Energy Econ Notes
Econ/Envi 213 Spring 2015
Prof Jacobson

This is as an informal discussion of the characteristics and the pros and cons of the energy sources of greatest interest to us, from the perspective of what we know today and today's concerns. In it, I provide data from reliable sources as well as my perspective (which, as always, should be taken with a grain of salt). This document should not be used as a major or primary source, particularly for a paper on energy, but it will point you in the direction of information sources you may find useful. Note that all of my graphs and tables and whatnot indicate the source from which they (or the data in them) came; these documents are generally really interesting and go into lots more detail than I include here.

Energy Choices

Economists generally believe that people and firms buy the cheapest inputs we can find. This applies to energy just as to everything else. The implication of this is that the pattern of energy use we observe should allow us to infer the relative prices of different kinds of energy. (Obviously, we can make these inferences about market prices and not "true costs" of the energy sources; i.e., externalities are excluded.) In other words, the resources we use a lot of must be providing cheap energy; the resources we don't use much must be more expensive for the same amount of energy. So what kind of energy do we use? Cheap energy.

Because we think people are so driven to increase profits and/or decrease costs, it seems unlikely that miraculous alternative energy sources are hidden in plain view or are being suppressed by some corporate establishment. There are no miracle cures to provide limitless energy at low cost. If someone tells you there is an overlooked energy source that would solve all of our problems, ask yourself why no-one's bought up all the rights to it. Such a source would be very profitable, and I can't imagine firms leaving so much money on the table. If an energy source is overlooked, it's probably overlooked for a reason. There are certainly conspiracy theories that "big oil" and related interests are blocking these miracle energy solutions, but doesn't it seem more likely that they'd be buying them up and profiting from them?

What kind of energy will we use in the future? Let's recall that our most important energy sources, fossil fuels, are nonrenewable in the sense that they don't regenerate at a meaningful rate. Right now they are all still very plentiful, and we are continuing to explore and find more reserves. On the other hand, we may have found a lot of the easiest-to-exploit mines and wells already (we may have picked the "low-hanging fruit"). At some point these fuels will show increasing scarcity, and even now we're finding ourselves exploiting harder-to-get-at resources. Thus marginal extraction costs will probably continue to rise even in the face of technology improvements. So how will we react to this?

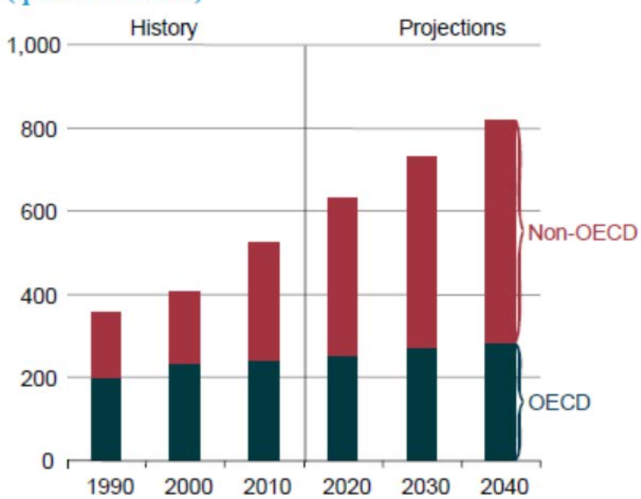
First, price will increase. This is almost certain to happen eventually even though we're seeing the opposite right now. This increasing price will cause us to use less energy and to develop technologies that more efficiently extract that energy or that more efficiently turn that energy into the light, heat, power, etc. that we use. This increasing efficiency may or may not cause us to lower our fossil fuel use; we'll use less resource per unit of energy but each unit of energy is probably cheaper so we want more of it. This is the "Jevons paradox" (also known as the rebound effect) in action. In the end, however, we can't infinitely increase our efficiency. Thus with a growing population and with demand, particularly from developing countries, not all of the world's energy problems can be solved simply by conservation and efficiency gains.

Second, the increasing price will drive us to other energy sources. Other energy sources serve as a backstop technology: when energy from fossil fuels becomes too expensive, it will be cheaper to use something else to serve our energy needs. This is why some economists don't worry much about future energy. A free market's energy prices will transmit the signal "We need more energy, and we're willing to pay for it!" There will be money to be made in providing cheap energy, so profit-seeking firms will research and develop new energy sources. In other words, increasing prices because of increasing scarcity will inevitably cause us to switch from nonrenewable (fossil fuel) energy sources to other sources as we continue to seek the lowest-cost source at every moment in time. That's the fundamental picture, but there are details that matter: externalities may distort this path, and the market may not be as free as we'd like, for example. Plus, the transition from fossil fuels to other energy sources may be painful in the costs it imposes on people and firms; there may be a role for policy in easing that transition.

International Energy Use

We measure energy use in Btu (British thermal units), which allows us to compare energy use and other factors across energy sources. Historically, energy use in developed (rich) countries was much greater than energy use in developing (poor) countries. However, now we see the growth in energy use slowing in developed countries with their mature economies as it skyrockets in developing countries where the economies and populations are growing. The figure below looks at energy consumption in OECD and Non-OECD countries. The OECD (Organization of Economic Cooperation and Development, a group including developed countries) includes 34 countries, with 1.26 billion people, while the Non-OECD group includes the rest of the world—and remember that world population has passed 7 billion people.

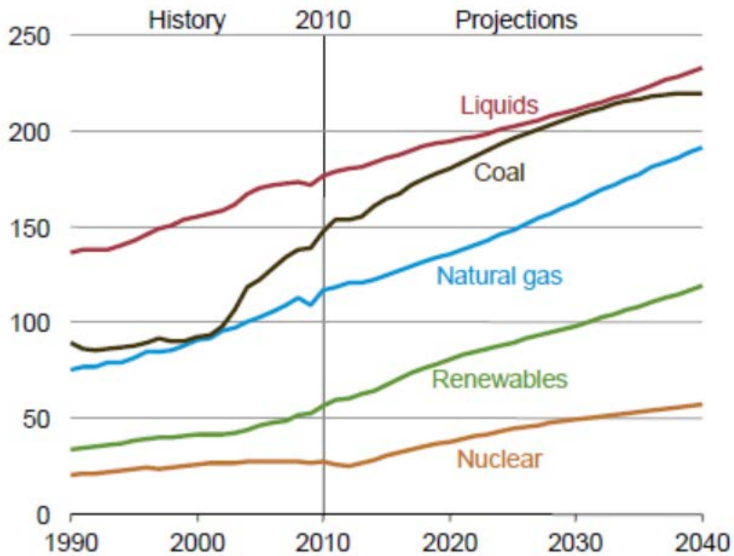
Figure 1. World energy consumption, 1990-2040 (quadrillion Btu)



Source: US Energy Information Administration *International Energy Outlook 2013*

We get energy from a number of different kinds of sources. Currently, most of it comes from fossil fuel sources: liquids (including oil), coal, and natural gas.[1] Non-fossil fuel sources (nuclear and renewables) make up a portion of the sources, but they are still dwarfed by the fossil fuels.

Figure 2. World energy consumption by fuel type, 1990-2040 (quadrillion Btu)



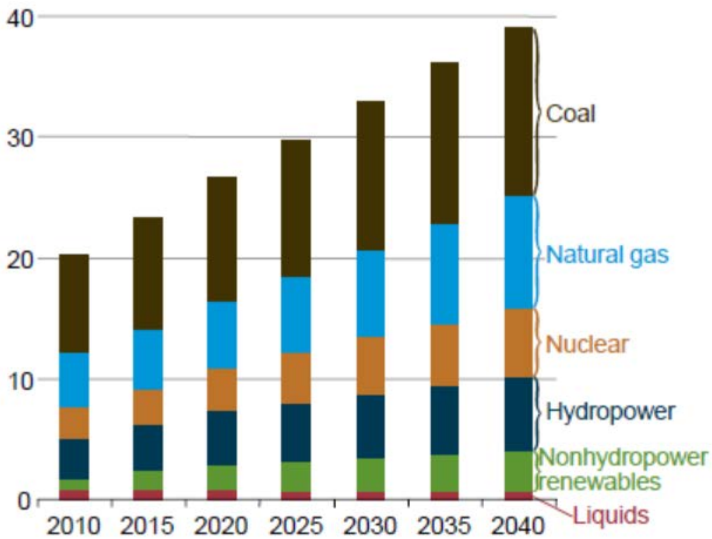
Source: US Energy Information Administration *International Energy Outlook 2013*

In this context, it's pretty clear that fossil fuels will be with us for a long time. Even if renewables increase by leaps and bounds, oil, coal, and natural gas are simply too central to be immediately replaced. We should think about our energy future in terms of an energy portfolio: our future energy needs can only be met by a mix of a variety of sources. Deliberate energy policy is a choice to encourage a rebalancing of that portfolio. We may decide that we want renewables to make up a larger part of the portfolio, but that shift will take decades.

Different energy sources go to different uses. Much, although certainly not all, of the liquid fuel produced in the world is used for transportation. Electricity, on the other hand, largely uses coal and natural gas, with small but growing elements contributed by renewable and nuclear. The mix of electricity sources varies quite a bit from country to country and across recent time. That mix is expected to continue to change somewhat in coming years. Interestingly, bright prospects for natural gas in the coming decades have deflected the trajectory of energy use change—as recently as last year we expected renewables to expand more than we currently do.

[1] Fossil fuels are formed by decomposition of organic matter over millions to hundreds of millions of years. They do not regenerate at an economically meaningful rate. They are dense sources of carbon, and energy locked in atomic bonds is released when the fuels are burned. Unfortunately, pollutants are also released at the same time—notably CO_2 and other greenhouse gases.

Figure 6. World net electricity generation by energy source, 2010-2040 (trillion kilowatthours)



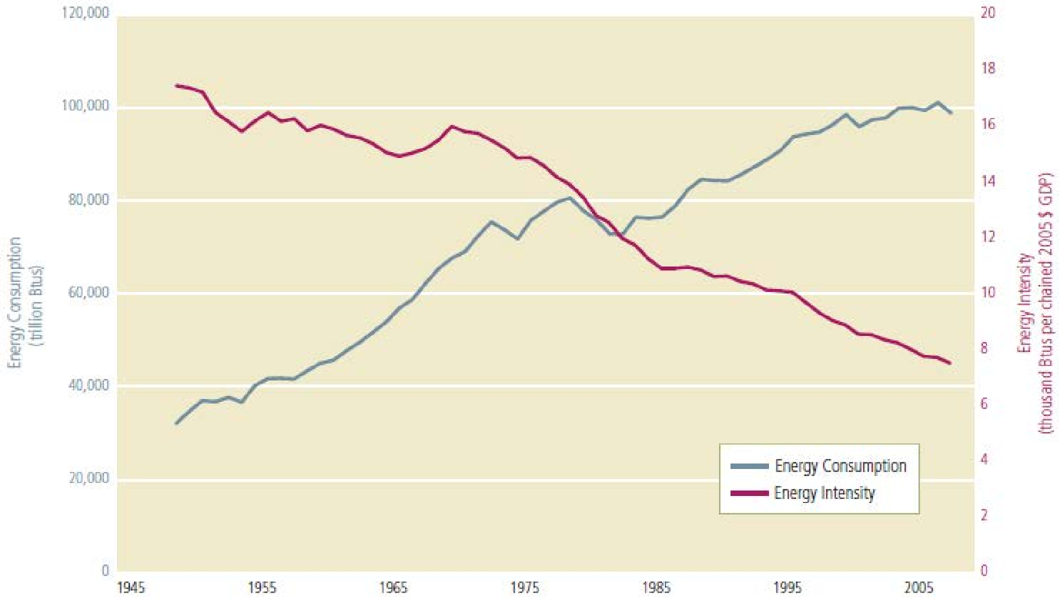
Source: US Energy Information Administration *International Energy Outlook 2013*

To summarize a few important points about international energy use:

- It's grown a lot over the last decades
- We expect it to continue to grow; a lot of that growth comes from developing countries
- Fossil fuels make up a tremendous part of our current energy portfolio
- Projected growth in non-fossil fuel sources is relatively large, particularly in electricity, but even so these sources will be a small part of overall energy use at least for a while

US Energy Use

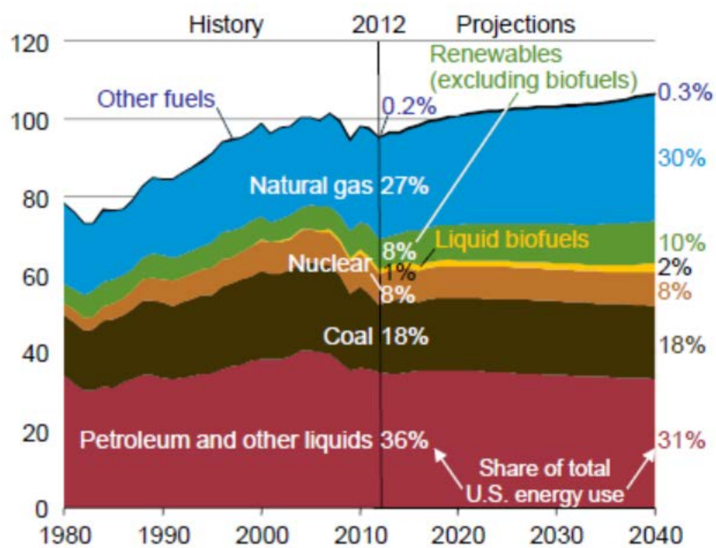
US energy consumption has grown a lot over the decades, but it's been flattening out over recent decades; per capita energy use (not shown here but available in the US EIA *Annual Energy Outlook 2014*) has been roughly flat for decades and is expected to decline in coming decades. The graph below shows this, and also shows some dips in energy use for recessions. The graph below also shows declining energy intensity, defined as energy used normalized by GDP. Basically, energy per unit of output is dropping, which means that we're becoming more efficient (it takes less energy to produce the same stuff).



Source: Resources for the Future and the National Energy Policy Institute. *Toward a New National Energy Policy: Assessing the Options*. Washington, DC: Resources for the Future, 2010.

What are our main sources of energy in the US? See here:

Figure MT-9. Primary energy use by fuel in the Reference case, 1980-2040 (quadrillion Btu)



Source: US Energy Information Administration *Annual Energy Outlook 2014*

Here the dip in energy use caused by the recent recession is very obvious, and carries across energy sources. In the US, as worldwide, fossil fuels make up a very large percent of our energy use. Nuclear makes up a small but steady slice, while renewables and biofuels are small but seem likely to grow a bit. Still, the scale of these other sources is small relative to the fossil fuels.

Oil (Petroleum)

Oil is one of our favorite sources of energy, particularly for transportation. Oil is a fossil fuel source, which means that it is energy-dense and nonrenewable. But with use of oil, as with use of other fossil fuels, we also release an array of pollutants, including greenhouse gases such as CO_2.

There are many kinds and qualities of oil. Oil as it is pulled out of a well is crude; it must then be refined so it can be turned into a usable fuel source. In the US, many refineries are in the Gulf Coast region, but there are others scattered across the country, particularly in the Midwest. Slack demand for gas forced US refineries make some adjustments in the couple of years; some shut down, but others are finding it profitable to sell their refined oil overseas.

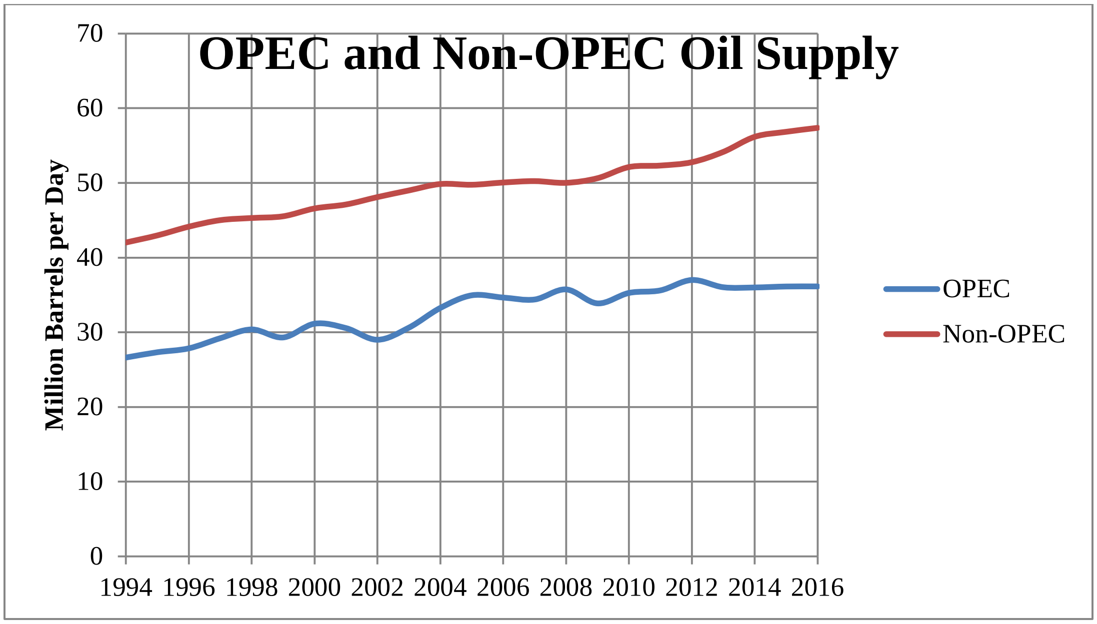
Also, there are different kinds of crude. “Light” crude is low density and yields more fuel than does “heavy” oil; “sweet” crude has less sulfur and other nasty things in it than does “sour.” You may remember that when Libya was in conflict, oil prices reacted strongly even though Libya is not a huge producer of oil relative to the market; it had this effect because Libya produces light sweet crude, which is the best kind of crude oil there is.

Finally, there’s a distinction between conventional and unconventional oil. Conventional oil is extracted from an oil well. This includes offshore drilling, which has expanded in recent years because of high oil prices. Unconventional oil uses other methods. One example is the “oil sands” or “tar sands” (the technical name is “bituminous sands”). These oil sands contain heavy oil mixed with various chemicals in deposits that are very hard (costly) to extract from. The chemicals in the oil make it “dirtier” the refined oil is eventually burned. There are big deposits of unconventional oil in Canada and Venezuela, among other places. Since the price of oil has risen and technology has progressed, it’s become economically viable to use these resources. Environmentalists are concerned about both the impact on habitats of extracting the oil and the impact on air quality of burning fuel thus derived. The hullaballoo about the Keystone XL pipeline is about whether we will extend a pipeline that currently runs from Canada into the US, where this extension would go all the way to the Gulf Coast so that tar sands oil can be transported there to be refined.

Another source of unconventional oil is “tight oil,” also known as “shale oil.” You’ve heard of fracking, and you may think it’s mostly natural gas, but in reality natural gas and oil are both found in underground formations of shale or other rock. I’ll write more about the “fracking” that extracts fuel from these formations below.

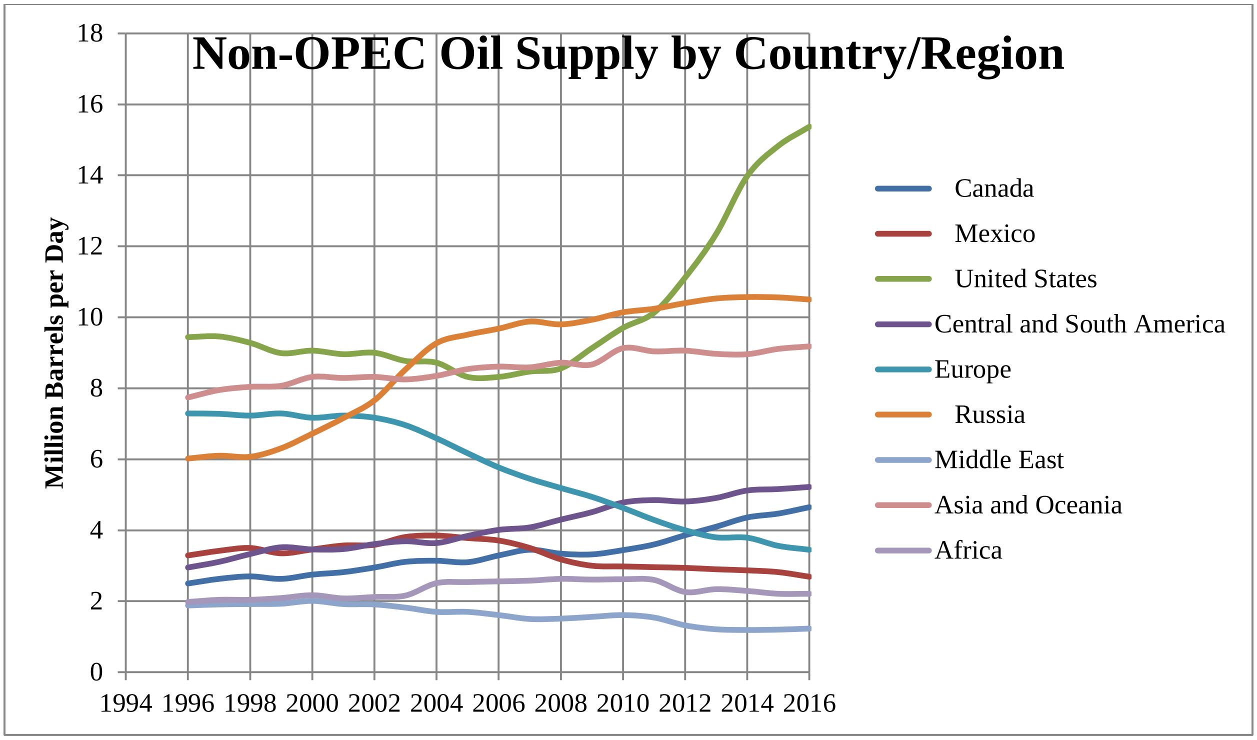
In general, where does oil come from? The biggest single player is the cartel OPEC (the Organization of Petroleum Exporting Countries). There is a competitive fringe of independently-operating non-OPEC states. OPEC meets regularly and decides how much each member state will produce, supposedly to ensure stable supply and prices. OPEC countries are: Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela. Saudi Arabia produces over twice as much oil as the next largest producer (Iran). However, OPEC no longer seems to be so big that it can really control the price of oil very well, and there’s question about how well Saudi Arabia can control the rest of OPEC.

Total non-OPEC production is actually greater than OPEC production, although non-OPEC countries do not coordinate at all while OPEC tries to. Oil production overall, from both OPEC and non-OPEC countries, has continued to increase over recent years.



Source: Data comes from US Energy Information Administration Short-Term Energy Outlook release Jan 13, 2015 (http://www.eia.gov/forecasts/steo/tables/?tableNumber=29#startcode=1996); 2015-16 numbers are projections

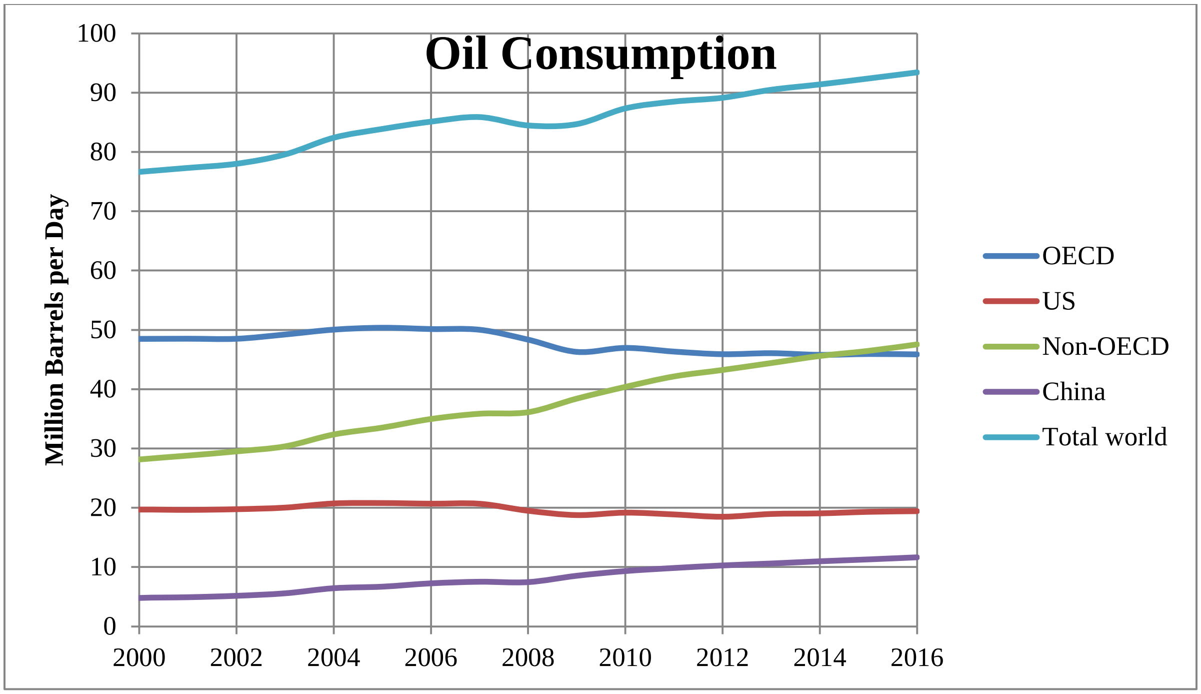
Major non-OPEC players include Russia and the US—in fact, we are now, and quite suddenly, the largest non-OPEC oil producer in the world. A surprising amount of oil comes from Asia and Oceania, about half of that from China. Quite a bit of oil comes out of Central and South America (Brazil and Argentina make up a lot of that; remember that Venezuela and Ecuador are in OPEC). Canada produces a lot of oil and that is increasing (remember the unconventional oil discussed above). Supplies from Mexico are also large but seem to have dropped for the last decade. Norway and the UK were stalwarts of European supply, but both of those are declining as their reserves are dwindling. Non-OPEC Middle East does not produce a whole lot of oil as a group. Non-OPEC African oil supply is slowly creeping up; remember that Nigeria and some other major producers are in OPEC.



Source: Data comes from US Energy Information Administration Short-Term Energy Outlook release Jan 13 2013 (http://www.eia.gov/forecasts/steo/tables/?tableNumber=6#startcode=1993); 2015-2016 numbers are projections

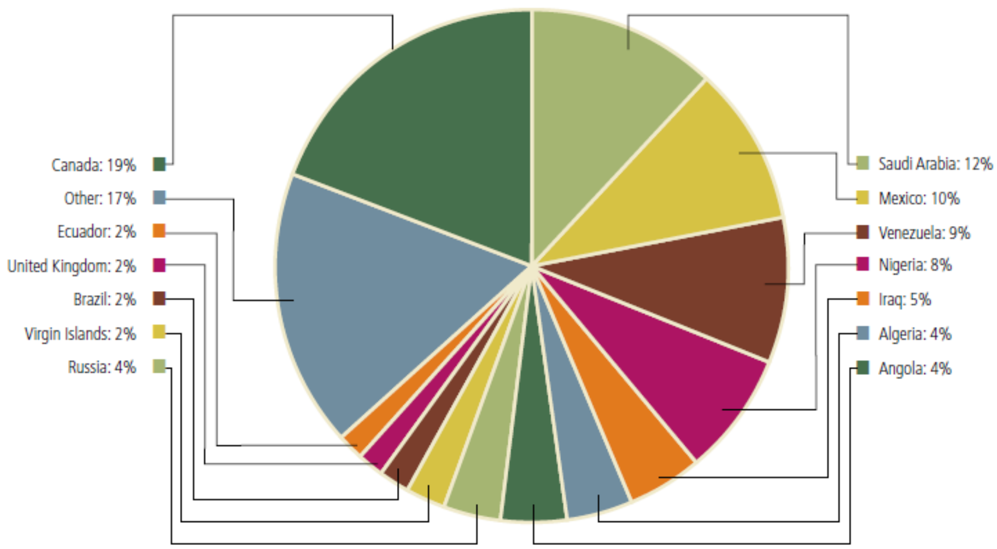
Oil production is very important to countries' economies. Oil production companies receive explicit and implicit subsidies in a variety of ways. (Here's an example of an implicit subsidy: if oil is drilled from an area that the government owns, the government is entitled to some kind of "royalty" payment. Those payments are far lower than the value that firms get from the right to this extraction, so this is an implicit subsidy.) In the US, President Obama and others propose reducing some of those subsidies. This is very controversial and I will be interested to see if there's any action on this. But countries worldwide have close relationships with their oil producers. In fact, many countries have national oil companies.

What about oil consumption? Again let's divide countries into OECD and non-OECD. Clearly the US uses a lot of oil, and we make up a large fraction of what the OECD uses. The OECD countries' oil consumption is mostly flat or declining. But notice that non-OECD oil use is rising, and China is only a part of that—a lot of that shape is driven by fast growth in other non-OECD countries in and out of Asia.



Source: Data comes from US Energy Information Administration Short-Term Energy Outlook release Feb 7 2012 (http://www.eia.gov/forecasts/steo/tables/?tableNumber=6#startcode=1993); 2012-2013 numbers are projections

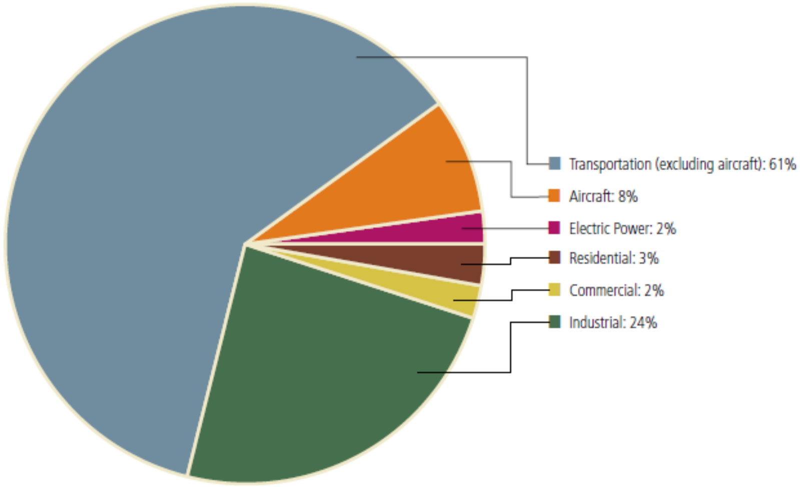
Where does imported US oil come from? It does not quite mirror the mix of countries that produce oil—we get a lot of oil from Canada, for example. Still, we buy oil from a lot of countries with which we have complicated relationships. This this is why we have concern about "oil security." You can think of some of these geopolitical concerns as an additional social external cost of the fuel source.



Source: Resources for the Future and the National Energy Policy Institute. *Toward a New National Energy Policy: Assessing the Options*. Washington, DC: Resources for the Future, 2010.

Obviously, oil prices have dropped a whole lot lately, and as they do, our net imports of oil have dropped with them.

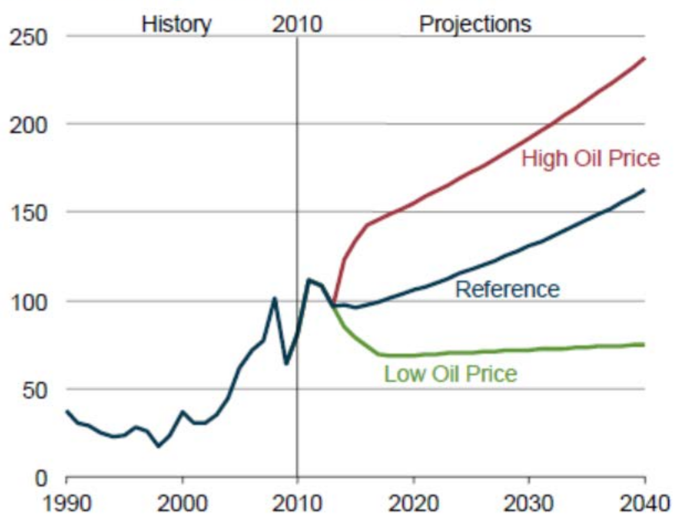
How is oil used? Much of it goes into transportation, especially in the US, but some is used in industry. Remember, too, that transportation is used directly by consumers but production and retail of goods also require transportation, so when oil prices rise that feeds into the cost of consumption directly and by increasing the costs of industrial use and business transportation.



Source: Resources for the Future and the National Energy Policy Institute. *Toward a New National Energy Policy: Assessing the Options*. Washington, DC: Resources for the Future, 2010.

Now let's think about oil prices. The figure below shows oil prices over time with projections into the future by the US Energy Information Agency. You can't really see it, but oil prices started to rise sharply in 1974 when OPEC and some of its allies levied an oil embargo against the United States. Oil prices shot up even further in the 1979 oil crisis. But you can see that prices spiked in 2007-2008 (other commodity prices were spiking then), and then the recession hit, depressing prices again. They rose again and started to fall, and the EIA predicted three possible cases: the reference, or most likely, case shows a continued increase that flattens over time. The high and low price scenarios play out predicted worst-case and best-case situations.

Figure 33. World oil prices in three cases, 1990-2040
(2011 dollars per barrel, Brent crude oil)



Source: US Energy Information Administration *Annual Energy Outlook 2014*

Obviously, since this report came out oil prices have dropped way further, but everyone fundamentally expects that oil prices have to start rising again at some point. But the current low oil prices are a mixed blessing for us—it's great for consumers and businesses that use oil, but less good for oil producers. Some unconventional sources may be becoming "uneconomical," meaning too costly to extract from at least for the short term.

Where does the price of oil come from? Oil is a globally-traded commodity, so its price is set on a global market. In some American political campaigns we hear talk about how allowing drilling in this or that place will bring gas prices back down to $X per gallon. This is just political rhetoric. You've seen the scale of US production relative to global production; increasing our oil production by any feasible amount could not possibly drive price down that much. Relatedly, I don't have much interest in "energy independence" per se—the idea of producing as much energy as we use—since it will not decouple us from global energy markets (nor would we want it to!). As long as there is a global market out there, the opportunity cost of energy produced here is still the global price of energy (unless we erect massive barriers to trade, which is not a good idea). We do have an export ban on oil at the moment, but that's kind of a weird thing and definitely very political, and most economists think it's a bad idea.

The last thing I want to mention about oil is an idea called "peak oil." Since the 1970's, people have argued that we are nearing or past the point at which the world's ability to produce oil is peaking, and thus oil production will diminish forever after. It's not clear to me that this is a meaningful concept. At some point, oil extraction and use will decline because it's a nonrenewable resource. But I don't think this a problem per se. Why? Because this is the way the allocation of a scarce resource ought to work. Producers have some idea how much oil is left in known wells and how much oil they expect to find with discovery activities, and they know that every unit extracted makes oil scarcer. This scarcity means that the opportunity cost of taking a unit of oil out right now is increasing, and thus the price of oil should rise to reflect that scarcity rent. At some point, the high price of oil will render the provision of energy from alternative sources economically profitable. At that point, we switch. The only question is whether we make that switch efficiently, and whether governments ought to be involved to ease the transition.

Now, let's summarize some of the pros and cons of oil.

Pros:

- Cheap
- Energy-dense
- Plentiful

Cons:

- Consumption externalities:
  - Burning creates greenhouse gases and other pollutants
- Extraction externalities:
  - Drilling, particularly offshore, may result in environmental damage and costs to health and safety of workers. (NOT external if the firms are held liable!)

- o Unconventional sources (such as tar sands and tight oil) may result in major environmental damage. The oil thus generated is also often dirtier (and thus creates worse consumption externalities when burned).
- Externalities in transporting the fuel:
  - o Oil spills from pipelines or tankers (NOT external if firms are fully liable)
- Other concerns:
  - o International security: oil revenues fund "problem states"
  - o Energy dependence: it would be possible for major oil producers (mainly OPEC) to really hurt any particular country (even the US) if they wanted to
  - o The market for oil is not perfectly competitive, although the environmental economic implications from this are not entirely bad!

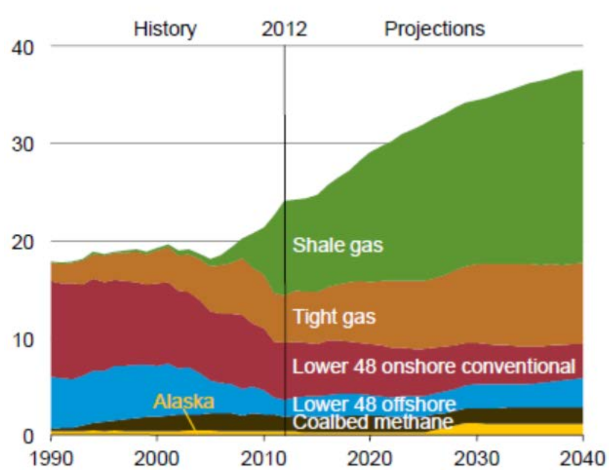
Natural Gas

Natural gas is another fossil fuel, so it has some of the same characteristics as oil: it's an energy-dense hydrocarbon. It's a cocktail of gases, primarily methane, that are often found with deposits of other things, so it's also called "associated gas." Deposits of natural gas are distributed pretty widely across the globe. Natural gas has historically been used for electricity and heat, and often used near its extraction site because of its availability and the difficulty in transporting it. Now transportation of natural gas has become more feasible through pipelines. Natural gas can also be converted into LNG (liquefied natural gas) or CNG (compressed natural gas) for use as a transportation fuel.

One aspect of natural gas is that it is relatively "clean": when burned, it produces less pollution (including less CO_2) per energy produced when compared to other fuels. On the other hand, there's increasing evidence that leaks of natural gas generate so much pollution that they may offset these environmental gains. Leaked natural gas is a much more potent greenhouse gas than CO_2. Leaks occur in extraction, when the gas is stored in tanks, and when the gas is transported through pipelines. Expect more attention to be paid to this in the near future.

In the US, our natural gas comes from the following sources:

Figure MT-44. U.S. natural gas production by source in the Reference case, 1990-2040 (trillion cubic feet)



Source: US Energy Information Administration *Annual Energy Outlook 2014*

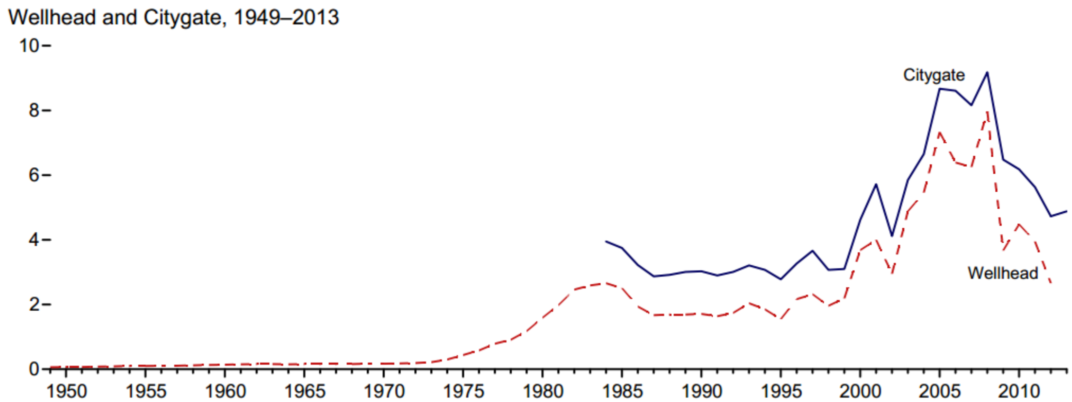
Remember, natural gas is often found with oil or coal. When you see fires flaring atop an oil well, you're seeing excess natural gas being burning off. That gas can be captured and sold if it is profitable to do so, but often it is not. Shale gas is found laces through shale formations like the "Marcellus Formation" that underlies parts of New York, Pennsylvania, Ohio, Maryland, West Virginia, and Virginia. Tight gas is similar to shale gas, in that both are very hard to extract, but whereas shale gas is laced into soft, fine-grained rock, tight gas is stuck amid hard, impermeable rock. In both cases, innovations in extraction have made it possible to get the gas out in cases that may have been impossible in the past. Hydraulic fracturing (also known as "fracking") uses high-pressure water and chemicals to crack the rock in which the gas is hiding and force the gas to the surface, and this method, in combination with advances in ability to drill long horizontal shafts and discovery of vast reserves, has transformed the natural gas market. This change in natural gas is the biggest thing to happen in energy in a long time. As you've seen, natural gas is predicted to expand in the near future, and that's largely because of shale gas. This not only changes the composition of our energy but also reduces energy prices, and perhaps climate pressures, too. Because natural gas is cleaner than coal (*if* leaks are minimal), power plant switches from coal to natural gas may be our main hope for near-term reductions in climate gas emissions, though there's a lot of research and debate about whether these benefits are really large. One downside is that the energy price reductions brought about by plentiful natural gas makes us delay making investments to build up renewable energy capacity.

Hydraulic fracturing, however, is incredibly controversial right now. The chemicals used in the process ("fracking fluids") are not publicly disclosed and some fear they are very toxic, although gas companies say they are largely inert. People have concerns that both natural gas and these chemicals can get into the groundwater and into wells near the drilling site; there are also concerns about disposal of the leftover water and chemicals that were used in the drilling. Whether fracking should be allowed is hotly debated—drive over any portion of the Marcellus shale and you'll see tons of lawn signs both for and against fracking for a variety of reasons.

The local nature of natural gas has created some interesting institutional features over the years. Local natural gas suppliers in the US were often monopolies or near-monopolies in their local areas. The US government was concerned that customers were being exploited because of this market power. They were concerned about prices that they felt were too high. As a result, price controls were instituted. From 1954 to 1978, price ceilings were imposed in various ways. This caused severe shortages and common wisdom is that the price ceilings were a bad idea.

Here's what natural gas prices have looked like in the US over the last few decades.

Figure 9.4 Natural Gas Prices
(Dollars[a] per Thousand Cubic Feet)



Source: US EIA December 2014 Monthly Energy Review
(http://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf)

Now, let's summarize some of the pros and cons of natural gas.

Pros:

- Cheap (and may stay cheap for a while)
- Energy-dense
- Plentiful
- "Local"
- Relatively clean (for a fossil fuel)

Cons:

- Externalities from leaked natural gas at all points in the process
- Consumption externalities:
  - Burning creates pollutants including greenhouse gases (albeit less than other fossil fuels)
- Extraction externalities:
  - Extraction of some associated and non-associated gas involves drilling or mining, which may damage some ecosystems, and accidents can happen.
  - Methods used to extract natural from shale deposits ("fracking") may be particularly damaging because of groundwater contamination and disposal of "fracking fluids"
- Externalities in transporting the fuel:
  - Pipeline ruptures may be nearly inevitable (not external if producer is liable)
- Other concerns:
  - Geopolitics: Russia provides natural gas to a lot of Eastern Europe through a pipeline that traverses Ukraine. Disputes between Ukraine and Russia have caused disruption in supplies to Europe, though they're trying to find other routes.

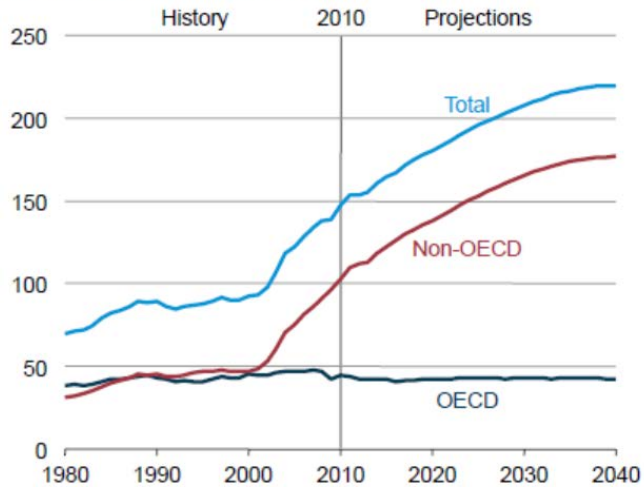
Coal

Coal is another fossil fuel, a nonrenewable energy-dense hydrocarbon. Some coal is naturally cleaner (less sulfur) and some is dirtier (more sulfur). Thus when coal is burned (generally to generate electricity), we produce not just greenhouse gases like CO_2 but also sulfur and nitrogen compounds (SOx and NOx). These pollutants also contribute to acid rain. When coal is burned, however, power plants can take abatement actions to reduce emissions, including installing scrubbers. There is some other clean coal technology that's been proposed, but my understanding is that a lot of it really has not been fully developed or tested, like carbon capture and storage (storing CO2 emissions underground rather than emitting into the atmosphere).

Coal is scattered around the world in localized deposits, and is extracted, often at relatively low cost, through mines. Scarcity doesn't seem to be a real problem with coal yet. However, we are moving toward harder-to-extract sources, and this includes techniques like mountaintop removal. Regular mining can be very dangerous for the miners; this is particularly a problem in countries where safety regulations are poor or not well-enforced. With good safety regulations, this just increases the cost of mining. Because of the increasing costs of coal extraction, the US EIA is now predicting that coal prices will increase noticeably in the coming years. Even so, coal will still be relatively cheap.

Coal has remained a reliable source of energy worldwide in recent years. Coal use in Asia (particularly China) has grown tremendously and is expected to continue to do so for the foreseeable future. Electricity demand in developing countries is strong and there's been a rush to increase supply to meet the need.

Figure 70. World coal consumption by region, 1980-2040 (quadrillion Btu)



Source: US Energy Information Administration *International Energy Outlook 2013*

Now, let's summarize some of the pros and cons of coal.

Pros:

- Cheap (may get modestly more expensive)
- Energy-dense
- Plentiful
- "Local"

Cons:

- Consumption externalities:
    - Burning creates pollution that causes both climate change and acid rain (among other pollution problems)
    - Clean coal technology may be costly and is untested
- Extraction externalities:
    - Simple coal mining can be damaging to habitats and dangerous for workers (not external if firm is liable)
    - Mountain-top removal mining may have serious environmental externalities

Nuclear Power

Nuclear energy uses nuclear fission to break up atoms into smaller atoms, in the process releasing a lot of energy from a small amount of fuel. We use nuclear energy for electricity. The fuel is uranium ore that has been enriched. Uranium exists abundantly in the earth. But since uranium can also be enriched to provide ingredients for nuclear bombs, there's a lot of concern about security of enriched uranium.

Nuclear power comes from immense reactors that perform fission on the uranium fuel. Building a reactor is expensive, so nuclear is associated with tremendous fixed costs, but because each unit of fissioned fuel produces so much energy, the marginal costs of energy production are low.

Nuclear energy is considered a "no-carbon" fuel source by some, since no fossil fuels are burned to generate the energy. It is considered "low-carbon" by others, since it takes energy to build and operate the plant, and that energy generally comes from fossil fuel sources. (I think that's not quite fair, since that energy could arguably come from nuclear if there were more nuclear plants.)

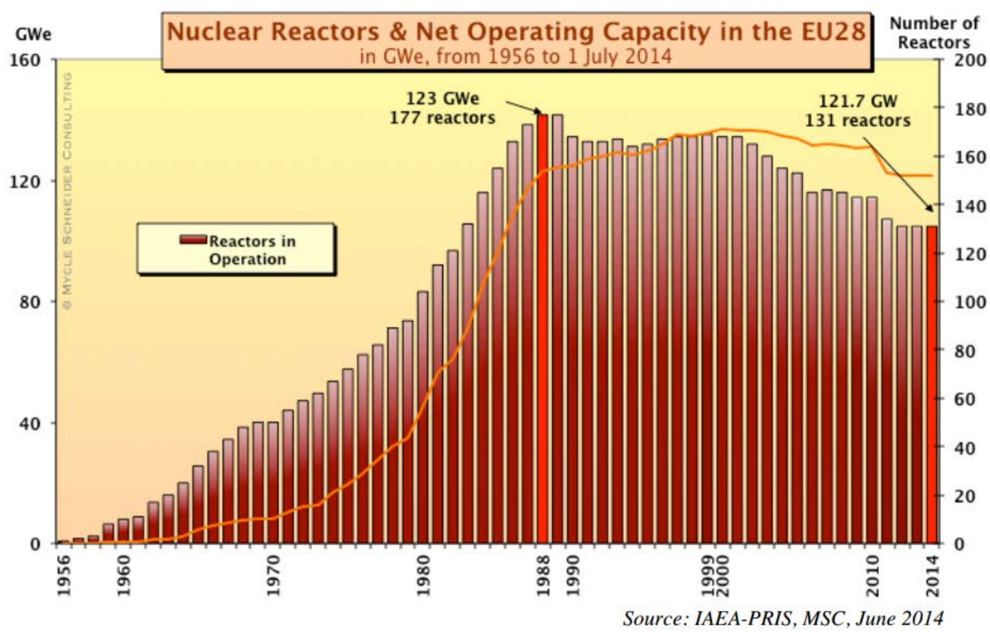
There are three main problems with nuclear energy. First, it's not always economical to use nuclear energy. This is because of the massive fixed costs. Governments nearly always are involved in building or at least financing nuclear power plants, and that's because these high fixed costs make nuclear energy even more of a natural monopoly than other energy sources. In fact, I've seen it argued that with energy prices as low as we expect them to stay for the near future (because of natural gas), building new nuclear plants now may not make a lot of sense, at least in the US. Interestingly, in February 2012 the US approved our first new nuclear plants since 1978.

Second, people are very concerned about safety of nuclear power. Nuclear power plant designs have improved greatly over the years. Of course, improved safety measures also increase the fixed costs associated with nuclear energy. But I'm sure we won't soon forget the Fukushima Dai'ichi disaster of 2011, when a Japanese nuclear power plant had a massive failure and the local area was subjected to radioactive contamination. Other nuclear disasters in the past, such as the Chernobyl disaster of 1986, have left some people dead set against the value of nuclear power, period. Some people also point out that aside from the inherent safety of a nuclear reactor, we have to consider the possibility of a terrorist attack that targets nuclear facilities. After Fukushima Dai'ichi, Japan and Germany both declared an end to nuclear power in those countries. (Of course, at least in Germany I've seen that this means an increase in coal use, which increases air pollution with concomitant bad effects…)

Third, after nuclear fuel has been used, we are left with radioactive waste that must be disposed of. Some elements of this waste will remain radioactive for hundreds or thousands of years, while other elements may last much longer. The basic goal with nuclear waste is to store it in a very well-sealed container deep underground. People have concerns that these containers may leak or that unsuspecting future generations may come across them somehow. Nuclear waste that has not yet been disposed of is a security concern: it can be stolen and used in a "dirty bomb." Thus nuclear waste security is also an issue of international concern.

How has the use of nuclear power evolved over the decades? It boomed through the 1970's and 1980's, and has flattened out since then, and started to decline in recent years. It may be that the post-1970 increase was driven by a desire to reduce our worldwide dependence on oil (remember the 1973-4 oil embargo that was so unpleasant to the US). The decreasing rate of opening new reactors seems to have started after the 1986 Chernobyl disaster.

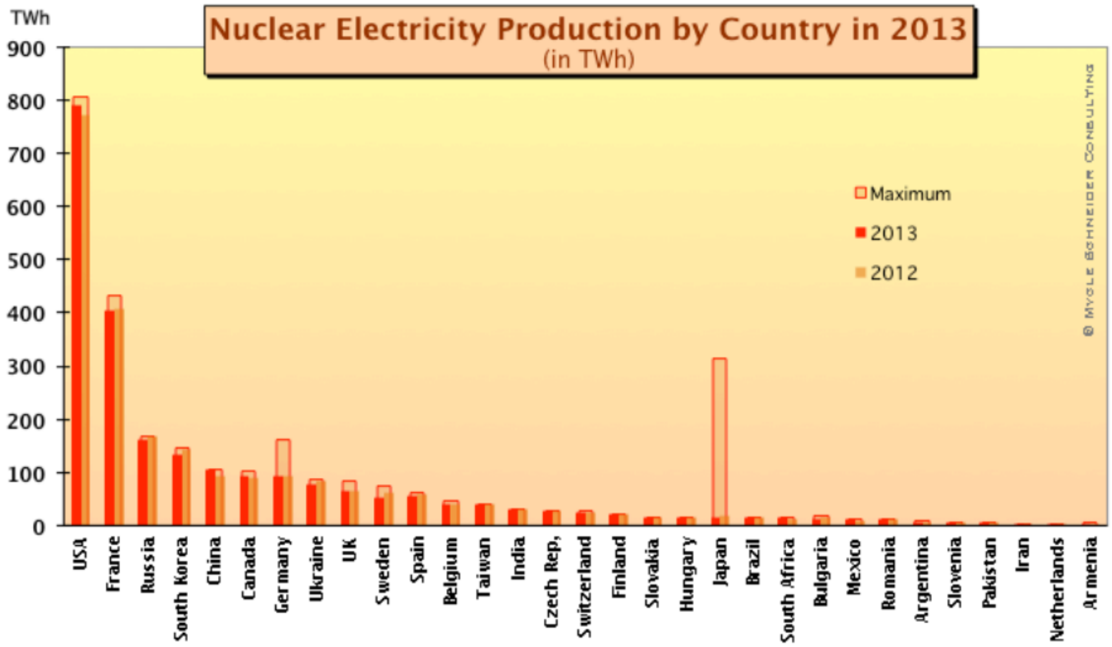
Figure 32: Nuclear Reactors and Net Operating Capacity in the EU28, 1956–2014



Source: Schneider and Froggatt, *The World Nuclear Industry Status Report 2014*, Mycle Schneider Consulting

Let's look at how nuclear power is distributed across the world. In raw numbers, the US generates the most nuclear energy, although of course we generate more of all kinds of energy because we're such a big economy. Percent-wise, France is the most dependent on nuclear energy; there, the state is heavily involved with nuclear power. Japan used to be in third place, but both they and Germany have lowered their nuclear generation significantly in recent years.

Figure 2: Annual Nuclear Power Generation by Country and Historic Maximum



Source: Schneider and Froggatt, *The World Nuclear Industry Status Report 2014*, Mycle Schneider Consulting

Now, let's summarize some of the pros and cons of nuclear power.

Pros:

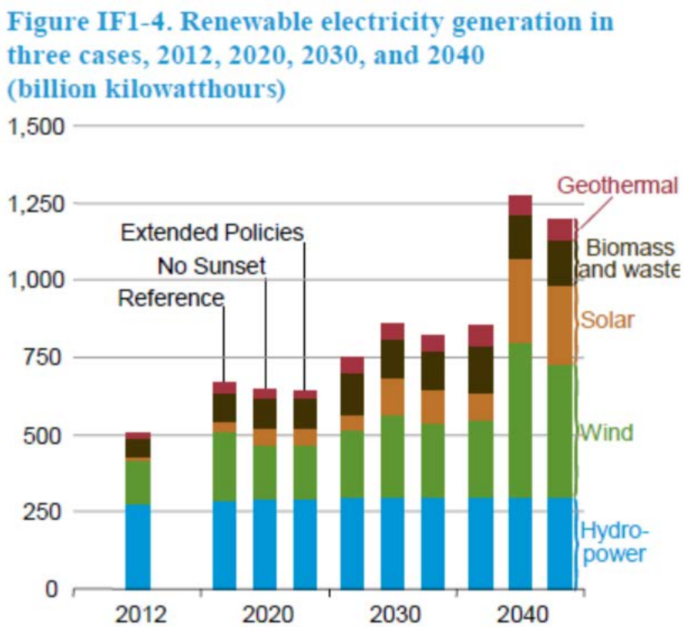
- A lot of energy from a little fuel
- Fuel is relatively abundant
- Low-carbon or no-carbon
- Very low marginal costs of energy provision once the reactors are built

Cons:

- Production externalities:
  - Small possibility of nuclear reactor accident (small change of very large damages) – not external if firms are liable
  - Spent fuel is radioactive waste, and must be safely stored for an extremely long time (10,000 to 1 million years). Accidents can happen with this spent fuel.
- Extraction externalities:
  - Some accidents occur in mining nuclear fuel, as with any other kind of mining
- Other concerns:
  - Very high fixed (start-up) costs; government generally must be involved
  - Security concern with fuel, reactors, and waste: reactors could be terrorist targets, and the fuel and waste could be used as weapons
  - Concern about letting "trouble states" (e.g. Iran) develop nuclear power because they may enable the regime to develop nuclear weapons

Renewables

This phrase refers to a variety of sources that either can regenerate or are basically not affected by our use of them. Solar, hydroelectric, wind, and geothermal are low-carbon/no-carbon energy renewable resources: they create very little pollution in their consumption. Biofuels are renewable hydrocarbon fuels. Mostly we think about renewables with regard to electricity; they can be used for other energy needs (e.g. solar cars or biomass heat), or we can use the electricity thus generated to power those other energy needs (e.g. plug-in electric cars).



Source: US Energy Information Administration *Annual Energy Outlook 2014*

(The US subsidizes renewable energy with a set of tax credits and subsidies; a lot of the projections into the near future about what will happen with these energy sources depends on whether those credits run out or are renewed. The three cases in the figure above depend on how and whether the policies will be extended.)

Renewable energy sources are generally more expensive (per unit of energy generated) than fossil fuels, which is why they are not in heavy use, although some are viable in some places and wind is looking particularly good these days. Use of renewable may inevitably increase as scarce fossil fuels rise in price and we innovate to make renewables cheaper, more efficient, and more reliable. Renewables are our "backstop technology:" once fossil fuels are expensive enough, we will switch to renewables not out of the goodness of our hearts but because it's simply cheaper.

Right now, in the United States, 29 states and the District of Columbia have Renewable Portfolio Standards, which require at least certain percentage of a state's electricity to come from renewable sources by a certain date, and this should force renewable electricity sources to increase over coming decades.

Let's look at biofuels and then at the other renewables.

Biofuels

Biofuels is a broad class of hydrocarbon fuels that don't come from fossil sources. Essentially, you find a plant source, process it in some way, and then you burn it. Biofuels were long favored by some green-oriented people, but now the picture of their environmental impact is not as clear. The net carbon impact of these fuels is very tricky to calculate: for each biofuel, you plant some plants, and perhaps use fossil fuel-based fertilizers, and use energy for tractors and what not. The plants absorb carbon dioxide for the time they grow; then you harvest them and burn them. And demand for biofuels may force some land that would otherwise be standing forests to be cleared periodically (for wood biofuels) or to be converted to agriculture (for corn or other agricultural biofuels). Because this is so complicated, some have proposed that biofuels are not only not good, but perhaps actively bad for the environment (others debate this). Still, biofuels are renewable if they are managed sustainably, which can't be said for fossil fuels.

One popular kind of biofuel is ethanol, which is an alcohol used as a fuel or a fuel additive. It can come from corn, sugar cane, or other sources. Corn is a big source of it in the US right now, and it is heavily subsidized. In some places in the US, gasoline is required by law to have a percentage of ethanol added, ostensibly with the goal of environmental goodness. However, it has been argued that ethanol policy in the United States is largely political: agricultural lobbies are strong, and support of farm state voters is coveted by politicians. Whenever corn prices are high, the ethanol mandates look like a particularly bad idea, feeding through into increased gas prices and taking corn out of the food market.

Another popular biofuel is biodiesel: vegetable oils (palm oil, corn oil, soybean oil) that can be used as a liquid fuel in diesel-type engines. Some people celebrate used cooking oils (collected from restaurants) as a fantastic fuel for cars; obviously that's not going to fuel the entire US commuter fleet.

Various kinds of solid biomass can also be used, including biomass from wood or waste wood (which comes largely from the paper industry). Other sources people have been exploring range from algae to switchgrass to garbage.

One of the big problems with biofuels is the interaction between the production of these fuels and the production of agricultural products for food. If biofuels are grown on land that would otherwise have been used to grow food, or are derived from products that could otherwise be used for food, these biofuels will drive up the price of food. There's concern that the global food price spikes we saw in 2007-8 and the high food prices we've seen since the start of 2011 are related to biofuel's influence.

Also, there are many conflicting estimates, but it's unclear to me how economically important biofuels will be. It simply takes space and resources to grow them. Of course, as discussed above, we shouldn't think that we're trying to meet all of our energy needs with one alternative source, be it biofuel or anything else. The question is: can enough biofuels be provided (without too much of an impact on food production) to make a substantial portion of our energy portfolio?

Now, let's summarize some of the pros and cons of biofuels.

Pros:

- Somewhat cheap (but note that ethanol is heavily subsidized)
- Renewable
- May or may not be less polluting on net

Cons:

- Not yet quite economically competitive (i.e. they are still more expensive)
- Consumption externalities:
    - Burning creates greenhouse gases and other pollutants
- "Extraction" externalities:
    - Intensive agriculture may hurt habitats, generate carbon-type pollution, and generate water pollution
- Other concerns:
    - May drive up food prices
    - How much energy can we get from it, really?

Solar, Wind, Hydropower, and Geothermal

The other main kinds of renewable energy are solar, wind, hydropower, and geothermal. I will not discuss wave and tide power, since they don't seem to be in great use right now and I don't know much about them. All of these sources are "no-carbon" or "low-carbon" in just the same way that nuclear power is: in operation they do not generate greenhouse gases, but to start generating energy, the plants (or panels or windmills) must be built, and that building takes energy, which often comes from fossil fuels. Again, as our energy portfolio changes over the next few decades, this will be much less true.

Hydropower is an old source and is the most established, and most used, of the renewable energy sources. It captures kinetic energy from flowing water and turns it into electricity. This often involves damming up a water source, and thus changes the flow of a river. These changes, which often include flooding one area and limiting the flow where the river has historically run, can be quite environmentally damaging and can have tremendous effects on people living either in the area of the dam or in downstream areas where flow patterns are changed. The good thing about hydropower is that of the renewables, it's one of the few that's really reliable for generating a lot of power all day. On the other hand, hydropower plants also are fairly capital-intensive to build (high fixed cost and low marginal cost), and thus governments tend to be involved. Obviously, hydropower only works in some areas; the electricity thus generated must be transported to regions that don't have access. As a side note, hydropower plants may need to consider changing patterns of water availability caused by climate change. Also, there is a new trend to create more small dams that will produce less energy but cost less and have less of a negative local impact.

Solar energy captures energy from the sun and makes it available to us, usually in the form of electricity or heat. Electricity from solar energy generally uses panels made up of photovoltaic cells to convert energy from the sun into electricity. Solar energy has improved over the years, but it needs to become more efficient before it's cost-competitive. China is now producing pretty cheap solar panels, but they are subsidizing the industry quite a bit, and overall solar is still more expensive than other energy sources. There is some really nasty pollution associated with the construction of solar panels. There's a lot of concern about whether solar can produce enough energy to be really meaningful; you need to cover a lot of area with panels to get a meaningful amount of energy. Should solar panels be distributed across rooftops? Would that be enough? Probably not. Should we build massive solar farms in the desert? That could have a big environmental impact on habitats and species. The other big problem with solar energy is that it only works where and when the sun shines. We must collect the energy while the sun shines and then store it so we can use it later. Efficient energy storage (batteries) is a focus of research and development right now, but we just don't have the storage technology we need yet.

Wind power uses windmills to capture kinetic energy from wind and convert into electricity. Wind is really beloved in some areas, because there are few externalities associated with it, although bird populations can be hurt (less now than with older windmills). Starting up a wind farm doesn't require a huge investment up front, particularly since wind farms can be built in a piecemeal fashion (you can add a windmill at a time). Some people feel that windmills destroy a landscape's visual or spiritual qualities; others say that the sound of massive windmills is disturbing and some say causes ill health effects, but I think that's probably baloney. Here in Massachusetts, major wind projects offshore near Boston (Cape Wind) and out here in the Berkshires have been very controversial. Wind power still is somewhat "too expensive" so more cost reductions are needed, although wind is much closer to being on competitive terms with the fossil fuels. Wind, also, only works at some times and in some places, and so storage technology must improve. In addition, I understand that windmills still tend to break down a lot.

Geothermal energy converts the energy of subterranean heat into electricity. One way of getting this energy out is to find areas where geothermal steam is naturally available at the ground level, and another is to generate geothermal steam by pumping water into the ground through one hole and capture the heated steam that comes out another hole. You then essentially extract energy from the steam. It's not in terribly great use worldwide, although some countries use it quite a bit (Iceland gets 30% of their energy from geothermal, and the Philippines uses a lot as well). Geothermal is another source that has high fixed costs to build a plant but may have lower marginal costs of generation. It's not clear to me how much potential geothermal has as a worldwide energy source—it seems particular to the geological characteristics of a region.

For the US, the EIA has come up with estimates of the expected costs of each energy source in the near term. Prices vary regionally, but it's still useful to look at the average values in the final column—total system levelized costs for each energy source. Natural gas is very cheap now. Geothermal is cheap where it can be used, which is new—the last time I updated this, it was much more expensive. Hydro and wind come next but they are "non-dispatchable," i.e. not very flexible. Only then do coal and nuclear come in, and the rest are behind that. Remember, though, these costs change all the time based on technology, supply, and demand.

Eventually renewables will be cost-competitive even when unsubsidized because fossil fuel prices will rise. Self-interested firms will find it increasingly worthwhile to invest in these energy sources. However, given the externalities associated with fossil fuels, this transition may happen later than is efficient. Remember, too, that fossil fuels get a lot of implicit and explicit subsidies from governments. Many economists favor subsidies for research and development of new fuel sources to “level the playing field” and to correct for those externalities.

Table 1. Estimated Levelized Cost of Electricity (LCOE) for New Generation Resources, 2019

		U.S. average levelized costs (2012 $/MWh) for plants entering service in 2019						
Plant type	Capacity factor (%)	Levelized capital cost	Fixed O&M	Variable O&M (including fuel)	Transmission investment	Total system LCOE	Subsidy[1]	Total LCOE including Subsidy
Dispatchable Technologies								
Conventional Coal	85	60.0	4.2	30.3	1.2	95.6		
Integrated Coal-Gasification Combined Cycle (IGCC)	85	76.1	6.9	31.7	1.2	115.9		
IGCC with CCS	85	97.8	9.8	38.6	1.2	147.4		
Natural Gas-fired								
Conventional Combined Cycle	87	14.3	1.7	49.1	1.2	66.3		
Advanced Combined Cycle	87	15.7	2.0	45.5	1.2	64.4		
Advanced CC with CCS	87	30.3	4.2	55.6	1.2	91.3		
Conventional Combustion Turbine	30	40.2	2.8	82.0	3.4	128.4		
Advanced Combustion Turbine	30	27.3	2.7	70.3	3.4	103.8		
Advanced Nuclear	90	71.4	11.8	11.8	1.1	96.1	-10.0	86.1
Geothermal	92	34.2	12.2	0.0	1.4	47.9	-3.4	44.5
Biomass	83	47.4	14.5	39.5	1.2	102.6		
Non-Dispatchable Technologies								
Wind	35	64.1	13.0	0.0	3.2	80.3		
Wind-Offshore	37	175.4	22.8	0.0	5.8	204.1		
Solar PV[2]	25	114.5	11.4	0.0	4.1	130.0	-11.5	118.6
Solar Thermal	20	195.0	42.1	0.0	6.0	243.1	-19.5	223.6
Hydro[3]	53	72.0	4.1	6.4	2.0	84.5		

[1]The subsidy component is based on targeted tax credits such as the production or investment tax credit available for some technologies. It only reflects subsidies available in 2019, which include a permanent 10% investment tax credit for geothermal and solar technologies, and the $18.0/MWh production tax credit for up to 6 GW of advanced nuclear plants, based on the Energy Policy Acts of 1992 and 2005. EIA models tax credit expiration as in current laws and regulations:Â new solar thermal and PV plants are eligible to receive a 30% investment tax credit on capital expenditures if placed in service before the end of 2016, and 10% thereafter. New wind, geothermal, biomass, hydroelectric, and landfill gas plants are eligible to receive either: (1) a $21.5/MWh ($10.7/MWh for technologies other than wind, geothermal and closed-loop biomass) inflation-adjusted production tax credit over the plant’s first ten years of service or (2) a 30% investment tax credit, if they are under construction before the end of 2013.

[2]Costs are expressed in terms of net AC power available to the grid for the installed capacity.

[3]As modeled, hydroelectric is assumed to have seasonal storage so that it can be dispatched within a season, but overall operation is limited by resources available by site and season

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2014*, April 30, 2014, DOE/EIA-0383(2014).

Source: http://www.eia.gov/forecasts/aeo/electricity_generation.cfm

The difficulty is that we don’t know what innovations will come in the future, so we don’t know *which* energy sources will be the best in the future. In other words, we don’t want to subsidize one energy source (say, hydrogen fuel cells) and have that turn out to be a dud. That’s what’s called “picking a winner.” We want the market to pick the winner: all other things equal, the cheapest and most efficient technology should win out because that’s what would be most profitable in a level-playing-field world. So the trick is to structure subsidies so that they reward innovation in general without preferring one technology over another.