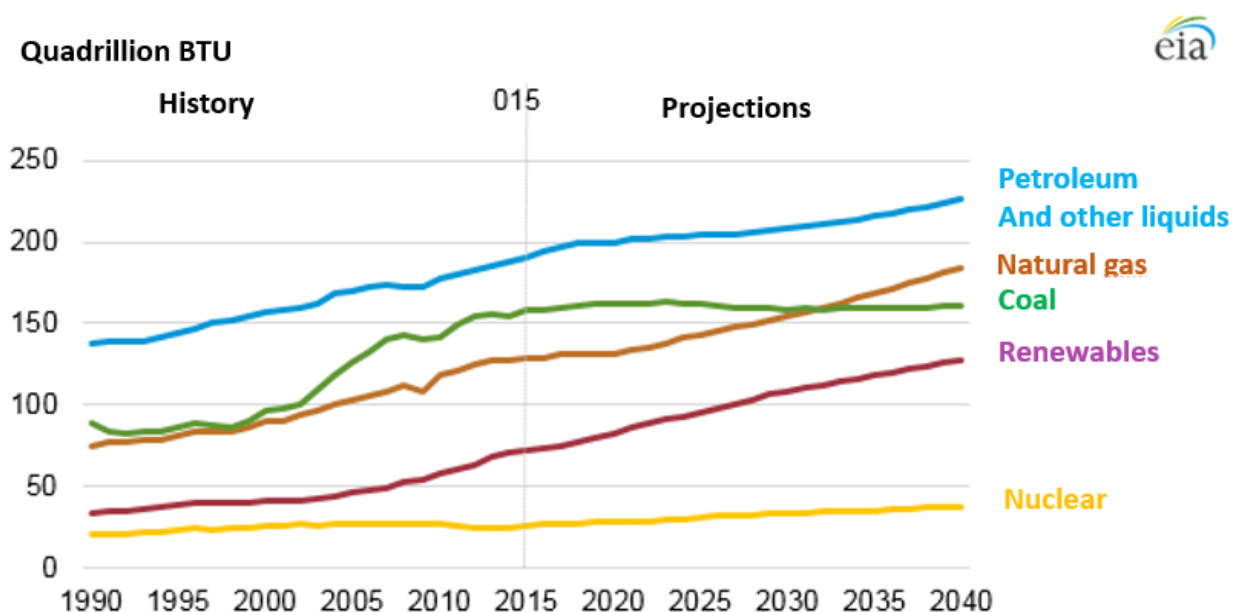
Economic growth—as measured by gross domestic product (GDP)—is a key determinant in the growth of energy demand. The world's GDP (expressed in purchasing power parity terms) rises by 3.0%/year from 2015 to 2040. The fastest rates of growth are projected for the emerging, non-OECD regions, where combined GDP increases by 3.8%/year, driving the fast-paced growth in future energy consumption among those nations. In the OECD regions, GDP grows at a much slower rate of 1.7%/year between 2015 and 2040, at least in part, because of slow or declining population growth in those regions. Economic growth—as measured in gross domestic product (GDP)—is a key determinant in the growth of energy demand. The world's GDP (expressed in purchasing power parity terms) rises by 3.3%/year from 2012 to 2040. The fastest rates of growth are projected for the emerging, non-OECD countries, where combined GDP increases by 4.2%/year. In OECD countries, GDP grows at a much slower rate of 2.0%/year over the projection as a result of their more mature economies and slow or declining population growth trends. The strong projected economic growth rates in the non-OECD drive the fast-paced growth in future energy consumption among those nations.

World energy markets by fuel type

In the long term, the IEO2017 Reference case projects increased world consumption of marketed energy from all fuel sources—except coal, where demand is essentially flat—through 2040 (Figure

2). Renewables are the world's fastest-growing energy source, with consumption increasing by an average 2.3%/year between 2015 and 2040. The world's second fastest-growing source of energy is nuclear power, with consumption increasing by 1.5%/year over that period.

Figure 2. World energy consumption by energy source (2015 – 2040)



Although consumption of non-fossil fuels is expected to grow faster than fossil fuels, fossil fuels still account for 77% of energy use in 2040. Natural gas is the fastest-growing fossil fuel in the projections. Global natural gas consumption increases by 1.4%/year. Abundant natural gas resources and rising production—including supplies of tight gas, shale gas, and coalbed methane—contribute to the strong competitive position of natural gas. Liquid fuels—mostly petroleum-based—remain the largest source of world energy consumption. However, the liquids share of world marketed energy consumption falls from 33% in 2015 to 31% in 2040, as oil prices rise steadily, leading many energy users to adopt more energy-efficient technologies and to switch away from liquid fuels when feasible.

Compared with the strong growth in coal use in the 2000s, worldwide coal use remains flat in the IEO2017 Reference case³⁶. Coal is increasingly replaced by natural gas, renewables, and nuclear power (in the case of China) for electric power generation, and demand for coal also weakens for industrial processes. China is the world's largest consumer of coal, but coal use is projected to

³⁶ The IEO 2017 Reference case projections include the impacts of the U.S. Clean Power Plan (CPP) regulations. According to EIA's analysis, U.S. coal consumption would be 15.2 quadrillion Btu in 2040 without the CPP, relative to the IEO2017 Reference case projection of 10.6 quadrillion Btu.

decline in China by 0.6%/year from 2015 to 2040, and in the combined OECD countries coal also declines by 0.6%/year over that same period. With coal consumption in India and other nations in non-OECD Asia growing over the projection period, worldwide coal consumption is not as low as it would otherwise be in 2040. The coal share of total world energy consumption declines significantly over the projection period, from 27% in 2015 to 22% in 2040.

Liquid fuels

World use of petroleum and other liquid fuels grows from 95 million barrels per day (b/d) in 2015 to 104 million b/d in 2030 and to 113 million b/d in 2040. Most of the growth in liquid fuels consumption is in the transportation and industrial sectors. In the transportation sector, liquid fuels continue to provide most of the energy consumed. Although advances in nonliquids-based transportation technologies are anticipated, they do not fully offset the rising demand for transportation services worldwide. Liquid fuels consumed for transportation increases by an average of 0.7%/year from 2015 to 2040. The transportation sector accounts for 60% of the total increase in delivered liquid fuels use. Most of the remaining increase in liquid fuels consumption is attributed to the industrial sector, where the chemicals industry continues to consume large quantities of petroleum throughout the projection. The use of liquids declines for electric power generation.

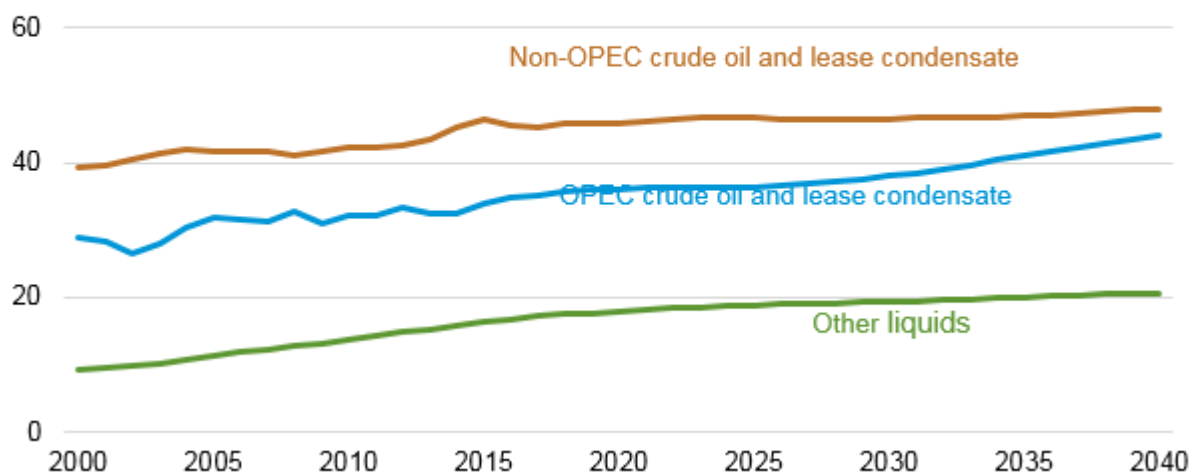
To satisfy the increase in world liquids demand in the IEO2017 Reference case, petroleum and other liquid fuels³⁷ production increases by 16.1 million b/d from 2015 to 2040. The Reference case assumes that countries in the Organization of the Petroleum Exporting Countries (OPEC) will invest in incremental production capacity to maintain a 39%–44% share of total world liquids production through 2040, consistent with their share over the past 15 years. Increasing volumes of crude oil and lease condensate from OPEC producers contribute 10.3 million b/d to the total increase in world liquids production, and crude oil and lease condensate volumes from non-OPEC countries add 1.6 million b/d (Figure 3).

The production of other liquid fuels grows by 4.2 million b/d between 2015 and 2040. Natural gas plant liquids and biofuels combined account for 97% of the increase in other liquids fuels production, and gas-to-liquids, coal-to-liquids, kerogen (shale oil), and refinery gain accounting for the remainder. Other liquids resources from both OPEC and non-OPEC sources grow on average by 0.9%/year in the IEO2017 Reference case, and they remain a relatively small share of total world petroleum and other liquid fuels production. In 2015, other liquids accounted for about 17% of total liquid fuels production; that share is projected to increase modestly to 18% in 2040.

³⁷ Petroleum production is composed of crude oil and lease condensate, including tight oil, shale oil extra-heavy crude oil, field condensate, and bitumen. Other liquid fuels include natural gas plant liquids (NGPL), biofuels, gas-to-liquids (GTL), coal-to-liquids (CTL), kerogen, and refinery gain.

Figure 3. World petroleum and other liquid fuels production

million barrels per day

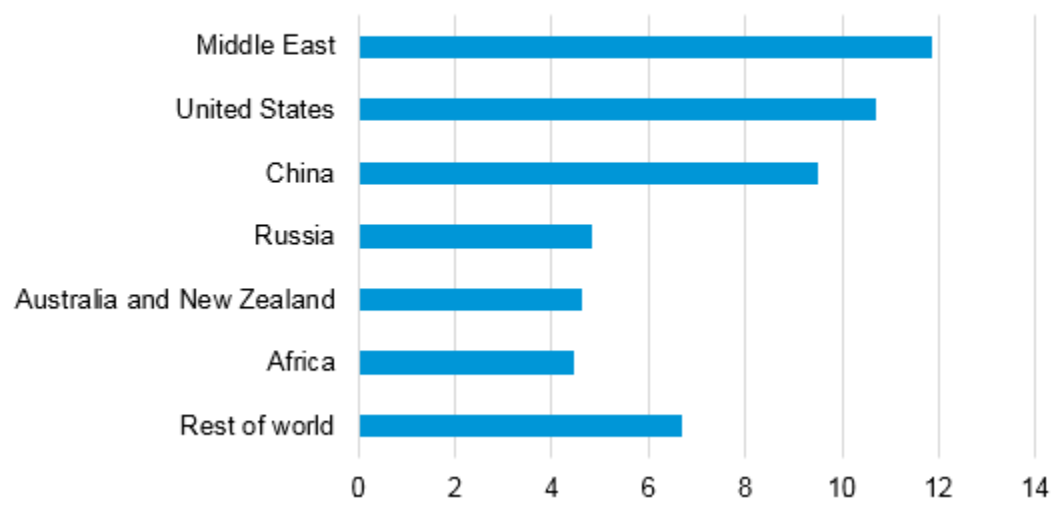


Natural gas

Worldwide natural gas consumption is projected to increase from 124 trillion cubic feet (Tcf) in 2015 to 177 Tcf in 2040 in the IEO2017 Reference case. By energy source, natural gas accounts for the largest increase in world primary energy consumption, second only to renewable energy sources. Abundant natural gas resources and rising production contribute to the strong competitive position of natural gas among other resources. Natural gas remains a key fuel in the electric power sector and the industrial sector. In the power sector, natural gas is an attractive choice for new generating plants because of its relative fuel efficiency. Natural gas also burns more cleanly than coal or petroleum products, and as more governments begin implementing national or regional plans to reduce carbon dioxide (CO₂) emissions, they may encourage the use of natural gas to displace more carbon-intensive coal and liquid fuels.

To meet the growth in natural gas demand projected in the IEO2017 Reference case, the world's natural gas producers increase supplies by 42% from 2015 to 2040. The largest increases in natural gas production from 2015 to 2040 occur in the Middle East (11.8 Tcf), China (9.5 Tcf), the United States (10.7 Tcf), and Russia (4.8 Tcf) (Figure 4). In Russia, production growth is supported primarily by increasing development of resources in the country's Arctic and eastern regions. U.S. production growth comes mainly from shale resources. In China, most growth in the long-term comes from the country's development of its shale resources, which are projected to account for more than half of its total natural gas production in 2040.

**Figure 4. World increase in natural gas production, 2015-40
(trillion cubic feet)**



World natural gas trade, both by pipeline and by shipment in the form of liquefied natural gas (LNG), is poised to increase in the future. World LNG trade nearly triples, from about 12 Tcf in 2015 to around 31 Tcf in 2040. Most of the near-term increase in liquefaction occurs in Australia and North America, where a number of new liquefaction projects are planned or under construction, many of which will become operational within the next decade. U.S. LNG exports are projected to increase significantly over the projection period and to account for more than 60% of total U.S. natural gas exports in 2040.

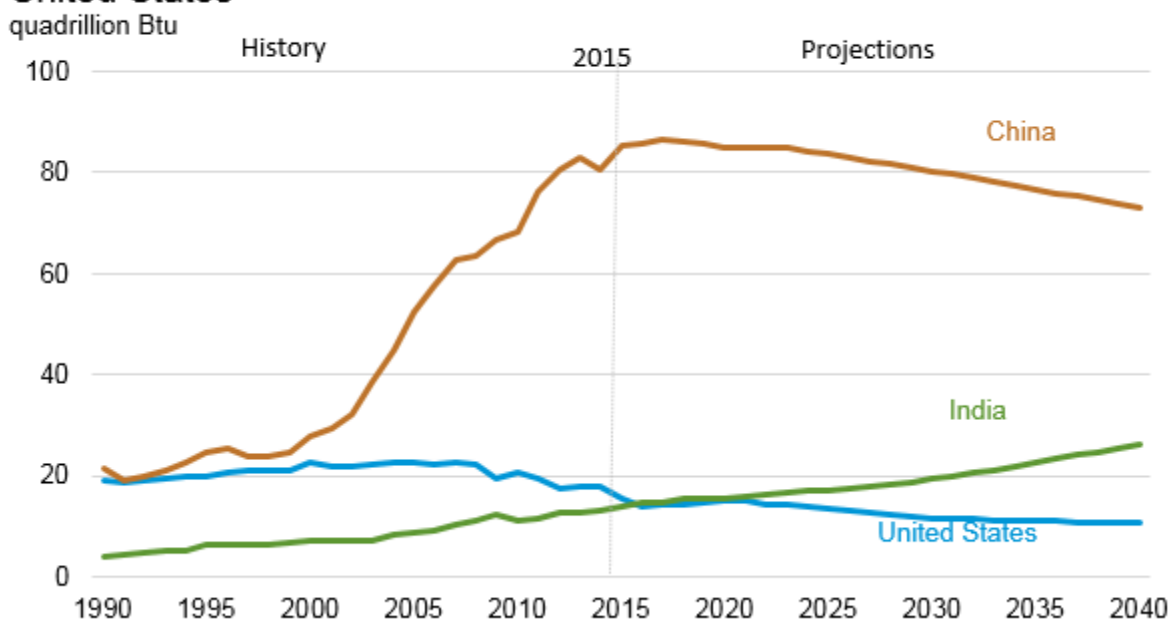
In addition to the strong growth in LNG trade, natural gas trade by pipeline also increases in the IEO2017 Reference case, as several new long-distance pipelines are completed, and existing infrastructure expands through 2040. Currently, the largest volumes of natural gas traded internationally by pipeline are in Europe (among a number of OECD and non-OECD countries) and in the Americas (between Canada and the United States). U.S. pipeline exports to Mexico are also becoming a more important component of trade in the Americas. Mexican pipeline imports from the United States have more than quadrupled since 2009, and they are expected to continue to increase over the next several years. By 2018, the United States becomes a net exporter of natural gas on an average annual basis, as pipeline exports to Mexico and LNG export volumes grow.

Coal

Worldwide consumption of coal remains flat throughout the IEO2017 Reference case, rising by 0.2%/year from 2015 to 2025, and then declining by 0.1%/year, reaching 161 quadrillion Btu in 2040. The top three coal-consuming countries are China, the United States, and India, which

together account for around 70% of world coal use throughout the projection. China alone currently accounts for slightly more than half of the world's total coal consumption, but a slowing economy and plans to implement policies to address air pollution and climate change mean that coal use in China will decline over the projection period (Figure 5). Coal consumption projections in the IEO2017 Reference case include the impact of the Clean Power Plan (CPP) regulations in the United States. Excluding the CPP would increase world coal consumption to 165 quadrillion Btu in 2040, 4 quadrillion Btu higher than the Reference case.

Figure 5. Coal consumption in China, India, and the United States



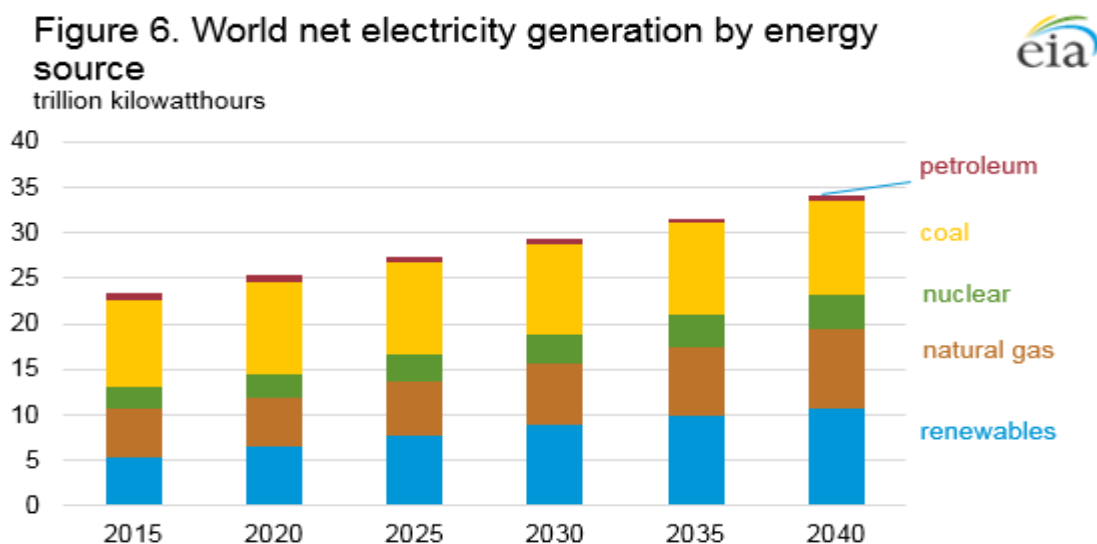
Global coal production is projected to remain at about 9 billion short tons from 2015 to 2040. Although the total world production volumes do not change over the projection, the producer profiles will likely change. China, the United States, and India are currently the world's largest coal producers, but India is the only one of the three countries where coal production increases in the IEO2017. Coal production in both China and the United States declines through 2040. In the projection, India's coal production overtakes U.S. production by 2025, and by 2040 India is projected to produce twice as much coal as the United States. Outside of India, coal production is expected to increase primarily in Australia, in nations of Asia outside of China and India, and in Africa. In the IEO2017 Reference case, China—currently the world's leading coal producer—will experience a decline in its market share of world coal production, which falls from 50% in 2015 to 42% in 2040, as India's share rises from 8% in 2015 to 14% in 2040.

Electricity

In the IEO2017 Reference case, world net electricity generation increases by 45%, rising from 23.4 trillion kilowatt-hours (kWh) in 2015 to 34.0 trillion kWh in 2040. Electricity is the world's fastest-growing form of end-use energy consumption, as it has been for many decades. Power systems continue to evolve from isolated, noncompetitive grids to integrated national and international markets.

The strongest growth in electricity generation is projected to occur among the developing, non-OECD nations. Increases in electricity generation in non-OECD countries average 1.9%/year in the Reference case as rising living standards increase demand for home appliances and electronic devices, and for commercial services, including hospitals, schools, office buildings, and shopping malls. In the OECD nations, where infrastructures are more mature and population growth is relatively slow or declining, electric power generation increases by an average of 1.0%/year from 2015 to 2040 in the IEO2017 Reference case.

Long-term global prospects continue to improve for generation from renewable energy sources and natural gas (Figure 6). Renewables are the fastest-growing source of energy for electricity generation, with average increases of 2.8%/year from 2015 to 2040. Non-hydropower renewable resources are the fastest-growing energy sources for new generation capacity in both the OECD and non-OECD regions. Non-hydropower renewables accounted for 7% of total world generation in 2015; their share in 2040 is 15% in the IEO2017 Reference case, with more than half of the growth coming from wind power. After renewable energy sources, natural gas and nuclear power are the next fastest-growing sources of energy used to generate electricity.



Many countries, particularly those in the OECD, have enacted environmental policies and regulations intended to increase the pressure on electric power generators to reduce greenhouse gas emissions from electric power plants by decreasing the use of fossil fuels. As a result, the consistent role of coal as the least expensive fuel for electric power plants will change. Coal-fired net generation increases by 0.4%/year, compared to the 2.8%/year increase in projected renewable generation. By 2040, generation from renewable energy sources surpasses generation from coal on a worldwide basis.

Electricity generation from nuclear power worldwide increases from 2.5 trillion kWh in 2015 to 3.2 trillion kWh in 2030 and to 3.7 trillion kWh in 2040 in the IEO2017 Reference case. Concerns about energy security and greenhouse gas emissions support the development of new nuclear generating capacity, but reactor retirements and opposition from local populations keep nuclear from expanding in many parts of the world. Virtually all of the projected net expansion in world installed nuclear power capacity occurs in non-OECD countries, led by China's addition of 111 gigawatts (GW) of nuclear capacity from 2015 to 2040.

The combined capacity of all OECD nuclear power plants drops by a net 14 GW from 2015 to 2040. Among the OECD regions, only South Korea has a sizable (16 GW) increase in nuclear capacity. Capacity reductions in the United States, Canada, OECD Europe, and Japan (where nuclear capacity in 2040 in the Reference case remains below the total before the March 2011 Fukushima Daiichi nuclear disaster) more than offset the increase in South Korea's nuclear capacity.

World delivered energy use by sector

Residential and commercial buildings

The buildings sector is made up of residential and commercial end users and presently accounts for 20% of the total delivered energy consumed worldwide. In the residential sector—where energy use is defined as the energy consumed by households, excluding transportation uses—world delivered energy consumption grows by an average of 1.1%/year from 2015 to 2040. In non-OECD countries, residential energy use increases by an average of 1.7%/year from 2015 to 2040, a result of strong economic growth and rising standards of living. In the OECD economies, residential sector energy use grows much more slowly, averaging 0.3%/year over the projection period. The lower growth rate in OECD countries results from relatively slow GDP and population growth, as well as improvements in building shells and in the efficiency of appliances and equipment.

In the commercial sector, energy consumption occurs in enterprises engaged in commercial-scale activity (often called the service sector). Globally, the IEO2017 Reference case projects average growth in commercial energy use of 1.2%/year from 2015 to 2040, with the highest rates of growth in non-OECD nations. Non-OECD commercial sector delivered energy use increases by 1.9%/year from 2015 to 2040. OECD commercial energy use expands by 0.7%/year. Slow expansion of GDP and low or declining population growth in many OECD nations contribute to slower anticipated rates of growth in commercial energy demand. In addition, continued efficiency improvements moderate the growth of energy demand over time, as relatively inefficient equipment is replaced with newer, more efficient stock.

Industrial

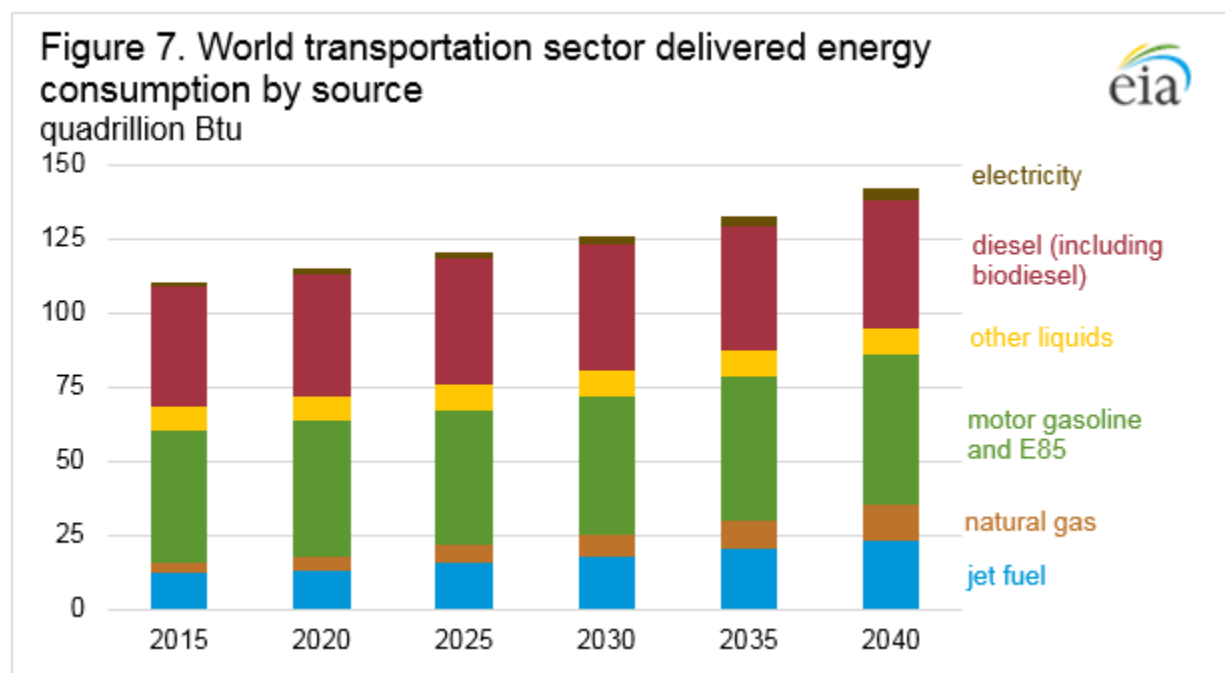
The industrial sector continues to account for the largest share of delivered energy consumption to end users throughout the projection period. In the IEO2017 Reference case, the world's industrial sector accounts for more than half of total delivered energy use through 2040. Although the industrial sector is the largest energy-consuming end-use sector throughout the projection, it is not the fastest-growing end-use sector, with growth in the buildings and transportation sectors outpacing industrial sector growth through 2040.

In the IEO2017 Reference case, worldwide industrial sector energy consumption is projected to increase by an average of 0.7%/year from 2015 to 2040. Most of the long-term growth occurs in non-OECD countries. From 2015 to 2040, industrial energy consumption in non-OECD countries grows by an average of 0.8%/year, compared with 0.2%/year in OECD countries. Despite the expected growth in non-OECD industrial sector energy use, the industrial share of total delivered energy in the non-OECD declines over the projection period, from 64% in 2015 to 58% in 2040. Many emerging non-OECD economies, especially China, move away from energy-intensive manufacturing, while energy use grows more rapidly in all other end-use sectors.

Transportation

Energy use in the transportation sector includes the energy consumed in moving people and goods by road, rail, air, water, and pipeline. In the IEO2017 Reference case, delivered energy consumption in the world transportation sector increases at an annual average growth of 1.0%. All of the growth in transportation energy use occurs in the developing, non-OECD economies from 2015 to 2040. Strong economic growth leads to rising standards of living that translate to demand for personal travel and freight transport to meet growing consumer demand for goods in non-OECD nations. In OECD nations, where consuming patterns are already well established, relatively slower economic and population growth rates and strong vehicle efficiency improvements lead to a nearly 2% decrease in transportation energy use between 2015 and 2040.

Worldwide, liquid fuels remain the dominant source of transportation energy consumption, although its share of total transportation energy declines over the projection period, from 95% in 2015 to 88% in 2040. World liquid fuels used in the transportation sector grows by 20 quadrillion Btu, from 105 quadrillion Btu in 2015 to 125 quadrillion Btu in 2040. Jet fuel consumption shows the largest gain (11 quadrillion Btu), followed by motor gasoline—including ethanol blends (7 quadrillion Btu), and diesel (3 quadrillion Btu) (Figure 7). Motor gasoline remains the largest transportation fuel, but its share of total transportation energy consumption declines from 40% in 2015 to 36% in 2040.



Natural gas—driven by favorable economics in heavy trucking—and electricity—because of its use in passenger rail and light-duty vehicles—are expected to be the fastest-growing forms of transportation energy. The share of natural gas as a transportation fuel grows from 4% in 2015 to 9% in 2040. Natural gas consumption for passenger and freight transportation—excluding natural gas pipeline consumption—grows to nearly six times its 2015 level by 2040, reaching 9 quadrillion Btu in 2040. Electricity consumption in the transportation sector rises to more than 4 quadrillion Btu in 2040, when electricity accounts for 3% of global transport energy use.

World carbon dioxide emissions

World energy-related carbon dioxide (CO₂) emissions rise from 33.9 billion metric tons in 2015 to 36.4 billion metric tons in 2030 and to 39.3 billion metric tons in 2040 in the IEO2017 Reference case—an increase of 16% over that period. Much of the growth in emissions is attributed to developing non-OECD nations, many of which continue to rely on fossil fuels to meet the growth

in energy demand. In the IEO2017 Reference case, non-OECD emissions in 2040 total 26.9 billion metric tons, or about 25% higher than the 2015 level. In comparison, OECD emissions remain at about the same level of 12.4 billion metric tons throughout the projection period.

On November 4, 2016, the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement became effective, with signatory parties committing to take actions to keep the rise in the global temperature to less than 2 degrees Celsius above preindustrial levels when fully implemented³⁸. Parties to the agreement were asked to submit their first nationally determined contributions (NDCs) that listed the actions they would take to achieve the Paris Agreement goals. NDCs can be adjusted if they are expected to be—in aggregate—insufficient to meet the agreed-upon 2-degree long-term goal. As of September 2017, 155 parties have submitted their NDCs to the UNFCCC³⁹.

EIA tried to incorporate some specific details of the NDCs into the IEO2017 Reference case, such as renewable energy and other lower-emitting generation mix goals. However, a great deal of uncertainty remains about the full implementation of policies to meet the stated goals, because most commitments have been made only through 2030, and it is uncertain how they will ultimately achieve these goals. In addition, beyond energy-related CO₂, other gases (e.g., methane) and sources (e.g., deforestation) that contribute to net greenhouse gas (GHG) emissions but are not considered in IEO2017 projections could have significant effects on national or regional shares of total GHG emissions and the achievement of NDCs. In the future, EIA's projections for CO₂ emissions may change significantly as laws and policies aimed at reducing GHG emissions are implemented and enforced, or if existing laws are enhanced.

On June 1, 2017, the United States announced that it would withdraw from the Paris Agreement. However, the primary mechanism for U.S. participation is the Clean Power Plan (CPP), which is still in place, but currently being challenged in court. Even with the CPP, the United States does not meet its NDC targets based on reductions projected from compliance with the CPP alone in the Reference case.

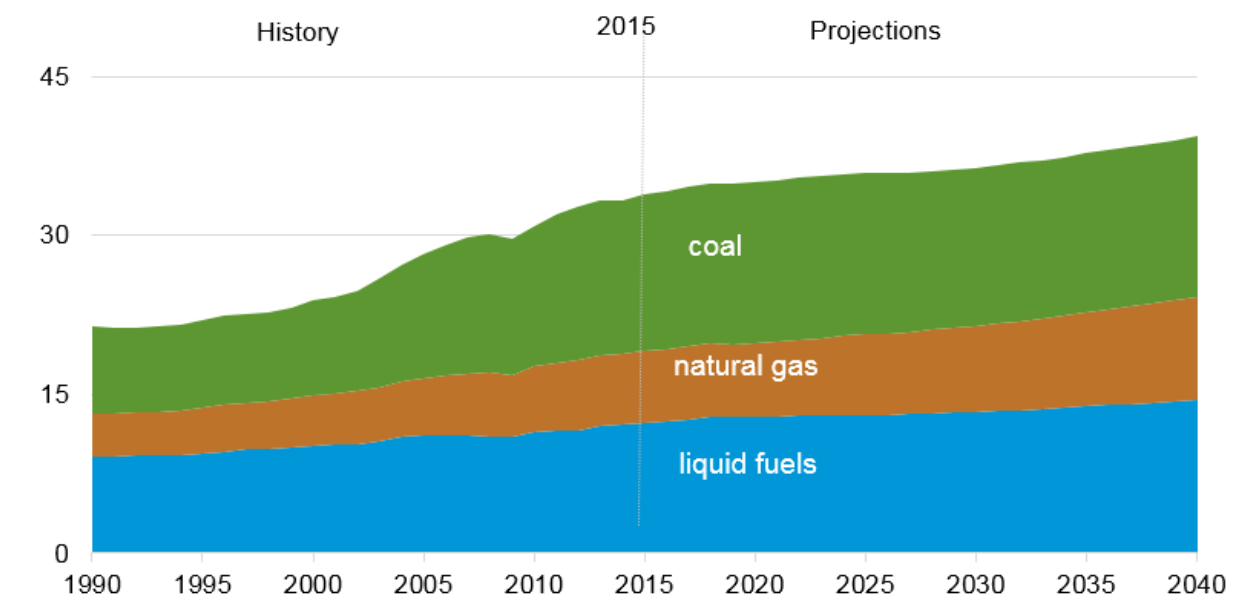
World energy-related CO₂ emissions from the use of liquid fuels and natural gas increase in the IEO2017 Reference case, while coal-related emissions remain largely flat through 2040 (Figure 8). CO₂ emissions related to the combustion of liquids grow at an annual rate of 0.7% from 2015 to 2040. With the exception of some penetration of electric- and natural gas-powered vehicles, no ready substitutes are available for liquids in the transportation sector, which drives up the demand for liquids. By 2040, the global emissions from liquid fuels are almost the same as those from coal.

³⁸ See "The Paris Agreement," http://unfccc.int/paris_agreement/items/9485.php.

³⁹ See "NDC Registry (interim)," <http://www4.unfccc.int/ndcregistry/Pages/Home.aspx>

CO₂ emissions from natural gas rises by 1.4%/year from 2015 to 2040, as natural gas increasingly displaces coal for electricity generation.

Figure 8. World energy-related carbon dioxide emissions by fuel type
billion metric tons



Worldwide coal-related CO₂ emissions are relatively stable throughout the projection, increasing by only 0.1%/year from 2015 to 2040, or 260 million metric tons. Coal consumption in China and the United States—currently two of the world’s largest coal-consuming nations—drops substantially in the Reference case, with coal-related CO₂ emissions declining by 1,166 million metric tons in China and by 478 million metric tons in the United States. However, coal use in India and other developing nations continues to increase, offsetting the decreases in coal-related CO₂ emissions that occur elsewhere.

Role of technology in the future of energy

Current trends in energy supply and use are patently unsustainable – economically, environmentally and socially. Without decisive action, energy-related emissions of carbon dioxide (CO₂) will more than double by 2050 and increased fossil energy demand will heighten concerns over the security of supplies. We can and must change our current path, but this will take an energy revolution; and low-carbon energy technologies will have a crucial role to play. Energy efficiency, many types of renewable energy, carbon capture and storage (CCS), nuclear power and new transport technologies will all require widespread deployment if we are to sharply reduce

greenhouse gas (GHG) emissions. Every major country and sector of the economy must be involved. The task is urgent if we are to make sure that investment decisions taken now do not saddle us with suboptimal technologies in the long term.

Dooley et al. (2006) estimated CO₂ capture costs ranging from zero (for plants that already separate a high purity CO₂ stream) to \$57 per ton CO₂ (for a low-purity natural gas-fired combined-cycle power plant), and compression costs of \$6–12 per ton CO₂. Transportation costs were estimated to range from \$0.2 to \$10 per ton CO₂, with the low-cost end of the range being for large-volume pipelines. Geologic storage costs are also likely to vary with the specific application. Dooley et al. estimated costs of minus \$18 to plus \$12 per ton CO₂ for saline aquifer, enhanced oil recovery (EOR), and enhanced coal bed methane-injection projects, with the negative- and low-cost estimates applicable when cost recovery through sale of hydrocarbons is possible.

Awareness is growing on the need to turn political statements and analytical work into concrete action. To spark this movement, at the request of the G7 nations, the International Energy Agency (IEA) is leading the development of a series of roadmaps for some of the most important technologies. By identifying the steps needed to accelerate the implementation of radical technology changes, these roadmaps will enable governments, industry and financial partners to make the right choices – and in turn help societies to make the right decisions. Energy storage technologies can support energy security and climate change goals by providing valuable services in developed and developing energy systems. A systems approach to energy system design will lead to more integrated and optimized energy systems. Energy storage technologies can help to better integrate our electricity and heat systems and can play a crucial role in energy system decarbonization by:

- improving energy system resource use efficiency
- helping to integrate higher levels of variable renewable resources and end-use sector electrification
- supporting greater production of energy where it is consumed
- increasing energy access
- improving electricity grid stability, flexibility, reliability and resilience.

While some energy storage technologies are mature or near maturity, most are still in the early stages of development and currently struggle to compete with other non-storage technologies due to high costs. They will require additional attention before their potential can be fully realized. Governments can help accelerate the development and deployment of energy storage technologies by supporting targeted demonstration projects for promising storage technologies and by eliminating price distortions that prevent storage technologies from being compensated for the

suite of services they provide. Energy storage technologies have the potential to support our energy system's evolution, but realizing this potential will require government, industry, academia and financial stakeholders to work together to help overcome existing barriers. (van der Hoeven, 2014)

In exploring the role of technology in the future of energy, it is important to keep in mind that while technology is and will continue to be a momentous component in the way we explore, discover, extract, distribute, and use energy, it will not make or create new sources of energy. This prospect begets some pessimism and bring to light the gray areas in our rosy outlook for the future of energy. Authors such as Martenson (2011) think that when we transform energy, we lose energy to the universe along the way in the form of diffuse heat. Therefore, it's appropriate to view the fossil fuel store of the Earth as if it were a gigantic pile of food that can only be eaten once. When we eat this bounty of the earth – our inheritance – it's gone, never to be seen again. And technology holds little sway over economic and sociological impediments to rapid energy transitions. Because economic order, complexity, and growth all require energy, and because our original allotment of energy cannot be increased by technology, technology alone cannot “fix” the predicament of needing more energy than we have. Technology has an enormous role to play in helping us to use our energy more wisely and with greater efficiency and utility...Technology can provide a lot of things, but it cannot violate the laws of the universe. They are immutable and working just as they always have.

If we want to take that pessimism one step further – still while acknowledging the importance of technology in the future of energy, there is something else we need to put in perspective: the effect of the transition from fossil fuels on climate and the environment. In that regard, Laughlin (2001) states that climate and the environment will continue to be problematic through the transition away from fossil fuels, notwithstanding the cessation of carbon dioxide buildup in the air and the plateauing of global temperature increases. The core problem, ever-increasing human demands on the Earth's resources, will still be present and may even have worsened. People of this future time will still want clean air and water, natural surroundings, large tracts of land kept wild, fisheries and forests kept healthy, and factories somewhere other than their back yards. They might not be able to have all these things, however, perhaps because the Earth is warmer, but mostly because these things will come at a cost in economic well-being (for some) and because they'll be incompatible with large populations. Human burdens on the Earth are a specific case of burdens that plants and animals impose generally on their respective ecological niches. The Earth's limited ability to sustain such burdens is a major factor in the fight for survival and thus the rise and fall as species over the span of geologic time. Even though the final outcome of the transition away from fossil fuels is likely to be positive, the transition itself could be terrible. It will a major global event, like an ice age or a comet impact, not a mere budgeting shortfall or overcrowded highway that an act of Congress can whisk away.

Whether one is pessimistic or optimistic about transition from fossil fuels, it will happen. Right now, our use of energy is unsustainable, meaning likely to negatively impact future generations. We use too much of it and we use it inefficiently. Technology does not create energy, but it can help improve the way discover, extract or tap into, distribute, and consume it. Thus, technology can transform our energy system. It's not easy to predict what technology will exactly look like, but we know for sure what we expect from future technologies, especially in the field of energy. According to National Academy of Sciences et al., 2009, transforming U.S. system will require the continued improvement of existing technologies, as well as the development and national-scale development of new technologies, including:

- Existing and new efficiency technologies
- Existing and new energy-supply technologies – including wind, solar, geothermal, biofuels, and nuclear power.
- Carbon capture and storage (CCS) technologies on a large-enough scale to reduce CO₂ emissions from the burning of fossil fuels.
- Modern electrical transmission and distribution systems to accommodate 21st-century electricity supplies (especially from intermittent resources such as wind and solar), support future growth in electricity demand, and enable national-scale deployments of sophisticated demand-side technologies.

CCS technologies have been demonstrated at commercial scale, but no large power plant today captures and stores its CO₂. The few large storage products now underway are all coupled to CO₂ capture at nonpower facilities; for example, in one offshore operation in Norway, 50 million standard cubic feet per day of CO₂ (1 million tons per year) are separated from natural gas before the fuel is inserted into the European grid; the CO₂ is injected under the North Sea. CO₂ storage could be implemented in oil and gas reservoirs, deep formations with salt water and deep coal beds.

As to nuclear energy, the nuclear plants in place in the United States were built with technologies developed in the 1960s and 1970s. In the intervening decades, ways to make better use of existing plants have been developed, along with new technologies that improve safety and security, decrease costs, and reduce the amount of generated waste – especially high-level waste. These technological innovations, now available or under development, include the following:

- *Improvements to existing plants:* modifying existing plants to increase power output, referred to as “uprates”, is considerably less costly than adding new capacity, and additional power uprates are expected in the future.
- *Evolutionary nuclear plants:* new plants constructed will be based on modifications of existing plant designs, using technologies that are largely ready for deployment now.
- *Alternative nuclear plants:* thermal neutron reactor designs and fast neutron reactor designs. All current U.S. reactors are thermal. Thermal neutron reactor designs include plants that operate at higher temperatures, thereby offering process heat (which could be used, for example, for producing hydrogen) in addition to electricity production. On the other hand, fast neutron reactor designs include plants intended to destroy undesirable isotopes associated with much of the long-lived radioactive waste burden in used fuel, and, in some cases, to breed additional fuel. These plants could reduce the volume of and the heat emitted by long-lived nuclear waste that must go to a repository for disposal. Much R&D will be needed before any of these alternative reactor types can be expected to make significant contributions to the U.S. energy supply.
- *Alternative fuel cycles:* The United States currently employs a once-through nuclear fuel cycle in which used fuel is disposed of after removal from the reactor. In contrast, alternative (closed) nuclear fuel cycle involves the reprocessing of used fuel to produce new fuel. In principle, these alternative fuel cycles could extend fuel supply and reduce the amount of long-lived nuclear waste requiring disposal. The reprocessing technology, in common use today, called plutonium and uranium extraction (PUREX), is associated with an increased risk of nuclear weapons proliferation, as well as an increased risk of theft or diversion of nuclear materials, because it yields a separate stream of plutonium. A modified version of PUREX that keeps uranium with the plutonium could result in modestly reduced proliferation risks relative to PUREX and could be deployed after 2020. Other alternatives are being investigated, but they are unlikely to be ready for commercial deployment before 2035. R&D is still needed on fuel design, separation processes, fuel fabrication, and fuel qualification, as well as on the associated alternative reactors.

Furthermore, the NAS warns that the national-scale deployment of new technologies will have learning curves and will entail a variety of risks, and such deployments can have unforeseen economic and environmental impacts. Thus, in addition to evaluating the potential contributions of existing and emerging technologies, we also need to understand the non-technological

constraints on their rates of deployment and to decide on the roles of the public and private sectors and current and future generations for shouldering deployment costs and risks. In short, transformation of our nation's energy system will require a sustained national effort involving carefully focused technology, research, development, and demonstration. Realignments of public policies and regulations; substantial capital investments; and allied resources (material, infrastructure, and people) in both the public and the private sectors...Many energy-supply and end-use technologies are ready for significant development now, but others will not be available until they have been demonstrated at scale⁴⁰ or until important technological barriers have been overcome. Of course, once a technology is ready for deployment, a number of important economic, regulatory and policy, and resource factors will govern the actual pace, scale, and cost of deployment. Especially important in this regard are the prices for fossil fuels and other materials, the availability and costs of specialized resources and capital, and key public policies and regulations that address, for example, renewable-energy portfolio standards, building regulations, corporate average fuel economy (CAFE) standards, and carbon prices⁴¹. Because of the uncertainties about how these factors will play out in the decades ahead, the technology-deployment options...should be considered as important first-step technology assessment rather than as forecasts as to which technologies will be implemented and how important each technology will be.

Unpredictable developments in technology could have dramatic impacts on future deployment options. There is little doubt that beyond the next few decades, new technologies – which employ, for example, advanced materials and innovative chemical processes not yet in view – could play transformative roles. Along these same lines, better understanding of how geoengineering⁴² or how the ecology of microbial systems affects climate could yield new insights on managing new greenhouse gas emissions from energy production and use. In fact, unexpected breakthroughs might even enable fusion technology to contribute to U.S. energy supply before 2050. Given the contingent nature of technology development, there will always be uncertainties in future technology pathways. (National Academy of Science et al., 2009)

⁴⁰ The scale of a demonstration should be large enough to give an investor or company the confidence in the technology's economics, performance, and regulatory acceptability to build a commercial plant. The actual scale of demonstration required will vary across technologies.

⁴¹ The term "carbon prices" denotes the cost that would be imposed through statute or regulation for emitting CO₂ and other greenhouse gases to the atmosphere.

⁴² Geoengineering involves the use of technology to change the environment of Earth. For example, the emission of greenhouse gases into the atmosphere from human activity is now judged with very high confidence by climate scientists to cause global warming. Some scientists have proposed geoengineering as a way to reduce global warming – such as by changing the amount of sunlight that reaches the planet's lower atmosphere and surface or by removing greenhouse gases from the atmosphere.

ENERGY SUPPLY AND USE OF TECHNOLOGIES IN THE FUTURE	
In summary, the role of technology in the future of energy, especially in the United States, will show at eight levels:	
• With a sustained national commitment, the United States could obtain substantial energy efficiency improvements, new sources of energy, and reductions in greenhouse gas emissions through the accelerated deployment of existing and emerging energy-supply and end-use technologies.	• The deployment of existing energy efficiency technologies is the nearest-term and lowest-cost option for moderating our nation's demand for energy...The potential energy saving available from accelerated deployment from existing energy efficient technologies in the building, transportation, and industrial sectors could more than offset the U.S. Energy Information Administration's (EIA) projected increases in energy consumption through 2030.
• The United States has many promising options for obtaining new supply of electricity and changing its supply mix during the next two to three decades, especially if carbon capture and storage and evolutionary nuclear plants can be deployed at required scales. However, the deployment of these new supply technologies is very likely to result in higher consumer prices for electricity.	• Expansion and modernization of the nation's electrical transmission and distribution systems (i.e., the power grid) are urgently needed. Expansion and modernization would enhance reliability and security, accommodate changes in load growth and electricity demand, and enable the deployment of new energy efficiency and supply technologies, especially intermittent wind and solar energy.
• Petroleum will continue to be an indispensable transportation fuel...Maintaining current rates of domestic petroleum production...will be challenging. These are limited options for replacing petroleum or reducing petroleum use before 2020, but there are more substantial longer-term options that could begin to make significant contributions in the 2030 – 2035 timeframe.	• Substantial reductions in greenhouse gas emissions from the electricity sector are achievable over the next two to three decades through a portfolio approach involving the widespread deployment of energy efficiency technologies; renewable energy; coal; natural gas, and biomass with carbon capture and storage; and nuclear technologies. Achieving substantial greenhouse gas reductions in the transportation sector over the next two to three decades will also require a portfolio approach involving the widespread deployment of energy efficiency technologies, alternative liquid fuels with low life-cycle CO₂ emissions, and light-duty vehicles electrification technologies.
• To enable accelerated deployments of new energy technologies starting around 2020, and to ensure that innovative ideas continue to be explored, the public and private sectors will need to perform extensive research, development and demonstration over the next decade.	• A number of current barriers are likely to delay or even prevent the accelerated deployment of the energy-supply and end-use technologies. Policies and regulatory actions, as well as other incentives, will be required to overcome these barriers.
Source: NAS	

But, can we speculate beyond the year 2050? Do we really know what the future has in store for us in terms of energy sources, their exploitation, distribution, and use, in other words, their economics? Will energy still be the primary source of wealth for nations? No one knows for sure. However, commenting on Robert Laughlin's book, *Powering the Future*, its publisher states that two hundred years from now, we will seek energy in unlikely places. Forget deep-water drilling in the Gulf of Mexico or coal mines in central Pennsylvania – in the centuries to come, remotely controlled robots will scour the deep seas for pockets of geothermal heat; we will be manipulating animal manure to produce microbe-generated fuel; we may even be mining landfills as a carbon source. It sounds like science fiction, but such far-fetched ideas will be an important component of our energy future...when fossil fuels have run out and when outlandish concepts become feasible options for supplying our energy needs. In the year 2211, we will still drive cars, fly in airplanes, and flip a switch to turn on the lights, but our ways of powering these technologies will of necessity be completely different. Once fossil fuels have been depleted, Laughlin argues, the laws of economics will take over, and consumers and providers alike will eagerly adopt the next cheapest thing, whether it's nuclear energy, solar thermal arrays, or the wise reuse of garbage and animal waste. (Laughlin, 2011)

For his part, (Martenson, 2011) thinks that we should continuously ask ourselves questions such as: how can we change the future? Where do we even start? We must begin by taking an unflinching look at our predicament and facing it squarely. No more kicking the can the road for the next generation to deal with, and no more pretending that real issues don't exist. The measure of any generation is what it does with what it has. Luckily, we still have abundant natural resources, and we have all the information we need to make a better future. But our window of opportunity is closing rapidly. Solutions are becoming fewer, and options are shrinking. Someday, they will disappear entirely, our opportunities to be proactive will have been permanently squandered, and we will be left to choose among an unpleasant palette of reactions to an unfortunate set of circumstances that are mostly out of our control.

I think that if our goal is to ultimately move away from fossil fuels, we should work on our energy storage technologies for the sun will never shine during the night and the wind will never blow constantly. Storing the energy when there is a surplus of it and returning it back when there is a lack of it must be mastered.

“One of the distinctive characteristics of the electric power sector is that the amount of electricity that can be generated is relatively fixed over short periods of time, although demand for electricity fluctuates throughout the day. Developing technology to store electrical energy so it can be available to meet demand whenever needed would represent a major breakthrough in electricity distribution. Helping to try and meet this goal, electricity storage devices can manage the amount of power required to supply customers at times when need is greatest, which is during peak load.

These devices can also help make renewable energy, whose power output cannot be controlled by grid operators, smooth and dispatchable.

They can also balance microgrids to achieve a good match between generation and load. Storage devices can provide frequency regulation to maintain the balance between the network's load and power generated, and they can achieve a more reliable power supply for high tech industrial facilities. Thus, energy storage and power electronics hold substantial promise for transforming the electric power industry.

High voltage power electronics, such as switches, inverters, and controllers, allow electric power to be precisely and rapidly controlled to support long distance transmission. This capability will allow the system to respond effectively to disturbances and to operate more efficiently, thereby reducing the need for additional infrastructure. A major challenge being addressed by DOE is to reduce the cost of energy storage technology and power electronics and to accelerate market acceptance. (U.S. Department of Energy, 2018)

A good example is the energy storage program of the U.S. Office of electricity delivery and energy reliability. As energy storage technology may be applied to a number of areas that differ in power and energy requirements, OE's Energy Storage Program performs research and development on a wide variety of storage technologies. This broad technology base includes batteries (both conventional and advanced), electrochemical capacitors, flywheels, power electronics, control systems, and software tools for storage optimization and sizing. The Energy Storage Program works closely with industry partners, and many of its projects are highly cost-shared.

The Program also collaborates with utilities and State energy organizations such as the California Energy Commission, Massachusetts Clean Energy Center (MASS CEC), Oregon DOE, Vermont, Hawaii, Washington, and New York State Energy Research and Development Authority (NYSERDA), to name a few, to design, procure, install, and commission major pioneering storage installations that are up to several megawatts in size. It also supports analytical studies on the technical and economic performance of storage technologies as well as technical evaluations of both ES systems components and operating systems. Enhanced energy storage can provide multiple benefits to both the power industry and its customers. Among these benefits are:

- Improved power quality and the reliable delivery of electricity to customers;
- Improved stability and reliability of transmission and distribution systems;
- Increased use of existing equipment, thereby deferring or eliminating costly upgrades;
- Improved availability and increased market value of distributed generation sources;
- Improved value of renewable energy generation; and
- Cost reductions through capacity and transmission payment deferral.

The Energy Storage Program also seeks to improve energy storage density by conducting research into advanced electrolytes for flow batteries, development of low temperature Na batteries, along with and nano-structured electrodes with improved electrochemical properties. In Power Electronics, research into new high-voltage, high power, high frequency, wide-band-gap materials such as silicon-carbide and gallium-nitride is underway. In addition, advanced power conversion systems using advanced magnetics, high voltage capacitors, packaging and advanced controls to significantly increase power density and performance is ongoing. (Office of electricity delivery and energy reliability, 2018)

Energy Storage: Facts & Actions to Be Taken	
Facts	Actions to Be Taken
- Energy storage technologies include a large set of centralized and distributed designs that are capable of supplying an array of services to the energy system. Storage is one of a number of key technologies that can support decarbonization. - Energy storage technologies are valuable in most energy systems, with or without high levels of variable renewable generation. Today, some smaller-scale systems are cost competitive or nearly competitive in remote community and off-grid applications. Large-scale thermal storage technologies are competitive for meeting heating and cooling demand in many regions. - Individual storage technologies often have the ability to supply multiple energy and power services. The optimal role for energy storage varies depending on the current energy system landscape and future developments particular to each region. - To support electricity sector decarbonization in the ETP 2014 2DS, an estimated 310 GW of additional grid-connected electricity storage capacity would be needed in the United States, Europe, China and India. Significant thermal energy storage and off-grid electricity storage potential also exists. Additional data are required to provide a more comprehensive assessment and should be prioritized at the national level. - Market design is key to accelerating deployment. Current policy environments and market conditions	- Determine where near-term cost-effective niche markets exist and support deployment in these areas, sharing lessons learned to support long-term development. - Incentivize the retrofit of existing storage facilities to improve efficiency and flexibility. - Develop marketplaces and regulatory environments that enable accelerated deployment, in part through eliminating price distortions and enabling benefits stacking for energy storage systems, allowing these technologies to be compensated for providing multiple services over their lifetime. - Support targeted demonstration projects for more mature, but not yet widely deployed, energy storage technologies to document system performance and safety ratings. Share information collected including lessons learned widely through storage stakeholder groups. - Support investments in research and development for early stage energy storage technologies including technology breakthroughs in high-temperature thermal storage systems and scalable battery technologies, and systems that incorporate the use of both electricity and thermal energy storage (i.e. hybrid systems) to maximize resource use efficiency. - Establish a comprehensive set of international standards in a manner that allows for incremental revisions as energy storage technologies mature.

Energy Storage: Facts & Actions to Be Taken	
Facts	Actions to Be Taken
often cloud the cost of energy services, creating significant price distortions and resulting in markets that are ill-equipped to compensate energy storage technologies for the suite of services that they can provide. - Public investment in energy storage research and development has led to significant cost reductions. However, additional efforts (e.g. targeted research and development investments and demonstration projects) are needed to further decrease energy storage costs and accelerate development. - Thermal energy storage systems appear well positioned to reduce the amount of heat that is currently wasted in the energy system. This waste heat is an underutilized resource, in part because the quantity and quality of both heat resources and demand is not fully known.	- Evaluate and broadly disseminate the learning and experience from established installations. Information should include data on both technical aspects (e.g. generation, cost, performance) and contextual details (e.g. market conditions, energy pricing structures) specific to a region/market. - Establish international and national data cooperation to foster research, monitor progress and assess the research and development (R&D) bottlenecks. Complete analysis in support of regional assessments to quantify the value of energy storage in specific regions and energy markets and promote the development and adoption of tools devoted to evaluating energy storage project proposals.
Source: International Energy Agency, 2014.	

Probable and Possible Future Energy Sources

“So just how will our grandchildren meet their energy needs? We'll continue to use oil and natural gas for decades, if not centuries, but as a shrinking portion of our energy pie. We'll also use commonly proposed alternatives like corn-based ethanol and nuclear generators. But there are also big changes ahead, both in terms of what we use and how much we use technologies that already exist. Take wind generation. The industry is growing at about 30% a year, says Edward Guinness, co-manager of the Guinness Atkinson Alternative Energy Fund. That's faster than other renewable energy sources like solar and hydro-power. The price of wind-generated energy is currently competitive with fossil fuels, Guinness says.

Solar power is also poised to grow quickly. Today about 0.1% of the world's energy comes from solar power, most of it using photovoltaic cells. Guinness thinks that could grow to 10% over 20 to 35 years as manufacturing processes are improved. The expansion of solar thermal technology will also grow the sector. Government subsidies, favorable regulatory programs and the popularity of solar with consumers are also likely to boost usage. Newer ideas could also turn into future energy sources. Have you ever thought we might harness the power of bending floorboards, or turn algae into fuel? It could happen. Moreover, the future of energy is not just a question of what, but of how.” (Eaves, 2007)

Some people think that the best way to know is to travel into the future and see what it looks like. This may sound far-fetched for the technology that would allow us to do so is not here yet. Therefore, we would better explore on both a political level and an economic level what future energy technologies to invest in. It's important to remember that none of the current energy technology that we're currently enjoying just sprang into being. Each of those took years of research and development with government grants, loans, and capital investments from the private sector. For decades, it's been assumed that the best future source of energy would be nuclear fusion. There has been steady progress made but there's still a long way to go. We are really so early into how atomic matter behaves. There are certainly other potential sources that are worth considering but nuclear fusion is "a Holy Grail of clean-energy generation, it's nuclear fusion, which promises limitless carbon-free power without producing dangerous nuclear waste. By figuring out how to mimic the same kind of atomic reaction that occurs at the center of the sun in a controlled way, fusion reactors could supply a whole lot of energy with little environmental cost. While the technology may be 30 years from maturity, defense contractor Lockheed Martin has made inroads. In October its researchers developed a small fusion reactor design—one that might someday fit in a tractor-trailer and produce 100 megawatts of power. The company hopes to have a working prototype in five years and a commercial version within a decade." (CNBC, 2014)

Fusion is the energy source of the Sun and stars. In the tremendous heat and gravity at the core of these stellar bodies, hydrogen nuclei collide, fuse into heavier helium atoms and release tremendous amounts of energy in the process. Twentieth-century fusion science identified the most efficient fusion reaction in the laboratory setting to be the reaction between two hydrogen isotopes, deuterium (D) and tritium (T). The DT fusion reaction produces the highest energy gain at the "lowest" temperatures.

Three conditions must be fulfilled to achieve fusion in a laboratory: very high temperature (on the order of 150,000,000° Celsius); sufficient plasma particle density (to increase the likelihood that collisions do occur); and sufficient confinement time (to hold the plasma, which has a propensity to expand, within a defined volume). At extreme temperatures, electrons are separated from nuclei and a gas becomes a plasma—often referred to as the fourth state of matter. Fusion plasmas provide the environment in which light elements can fuse and yield energy. In a tokamak device, powerful magnetic fields are used to confine and control the plasma. (ITER, 2018)

First, there's the hydrogen fuel cell to consider: a battery that depends on oxygen and pure hydrogen gas and converts chemical energy into electrical energy. The real challenge is obtaining that pure hydrogen gas, but all Earth's hydrogen is already oxidized – unless you obtain it from hydrocarbons in oil and natural gas, which puts the focus back on nonrenewable fossil fuels.

Since we can't harvest pure hydrogen from the rich reserves on Jupiter or the sun just yet, we're left with one option: produce it through the electrolysis of water. Sadly, this process currently demands more energy than it supplies. If we can overcome this technological hurdle, however, hydrogen fuel cells could have a major impact on global energy.

While nuclear fission produces a great deal of energy without relying on fossil fuels, it also produces nuclear waste. Nuclear fusion, the source of the sun's energy, generates significantly less waste without all the radiation. But again, it occurs in the sun, where powerful gravity and heat strip hydrogen atoms down to their nuclei and fuse them together. Scientists are getting closer to pulling off this effect on Earth, but the fusion reactors are still expected to expend more energy than they produce. As the technology improves, however, fusion will become an increasingly attractive option, assuming we can figure out how to contain it, too.

Finally, there's good old solar energy. The amount of solar energy we can harvest on Earth is somewhat limited by varying cloud cover and the cycle of night and day. Space-based solar power (SBSP) would allow us to work around these challenges. Solar harvesters in orbit, on the moon or elsewhere in space could collect solar energy and transmit it back to Earth. While the idea originated in the 1960s, SBSP gains more and more potential as solar technology improves and the cost of deployment decreases. These three energy sources continue to tantalize us with their potential for clean, renewable energy. The question is, which will we figure out how to master first? (Lamb, 2010)

ITER, International Thermonuclear Experimental Reactor ("The Way" in Latin) is one of the most ambitious energy projects in the world today. In southern France, 35 nations are collaborating to build the world's largest tokamak, a magnetic fusion device that has been designed to prove the feasibility of fusion as a large-scale and carbon-free source of energy based on the same principle that powers our Sun and stars. The experimental campaign that will be carried out at ITER is crucial to advancing fusion science and preparing the way for the fusion power plants of tomorrow.

ITER will be the first fusion device to produce net energy. ITER will be the first fusion device to maintain fusion for long periods of time. And ITER will be the first fusion device to test the integrated technologies, materials, and physics regimes necessary for the commercial production of fusion-based electricity. Thousands of engineers and scientists have contributed to the design of ITER since the idea for an international joint experiment in fusion was first launched in 1985. The ITER Members—China, the European Union, India, Japan, Korea, Russia and the United States—are now engaged in a 35-year collaboration to build and operate the ITER experimental device, and together bring fusion to the point where a demonstration fusion reactor can be designed. The amount of fusion energy a tokamak is capable of producing is a direct result of the

number of fusion reactions taking place in its core. Scientists know that the larger the vessel, the larger the volume of the plasma ... and therefore the greater the potential for fusion energy.

With ten times the plasma volume of the largest machine operating today, the ITER Tokamak will be a unique experimental tool, capable of longer plasmas and better confinement. The machine has been designed specifically to:

1) Produce 500 MW of fusion power. The world record for fusion power is held by the European tokamak JET. In 1997, JET produced 16 MW of fusion power from a total input heating power of 24 MW ($Q=0.67$). ITER is designed to produce a ten-fold return on energy ($Q=10$), or 500 MW of fusion power from 50 MW of input heating power. ITER will not capture the energy it produces as electricity, but—as first of all fusion experiments in history to produce net energy gain—it will prepare the way for the machine that can.

2) Demonstrate the integrated operation of technologies for a fusion power plant. ITER will bridge the gap between today's smaller-scale experimental fusion devices and the demonstration fusion power plants of the future. Scientists will be able to study plasmas under conditions similar to those expected in a future power plant and test technologies such as heating, control, diagnostics, cryogenics and remote maintenance.

3) Achieve a deuterium-tritium plasma in which the reaction is sustained through internal heating. Fusion research today is at the threshold of exploring a "burning plasma"—one in which the heat from the fusion reaction is confined within the plasma efficiently enough for the reaction to be sustained for a long duration. Scientists are confident that the plasmas in ITER will not only produce much more fusion energy but will remain stable for longer periods of time.

4) Test tritium breeding. One of the missions for the later stages of ITER operation is to demonstrate the feasibility of producing tritium within the vacuum vessel. The world supply of tritium (used with deuterium to fuel the fusion reaction) is not sufficient to cover the needs of future power plants. ITER will provide a unique opportunity to test mockup in-vessel tritium breeding blankets in a real fusion environment.

5) Demonstrate the safety characteristics of a fusion device. ITER achieved an important landmark in fusion history when, in 2012, the ITER Organization was licensed as a nuclear operator in France based on the rigorous and impartial examination of its safety files. One of the primary goals of ITER operation is to demonstrate the control of the plasma and the fusion reactions with negligible consequences to the environment. (ITER, 2018)

Finally, MIT's buoyant airborne turbine (BAT) should not be overlooked when it comes to future energy sources technology. "Founded by alumni Ben Glass and Adam Rein MBA, Altaeros has developed the world's first commercial airborne wind turbine, which uses a helium-filled shell to float as high as a skyscraper and capture the stronger, steadier winds available at that altitude. Proven to produce double the energy of similarly sized tower-mounted turbines, the system, called Buoyant Air Turbine (or BAT), is now readying for commercial deployment in rural Alaska.

Surrounded by a circular, 35-foot-long inflatable shell made of the same heavy-duty fabric used in blimps and sails, the BAT hovers 1,000 to 2,000 feet above ground, where winds blow five to eight times stronger, as well as more consistently, than winds at tower level (roughly 100 to 300 feet). Three tethers connect the BAT to a rotating ground station, automatically adjusting its altitude to obtain the strongest possible winds. Power generated by the turbine travels down one of the tethers to the ground station before being passed along to microgrids.

'Think of it as a reverse crane,' says Glass, who invented the core BAT technology. 'A crane has a nice stationary component, and an upper platform that rotates in order to suspend things down. We're doing the same thing but suspending things up.' Next year, the BAT will test its ability to power microgrids at a site south of Fairbanks, Alaska, in an 18-month trial funded by the Alaska Energy Authority. People in rural Alaska rely on gas and diesel generators for power, paying upward of \$1 per kilowatt-hour for electricity. The BAT, which has a capacity of 30 kilowatts, aims to drop that kilowatt-hour cost down to roughly 18 cents, the co-founders say.

'But despite its efficiency, the BAT is not designed to replace conventional tower-mounted turbines, Rein says. Instead, its purpose is to bring wind power to remote, off-grid areas where towers aren't practically or economically feasible. Conventional turbine construction, for instance, requires tons of concrete and the use of cranes, which can be difficult to maneuver around certain sites. The modular BAT, Rein says, packs into two midsize shipping containers for transport 'and can just be inflated out and self-lift into the air for installation.'

Target sites include areas where large diesel generators provide power — such as military bases and industrial sites — as well as island and rural communities in Hawaii, northern Canada, India, Brazil, and parts of Australia. The BAT could also provide power to places blacked out by natural disasters, as well as at amusement parks, festivals, and sports venues. 'It's really about expanding wind energy to all those places on the fringes where it doesn't really work today and expanding the amount of wind power that's able to be deployed globally,' Rein says." (Matheson, 2014)

Ultimately, the key word will always be innovation in all aspects of energy exploration, discovery, retrieval, storage, distribution, and consumption. The focus should remain on "new technology that lowers industry's energy use. In some cases, more important energy savings come from

adapting the new technology for use in other sectors. For example, developing a new generation of fuel cells may lead to greater savings in motor vehicles. Other possibilities include “on-demand” manufacturing that applies ink-jet printing systems to three-dimensional fabrication, or new plastics that double as integrated photovoltaic systems. This role of industry in the development of emerging technologies highlights even greater energy savings than might be apparent from looking at industry’s own energy-use patterns alone. With the growing focus on corporate sustainability, industry is adopting a much broader view of its energy and environmental responsibilities, extending its concern to issues surrounding the sustainability of the products and services that it offers, and including the sustainability of its chain of suppliers. Wal Mart, for example, has included indicators of energy sustainability in metrics used to select product and service providers. Accordingly, contractors that create minimal environmental impact are preferred.” (NAS, 2010)

“The future holds great promise. New discoveries, advanced technologies, and high-tech engineering may transform the energy landscape – and with it the shape of society. Public-private partnerships will play an important role in the development of these new technologies and will increase the chances of their adoption in the marketplace. But our energy makeover will be a very gradual and uneven process. The current energy infrastructure is...hugely valuable. Changing it will and should be a careful, deliberative matter unaffected by sudden popular enthusiasms or technological fads. One thing is certain: There will be no single ‘silver bullet’ solution to our energy needs. Tomorrow’s energy, like today’s, will come from a robust variety of sources. New devices, processes, and systems will surely be offered, but not every new technology works, and even those that do are not always adopted by consumers. If the history of human ingenuity is a reliable guide, however, America will find ways to flourish on energy that is sustainable, responsible, and secure.” (National Academies Press, 2008)

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VIII. FROM THE SAME AUTHOR

- Exploring the Possibilities for the Emergence of a Single and Global Native Language
- Philosophical Essay on the Works of Louise-Victorine Ackermann
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The title of the French version of this book is: *Les coûts et implications de notre demande d'énergie : une analyse comparée et complète des ressources énergétiques disponibles*

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