Search this site

Transportation Fuels & Policy

- Transportation Overview: The Journey and the Destination
  - The Energy World of Petroleum
- The Peak Oil Debate
  - Energy of Extraction
- Deep-Sea Oil Production
  - Brief History
  - The Energetics
  - By the Numbers
  - The BP Oil Spill
  - The Government and Legislation
  - Concluding Remarks
- What Should Your Next Car Purchase Be?
  - Background Information
  - The History of the Electric Vehicle
  - Past and Current Legislation
  - Electric Vehicle Batteries
  - The Energy Involved
  - Electricity Source
  - Current and Future EV's
  - Plug-In Hybrid Vehicles
  - Conclusion
- The Question of Urban Growth
  - Americans are Going Places
  - Embodied Energy of Suburban Sprawl
- Selected Links and Sources
- The Team
- Sitemap

Transportation: The Journey and the Destination

As it exists today, the global transportation system is comprised of relationships between fuels, vehicles, politics, consumer habits, and infrastructure. The system has evolved over time through the complex interdependence of all these elements: new fuel discoveries led to new transit technologies, which led to changes in consumer habits and government policy regarding infrastructure, which required fuel to expand, and etc.

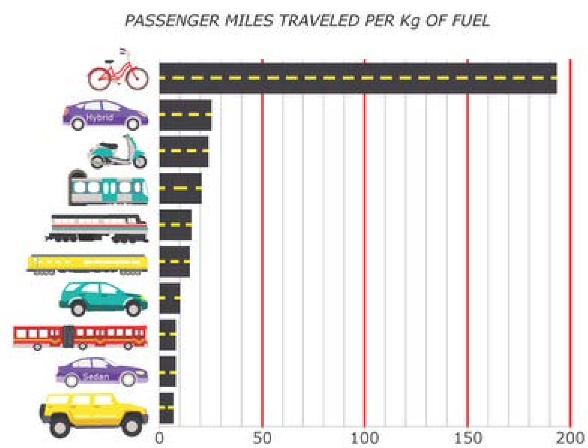

Figure 1: Different Modes of Transportation can travel varying distances using the same amount of fuel

The Beginning: Muscle Power

Prior to the Agricultural Revolution of approximately 10,000 BCE, and up until the Industrial Revolution, hunter-gatherer and agrarian societies relied on muscle power (human or animal) to transport goods and people. With such a limited amount of power, the average person would rarely travel more than 15 or 20 miles from their home and societies were dispersed and disconnected. Transportation has gradually evolved alongside human culture, and as societies have grown more advanced and complex, so too have our means of movement.

Transportation Prior to the Industrial Revolution

The original (and still essential) mode of transportation is the simple act of walking. Walking is an extremely efficient process that relies on the energy derived from food to generate muscle power. However, walking is a slow process and thus limits the distance which can be traveled. As human society developed and grew, transportation methods with greater ranges and speeds were needed to provide for the expansions of populations. Technological advancements such as wheeled carts and boats allowed for movement spanning much greater distances and could move larger loads. Soon, such modes of transportation became essential to the advancement and survival of societies.

The Discovery of Coal and the Industrial Revolution

The transportation methods used prior to the industrial revolution all shared an important common element: They all relied on renewable energy sources. These sources (food-to-muscle power, wind power, river and ocean currents, etc.) were all essential to the movement of people and goods.[1] However the discovery of coal soon changed all this. As populations urbanized during the Industrial Revolution of the 18th and 19th centuries, transportation and related infrastructure began to develop rapidly.[2] Laborers were concentrated into factories and needed to live close to their places of employment, and as the capabilities of mass production evolved, cheaper production costs emerged. Although coal was initially used primarily as a heat source, its abundance, low cost, and high energy density soon led to its employment in transportation with the development of the steam engine. Steam engines allowed for greater amounts of goods to be transported at a higher rate via railways, and people began to travel halfway across nations in a day, where they previously may never have left their villages.

Petroleum and the Internal Combustion Engine

Petroleum has been in use for nearly 4000 years with records of the Babylonians obtaining the versatile substance from pits and using asphalt to strengthen their city walls.[7] Although coal dominated the transportation industry for much of the 18th century, by the mid- to-late 1800's petroleum production began to rise. Petroleum in the 1800's was primarily used for kerosene lighting, preferred too whale blubber. The first oil well was established in Baku, Azerbaijan in 1846 with wells soon to follow in Poland and Pennsylvania.[8] Readily available oil sparked a new age of transportation and technology with the advancement of internal combustion engine (ICE) toward the end of the 19th century, petroleum became an important transportation fuel.[3] Petroleum-based fuels, with their high energy densities and combustibility, made them perfect for ICEs. The transition to a fossil-fuel-based

Figure 2: Humble origins of transportation system

transportation infrastructure was motivated by the cheaper cost of doing work, as opposed to the concern that natural resources were limited.

The Automobile and Suburbanization

The process of suburbanization in the United States is widely attributed to the post-WWII boom in national and personal wealth, and the availability of personal vehicles in large and affordable numbers. While both of these issues factored into creating today's suburban fabric, the story of suburbanization actually began in the mid 19th century. These early ex-urban communities were largely composed of wealthy, upper-class villas and mansions located in a more rural environment as a way for their inhabitants to escape the cramped conditions of industrial US cities.

As steam-powered rail lines and then electric street-cars began to spring up around the turn of the 19th century, development along those lines began to increase. The emergence of a middle class who worked in the city but sought the 'country life' in the manner of their wealthier predecessors provided an impetus for the real-estate industry to develop increasing amounts of land outside of major urban areas.

With the invention of the automobile and the foundation of the Ford Motor Company in 1903, the availability of motor vehicles increased, and the personal automotive became an affordable commodity as opposed to an exclusive luxury in the United States.The construction of roads increased to cater to personal vehicles, and after WWII the rise in income promoted increased leisure travel. By the 1960's, the majority of households in the United States owned a motor vehicle. Suburbanization has only increased with modern highway systems. In fact, the average distance Americans live from their place of work is 16 miles.[4]

Energy consumption (Btu) - Petroleum Products - Transportation Sector Loading...

Globalization: The Unification of the World Transportation Infrastructure

As societies continued to grow on a foundation of fossil fuels, transportation began link the entire world, increasing accessibility for trade and travel. Today, everything from agricultural products to consumer goods are traded internationally, often across oceans by boat or plane. However, as global dependence on fossil fuels increases, cracks in the petroleum-based transportation infrastructure are forming. The peaking of U.S. oil production in the 1970's, and the concurrent fuel crisis, was the first widespread indication of oil's finite nature.[5] This inability to produce enough petroleum to fuel the domestic transportation industry coincided with the increasing reliance on foreign oil sources. Thus, oil corporations around the world have begun scouring the earth for new sources of oil. The United States reliance on oil has led to increased drilling in remote locations, including deep seas and the Arctic. Extraction from new sources of oil, such as shale formations, have also begun, even though the process is much more expensive and environmentally damaging than conventional oil extraction. These unconventional sources may be able to produce oil for a few more years, however it is becoming more evident that our transportation future must be fossil fuel independent.

The Future of Transportation Fuel

Despite the forecast of imminent end of petroleum, the future of transportation fuels is bright. Concerns over peak oil and climate change have motivated the research and development of alternative energy and transportation fuel sources.[5] Electric and hybrid electric vehicles, cellulosic bioethanol, biodiesel from algae and hydrogen fuel cell vehicles all serve as potential game changers in the transportation sector. The status quo is changing, moving away from the fossil fuels which enabled the unprecedented growth in the past. But what is equally important is understanding your own consumption habits. By being conscientious of your own decisions, you can help ease the transition from our currently unsustainable transportation sector. This website is designed to help inform you about the current status of petroleum, and what you can do to help our transition to a sustainable future.

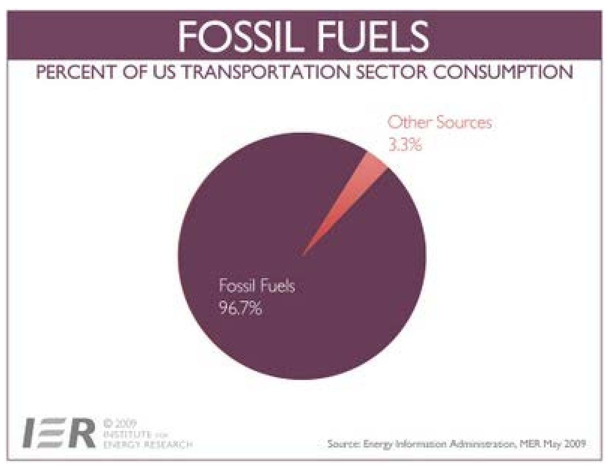

Figure 3: Nearly all of the fuel used for the transportation sector comes from fossil fuels.[6]

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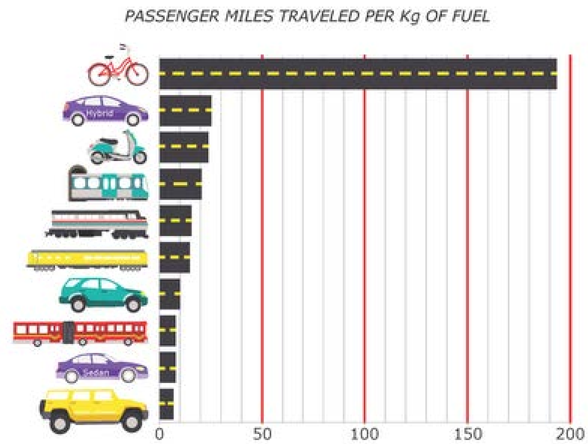

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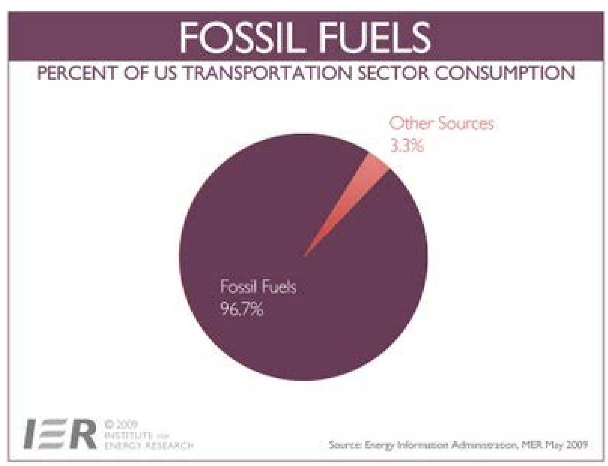

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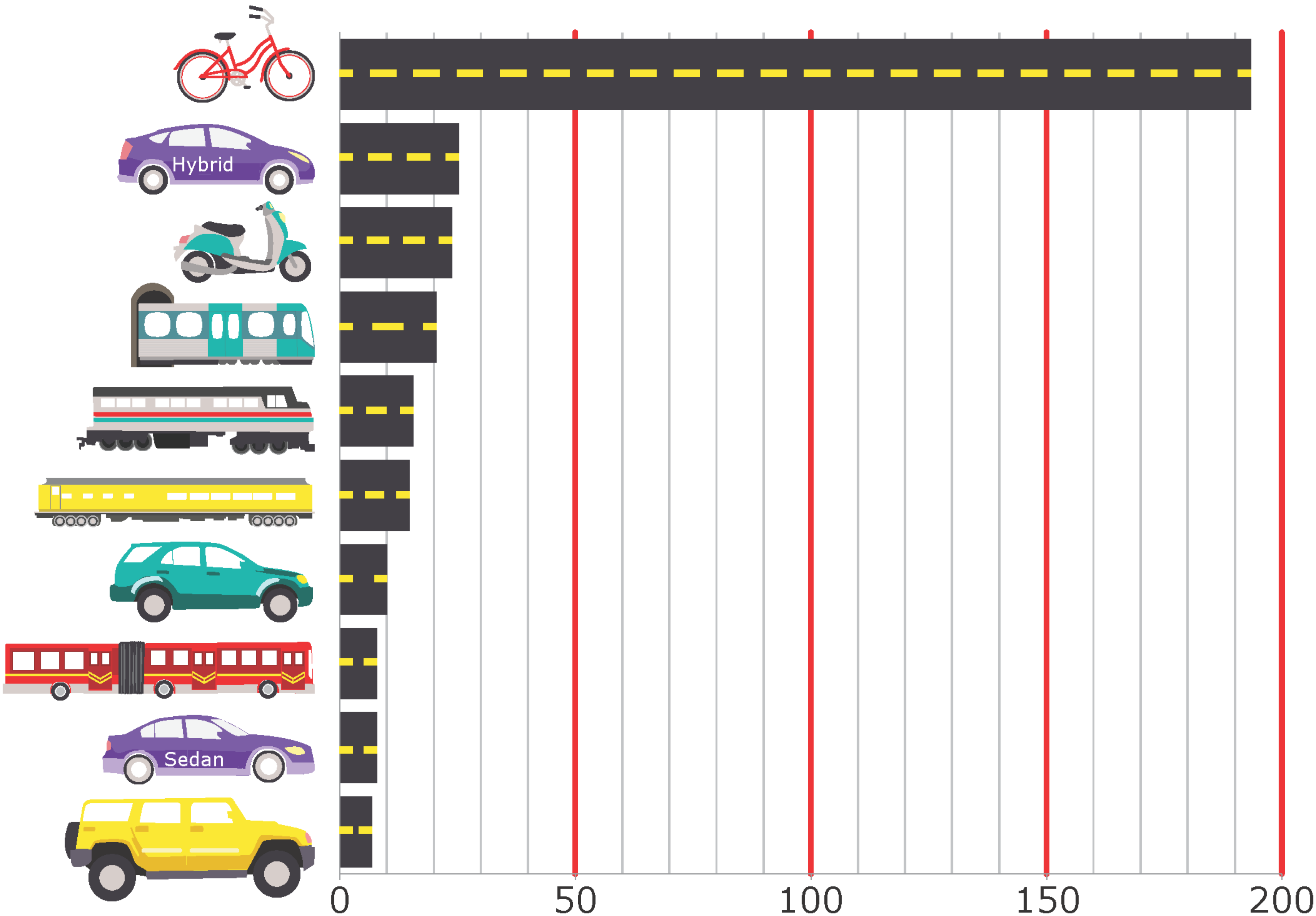
PASSENGER MILES TRAVELED PER Kg OF FUEL



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The Energy World of Petroleum

Petroleum: The Status Quo of Transportation Fuel

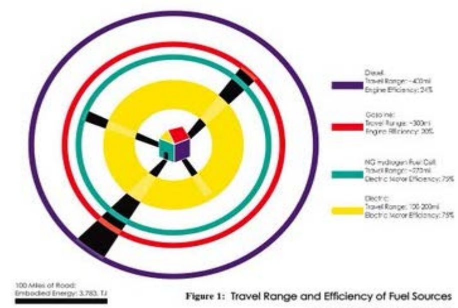


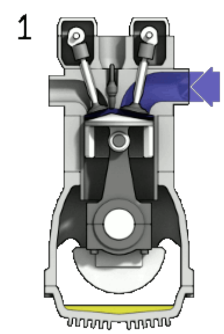
Figure 1: Travel Range and Efficiency of Fuel Sources
Embodied Energy of Roads

Of the different natural energy sources that humans consume, approximately 58% comes from petroleum.[1] Most of this oil is used to fuel the transportation industry, in which 94% of the energy used comes from petroleum.[1] The massive scale of the current transportation system has led to vast consumption. In 2010, 28.1% of the total U.S. energy consumption came from the transportation sector, the majority of which was in the form of gasoline, of which the U.S. used 3 billion barrels.[2]

Why Do We Use Petroleum Products?

Fuels derived from petroleum have a high energy density, which allows vehicles to travel vast distances using a relatively small amount of fuel. For example gasoline has an energy density of 33 kilowatt-hours per gallon, equivalent to the average amount of solar energy 1 m^2 earth's surface receives in 55 hours.[3,4] The internal combustion engine (ICE) is by far the most common means of converting the chemical energy in gasoline into mechanical work. This process uses the energy derived from the oxidation of petroleum (in the form of heat and pressure) to create a uniform force on a piston, which then turns the wheels of the car.

The 4-stroke engine, as its name implies, uses a four-step process to convert the chemical energy of fuel into the rotational kinetic energy used to spin the wheels of your car. **Figure 1** depicts a simplified version of the process. Power is generated during only one of the four strokes. Two full revolutions of the crankshaft occur for every one combustion event.



Step 1 (Intake) - Vaporized fuel enters the piston due to the partial vacuum created by the retraction of the piston.

Step 2 (Ignition) - The piston compresses the vaporized fuel, creating high pressure and temperature. The fuel is ignited, resulting in a rapid increase in volume as the molecules gain energy (i.e. heat up) and generate a force on the piston.

Step 3 (Power) - The heated gaseous molecules from the combustion exert a uniform force on the engine's piston, creating the physical work which can be used to turn the wheels.

Step 4 (Exhaust) - The exhaust, which is comprised of mostly CO_2 and H_2O, is pushed out of the engine by the piston, and the process begins again.

Figure 1: 4-Cycle Combustion Engine

How Efficiently Is Petroleum Used?

Before crude oil can be put into the tanks of cars, the oil must first be extracted and processed into a more usable form. Extraction and processing requires energy (input energy) which is generally derived from fossil fuels (for more on input energy, see Peak Oil's Thermodynamic Implications). Significant amounts of money and energy go into the refining process. In 2010, gross input into U.S. crude oil refineries was 15.17 million B/D (barrels/day), versus an operable capacity of 17.57 million B/D and this gives an operable utilization rate of 86.4%.[7] In 2001, the U.S. spent approximately $7 billion dollars refining fuels per year, and much of this cost stems from the energy required to distill and refine the crude oil into the end products used by consumers.[5] **Figure 2** shows the energy returned on energy invested (EROEI) for various fuels, which includes the costs of extraction, transportation, and refining of the fuel.[6] The figure shows that in 2005, imported oil and domestic oil each had fairly high EROEI's of approx. 30:1 and 14:1 respectively. However EROEI has dropped significantly when compared to the EROEI of oil in 1930.

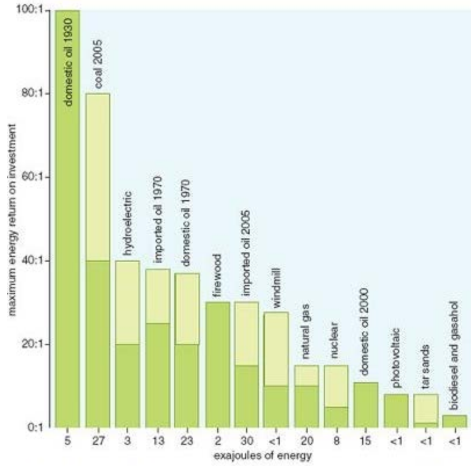


Figure 2: Energy Returned on Energy Invested (EROEI) of various fuels. The tan regions indicate uncertainty due to varying conditions and data. The EROEI does not necessarily correlate to the energy being produced from the source.

Once gasoline has been distilled from crude oil, it is available to be used as fuel for personal vehicles, but only between 14 and 26% of fuel actually produces work in the vehicle. The efficiency of the fuel depends on several factors, as energy can be lost in the following ways: As fuel is burned in the combustion engine, some of the energy is lost as heat (60-62% of total energy lost), some through engine friction (3%) and some energy is lost through pumping (4%).[8] Energy is also lost in the transfer of energy from the engine to the wheels (17-21% of energy total energy lost), and dissipated as wind resistance, rolling resistance, and braking. Parasitic losses (power steering, water pump, etc.) account for another 5-6% of the total energy lost, as do drive-train losses (energy lost in the transmission and drive-line).[8]

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The Peak Oil Debate

How and When Will Our Oil Production Peak?

The peak oil debate emanates from the controversial yet brilliant Shell geoscientist M. King Hubbert. In 1956, Hubbert stunned the oil industry by predicting that U.S. oil production would peak in the 70's and would thereafter enter a terminal decline of about 3% per year (See **Figure 1**).[1] At first, Hubbert was scorned by the oil industry, and few took his warnings seriously. Yet when oil production peaked in 1970, Hubbert was deemed a prophet. Hubbert's great insight was that extracting oil does not work like using gas in a car, i.e. you can't continue to extract oil at the same rate until you gauge reads 'empty.'[2] Instead the rate of extraction reaches a peak when about half of the oil is extracted. The chief reasons for this are 1) reservoir pressure falls as more oil is extracted from a well and 2) that the first reservoirs to be harvested are often the largest and most economical, so that when production at these large fields begins to fall, new production must come from smaller, less economical reservoirs.[3]

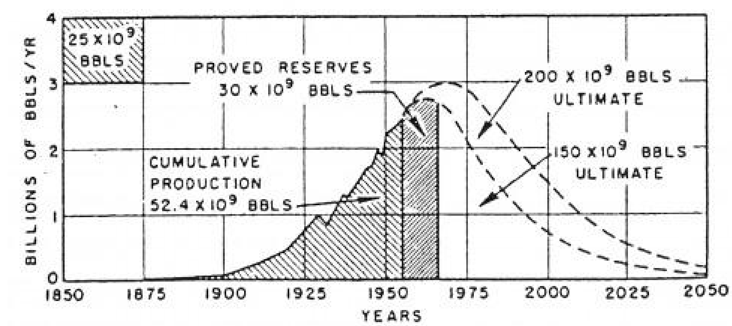

Figure 1 – Hubbert's model predicting the peak of U.S. oil production.[1] "Cumulative Production" refers to the amount of oil which had been produced up until 1954, while "Proved Reserves" were the amount of oil that was known to be in the ground at that time. "Ultimate" refers to the estimate of the total oil available for extraction in the U.S. At the time (and currently too) there was debate over how much oil was left in the earth. Hubbert therefore used both estimates of the ultimate in his calculations, showing that even a 33% increase in the estimated ultimate had only a small impact on the estimated date of the peak.

The peaking of U.S. oil production led to a significant increase on our reliance on foreign oil. Our consumption continued to grow while our domestic production fell. Such dependence on foreign oil contributed to the oil crises of 1973, when OPEC countries imposed an oil embargo on the United States.[4] Yet despite the crises of 1973, little has changed in regards to our continued growth of oil consumption. In 2005, the U.S. consumed about 21 million barrels of petroleum a day, of which 60.3% was imported from foreign countries.[5] With oil now being imported from around the world, the question of peaking oil production has shifted from a national to global focus. This discussion, however, is not about if a peak in oil production will occur, but how and when it may occur.

Divergent beliefs on the timing of the oil peak can be summarized by two prevailing opinions, each championed by a respected authority. Daniel Yergin, chairman of Cambridge Energy Research Associates (CERA) and author of *"The Quest: Energy, Security and the Remaking of the Modern World"*, is of the belief that the peak in oil production will occur as an "undulating plateau" (see **Figure 2**). Yergin believes that a combination of market forces (i.e. rising oil prices) and improved extraction techniques will mitigate the potential problems of a peak in oil production by increasing the amount of oil that is economically viable to extract.[6] David Strahan, author of "*The Last Oil Shock: A Survival Guide to the Imminent Extinction of Petroleum Man*" embodies the counterpart to Yerginite's belief in technological and economical salvation. "Strahanites" believe that the peak in oil production is right upon us, if not already passed.[7] Not only is the oil peak right upon us, but that we will be unable to alleviate the terminal decline in production through

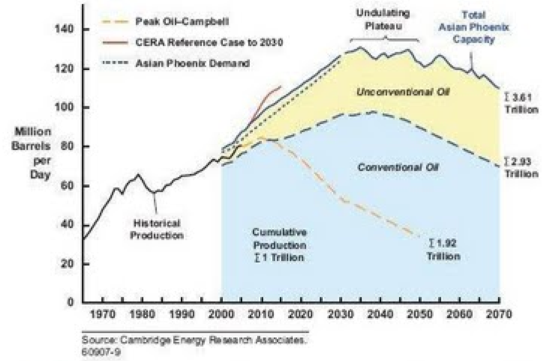

Figure 2.

Comparison of CERA "undulating plateau" and a peak "oil shock" (from Campbell). The upper trajectory shows CERA's estimate for future oil production, with a peak not occuring until mid-century. The lower trajectory shows a peak oil estimate, with a peak within ten years. It should be noted that this data is provided by CERA, the decline of the peak oil trajectory appears too steep, potentially explaining why the peak oil decline in production appears too steep. "Trillion" figures on the right indicate the cumulative reserve estimates for each projection. CERA estimates almost twice the available oil as Campbell.

unconventional oil sources or improved drilling techniques, and that petroleum production will see a sharp decline of about 3% per year, mirroring the oil peak in the U.S. Indeed Strahanites see the imminent peak as the end of a petroleum golden age which will have huge economic and social implications unless significant changes in our petroleum consumption are made.[8]

Should We Be Concerned? The Potential of Unconventional Oil

Are Yergin's predictions about an "undulating plateau" to be believed? or should we all be preparing for "the last oil shock" that Strahan warns of? To determine the fate of our current oil consumption habits, we need to look at the facts.

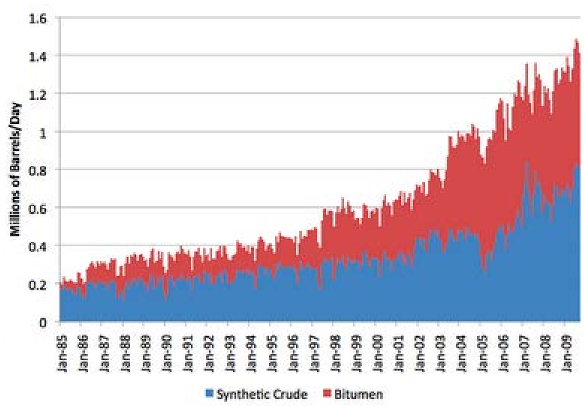

Figure 3. The increasing rate of tar sand oil production over the past 25 years. The blue area represents oil usable to create gasoline.

One of Yergin's beliefs is that as technology improves we will be able to extract oil resources previously unavailable for extraction. These sources, deemed unconventional oil, will more than compensate for the decline in conventional oil production. Currently, the biggest and most promising source of unconventional oil are the Canadian tar sands (see Energy of Extraction for more details). What is exciting to many is the size of the tar sand resource. CERA estimates that 1.75 trillion barrels of bitumen (i.e. the tar sands) are present in Alberta, covering an area approximately the size of England. Of this, it is estimated that 10% is feasibly recoverable, or 175 billion barrels. CERA's focus on available resources, however, obscures the debate. This is because estimations of reserves lead to poor assumptions. For example someone might assume that with 175 billion barrels of bitumen available, at current U.S. consumption levels, there would be enough oil to supply the U.S. for eight years. Yet such a statement does not take into account a huge range of externalities, such as current technological limits, the amount of capital investment required to extract the oil and most importantly flow rates.[9] Indeed flow rates are the heart of the peak oil debate, and not total available resources, because what matters is how fast we can extract oil and not necessarily how much oil remains. Measuring flow rates directly is a more straightforward, informative method to determine the amount of available oil. Lets use a group of apple orchards as an allegory for the worlds oil fields, and we want to know about the rate at which we can pick apples. CERA's analysis would equate to counting the total number of available apples, including overripe apples (heavy oils), the apples of a farmer who will not let us onto his farm, but gives us his word on how many apples he has (Saudi Arabia) and the apples high up on the trees which require heavy machinery to reach (unconventional oils). Once all of the apples are counted, CERA would then use an estimate to determine that rate at which apples could be produced.[10]

A much more direct method to determine future production rates would be to measure the growth rate of oil production, just as Hubbert did in his original calculations. Doing such an analysis for Canada's tar sands shows that they will never be more than a small portion of our future oil supply. In 2006, the Canadian tar sands produce about 1.5 million barrels of bitumen a day, out of which about eight-hundred thousand barrels of synthetic crude oil can be made (see **figure 3**).[11] This is a small fraction of current U.S. consumption of about 21 million barrels a day, and an even smaller portion of the world's 86 million barrels a day. Worse, Jackie Forest,one of the authors of the IHS CERA report, believes it would be

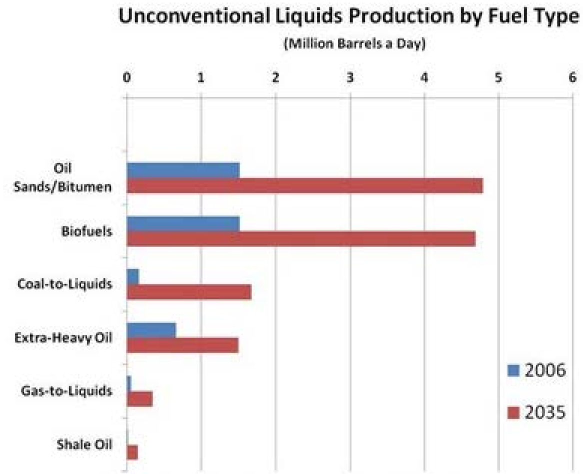

Figure 4. Data obtained from the International Energy Outlook.

'really pushing it' to ramp up tar sands production to 6.3 million barrels a day by 2035, a number often cited by Yerginites.[12] Another group, the International Energy Agency (IEA), estimates tar sand production will be even lower, with production in 2035 to be at most 4.8 million barrels a day (see **figure 4**).[13] Even at these maximum possible levels, Canada's tar sands would barely be able to make up one tenth of the estimated drop in production of conventional oils.[12] Similar stories play out for all unconventional oil sources. They are just unable to scale in terms of volume, are unable to be developed within any reasonable time frame and have much lower energy returns than conventional oil.

Will the Market Save Us?

Yergin references in his Wall Street Journal essay *There Will Be Oil* that Hubbert had no understanding of the economics of oil, and as such the influences of supply-and-demand were omitted from his estimates.[6] Yergin maintains that "activity goes up when prices go up; activity goes down when prices go down." Thus it would be expected that the rising costs of crude oil should be reflected by an increase in oil production, be it through new discoveries, technological advances or through the entrance of sources which were previously not cost-effective. This, however, is just not the case.As **figure 5** shows, despite the steady increase in the price of oil, U.S. production has fallen ever since the peak was reached in the 70's. Indeed of the sixty-five countries which have passed their oil production peak, not a single one has been able to re-obtain their peak production levels, despite oil prices rising over $100 a barrel.[12] If oil did follow a strict supply-and-demand relationship, it would be expected at least one of these countries would be able to recover their production levels through enhanced recovery techniques such as water injection, CO_2 injection, fracking, horizontal drilling, digitizing of the oil field or by increasing unconventional oil production, or any of the technologies which Yergin cites. Again, the best example of the inability of the market to influence production is the United States. Despite the influx of these enhanced recovery techniques, the discovery of shale oil out West and huge government support for "domestic oil", the United States has been unable to halt the decline in oil production simply because the geological limitations of oil extraction. Although enhanced recovery techniques are able to increase the yields of oil fields by as much as 20%, Strahan argues that they are never able to compensate for this geological root cause of a well's drop in production.

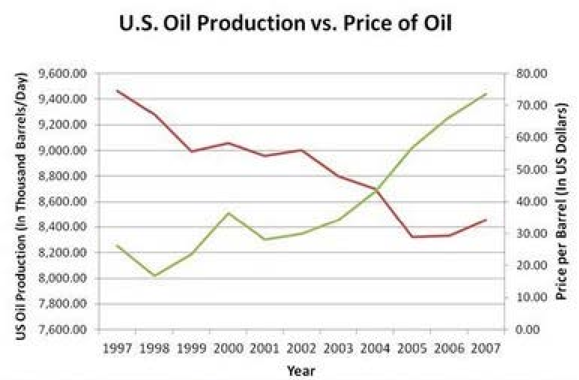

Figure 5. Data obtained from the Energy Information Administration (EIA). The red line depicts US oil production, while the green line depicts the price of oil per barrel. As prices have increased, production has continued on a downward trajectory since the 70's.

For this reason, oil doesn't follow a strict supply-and-demand relationship. Yet other factors do contribute to the failure of the invisible hand. One of the major assumptions of the Neoclassical economic theory is the presence of perfect information. Information in the oil industry, however, is severely lacking. Reliable data is difficult to obtain as countries and companies alike are reluctant to part with their carefully collected data. Without good data for over 90% of the world's oil supply, invisible hand solutions are unlikely to be able to cope with a surprise drop in oil production.[9] The fact is that market solutions are reactionary, yet freeing ourselves from our reliance on oil is a process which will take decades.

Peak or Plateau?

So who should we believe, Yergin or Strahan? Although the techno-optimism of Yergin is alluring, the fact is that CERA's estimates work to obscure the problem. By focusing on huge reserve estimates and not on the more relevant and telling production rates promoted by Strahan, CERA are providing "detailed road maps in the wrong direction."[10] The peaking of U.S. oil production in the 70's should serve as a lesson that once peak production has been reached, there is no turning back. But where does that leave you? Is there any hope, any way to help? The truth is there are no easy fixes. Like a house built on sand, our economy was erected upon a temporary foundation: fossil fuels. But there are steps you can take as an individual to help wean our dependence on oil. Reducing personal consumption of anything and everything, buying locally, riding a bike instead of driving a car. Taking such steps not only will help protect yourself from the oil shock, but will help reduce the effect globally. Finally, contact your local representative. Enacting such monumental change requires equally monumental legislation. Thus it is crucial to inform your local representative that the status quo is unsustainable and that now is the time for change.

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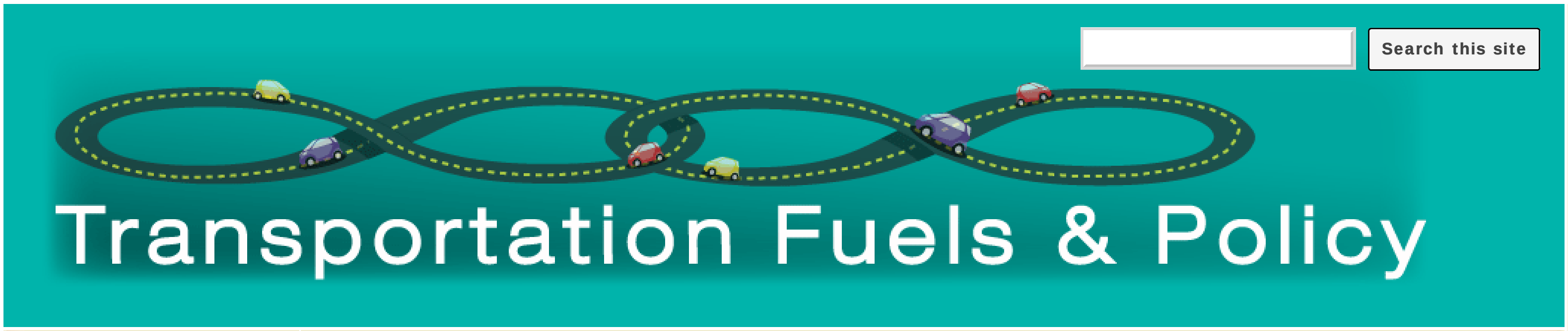
Subpages (1): Energy of Extraction



Energy of Extraction

The Growth of Unconventional Oil

For the majority of our petroleum history, oil was produced from "conventional" sources, where the oil is extracted on land and requires little more than drilling a hole into the earth. Just think *There Will Be Blood* and you will have a good idea of what conventional oil is. For much of our oil history, these conventional sources have supplied the majority of our petroleum. Yet the increasingly rapid rate of oil consumption has been paralleled by a rapid reduction in conventional oil reserves. To compensate for faltering conventional oil, new sources, deemed "unconventional oil",have risen. These unconventional oil sources, such as oil sands, shale oil, off-shore oil and arctic oil, were previously (and still are) untapped not because they were undiscovered, but because they were too expensive to process.[1] The rising price of crude oil has now made these sources economical, so much
so that Canada's tar sands compose over 23% of total U.S. oil imports, the largest single source of foreign oil.[2]

Decreasing EROEI: The Approach of 1:1

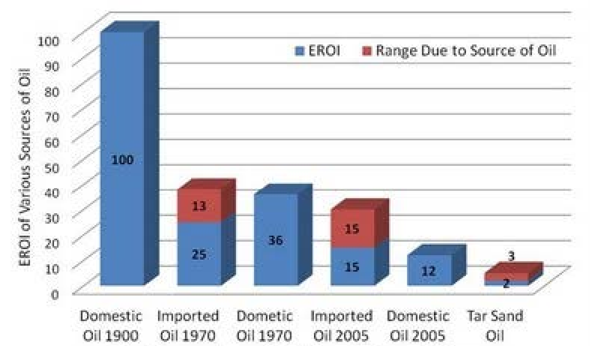


Fig. 1 Comparison of EROI from Various Oil Sources

Why is unconventional oil more expensive than conventional oil? Unconventional oil has higher costs because more input energy is required to extract the same amount of oil. This can be easily quantized through the use of energy returned on energy invested (EROI).[3] EROI is a ratio of the energy output to energy input, or in terms of oil, how many barrels of oil you can extract using the energy contained in one barrel of oil. In the early days of the U.S. oil industry, crude oil was found by seeing it literally seeping through the ground. To extract this oil, very little energy was required, so the EROI was about 100:1.[3] Like most resources, the oil fields which were found and exploited first were the largest and easiest to access. As our oil consumption has grown, the production of such fields declined and new fields were thus needed to replace the depleting sources, however replacing these fields was difficult, because the best fields had already been found. Thus, replacement fields were harder to find and produced less oil.[4] As a result, the amount of energy required to extract the oil increased, while the amount of oil found decreased, leading to lower EROIs.

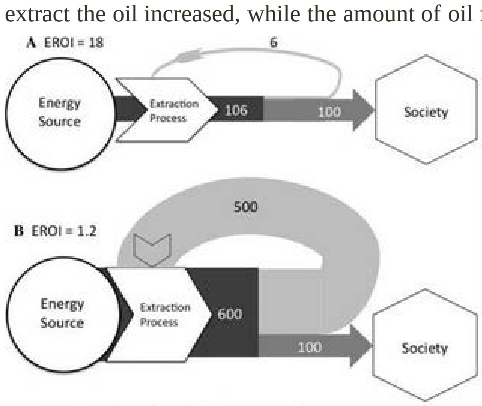


Figure 2. Effect of EROI on Total Energy Extracted

By 1970, the EROI of U.S. domestic oil had was about even with imported oil (see **figure 1**). The decline in EROI was mirrored in U.S. oil production, a major factor in the oil crises of 1973, after which the U.S. became heavily reliant on the cheap crude available from abroad. In 2005, the EROI of domestic oil had dropped to 12:1 and is continuing to decline. So what does the decline in EROI mean? As EROI drops, more and more oil must be extracted to maintain production levels. **Figure 2** illustrates this point. Say a source of oil has an EROI (analogous to EROI) of 18. In order to provide a net supply of 100 units of oil to society, 106 units of total energy must be extracted, with 6 units of power used for the extraction process. What happens if EROI drops, for example to 1.2? The effect of such a drop is monstrous. In order to provide the same net amount of energy (100 units), six times as much must be extracted, because 500 units are needed to power the extraction process! Now this example is assuming that the amount of energy required by society is constant, but in reality it is not. World oil demand has grown over 36% since 1980.[5] So not only is EROI declining, leading to more barrels of oil needed to be extracted for every oil eventually used, but the net amount of barrels of oil required is also increasing, compounding the effect and causing even rapider depletion of oil reserves. Currently oil from tar sands requires much more input energy than conventional oil. The energy returned on energy invested (EROI) for refined oil from oil sands is about 2 to 3. For conventional oil, EROI is about 12.[6] The higher EROI results in higher costs, more CO_2 emissions per mile driven and less net energy output as compared to conventional oil.[7] In fact, it has been calculated that at best, shale oil produces similar carbon dioxide emissions as an equivalent amount of lignite, the lowest grade of coal.[8]

How the Processes Differ: Extraction of Conventional Oil

Conventional oil is extracted by drilling a well through the earth to an oil reservoir. When the well is first drilled (called the primary recovery stage) the oil reservoir is usually pressurized, due to pressure of the rock sitting above the reservoir, the downward movement of water (which is denser than oil) and the presence of natural gas within the reservoir. This causes the oil to rise up t thousands of feet to the surface of the earth.[9] Since natural forces provide the energy for this migration, little external energy is required. For this reason the EROI for conventional oil extraction can be up to 40 times higher than the EROI for tar sand oil.[7] The recovery factor (what percent of the total oil is recovered) for the primary recovery stage is usually about 5-15%, though it varies greatly from well to well.[9]

Over the lifetime of the well the pressure within the reservoir begins to drop, slowing the rate at which oil can be produced. Eventually the pressure decreases to the point at which the pressure is insufficient to force the oil to the surface of the earth. At this point, secondary recovery techniques are required for further extraction of oil. External energy is required to force the oil to the surface of the well. This energy is usually provided using a fluid, such as water, carbon dioxide or natural gas. The fluid is pumped into the reservoir from a secondary well, pressurizing the reservoir.[6] Significant amounts of power are required to force the oil to the surface in a timely manner. The external energy used in secondary recovery is usually provided by burning fossil fuels, thereby decreasing the EROI of the oil extraction process significantly. Using secondary recovery techniques allows about 10-15% more oil to be extracted from the reservoir, bringing the total recovery factor to about 30%.

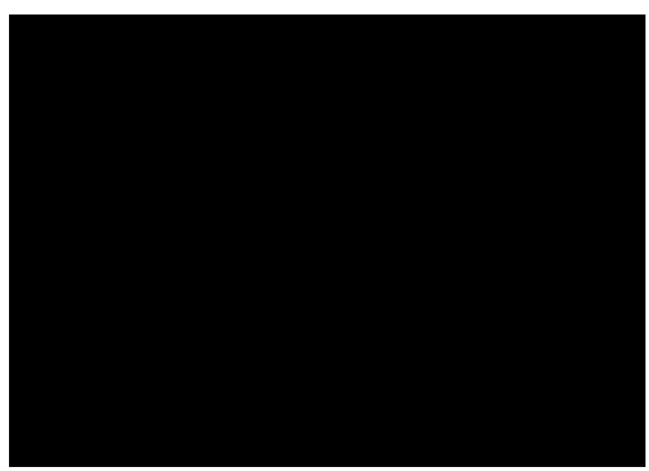
Tertiary recovery techniques can be used to further increase the recovery factor of the oil. Tertiary recovery techniques employ heat in the form of steam to raise the temperature of the oil.[10] As the temperature of a liquid rises, its viscosity, or stickiness, is reduced. Thus the steam makes the oil more fluid and easier to extract, allowing for more to flow to the surface. Heating up such vast quantities of petroleum require even more energy input into the system. Again, the energy for this process is provided by fossil fuels and the EROI of tertiary recovery is lowered even more than that of secondary recovery.

Extraction of Tar Sands

Extraction of oil from tar sands differs greatly from the extraction of conventional oil. Indeed the process of extraction resembles strip mining, with huge amounts of material being removed from the surface of the earth. The process uses heavy machinery to remove the ore from the mining site, transferring it to a processing plant. At the plant, the bitumen is extracted from the ore using hot water and agitation. This process can extract 90 to 100% of the bitumen from the ore. It is important to note that two processes are now being used for tar sand oil extraction. The process shown in the video is predominately surface mining, but another process known as "in-situ" extraction. In-situ extraction pumps hot steam and/or water into bitumen deposits too deep to extract via surface mining. the hot fluids decrease the bitumen viscosity, allowing it to be extracted by pumping, like conventional oil. Both of these processes are highly energy intensive, explaining why the EROI mentioned previously is so low.

Extraction of Shale Oil

extraction of shale oil has an even lower EROI than tar sand extraction. This is due to the even higher amounts of processing required to convert the shale oil ore into synthetic oil. This video, being made from a shale oil extraction company, should be viewed with a grain of salt, as many of the figures stated are skewed and give false impressions. For example there are an estimated 1.5 trillion barrels of oil in the Green River Oil formation, however Senator Hatch's implying that "1 trillion barrels" are able to be recovered is hugely inflated. That would assume a 66% recovery rate, almost twice as much as what we can currently extract from conventional oil wells, let alone from oil shale. Also keep an eye out for the amount of processing required before the shale is



converted into gasoline, specifically the step which requires "shipping the shale to Canada". This amount of processing is what leads to the incredibly low EROI. Finally, the goal of the company is to generate fifty thousand barrels of oil a day. Yet compared to the U.S. consumption rate of 23 million barrels a day, this is only a drop in the bucket.

Arctic Oil (click here)
Arctic oil is becoming increasingly attractive as conventional sources are depleted. This video gives a good overview of the challenges which face arctic oil extraction, both technically and politically.

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Transportation Fuels & Policy

Deep-Sea Oil Production

America's transportation habits require quantities of fuel that are becoming more and more difficult to obtain and so the question is; can offshore oil production solve climbing gas prices, decrease foreign oil dependence and solve America's fuel crisis?

The United States of America is now home to over 300,000,000 people according to the U.S. Census Bureau, and with over 90% of households owning a vehicle the use of petroleum is at an all time high.[1] Petroleum fuels 93% of our transportation needs, and in August of 2011 America imported 9 million barrels of oil per day to satisfy a national diet of 18.8 million barrels per day.[2,3] But importing oil comes at a price and this price is susceptible to weather patterns and international relations which opens the door for offshore oil production. Offshore oil production has received increased publicity lately thanks to the BP Oil Spill, which increased public awareness of offshore oil rig safety issues, and the environmental impact of offshore drilling. Increased offshore oil production could enhance our country's economy by creating jobs, lowering the cost of oil by avoiding the 6500 mile journey from the Middle East to the United States, lower the cost of gasoline, and establishing a national energy system with less dependence on international relations.

The Rise of the Need for Alternative Oil

The Oil crisis of 1973 created widespread panic amongst the public, as well as in the private oil sector, because it confirmed the predictions of pioneering oil geologists, such as Marion King Hubbert who predicted that the U.S. could not maintain its oil consuming habits and that sooner rather than later the world's oil supply would be less than adequate.[4] The reality was that conventional oil production methods, primarily drilling on dry land, could not nourish our oil hunger any longer so researchers focused their efforts in locating more remote oil deposits. Figure 1 shows a chronology of oil prices from 1970 to 2008 and highlights key events in recent world history that have impacted global oil prices.

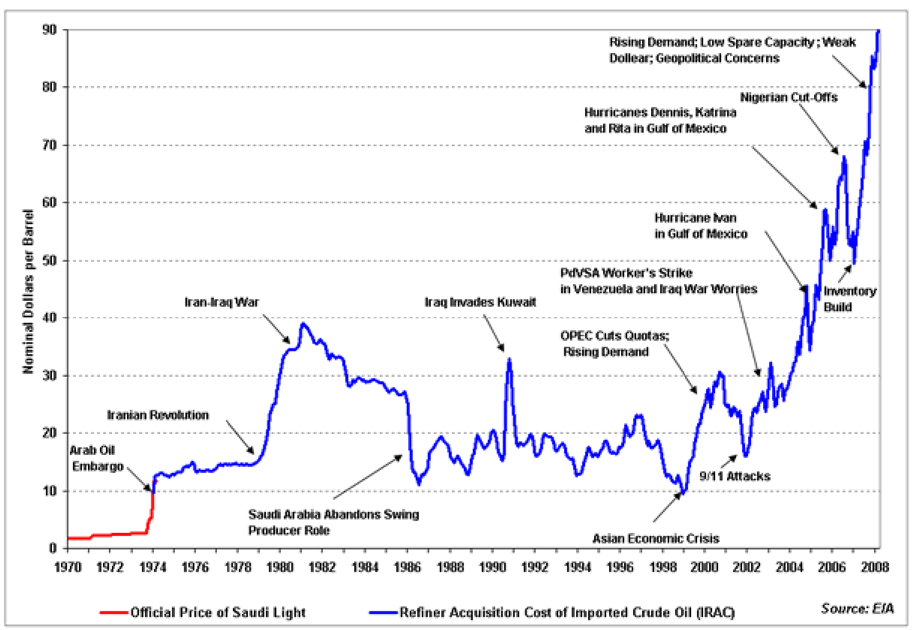

Figure 1. 1970 to 2008 global oil chronology from U.S. EIA.

It is immediately apparent that ripples between Middle Eastern countries have a direct impact on global oil prices, and even though their issues may be exclusive, the effect of these issues on worldwide oil prices is inclusive. This figure also demonstrates the effects of weather on oil prices which will be discussed in further detail in subsequent sections. In theory, if the U.S. could decrease its dependence on foreign fuel, then the U.S. oil market would be proportionally more stable. The oceans became a promising frontier for decreasing this dependence, and the motivations for more domestic oil sent people into the water.

Transporting Oil

Distance is the primary factor that contributes to gas and oil prices. The farther oil is sold from where it was extracted the more expensive it tends to be. Of all the crude oil processed by U.S refineries in 2010, 62% was imported and 26% of the gasoline American's used that year came from the Gulf of Mexico. Figure 2 from Oak Ridge National Laboratory, to the right, displays the percentage of U.S. crude oil imports over the last 60 years.

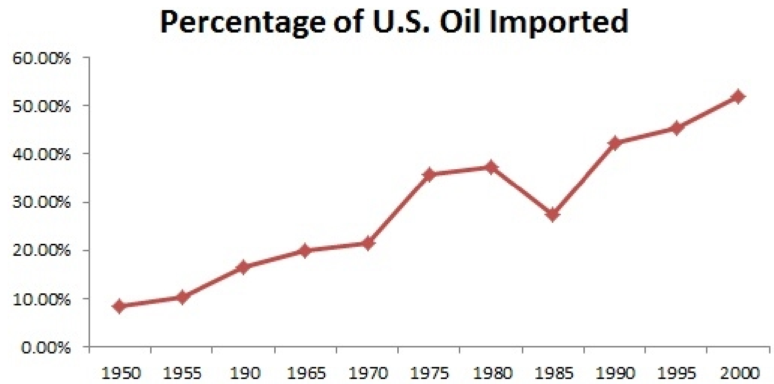

Figure 2. Percentage of consumed U.S. oil that is imported by year. Data from Oak Ridge National Laboratory.

This graph shows a clear trend of increasing dependence on foreign oil to satisfy our national diet. Data published in 2009 in the *Oil & Gas Journal* showed that shipping oil from the Gulf to Houston costs approximately $0.90 per barrel where as shipping from the Persian Gulf to Houston costs $2.08.[5] More domestic oil production would lead to decreased oil prices as the distance from supply would be decreased.[6]

As previously mentioned, weather also play a critical role in determining oil prices worldwide. Oil transportation vessels are unable to forgo hurricane-force winds to deliver oil therefore oil becomes relatively scarce and prices increase. .Immediately following Hurricane Katrina about 2 million barrels per day of refining capacity was lost. Figure 1 shows sudden spikes in oil prices immediately following Hurricane Ivan in 2004, and Hurricanes Katrina, Rita, and Dennis in 2005. If domestic oil production increased, then oil wouldn't have to be shipped from the Middle East, which would drastically reduce shipping costs. Also, shorter shipping distances decreases the oil trade's vulnerability to severe weather and this would keep costs more stable.

International Relationships and Oil

Wars are typically followed by periods of national economic recession and eight of the nine post-war recessions in this country were accompanied by sharp increases in the price of oil.[7] Figure one shows oil price fluctuations related directly to periods of international tension. Events such as the Iranian Revolution in 1978-79, the Iran-Iraq War in the 1980's, Iraq invading Kuwait in 1990, the 9/11 terrorists attack in 2001 and the Iraq War, which began in 2003, have all affected global oil prices. A country that can supply oil to meet it's own needs has better chance of successfully weathering tough times.

The Gas Price Argument

As previously mentioned, the effect of offshore drilling on fuel prices is a common promotional angle. The public, as well as the government, seem to believe that offshore drilling holds the answer to decreasing the climbing gas prices in the U.S. Unfortunately there is little data to support this optimistic idea. In a "TIME Business" article written by Bryan Walsh in 2008, he responds to the then recent action of President George W. Bush calling for nationwide outer Continental Shelf drilling, as well as drilling in the Arctic National Wildlife Refuge (ANWR), to decrease national gas prices. Walsh quotes the 2004 study by the government's own Energy Information Administration (EIA) who found that drilling in the ANWR would trim gas prices by only 3.5 cents a gallon by 2027. Walsh also quotes the National Resources Defense Council who estimated that opening up offshore drilling, prior to 2008, would cut gas prices by a whopping 3 to 4 cents per gallon.[8] Although it is the government's own organization, the EIA, that produced such pessimistic numbers for the effect of offshore and ANWR drilling on national gas prices, it was President George W. Bush who reinstated offshore drilling in 2008, and since then offshore drilling has been on the rise. Increased domestic oil production via offshore drilling and drilling in the ANWR would create a detectable decrease in the price of gasoline, but a 3 cent decrease is not substantial.

Local Jobs

Advocates of offshore drilling tend to pronounce the flux of jobs that would ensue with increased offshore drilling operations. More offshore drilling equates to more employees in the fields of drill equipment manufacturing, installation of oil rigs, oil rig operation, refinery operation and oil transportation. Rayola Dougher, senior economic advisor for the American Petroleum Institute, made the point that the oil industry now employs over 9 million Americans with 2 million of these being created in the last 10 years. Dougher also noted that 500,000 jobs and $150 billion per year would be created by open drilling practices in offshore drill sites and the ANWR. This $150 billion would shave a significant chunk off the country's foreign trade deficit which is $500 billion as of 2010, up from $700 billion in 2008.[9,10] Unemployment in the U.S. reached 9.6% in 2010, the highest its been since 1983 so there is no question that establishing offshore and ANWR drilling would benefit the national economy.[11]

The issues surrounding offshore oil production generate heated controversy and debate. Issues of oil rig safety, wildlife safety, environment safety, pollution, fuel prices, local jobs and foreign oil dependency are among the most commonly mentioned. What is undeniable is that the U.S. is using more oil than it produces, forcing the importation of oil from many regions around the globe, some of them volatile. The U.S. oil industry and transportation sector are feeling the pressure of limited resources.

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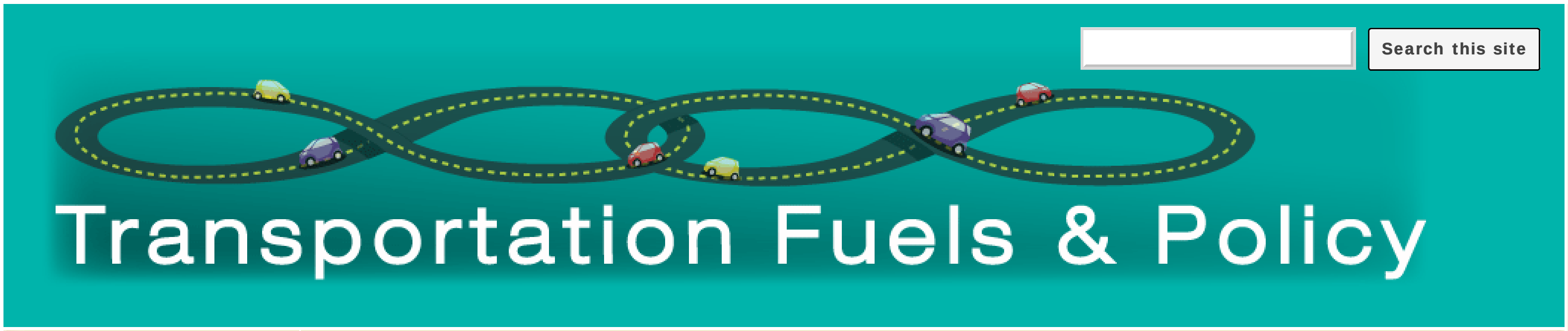
Subpages (6): Brief History By the Numbers Concluding Remarks The BP Oil Spill The Energetics The Government and Legislation



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- Transportation Overview: The Journey and the Destination
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- The Peak Oil Debate
  - Energy of Extraction
- Deep-Sea Oil Production
  - Brief History
  - The Energetics
  - By the Numbers
  - The BP Oil Spill
  - The Government and Legislation
  - Concluding Remarks
- What Should Your Next Car Purchase Be?
  - Background Information
  - The History of the Electric Vehicle
  - Past and Current Legislation
  - Electric Vehicle Batteries
  - The Energy Involved
  - Electricity Source
  - Current and Future EV's
  - Plug-In Hybrid Vehicles
  - Conclusion
- The Question of Urban Growth
  - Americans are Going Places
  - Embodied Energy of Suburban Sprawl
- Selected Links and Sources
- The Team
- Sitemap

Deep-Sea Oil Production >

Brief History

As with most refined things in this world, the process of deep-sea drilling underwent a long period of trial and error where past mistakes influence technological advancements. Deep-sea drilling is something of a misnomer when describing early deep-sea drilling practices, as primitive technology limited oil rigs to land based operation. The following events provide an basic timeline of events related to deep-sea oil production.

Late 19th century - first submerged oil wells were drilled.

1896 - The first salt water well was drilled from a pier off the coast of Santa Barbara, CA.[1]
Early 1930's - Texas Co. (later to become Chevron) developed the first mobile steel barges for drilling in the Gulf of Mexico.[2]

1940's - fixed drilling and production platforms increased domestic oil production but these structures were limited to depths of up to 20 ft. Fixed oil rigs came into use for drilling in depths of more than 100 ft with jack-up rigs (floating oil platforms on a vertical track of 3 legs fixed to the sea floor) developing soon after.[3]

1953 - The Submerged Lands Act of 1953 and Continental Shelf Lands Act of 1953 divided up the coastal land amongst state and federal governments with the seabed extending to 3.5 miles going to state governments; Texas and Louisiana own out to 10.5 miles.

1960's - The first drillship set sail off the coast of Mexico. The *CUSS1* drilled in water as deep as 12,000 ft and the well extended 600 ft below the sea floor but the venture was purely experimental.[4]

1969 - A 3 million gallon oil spill from a Unocal rig off the coast of Santa Barbara, California, resulted in drilling bans in offshore California and Florida, bans that continue to this day.[5]

1990 - Drilling in Texas and Louisiana went on uninterrupted until the nationwide offshore drilling ban administered by President George H. W. Bush.

2008 - Nationwide drilling ban was lifted by George W. Bush when the price of a barrel of oil reached an all time high of $145.29.[6]

2010 - BP oil spill in the Gulf of Mexico released 4.9 million barrels into the ocean creating significant controversy regarding wildlife safety and clean up methods.[7]

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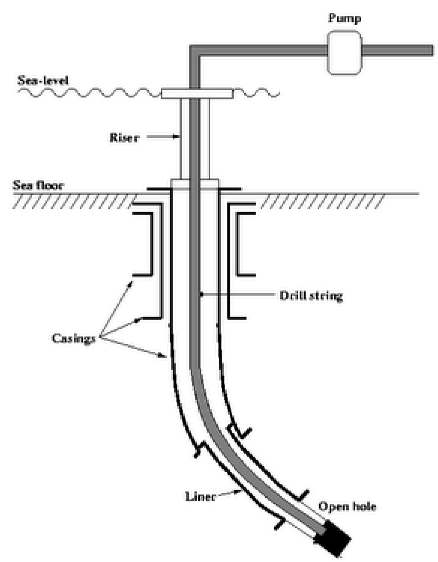
Deep-Sea Oil Production >

The Energetics

The process of drilling for oil is governed by the same set of Laws as every other physical process in the universe. The Laws of Thermodynamics describe the energetic world of microscopic phenomena. The physical process of oil extraction can be described by ideas of pressure, heat, entropy, and efficiency. Oil production companies sum these quantitative energetic principles and create a ratio known as the "energy return on energy invested" and this ratio provides a comprehensive figure that allows many energy related processes to be compared directly.

Oil Deposit Pressure Differential

Pressure is a double edged sword when it comes to oil extraction. On the one side, pressure differences between the oil deposit and the drilling complexes make oil extraction significantly easier. But on the other side, pressure differences between the inside of the drill casings and Earth require complex measures to avoid crushing.



An oil rig is positioned above an oil deposit based on seismographic data and a series of casings are lowered into the water until they reach the Earth's surface.[1] A drill string, consisting of the drill pipe and drill bit, is lowered down through the casings (Figure 1). The drill bit then bores through the Earth until it reaches the oil deposit. An oil deposit under 12,000 ft of water and 15,000 ft of Earth is under a pressure of 15,000 psi, compared to normal atmospheric pressure of 15 psi, and can reach temperatures of 650 degrees Fahrenheit.[2] When the drill bit penetrates the walls of the oil deposit the vast pressure differential causes the oil to spontaneously rise through the drill pipe. Once the oil reaches the oil rig an apparatus regulates the pressure, the transmitted volume of oil and the flow of lubricant and mud weight into the drill string. This apparatus, known as a "christmas tree valve", consists of valves, spools, and fittings necessary to monitor the dynamics of oil production. The christmas tree valve also regulates the injection of liquid water, steam or natural gas into the oil deposit. The spontaneity of the oil rising up the drill string only lasts as long as the pressure differential allows it to. At some point an equilibrium is established between the oil deposit and the scaffolding and the oil sits motionless. Injecting a substance into the well physically forces the black liquid gold to rise again and this process increases the value of the oil deposit. Pressure is a measure of the internal energy of the molecules and thankfully pressure does the majority of the heavy lifting in oil extraction.

The Value of Mud

When a hole is drilled into the Earth and a hollow metal tube (the drill casing) is inserted into the hole the Earth exerts a pressure on the hollow tube. This pressure is inevitable and is due to the weight of the overlying water and layers of sediment. In order to counteract the external pressure, oil companies fill the drill casing with mud to prevent crushing. But this issue becomes even more complicated when one considers that the further one drills, the more force there is acting on the outside of the casing. The mud that is used to fill the drill casing must account for this increase in pressure which means the mud closest to the drill bit must be more dense than mud used previously in the same casing. Mud weight is measured in terms of pounds per gallon (lbs./gal or ppg). Minerals and clays, such as bentonite and barite, are added to the mud to vary the weight per unit volume. Not only does mud prevent the casing from collapsing but the mud is constantly circulated down the drill string and up through the casing and this circulation helps to prevent cracking in the well walls, as well as suppress any oil or gas leaks.

The Intricacies of Randomness

The second Law of Thermodynamics describes the tendency of a physical process to occur spontaneously in one direction, gaining randomness, but not in the reverse direction, becoming more ordered.[3] For example, a metal rod that is heated at one end will possess one hot end and one cold end and, when left alone, the temperature will spontaneously equalize until the entire rod is the same temperature. But a metal rod of all one temperature does not undergo a spontaneous change to possessing two ends of different temperatures. The thermodynamics principle that describes the tendency of spontaneous processes is called entropy. Entropy plays a critical role in oil extraction. When the drill bit punctures the wall of the oil deposit, the potential for an increase in entropy, an increase in randomness, causes the oil to flow up the drill string. Penetration of the oil deposit leads to an instantaneous increase in entropy which is enabled by a constantly decreasing oil pressure as the oil rises to the rig. Without the driving forces of entropy, oil extraction would become much more energy intensive as driving forces must be introduced.

Efficiency

In general, efficiency describes the quantity of product that results from a quantity of work or effort. Oil extraction and cost are linked by efficiency. The more efficient an oil rig is at extracting oil, the less it costs to obtain a barrel of oil and profit increases. The areas that are targeted to provide the most value to the oil well construction process, subject to the greatest gain in efficiency, include drill string integrity, drill hole integrity and hydraulics management. Drill string integrity encompasses the prevention of mechanical overload, protection of high stress areas from fatigue and minimizing excessive shock and vibration during the production process. Drill hole integrity focuses on defining upper and lower drill hole pressure limits, and identifying the optimum mud weigh ratio. Hydraulics management includes maintain equal pressure around the circumference of the drill string within drill hole pressure boundaries, optimizing hole cleaning and clean-up cycles and optimizing circulating system pressures.[5] All of these components are extensively monitored via on-board software where the oil rig system makes critical adjustments as necessary all in the name of improving efficiency and minimizing cost.

Energy Return on Energy Invested

The process of extracting oil with optimal efficiency involves using the least amount of energy possible to obtain the maximum amount of oil which is essentially a currency of energy. The ratio of energy used to extract a source of energy compared to the amount of energy acquired is called the "energy return on energy invested (EROI)" (Equation 1).[6]

$$EROI = \frac{Quantity\ of\ energy\ sup\ plied}{Quantity\ of\ energy\ used\ in\ sup\ ply\ process}$$

Equation 1. The EROI ratio.

A higher EROI means an energy source is particularly cost effective since energy is gained. A lower EROI essentially shows an energy conversion from one form to another. Hydro-power, for example, has an EROI of nearly 100 which corresponds to process that generates energy while requiring almost no energy input. Biodiesel requires almost as much energy to create as actually exists in the substance so the EROI is less than 5. Figure 2 shows the EROI values for many forms of energy used in the USA in 2010.

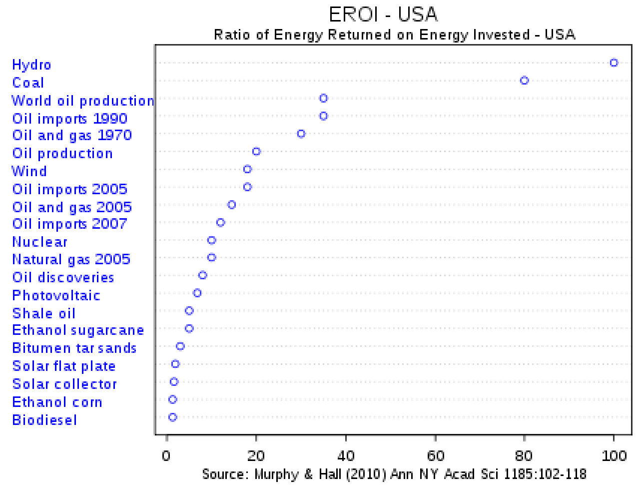


Figure 2. EROI for various energies in US in 2010.

The values for "oil imports 2005" and "oil and gas 2005" are of particular relevance to the issues surrounding offshore drilling because the difference between the two values equates to the energy required to import the oil. The energy required to import oil is even greater than these figures would suggest since natural gas is included in only one value. Offshore drilling, particularly in the Gulf of Mexico, would eliminate the expense of importation and decrease the price of oil for consumers in the US. EROI has further implications in oil production in terms of the energy used to extract the oil. If drilling equipment is operated with energy from a hydro-electric plant then that energy is less expensive than if it were produced from a nuclear plant. In this scenario the ratio of the cost of energy supplied to the price of energy acquired would be smaller for hydro-electric generated electricity and the oil would represent a greater gain in capital.

Nothing is independent of energy and oil is no exception. The Laws of Thermodynamics govern the physical behavior of oil and oil producers use this to their advantage by allowing entropy to pump the majority of the extractable oil from a deposit to the oil rig. Thermodynamic principles such as pressure and heat can also serve as impediments as the drill casings must be carefully filled with mud to avoid geothermal crushing. The EROI is a valuable indicator of a fuel sources, or fuel-related processes, true value and this figure can be used to demonstrate the potential upsides to offshore drilling. Offshore drilling presents a unique set of challenges that the microscopic world of energy is responsible for while providing the means to a solution.

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By the Numbers

The U.S. has several flavors of domestic oil production to experiment with including the oil sands, oil shale, and oil deposits in the Outer Continental Shelf (OCS). Drilling in the OCS currently produces the majority of domestic oil in the U.S. with 26% of gasoline coming from oil fields in the Gulf of Mexico in 2010. In 2009, the EIA published estimates of the proved reserves in the U.S. by area, and this data is shown in Figure 3.

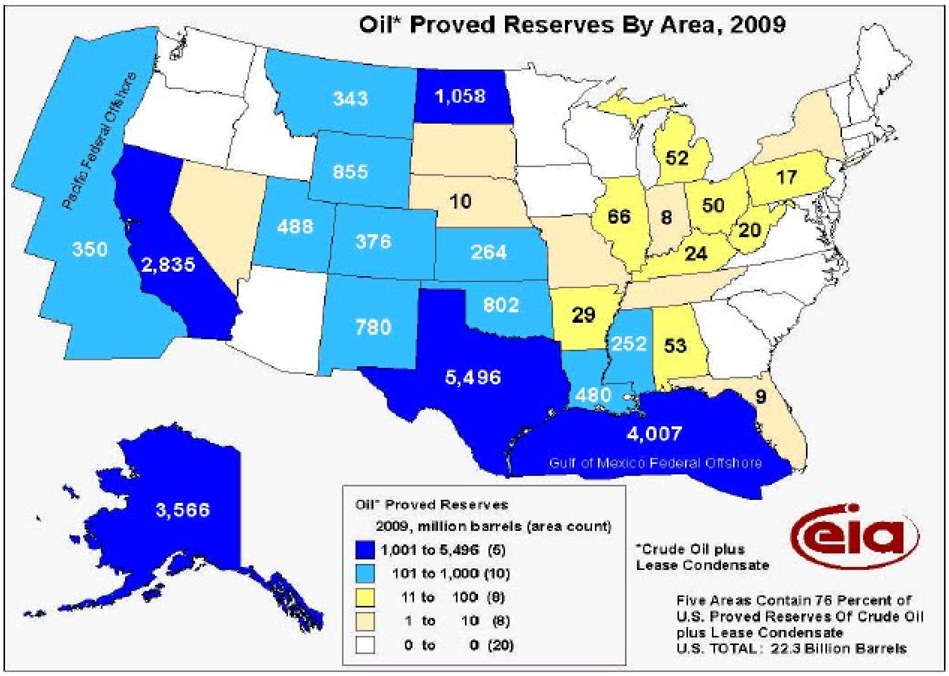

Figure 1. U.S. oil reserves by area in 2009.[1]

This map shows that there are 22.3 billion barrels proved reserves in the U.S with 18% of these reserves in the Gulf of Mexico, as well as 1.6% off the West coast (not including Canada). This figure for proved oil reserves is a source of optimism regarding U.S. offshore oil production but this figure shows nothing of current U.S. offshore oil trends. Figure 2 shows the number of barrels produced per day from offshore oil sites in the U.S. since 1981.

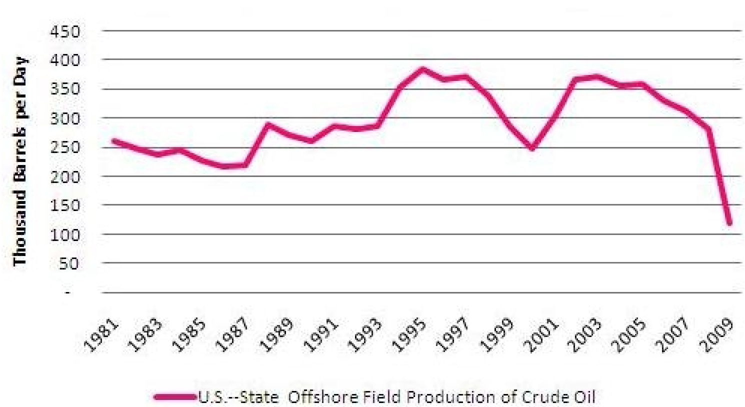

Figure 2. U.S. offshore oil production in thousands of barrels per day since 1981. Data Source: U.S. EIA.

Oil fields off the continental coast are now producing approximately 35% of what they produced just 9 years ago. Not only is the U.S. acquiring less and less oil from offshore deposits, but the oil they are acquiring is becoming harder and harder to obtain. The accessibility of an oil field as bearings on the ease of oil production. Figure 3 shows oil production trends in the Gulf of Mexico in relation to water depths.

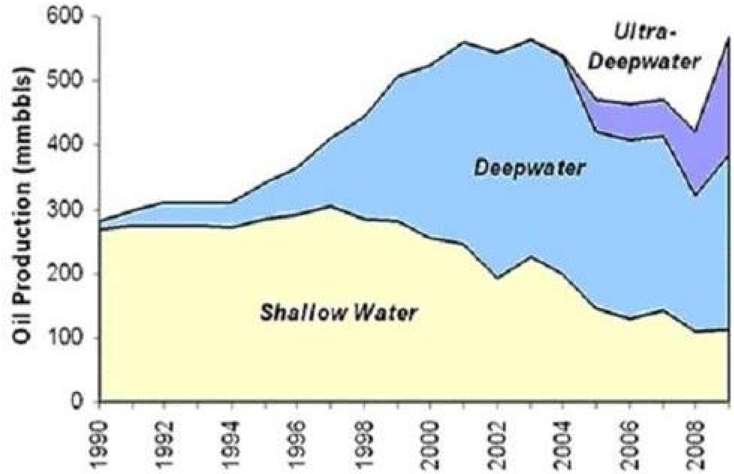

Figure 3. Gulf of Mexico Federal Offshore oil production in terms of water depth. Source: MMS, EIA.

Oil production in general follows a simple analogy regarding fruit picking. Of all the fruit picked from a tree, the fruit closest to the ground, the most accessible, is picked first and then it becomes progressively more difficult to obtain the same fruit from higher in the tree. Oil that is more easily accessible is extracted first while subsequent oil deposits become more and more difficult to harvest. In the Gulf of Mexico, the vast majority of oil production, 94%, occurred in relatively shallow water in 1990. Ten years later, shallow water oil production has decreased while deep water oil production has increased dramatically, about an 8 fold increase. Then in 2008 oil industries were forced to extract oil from ultra-deep water deposits, as more shallow deposits had been depleted.

The U.S. EIA estimated in 2009 that there are 23 billion barrels of oil in offshore oil reserves which provides promise for domestic oil production. Despite this optimistic figure, the trend in offshore oil production is cause for worry as the trend has seen a drastic decline in recent years with production down approximately 65% from 9 years ago. This trend can be attributed in part to the accessibility changes of oil reserves. The oil deposits in the shallowest water that are easiest to extract have been harvested leaving deposits in deep and ultra-deep water that require more advanced technology, more time and more money to extract.

Cost of Oil Production

Different methods of oil production require different amounts of effort, energy and money to obtain a barrel of oil. In general, conventional oil production costs the least per barrel, where as deep-sea drilling and arctic drilling cost the most per barrel. Figure 4 displays the cost of oil production by extraction method.

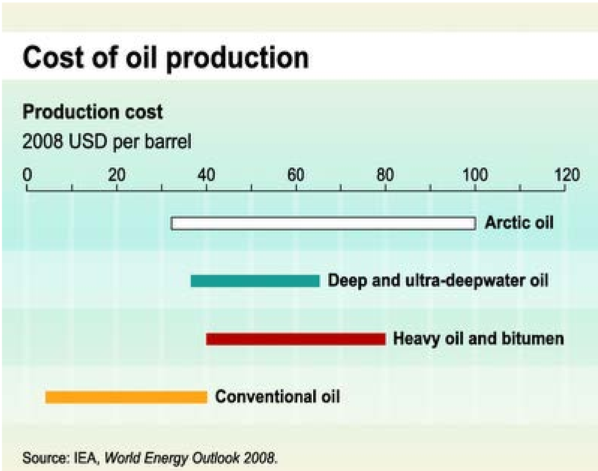

Figure 4. Production costs in USD per barrel for different extraction techniques.

This figure shows that on average one barrel of conventional oil costs approximately $20 to produce while the same barrel costs approximately $50 to produce from offshore sights. There are many factors that contribute to the cost of oil including finding costs, costs of placing an oil rig at the drilling site, costs of drilling infrastructure, the grade of the oil, the specific gravity of the oil, the sulffur content of the oil and the cost of transporting the oil to a refinery. There are certainly more factors that contribute to oil costs than those previously mentioned.

Conventional oil production remains the cheapest form of oil production but as conventional oil deposits near depletion, oil-centric society demands quantities of oil that force oil industries into more remote and challenging environments. Producing oil from reserves in the arctic or in deep/ultra-deep water require more equipment, more advanced technology and more time but these sources are becoming the only accessible reserves in the world.

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Deep-Sea Oil Production >

The BP Oil Spill

The BP oil spill, which occurred in April 2010, epitomizes the offshore oil controversy. Offshore oil has the potential to generate large amounts of revenue but often at the expense of wildlife and the natural environment. The oil industry is constantly under attack by environmental activists. The BP oil spill created a situation that left the oil industry scrambling and the environmental activists saying "I told you so." During a routine safety check of the blowout preventer (BOP) aboard the Deepwater Horizon, stationed in the Gulf of Mexico, a crew member mistakenly moved a lever which caused approximately 15 ft of the drill string to be forced through the closed BOP. Hours later pieces of black rubber began circulating up to the oil rig with the drilling mud, an issue that was promptly brushed under the rug. Several days later the equipment at the well head gave way resulting in an explosion that killed 11 people and the largest oil spill in U.S. history of 4.9 million barrels of oil.[1]

Environmentalists banded together against oil industry and offshore drilling to fight for wildlife protection and environmental conservation. Thousands of animals died in the months following the spill. The "Deepwater Horizon Response Consolidated Fish and Wildlife Collection Report" estimated that 7000 birds and mammals had died due to oil related complications.[2] Figure 1 shows a variety of method used to remove or treat the oil released in the BP oil spill along with the percentage of oil that was removed via a given method.

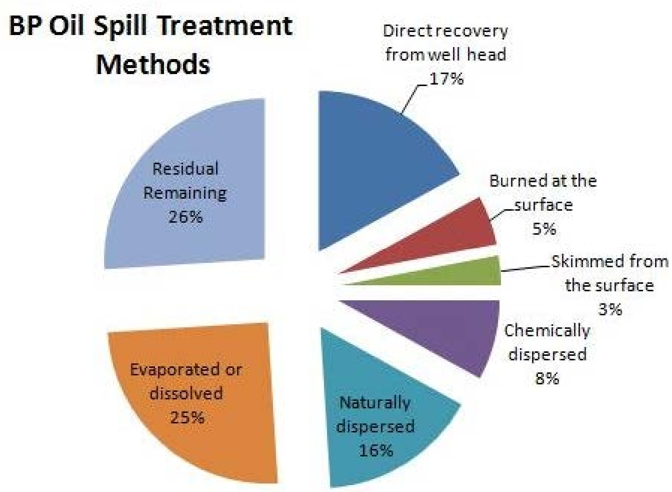

Figure 1. BP Oil Spill Treatment Method distribution.[3]

It is important to note that the categories of "Residual Remaining," "Evaporated or dissolved" and "Naturally dispersed" account for the treatment of 67% of the oil and none of this oil is removed from the water. This means that almost 3.3 million barrels of oil remain in the Gulf.

Organizations such as the *Committee Against Oil Exploration* (CAOE), *Greenpeace*, and the *Energy Action Coalition* rose up to defend the oceans and the marine life that calls them home. These groups showed their disdain with Facebook groups and picketing. Jim Footner, head of *Greenpeace's* energy campagin, stated in response to the BP oils spill that "The Government must step in right now and stop this by introducing a moratorium on deep water drilling... the real problem is our addiction to oil, which is pushing companies like BP to put lives and the environment at risk. Governments around the world must now stop the industry recklessly squeezing the last drops of oil from places like the Gulf of Mexico, the Arctic and the tar sands of Canada." [4] In the months following the spill, *Energy Action Coalition* affiliates held signs reading "Crude Awakening," and "BP: Guilty as Charged." Environmental activists made their voices heard calling for more policy to enforce stricter safety regulations and cleaner drilling practices.

Washington D.C. was shaken by the ripples of the BP oil disaster as well. The Deepwater Horizon exploded and sank in April of 2010 and in May of 2010 President Obama issued a moratorium on offshore drilling. The Obama administration lifted the moratorium one month ahead of schedule citing new policies that "strengthened safety measures and reduced the risk of another catastrophic blowout." [5]

The Deepwater Horizon epitomizes the offshore oil controversy because it was local oil rig, just 250 miles SE of Houston, that dug to record depths of 35,000 ft in search for oil that would help our countries economy by decreasing fuel prices and lessening our dependence on foreign oil.[6] An accident aboard the Deepwater Horizon led to an oil spill of 4.9 million barrels of oil that has cost BP $7.7 billion in claims as of December 1, 2011 that led to environmentalist and political
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chaos. Dozens of pieces of new legislation regarding safety and pollution standards await Congressional verdicts.

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Deep-Sea Oil Production >

The Government and Legislation

The U.S. Government has been aware of the potential dangers associated with deep-sea oil production for years. Every oil spill that has occurred off the U.S. continental coast has created ripples in Washington D.C., and this is seen by the history of legislation surrounding deep-sea oil production.

Past Legislation

In 1982 Congress imposed a moratorium on offshore drilling that removed 736,000 acres off the coast of northern and central California from leasing for oil and gas exploration and production. Removing these areas from the lease schedule was a response to the concern for possible environmental damage and social disruption caused by both routine activities and accidents, such as oil spills.

In 1990, President George H. W. Bush issued a directive that ordered the Department of Interior not to conduct leasing activity in areas other than Texas, Louisiana, Alabama and parts of Alaska. The moratorium extended to virtually all coastal areas including the Mid-Atlantic, North Atlantic, New England, Eastern Gulf of Mexico near the Florida Keys and the entire West Coast. President George H. W. Bush's directive was a response to growing concerns regarding the preservation of ocean and coastal environments. The EIA estimated that the moratorium protected 21% of the total oil in Federal reserves.

In 1998, President Clinton extended Bush's Executive Order until June 2012.

In July of 2008, President George W. Bush lifted the Executive Order that had banned drilling in large areas of the Federal Outer Continental Shelf (OCS) mainly in response to record oil prices of $145.29 per barrel.[1] In conjunction with lifting the moratorium, President Bush altered the lease status of the North Aleutian Basin of Alaska and the Central Gulf of Mexico which made them eligible for inclusion in the Minerals Management Service's (MMS) leasing agreement. According to the MMS, lifting the moratorium freed 18 billion barrels of oil for exploration.[2]

Present and Future Legislation

As awareness of global warming and pollution become more widespread, and accidents such as the BP oil spill illustrate the problems with fossil fuel dependence, the U.S. has been forced to entertain ideas regarding new offshore oil drilling legislation. There has been proposed legislation in favor of, and against, offshore drilling.

In May of 2011, Sen. Jeff Bingaman (D.-NM) sponsored the "S. 916: Oil and Gas Facilitation Act of 2011", which would facilitate the development of oil and gas production off the U.S. coast to limit the dependence of the U.S. on foreign oil and gas. The current status of this act is it awaits a vote from the Senate as of August 30, 2011.[3]

Frank Pallone (D.-NJ6) sponsored the "H.R. 261: No New Drilling Act of 2011" which would amend the "Outer Continental Shelf Lands Act" to prohibit the leasing of any area of the outer Continental Shelf for the exploration, development, or production of gas, oil, or any other mineral. This act is still in the infant stages and is undergoing revisions before it can be considered for general debate.[4]

Jay Inslee (D.-WA1) sponsored the "H.R. 1520: Offshore Drilling Safety Improvement Act" which amend the "Outer Continental Shelf Lands Act" to require that oil and gas drilling and production operations on the outer Continental Shelf must have in place the best available technology for blowout preventers and emergency shutoff equipment. This act is also in the infant stages and is undergoing revisions in order to be considered for general debate.[5]

Gerald Connolly (D.- VA11) sponsored the "H.R. 1870: Increase American Energy Production Now Act of 2011" in the summer of 2011 and this act is aimed at safely increasing domestic oil and gas production. This act is currently undergoing revisions by several subcommittees before it can be considered for general debate.[6]

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Concluding Remarks

The answer to the question of whether or not offshore oil production can solve climbing gas prices, decrease foreign oil dependence and solve America's fuel crisis is easy to answer. The short answer is no it cannot.

The trends in oil production, oil price, and demand over the last half of the 20th century, and into the 21st century, have forced people into the water in search of oil deposits that contain not only oil, but the answers to solving a fuel crisis. President George W. Bush lifted the ban on offshore drilling in 2008 to combat sky-rocketing oil prices but this attempt will most likely end in vain.

Those that advocate offshore drilling support their argument with claims that offshore drilling will separate the U.S. from the expense of foreign oil. They claim that gas prices will go down and that offshore drilling creates much needed local jobs while lessening our national trade deficit. Although it may be true that increased domestic oil production would create local jobs, generate revenue that brings the U.S. out of debt and decrease oil prices, but offshore drilling is not a practical place to put our faith.

The trends in offshore oil production suggest that there is little oil left and it is difficult to extract. In the last 10 years, offshore oil production has decreased by about 65% and the oil that is left is becoming extraordinarily hard to obtain. Extracting oil from remote deposits requires money and time that offset any benefits of obtaining that oil. In fact, offshore oil costs about $50 per barrel to produce while conventional oil harvesting costs only $20 per barrel. There is little money to be made from offshore oil production.

The EIA estimated that there were 23 billion barrels of obtainable oil in offshore reserves. The U.S. uses about 20 million barrels of oil per day. That means that if we obtain all the oil that is thought to be in offshore oil reserves, our country will gain about 3.1 years of oil, assuming our consumption doesn't increase.

There is a small amount of oil in the OCS relative to present-day consumption rates. Offshore oil costs more per barrel to produce than conventional oil production. Offshore oil deposits are becoming fewer and more remote, and therefore more expensive to access. Gas prices only stand to decrease by 3 or 4 cents. The everlasting possibility of a spill or explosion causing Earth-changing environmental damage is not worth the risk.

The oil industry, as well as consumers, need to turn their attention to more renewable sources of energy, as well as increased energy efficiency to answer our fuel crisis because there are no answers to be found in offshore oil production.

What Should Your Next Car Purchase Be?

Why you may be buying a car sooner than you think...

A car purchase is a complex decision, since a new vehicle must meet the personal needs of each individual. It is important to consider who and what will be transported, how frequently, and how far, so the vehicle range is a key factor. But, most importantly, we must evaluate the fuels that will power our vehicles. With the imminent global oil peak and the accelerating problem of climate change, we must alter the ways by which we travel. In addition, the US dependence on foreign oil raises a national security question that will only worsen as oil reservoirs are depleted. An expanded and improved infrastructure of public transit will be necessary, but this development will take time. For the times we must commute, transport children or elderly, and carry large objects, I would like to examine the practicality of hybrid and electric vehicles in contributing to the needed shifts in transportation. Through my evaluation of this alternative, I will show you what car you should buy next, with regard to resource depletion and environmental impact.

The Option of a Hybrid or Electric Vehicle

At present, there are many who believe that the development and implementation of electric and hybrid vehicle technology is important to our energy future as a society in terms of the conservation of resources, the types of available resources, and to limit pollution and greenhouse gas emission.[1] Hybrids also have better fuel economy than gasoline vehicles, and both hybrid and electric vehicles use less energy than other transportation alternatives.[2] For example, electric vehicles powered by batteries uses 3-4x less energy than a hydrogen fuel cell vehicle.[3] But, Electric and hybrid vehicles are expensive to manufacture and purchase, and do not eliminate the need to generate electricity.[4] In the case that the electricity is produced by burning coal, there is still a significant amount of carbon dioxide emitted, though it is released in a more localized area.[5] Additionally, electric vehicles must be charged more frequently than cars running on internal combustion engines (ICE's), which makes long trips in electric vehicles more difficult.[6] Hybrid and electric vehicles also pose an environmental justice question, since only the rich can afford to drive them.[7] But, the prices have been dropping significantly. For example, the 2012 Civic Hybrid is only a few thousand dollars more than its conventional counterpart, and the hybrid model has additional features, such as LED taillights and automatic headlamps.[8] Furthermore, it is now possible to create electric vehicles by converting the ones you already own, and some estimate part costs at only $8,000.[9] Though this is still costly, it is more affordable than buying a new hybrid.[10]

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Subpages (2): The Energy Involved The History of the Electric Vehicle

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Background Information

After almost a century of personal automobiles, the problems associated with the petroleum-fueled internal combustion engine have surfaced. The combustion of petroleum releases carbon dioxide, a polluting greenhouse gas that propagates climate change, and the recent release of 2010 CO_2 data shows that these emissions are significantly increasing.[1]

Figure 1 (9)

Energy consumption (Btu) - Petroleum Products - Transportation Loading...

According to *The End of Suburbia*, suburbanization is the biggest contributor to the use of fossil fuel energy.[2] These residential areas were created due to the availability of cheap oil, and some 50% of Americans now live in suburbs.[3] Suburbanization created a dependence on fossil fuels, as many commuters now travel 50-100 miles each way.[4] The 1990's also brought about the Sport Utility Vehicle (SUV), which further increased fossil fuel usage.[5] In present day, the average car on the road is less efficient than it was 20 years ago.[6]

Along with increased usage of fossil fuels came pollution and smog. In 1989, a study showed that 25% of the population between 15 and 25 in the Los Angeles area had lung and respiratory issues.[7] No matter the kind of car, each gallon of gasoline burned releases 19 lbs. of CO2 into the air.[8]

As pollution increased, so did the fears of peak oil. Though alternative drilling methods are being developed, more efficient vehicles will prove to be a better solution in the long run than improved and expanded drilling. For example, the oil reserves in the Arctic National Wildlife Refuge would provide the US with slightly more than a year's supply of oil, whereas raising fuel economy standards to 40 mpg would make this same amount of oil last for 15 years.[8]

The History of the Electric Vehicle

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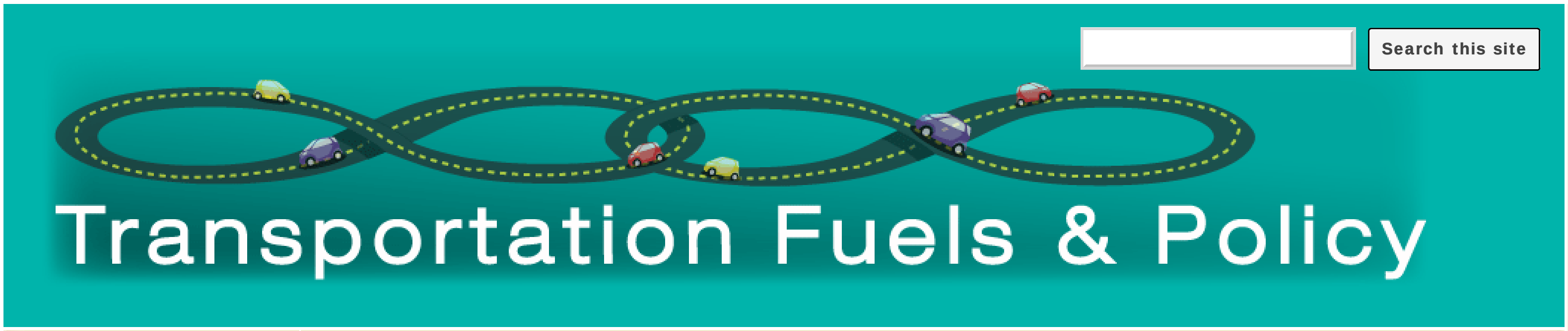

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What Should Your Next Car Purchase Be? >

The History of the Electric Vehicle

Figure 2: Thomas Edison with a Detroit Electric car[1]

There were more electric vehicles on the road than gasoline vehicles 100 years ago, and these vehicles were preferred over the gasoline vehicle.[2] Electric vehicles were quiet, smooth, and could be charged at home, whereas gasoline cars had to be cranked and produced exhaust. But, with the invention of automatic starters, cheaper oil, and mass production, the electric car fell into the shadows and the internal combustion engine won by 1920.[3] In the 1970's, after the OPEC oil embargo, the automotive industry rediscovered its interest in electric vehicles. General Motors eventually released the EV1 in 1996, though it was gone within 10 years.[4] The EV1's were easy to service, only requiring a tire rotation and washer fluid every 5,000 miles.[5]

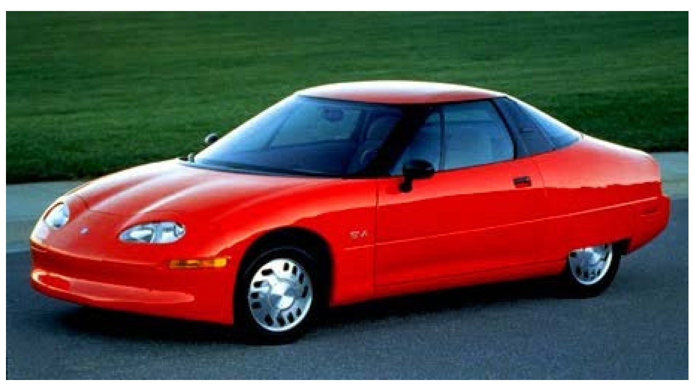

Figure 3: General Motors EV1[6]

Past and Current Legislation

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Past and Current Legislation

Past Legislation

After the OPEC oil embargo of the 1970's, the US government created Corporate Average Fuel Economy (CAFE) standards to improve fuel efficiency in American vehicles.[1] But, as the price of oil rapidly fell in 1985, improvements in fuel economy were discontinued.[2] The Clinton Administration compromised with auto companies and requested the release of hybrids in order for the federal government to stop pushing fuel economy standards. Though 8 or 9 years and $1 billion of taxpayer money were spent to develop hybrids, US car companies did not end up releasing any hybrid vehicles until Japanese manufacturers beat them to it. These Japanese auto companies were afraid that the US hybrid program would put them behind, so Toyota and Honda developed hybrids to stay in the game. Even once American automakers released their own hybrid models, the average fuel economy did not rival that of Japan. In 2006, the average fuel economy was 25 mpg for American hybrid vehicles and 42 mpg for Japanese hybrid vehicles.[3]

But, individual states, such as California, have taken measures to reduce vehicle emissions.[4] Since California has the worst pollution of any state in the US, it is the only state that is allowed to implement stricter fuel economy standards than the federal standards, and other states can then follow suit. In 1990, California passed the Zero-Emissions Vehicle Mandate, which stated that if automakers wanted to continue selling cars in CA, some would have to be exhaust-free. But, oil companies pressured the California Air Resources Board to drop the mandate, which eventually happened in 2003.[5]

Current Legislation

Though it is difficult to get fuel economy standards passed through congress, there has recently been a proposal to raise federal fuel efficiency standards. If passed, the legislation would roughly double the federal fuel economy standards by 2025.[6] The proposal is as follows:

Figure 4: Projected Fleet-Wide Emissions Compliance Targets under the Proposed Foot-print-Based CO2 Standards (g/mi) and Corresponding Fuel Economy (mpg)[7]

	2017	2018	2019	2020	2021	2022	2023	2024	2025
Passenger Cars (g/mi)	213	202	192	182	173	165	158	151	144
Light Trucks (g/mi)	295	285	277	270	250	237	225	214	203
Combined Cars & Trucks (g/mi)	243	232	223	213	200	190	181	172	163
Combined Cars & Trucks (mpg)	36.6	38.3	39.9	41.7	44.4	46.8	49.1	51.7	54.4

The US Congress is also currently voting on the Hybrid and Electric Trucks and Infrastructure Act (S. 1285), which proposes the expansion of tax credits for hybrid and electric vehicles.[8] This type of legislation is important, since past tax credits are in need of reform. For example, the maximum federal tax credit for an electric vehicle was $4,000 in 2002, while the maximum federal tax deduction for a 6,000 lbs.+ vehicle in 2003 was $100,000.[9] States have also been experimenting with regulations, such as allowing single-driver hybrids to drive in the carpool lane. However, this legislation has recently been reversed in California.[10]

But, overall, governmental support of hybrid and electric vehicles has been increasing.[11] For example, there are grants and stimulus funds that promote electric vehicle usage.[12] In addition, corporations have implemented employee incentives to help employees move toward the use of hybrid and electric vehicles.[13] The U.S. government has also taken measures to increase its support of renewable energy, which is an important component to the ideal performance of electric vehicles.[14] But, this support is less than enough, and is also scrutinized at all costs. After the crash of Solyndra solar company, subsequent reviews of such government loans have been reevaluated.[15]

Electric Vehicle Batteries

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Transportation Overview: The Journey and the Destination
- The Energy World of Petroleum

The Peak Oil Debate
- Energy of Extraction

Deep-Sea Oil Production
- Brief History
- The Energetics
- By the Numbers
- The BP Oil Spill
- The Government and Legislation
- Concluding Remarks

What Should Your Next Car Purchase Be?
- Background Information
- The History of the Electric Vehicle
- Past and Current Legislation
- Electric Vehicle Batteries
- The Energy Involved
- Electricity Source
- Current and Future EV's
- Plug-In Hybrid Vehicles
- Conclusion

The Question of Urban Growth
- Americans are Going Places
- Embodied Energy of Suburban Sprawl

Selected Links and Sources

The Team

Sitemap

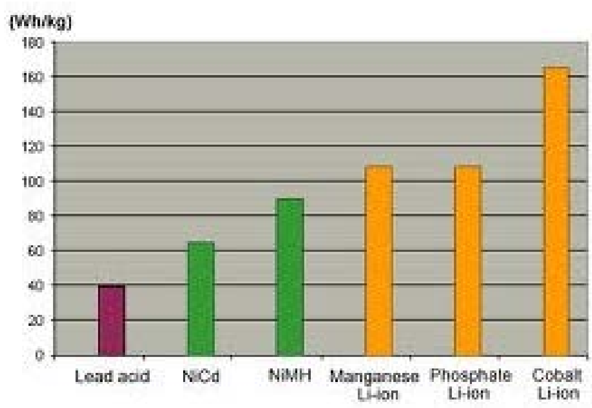
Electric Vehicle Batteries

Gasoline vehicles use lead-acid batteries, which were used in the first EV1's. These batteries had a 60-80 mile range, and the Bureau of Transportation estimated that average daily commutes were only 29 miles per day at the time.[1] The second version of the EV1 used nickel-metal hydride batteries, engineered by Stan Oshinsky, which roughly doubled the vehicle range, but were considerably bulky.[2] Though today's electric batteries make the electric vehicles expensive, the battery was still cheaper than an engine when Ovshinsky sold his battery company to Chevron in 2001.[3]

The newest electric vehicle battery technology is lithium-ion batteries.[4] Since lithium is the lightest solid element, and is 8 times lighter than nickel, it is ideal for lightweight batteries.[5] In fact, many cell phone and laptop batteries are also lithium-ion. Half of the world's known lithium reserves are in Bolivia (in the Salar de Uyuni salt flat), but the infrastructure isn't developed enough to export yet, which would cost over $600 million to build.[6] The geography of the Andes mountains is another obstacle, as well as Bolivian politics and public opinion. The mining costs are also high, since it is expensive to extract the lithium from the magnesium that is also present in the salt flat.[7] But, increased demand is likely to make such extraction more affordable.

Lithium is already being mined in other South American regions, as well as in China and Australia. Additionally, a very small amount of lithium is needed for each battery, since the energy density is so much higher than in other batteries (see Figure 4), and some of the lithium can be recycled. According to Lucie Bednarova Duesterhoeft, a Gm researcher, "Two countries-Argentina and Chile-could supply the whole world with cheap lithium past 2060."[8] In addition, the US federal government has recently increased its support for lithium-ion batteries through a grant to expand recycling facilities for such batteries.[9]

Figure 5: The Energy Density (Wh/kg) of Common Battery Materials[10]



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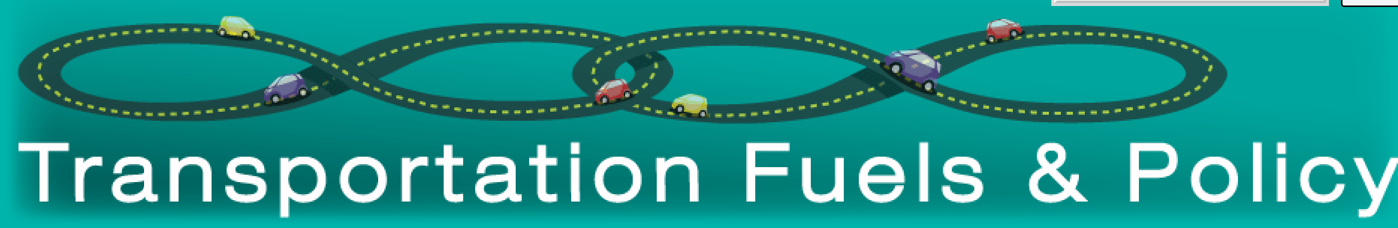


Transportation Overview: The Journey and the Destination
The Energy World of Petroleum
The Peak Oil Debate
Energy of Extraction
Deep-Sea Oil Production
Brief History
The Energetics
By the Numbers
The BP Oil Spill
The Government and Legislation
Concluding Remarks
What Should Your Next Car Purchase Be?
Background Information
The History of the Electric Vehicle
Past and Current Legislation
Electric Vehicle Batteries
The Energy Involved
Electricity Source
Current and Future EV's
Plug-In Hybrid Vehicles
Conclusion
The Question of Urban Growth
Americans are Going Places
Embodied Energy of Suburban Sprawl
Selected Links and Sources
The Team
Sitemap

What Should Your Next Car Purchase Be? >

The Energy Involved

Relationship of the issue to Thermodynamic Ideas

The entire process of electric and hybrid vehicles relates to thermodynamics, from the step of burning coal to create electricity to the step at which the car axles actually begin to rotate. Work, power, efficiency, and entropy, among other factors, are important throughout the study of whether or not to move toward hybrid and electric forms of transportation. For example, the efficiency of the ICE is much lower than that of electric motors,[1] and the energy lost as heat differs between the two types of engines.[2]

How the Energy-Using Process Works

Coal is burned in power plants to generate the electricity that charges the battery of the vehicle, which is depleted as energy is used to rotate the car axles. But, only 30% of the coal's energy can actually be turned into electricity, due to the energy lost as heat throughout the combustion process.[3]

The battery of the electric car does work on the axles of the vehicle, which can be calculated as the product of the electrical force supplied by the battery and the distance that the wheels cover in a given amount of time. In a hybrid vehicle, the work is done by both the ICE and the electric motor.[4]

Figure 6: The Energy Flow of an Internal Combustion Vehicle[5]

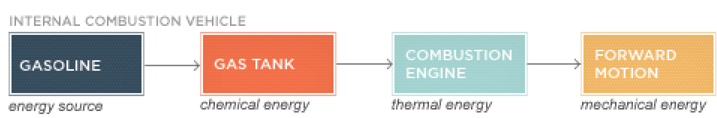


Figure 7: The Energy Flow of an Electric Vehicle[6]

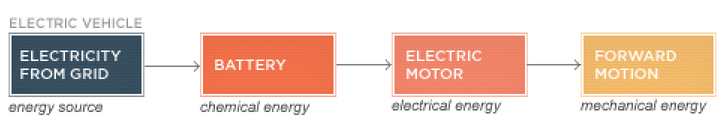
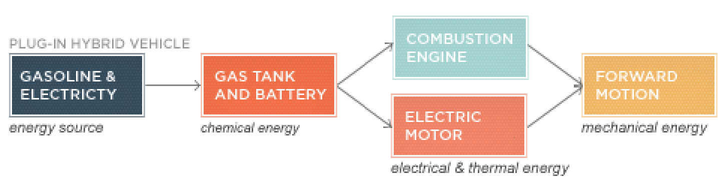


Figure 8: The Energy Flow of a Hybrid Vehicle[7]



Heat is released in the power plant as coal is burned to generate the electricity, and about 65% of the original energy is lost as heat.[8] Energy is also lost within the car engine as energy from the battery does work on the axles, and heat is also released in the ICE in a hybrid vehicle. The ICE is almost always in use, besides when the car is idling, slowing down, going downhill, or traveling under 15 or 20 mph.[9]

Since neither the production of electricity nor the work done on the axles are spontaneous processes, entropy must be created elsewhere in the universe to drive them. In this case, entropy is supplied as the heat is released during the electricity generation. In a hybrid vehicle, entropy is also produced as the gasoline combusts.[10]

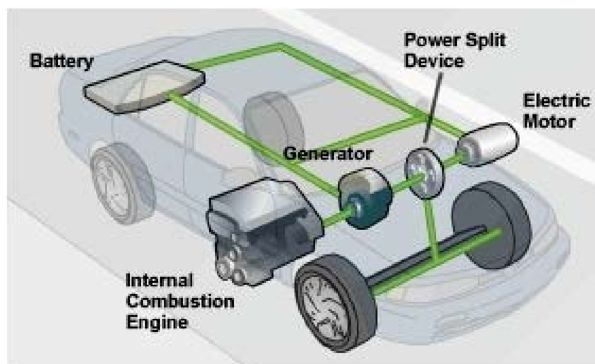
Efficiency

The efficiency of a hybrid vehicle could be measured in miles per gallon, or in miles per joule of energy provided by the electric battery in an electric car. The optimal combination of speed and distance would also be an efficiency factor. But, an important way of measuring the efficiency of an electric motor is the percent of the energy released by the battery that actually does work to move the axles. Electric motors are 75% efficient, whereas internal combustion engines are only 20% efficient.[11] In hybrid vehicles, energy that is wasted during braking and coasting in an ICE vehicle is converted back into electricity and stored in the battery.[12] Additionally, the engine is automatically turned off when the car stops, to conserve the energy that is normally lost during idling.

Power

Power is measured by work/time. So, in the case of the electric car, power would be the work done on the axle by the battery per unit of time, or the energy used by the battery per time driven.[13] Figure 9 shows the power split between the electricity and gasoline sources in a hybrid vehicle.

Figure 9: How a Hybrid Car Works[14]



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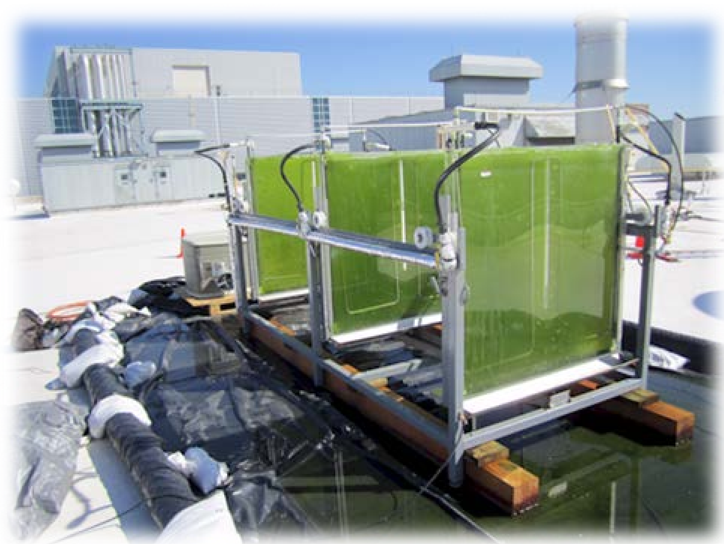
Electricity Source

Replacing oil with coal as a source of electricity for hybrid and electric vehicles does not eliminate CO2 emissions, but changes them. Coal plants produced localized pollution, whereas ICE's disperse exhaust wherever the vehicle is driven. But, some studies have shown that electric vehicles still release less CO2 than gasoline vehicles, even if powered by coal plants.[1] Additionally, after General Motors pulled the EV1 off the road, Southern California had its first stage-1 smog alert in five years.[2] So, it is likely that electric vehicles were, in fact, improving our air quality, regardless of the fuels burned to create the electricity. Furthermore, the US dependence on foreign oil raises a national security problem, since 2/3 of the world's proven oil reserves are in the Middle East.[3] So, the reliance on coal to provide electricity for hybrid and electric vehicles would at least diminish our dependency on foreign fuels. There is also the possibility of implementing Carbon Capture and Storage (CCS) technology to sequester the carbon released from coal plants, in addition to the possibility of sending the emissions through algae to convert the CO2 to nitrogen and oxygen.[4] (For more on carbon sequestration, see Coal Energy-Carbon Sequestration.)

Figure 10: Algae Tanks to Convert CO2 from Power Plant Emissions[5]



Current and Future EV's

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Current and Future EV's

At present, there are many hybrids on the market, and new plug-in hybrids and electric vehicles have been released this year (such as the 100% electric Nissan Leaf,[1] the plug-in hybrid Chevy Volt,[2] and electric DeLoreans.[3]) Outside of the auto industry, support for electric vehicles has also been increasing, such as with the introduction of charging stations in California's Bay Area Walgreens stores.[4] It is also now possible to convert a gasoline car into an electric vehicle, though the parts are still costly.[5] Additionally, there has been recent research into the possibility of charging electric vehicles wirelessly with the use of magnetic fields.[6]

Figure 11: The 2012 Nissan Leaf[7]

For a more in-depth study to determine the benefit of electric and hybrid vehicles from an energy and fuel efficiency perspective, I have chosen to focus on plug-in hybrid vehicles, since they are a bridge between conventional hybrids and all-electric vehicles. Based on the data, I will make a determination whether the findings suggest a commitment to full electric vehicles or a return to the status quo reliance on gasoline-powered automobiles.

Plug-in Hybrid Vehicles

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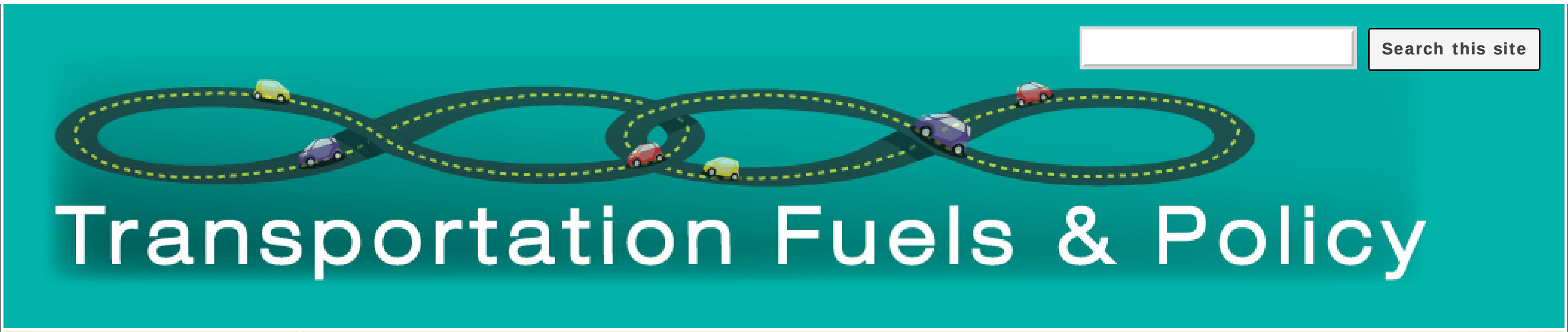

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Plug-In Hybrid Vehicles

Like conventional hybrid vehicles, plug-in hybrid electric vehicles run on both an electric battery and a gasoline engine.[1] But, unlike a conventional hybrid, the gasoline engine in the plug-in hybrids only kicks in as back up. Conventional hybrids switch from the battery to the ICE above a certain speed, generally around 15-20 mph, whereas plug-in hybrids run on solely the battery until the gas tank is needed to recharge the battery or run the car to the next charging stop. The plug-in Chevy Volt hybrid, for example, can go up to 35 miles on the battery until the gas engine starts up.[2] As can be seen in the following figures, the standard hybrids have much bigger gas tanks and engines than the plug-in hybrids, and the plug-in hybrids have larger batteries and electric motors than the standard hybrids.

Figure 13: Standard Hybrid[3]

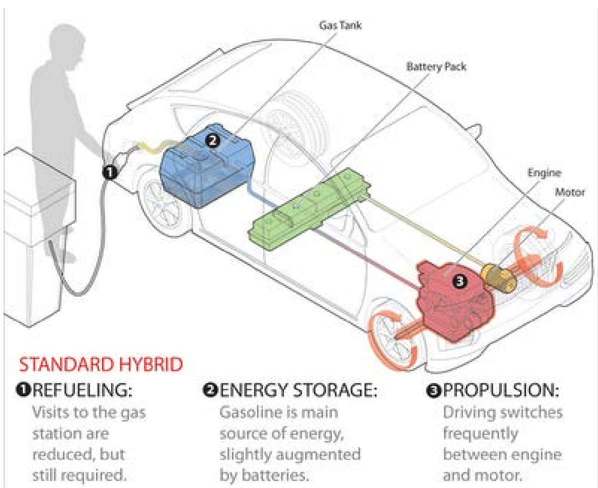
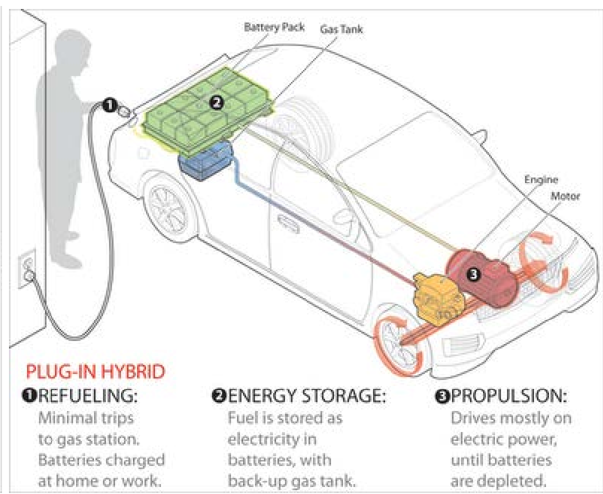


Figure 14: Plug-In Hybrid[4]



Electricity Source

The US electricity grid is made up of many electricity sources, and each US region has a different mix of electricity fuels.[5] Below (Figure 13) is a chart of energy mixes based on the following 13 US regions:

Figure 12: US Regions from the Annual Energy Outlook 2007[6]

FIGURE 1 NERC Regions from the Annual Energy Outlook 2007 (Source: EIA 2007) (see Table 2 for definitions of abbreviations)

Figure 13: Mix of Sources for Average Electric Generations among Regions in the U.S.[7]

TABLE 2 Mix of Sources for Average Electric Generation among Regions in the United States (% in 2020) (Source: EIA 2008)

Region	Coal	Oil	Natural Gas	Nuclear	Other
1. East Central Area Reliability Coordination Agreement (ECAR)	83.9	0.5	5.7	9.0	0.9
2. Electric Reliability Council of Texas (ERCOT)	45.2	0.5	37.3	11.9	5.1
3. Mid-Atlantic Area Council (MAAC)	44.1	1.2	5.5	34.2	15.0
4. Mid-America Interconnected Network (MAIN)	52.9	0.3	4.2	31.8	10.8
5. Mid-Continent Area Power Pool (MAPP)	73.1	0.4	1.8	12.3	12.4
6. Northeast Power Coordinating Council / NY (NPCC-NY)	12.3	5.6	33.9	29.3	18.9
7. Northeast Power Coordinating Council / NE (NPCC-NE)	17.5	1.8	43.0	21.9	15.8
8. Florida Reliability Coordinating Council (FRCC)	53.9	5.5	26.3	11.9	2.4
9. Southeastern Electric Reliability Corporation (SERC)	49.9	0.6	11.9	33.0	4.6
10. Southwest Power Pool (SPP)	74.1	0.6	15.9	4.3	5.1
11. Western Electricity Coordinating Council / Northwest Power Pool Area (WECC-NW)	28.8	0.1	6.4	3.2	61.5
12. Western Electricity Coordinating Council / Rocky Mountain and AZ-NM-Southern NV Power Area (WECC-RMP/ANM)	60.8	0.4	21.2	8.0	9.6
13. Western Electricity Coordinating Council / California (WECC-CA)	13.0	0.0	40.4	17.3	29.3

In order to evaluate the differences in overall energy consumed and greenhouse gases emitted between plug-in hybrid and gasoline vehicles, a comparison can be made between a US region with less renewable energy used (such as Illinois) and a region with a higher proportion of renewable sources (such as California). To strengthen the data, the average US mix and a renewable mix can also be added to the comparison.

Figure 14: Well-to-Wheels Total Energy Use for Plug-In Hybrid Vehicles with a 20-mile Range Using Different Marginal Electric Generation Mixes (Btu/mi) [8]

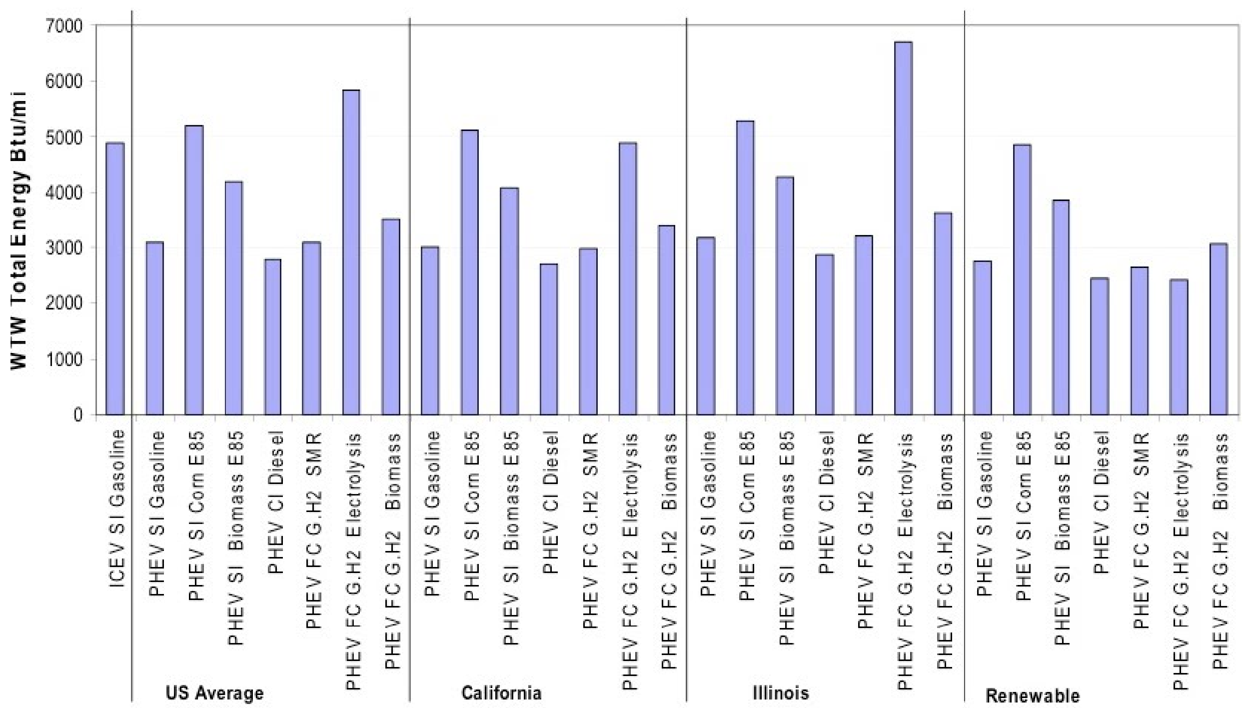
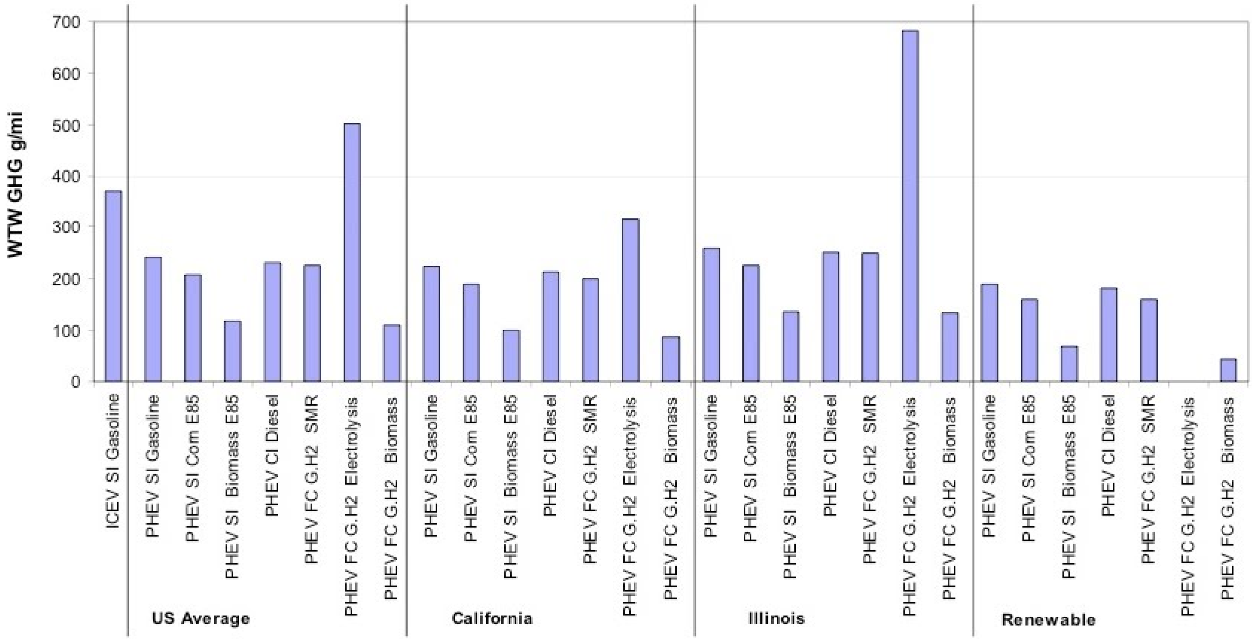


Figure 15: Well-to-Wheels Greenhouse Gas Emissions for Plug-In Hybrid Vehicles with a 20-Mile Range Using Different Marginal Electricity Generation Mixes (g/mi) [9]



As can be seen by the previous graphs, plug-in hybrid vehicles powered by gasoline clearly use less energy and emit less greenhouse gases than gasoline vehicles, in addition to using less petroleum and helping the foreign oil dependency problem, regardless of the electricity makeup of the region in which they are used. For a plug-in hybrid with an all-electric range (the range the vehicle can run on the battery alone) of 10-40 miles, the average reductions in petroleum energy use and greenhouse gas emissions are as follows:

Figure 15: Gasoline vs. Plug-In Hybrid Electric Vehicle Energy Use and Greenhouse Gas Emissions[10]

For an all-electric range (AER) between 10 mi and 40 mi, compared to an internal combustion vehicle that uses gasoline:

PHEV Fuel	Reduction in petroleum energy use	Reduction in GHG emissions
Petroleum (gasoline and diesel)	40-60%	30-60%
85% ethanol and 15% gasoline blend (E85)	70-90%	40-80%
Hydrogen	Over 90%	10-100%

Conclusion

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  - Concluding Remarks
- What Should Your Next Car Purchase Be?
  - Background Information
  - The History of the Electric Vehicle
  - Past and Current Legislation
  - Electric Vehicle Batteries
  - The Energy Involved
  - Electricity Source
  - Current and Future EV's
  - Plug-In Hybrid Vehicles
  - Conclusion
- The Question of Urban Growth
  - Americans are Going Places
  - Embodied Energy of Suburban Sprawl
- Selected Links and Sources
- The Team
- Sitemap

Conclusion

From the plug-in hybrid data, we can see that adding a proportion of energy supplied by electricity (compared to a gasoline vehicle) increases vehicle efficiency and lowers greenhouse gas emissions. From this data, we can conclude that an electric vehicle would, therefore, be even more efficient and less polluting than a hybrid vehicle. So, I am confident in suggesting that you consider an all-electric vehicle for your next car purchase. Or, if you are uncomfortable without a gasoline engine for back-up, I would urge you to buy a plug-in hybrid.

While the switch to coal-fired electric vehicles would lower our CO2 emissions and localize pollution, it is by no means an ideal solution. Regions with a high proportion of renewable energy, such as wind and hydropower, would provide a favorable environment in which to transition away from petroleum-fueled vehicles, due to the lack of emissions created from generating these types of electricity.[1] It is also necessary for the renewable energy and electric vehicle industries to work together, such as is being done by the new Advanced Energy Economy organization.[2]

It is also important that we reduce the amount of personal vehicle miles drive, even though it would be too drastic to do away with the personal vehicle altogether. Our way of life can be altered to reduce our dependence on fossil fuels, but there will still be situations where we will need transportation. For example, certain professions, such as construction, require the use of a vehicle to transport supplies, and there will always be instances where a personal vehicle will be needed (such as when crossing through an unsafe part of town not covered by public transportation or purchasing a large item). Additionally, though we may be able to make a large shift towards urbanization, it will be unlikely that all members of a family will live in the same urban center, and will therefore need a form of transportation in order to visit one another. I hope that public transportation evolves to cover many of these needs, but I believe that electric vehicles are a good solution in the meantime for situations in which driving is essential.

The Jevons Paradox

Will increased fuel efficiency standards actually cause us to drive more?

I do not not believe so. Though the money saved on gasoline from a hybrid or electric vehicle may be used for luxury goods and services that will require more energy anyways, the price of a hybrid or electric vehicle is higher than that of a car with a gasoline or diesel engine. So, the additional investment in the more efficient vehicle is quite possibly the same excess money that would have otherwise gone into luxury goods. The best solution, though, may be to raise gasoline and electricity prices in order to keep the demand lower.[3] Futhermore, certain studies have suggested that rising gas prices may have already caused Americans to begin to change their driving habits.[4]

Conclusion

In addition to switching to electric vehicles and moving our electricity sources towards renewable energy, I believe that we need to change the overall outlook on hybrid and electric cars. Though many models are now more energy efficient than gasoline vehicles, the auto companies are still very resistant to change, and are too committed to preserving the status quo. There are now many hybrids and a few electric vehicles on the market, but the majority of the models are still focused on maintaining performance and power, in addition to luxury options and accessories. In order to further the success of electric vehicles, it will be important to produce vehicles that do less, have a longer range, and use less energy.

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Urban Growth Boundaries and Growth Management

What is an Urban Growth Boundary?

Based on the description provided by a 2004 University of Michigan study[1], an Urban Growth Boundary (UGB) can be defined as "A Politically determined line that is drawn around an urbanized area, outside of which new development is severely restricted or prohibited."
The general goal of UGBs is to limit higher density residential and commercial development within the specified growth line, preserving the rural character and density of lands beyond its scope. What we will argue here is that by limiting development to a particular area, cities are more able to cut down on vehicular fuel consumption, as well as integrate public transportation into the urban fabric as an efficient and practical alternative to driving.

Portland, OR Urban Growth Boundary as seen from Google Earth

The Players

The two cities we will be comparing here are San Francisco
and Riverside, both in California. These case studies have been selected for a number of reasons. Firstly, the two cities lie in counties that in the 1980s had around the same population (see the population chart to the right). However, San Francisco has implemented an urban growth strategy (http://www.greenbelt.org/index.shtml). While Riverside City hasn't increased dramatically in population, the county itself has seen populations expand dramatically; sprawling outwards from urban centers and swallowing smaller unincorporated cities.

Population Growth

Population Loading...

Pick a Side

UGB **Advocates** claim that a boundary can help curb suburban sprawl, preserve productive agricultural land and open space on the outskirts of urban areas, and lower costs of new growth.

Additionally, by limiting outward expansion, proponents claim the resultant compact development and increased urban density reduces costs of infrastructure associated with urban sprawl. Furthermore, the costs of providing services to new developments are diminished.

The Greenbelt Alliance, an open space advocacy group in San Francisco, also argues that greenbelts (as UGBs are sometimes called) help to preserve community identity by preventing smaller towns and cities from being swallowed up by expanding neighbors. They also claim that implementation of a growth strategy involving boundaries encourages "long-term strategic thinking about community futures."[2]

Opponents of limiting urban growth to the area within a boundary make the following counter-claims. They feel that restricting quantity of land for development leads to decreases in housing production, crises in housing affordability, and de facto exclusionary zoning/social segregation (as higher housing prices have the effect of excluding poor or minority residents).

Other perceived consequences of UGBs include unnecessary overcrowding, infrastructure strain, and loss of existing open space within the boundary. The California Association of Realtors, who take a counter-UGB stance, believe that growth boundaries and greenbelts do not allow enough flexibility to accommodate population growth and changing socio/economic conditions in many communities. They claim that not only will boundaries contribute to higher housing prices in densified areas, but that property outside of UGBs will be devalued, with no just compensation provided for a governmental taking.

California Association of Realtors Have a Question (And a Suggestion)

Groups opposing UGBs (such as the C.A.R.) point to studies like this one (financed by the California Department of Real Estate and the Construction Industry Advancement Fund) to prove that while UGBs may achieve the goal of urban densification, they also force housing prices up by limiting the resource available to developers—in this case, cheap land. The authors of the aforementioned study have stated that as density increases, and more people move to cities like San Francisco or Portland, OR for economic reasons, suburban development must be allowed to provide a relief valve both to population growth and development costs.

On their website, the C.A.R. has a page dedicated to a polemic against UGBs. Their suggestions for how to deal with population growth in urban areas consist of zoning ordinances, congestion management plans, agricultural and open space preservation plans, local and regional parks, and tax preferences for agricultural lands. While these measures have all proven useful in preserving open space, they do not deal with another fundamental negative aspect of sprawling urban growth: vehicular traffic and fuel consumption.

Considering Negative Impacts of Sprawl on Energy Consumption

Most of the arguments against Growth Boundaries take a firmly economical stance. While it is true that UGBs have contributed to increased housing prices in places such as Portland, OR, it is also true that any limiting regulation of a resource—the deliberate decrease in availability of land in this case—will have the effect of raising the cost of that commodity. In essence, the argument against UGBs is akin to that against reducing Oil Production. Personal opinions about resource scarcity have very little impact on true existing reserves.

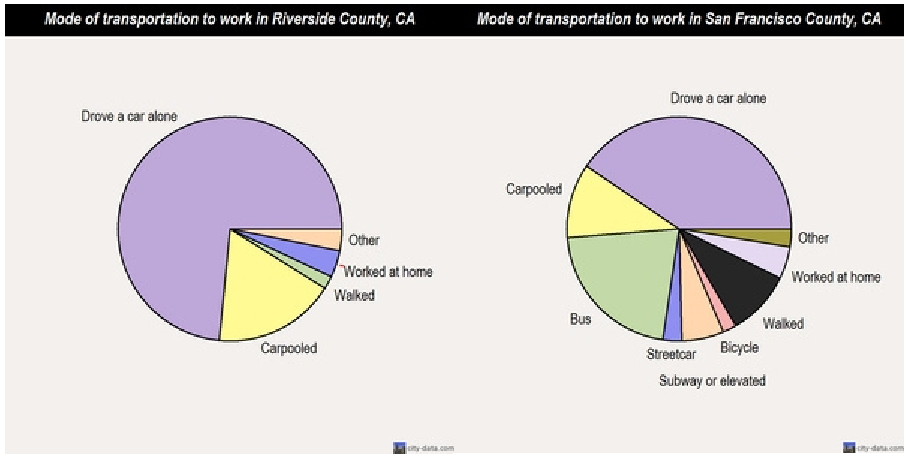
Here we come to another difference between our two case studies. While San Francisco is limited by physical boundaries as well as politically designated ones, Riverside has the convenience of a county the size of New Jersey in which to sprawl.

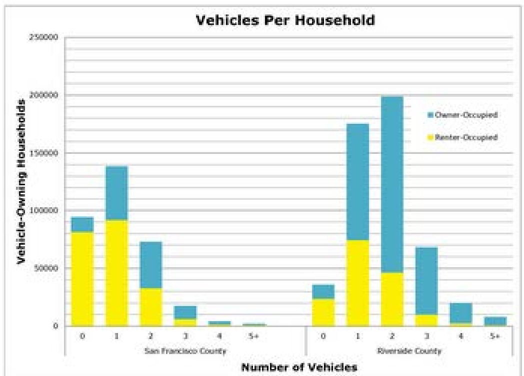
San Francisco City Limits

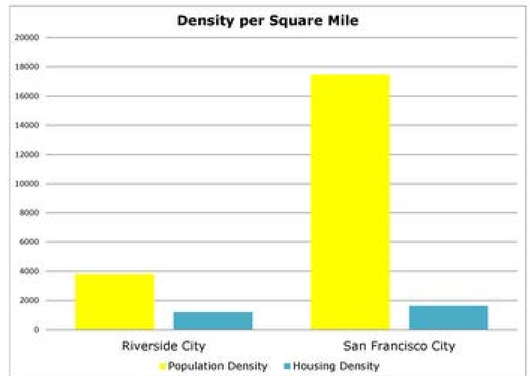
Riverside City Limits

Given these physical conditions, it is understandable that San Francisco felt more of a pressure to plan for future urban growth than Riverside. Smart Growth America, an organization advocating smart growth and UGBs as components of that goal, authored a paper along with academics from Rutgers University and Cornell University called 'Measuring Sprawl and its Impact' in which they set about defining parameters for defining sprawl and applied those parameters to cities in the US. The four key criteria in determining sprawl were: residential density; neighborhood mix of homes, jobs, and services; strength of activity centers and downtowns; accessibility of the street network.

Riverside, CA ranked as the number one overall most sprawling metro region out of 83 regions surveyed based off of the four criteria just mentioned. Over 66% of the population was found to live over ten miles from central employment centers, and less than one percent of the population live in communities with enough density to make mass public transit efficient or effective. As the figures below show, the population density of San Francisco vs. Riverside, as well as the number of people who own homes vs. those who rent, has direct implications on modes of transportation.





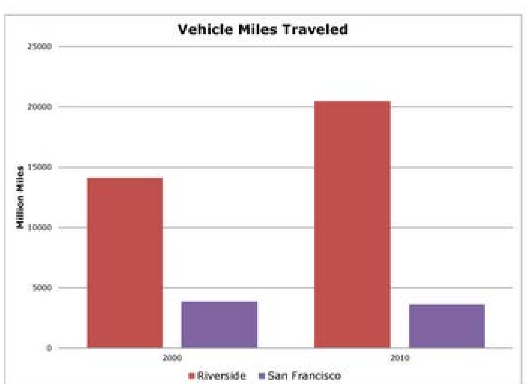


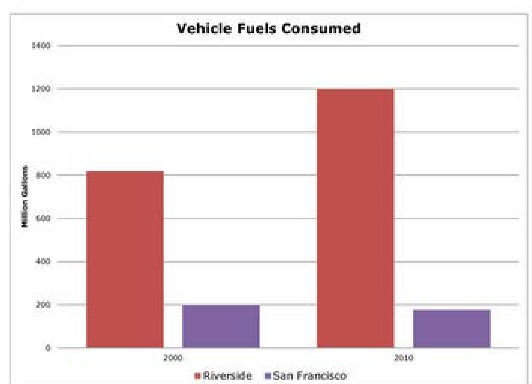
Clearly, the majority of San Francisco's population is able to make due with one or less vehicles per dwelling unit, whereas Riverside's population relies almost exclusively on automobiles for transportation, and tends more towards two vehicles per home. In examining population density, and with the knowledge that most residents live prohibitively far from places of employment or commerce, it is understandable that Riverside residents have no option but to increase their driving habits.

Burning Gas and Taking Names (Miles Traveled and Fuels Consumed)

If density were to increase in the Riverside area, and development of a more mixed-use character were encouraged, public transportation could play a much greater role in city and county transit. As of 2008 however, Western Riverside County commuters traveled an average of 27.5 miles per capita daily, with 85 miles per day for the average household. This led to annual delays of 38 hours per capita due to congestion. The costs of these delays (in wasted fuel, increased road maintenance, and lost time) totaled $582,533,000. Amending that number to include residents of unincorporated Riverside County added an additional $477,427,000. That means over 1 BILLION dollars are lost annually through congestion alone, and that number will only increase as the city sprawls and more people need to drive longer distances to get to work or the grocery store.

Another way to quantify this information is to look at Vehicle Miles Traveled and Vehicle Fuels Consumed.





As these figures make obvious, and as common sense would dictate, the more miles traveled, the more fuel consumed.

Yet despite increases in population for both San Francisco and Riverside counties over the past ten years or so, miles traveled and fuel consumed have both decreased in San Francisco while rising significantly in Riverside. This is further evidence of the impact that an Urban Growth Boundary can have when it is implemented as part of a growth management strategy.

All demographic information is from www.city-data.com

For more information on VMT/VMC for the State of California, click here

Where Does All This Leave Us?

While every situation is unique, there are several key points we can draw from examining San Francisco and Riverside as case studies. Any method of growth management has its tradeoffs; its pros and cons. In San Francisco, where a UGB has been implemented, it has contributed to reduced vehicular traffic, increased population density, and the prevention of sprawling development pushing into the bay area greenbelt. However, Riverside has cheaper development costs and as a result, lower housing prices. The tradeoff for sprawl is of course largely in quality and ease of life. The amount of money, fuel, and man-hours required to maintain an increasingly burdened auto-centric urban infrastructure is phenomenal, but the consequences of increasing fuel consumption in a time while we are already feeling the effects of peak oil is an American Dream that is likely to become a nightmare. Urban Growth Boundaries present a strong tool in the arsenal of urban growth management, and in the case of San Francisco, UGBs have certainly proven themselves. However, we should not disregard the suggestions of groups such as the C.A.R., whatever their agenda may be.

Based on the data presented in this argument, I believe that the City of Riverside should implement an urban growth boundary. While San Francisco has been limited by physical barriers to sprawl within the county/city limits, Riverside County has seen growth spread out from the urban centers in its western half with no real strategy for planning those patterns. The lack of physical borders among western Riverside County cities has made sprawl easy, but it also presents an opportunity for the City of Riverside and all adjacent cities to implement UGBs and set aside portions of land as urban reserves to accommodate future growth. These reserves are essentially land outside the UGB designated for longer-term future development (ie. the next 50 years). If needed, expansion can be planned for these reserve areas, acting as a safety valve for urban population growth, but providing the necessary structure and opportunity for community input to ensure that rural lands deemed valuable remain untouched by suburban expansion. Additionally, increased residential density in the City of Riverside would greatly increase opportunities for public transportation such as light rail, and if adjacent cities adopted similar policies, inter-city transit could increase in efficiency as well by simply connecting one city transit system to another, rather than servicing the entire County with a heavily taxed and overextended system. In this fashion, Riverside could begin to decrease the local dependency on personal vehicles, improve quality of life for local residents, and dramatically decrease the costs of vehicular congestion on citizens, the city, and the environment.

San Francisco Urban Fabric

Google Map

Loading...

Riverside Urban Fabric

Google Map

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Subpages (2): Americans are Going Places Embodied Energy of Suburban Sprawl

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  - Plug-In Hybrid Vehicles
  - Conclusion
- **The Question of Urban Growth**
  - **Americans are Going Places**
  - Embodied Energy of Suburban Sprawl
- **Selected Links and Sources**
- **The Team**
- **Sitemap**

The History of US Urban Growth

The story of urban growth in the United States is largely told between the 19th and 20th centuries. Following the 1807 Trade Embargo Act and the War of 1812 against Great Britain, the United States began the process of industrialization (especially in northern states) in order to end reliance on European imports. This brought more residents from rural and agricultural communities into cities like New York and Philadelphia, where they found work in rapidly growing factories and mills. These industrial cities were densely packed, and over time became highly polluted.

By the middle of the 19th century, the primary mode of transportation was still either foot or horse-drawn coach, however the steam engine had made railroads the cornerstone of commercial transit. As railroads continued to spread, they sought additional sources of revenue through transporting people as well as goods. By the 1850s and 60s, suburban development along rail-lines was already being promoted by realtors and rail companies as a way for wealthy and middle-class Americans to escape the filth of industrial cities, and enjoy the comforts of country living along with the convenience of an easily accessible urban center. It was also around the turn of the 20th century that American culture began to place higher value on owning a home and yard in which to raise the ideal nuclear family. These values coupled with evolving technological advances in the transportation industry such as the electric streetcar led to a societal vision of success and prosperity in which suburban living became the ideal, and dense urban lifestyles become synonymous with inner-city poverty and squalor.[1]

Cars, Troops, and Oil

Despite the trends in American culture that encouraged suburbanization and exodus from urban centers over the course of the 19th century, the two events that most impacted what we call 'Suburban Sprawl' were 20th century phenomena. In 1908, the Ford Motor Company began mass production of the Model T personal automobile. This would revolutionize the way Americans traveled, making personal transit affordable and easy. By the late 1920s, efforts by General Motors to replace all electric rail lines with paved streets and gasoline-powered buses were well underway, the Federal Road Act had created a Bureau of Public Roads in order to plan a highway network connecting all cities with over 50,000 residents, and Americans came to the final realization that the automobile was no longer a luxury item or even a mere commodity; cars had become a necessity to urban and suburban life.

The second major event after the expansion of auto-based transit was the creation of the Federal Housing Administration in 1934, followed by the Servicemen's Readjustment Act of 1944. These regulatory acts established new mortgaging and loaning systems which made the development and purchase of new single-family homes outside of existing urban cent

ers not only easier, but also cheaper than repairing existing structures or renting an apartment in the city.[2]

Americans were all too happy to move out to the suburbs, and drive to and from work every day, until the energy crisis of the 1970's. It was around this time that oil production in the US peaked, and dependence on foreign sources of oil, especially Middle Eastern sources produced by OPEC nations, began to exceed domestic production. A 1973 trade embargo imposed by the Arab members of OPEC, followed by revolution in Iran in 1979, shocked US energy consumers by showing how crucial imported oil was to their day to day lives. President Jimmy Carter addressed the nation in his "Crisis Of Confidence" speech and vowed to implement stricter energy policies regarding fuel imports, domestic production, and most importantly for suburbanites, mile per gallon efficiency of vehicles in the United States.

YouTube Video

Despite the rude awakening of the 1970s, America has remained dependent on fossil fuels, and therefore foreign fuels, for transportation. The suburban development pattern that evolved over the past century has continued despite our new awareness of its impacts on the environment and our general health.

Current Urban Development Trajectories

Current Real Estate mortgaging policy and Federal Housing Administration zoning laws continue to favor single-use, auto-centric suburban development. The Department of Housing and Urban Development limits the retail portions of mixed-use development areas to 20% of the total value, while Fannie Mae and Freddie Mac limit value to between 20 and 25% respectively.[3] This essentially discourages densification and creation of pedestrian-centered urban areas, forcing sprawling infrastructural expansion.

Dealing with Growth and Density

The Congress for New Urbanism, as well as many other smart-growth oriented organizations, is seeking to promote the creation of pre-WWII style walkable communities, through both the halting of suburban sprawl as well as the densification and re-densification of existing suburban and urban areas. This will entail dramatically improving availability of public transportation, and creating more opportunities to live and work in the same area.[4] In addition, certain cities and states in the US have implemented Urban Growth Boundary initiatives, restricting development of urban areas to a limited area and thereby ensuring a densification process rather than sprawl. Oregon and California both present strong case studies for this approach.

Current Status

The Federal Government has directed stimulus funds towards both public transportation (19,299 Job-Months/Billion Dollars) and highway infrastructure (10,493 Job-Months/Billion Dollars). Focusing on public transit has created more jobs despite more money being poured into highways. Supporters of New Urbanism have used this fact to push for more governmental support in ending sprawl and increasing density of urban centers. Additionally, the UGBs being implemented across the country are currently subject to intense debate over whether or not the benefits outweigh the costs.

Relationship of the Issue to Thermodynamic Ideas

Suburban sprawl requires the use of vast quantities of concrete and steel, both of which have a high embodied energy cost (turning heat from gasoline/diesel combustion into work for excavation, refining, and transporting raw materials). Additionally, sprawl is auto-centric, meaning transportation is dependent upon gasoline-powered vehicles, where once again heat is used to do the work of propelling an automobile and its driver.

[1] P. 115; Kenneth T. Jackson (1985); *Crabgrass Frontier: The Suburbanization of the United States*; Oxford University Press

[2] P. 206; Kenneth T. Jackson (1985); *Crabgrass Frontier: The Suburbanization of the United States*; Oxford University Press

[3] Angie Schmitt (7/26/2011); *Federal Regulations at Odds with Demand for Urban Housing*; accessed 10/9/2011; http://dc.streetsblog.org/2011/07/26/federal-regulations-at-odds-with-demand-for-urban-housing/

[4] *Fannie Mae and Freddie Mac Reform* (7/12/2011); accessed 10/8/2011; http://www.cnu.org/fanniereform

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Embodied Energy of Suburban Sprawl

The Cost of White Picket Fences

I. How the Energy-Using Process Works

Building roads requires the use of two key materials (aggregate and driving surface), often with some sort of reinforcement (steel). The process of obtaining, refining, and transporting those materials gives us the embodied energy of a given distance of road. This is achieved using conventional gasoline or diesel burning vehicles.

a. Work in the case of urban and suburban development largely refers to the conversion of heat energy into work through the use of an internal combustion engine (ICE).

b. Heat is required in the processes of producing steel from carbon and iron ore. Approximately 18.6 GJ of energy as heat are required to reduce the ore to produce one ton of steel.[1] The ultimate embodied energy as heat in the production process is approximately 35 GJ/t.[2] After factoring in transportation energy costs, steel reinforcement has an embodied energy rate of 68.6 GJ/t.[3] Asphalt and concrete, the two most commonly used road-building materials, have embodied energies of 10.8 GJ/m^3 and 5.85 GJ/m^3, respectively.[4]

c. Entropy increases in a number of ways: the production of steel from iron ore and coke, as well as the production of concrete from its components (cement, aggregate, and water) are spontaneous processes requiring heat in the form of a blast furnace and a chemical reaction (respectively) to be activated. Once poured into roads, the constant friction and pressure of auto traffic, as well as changes in temperature and humidity, increase the entropy of the system and accelerate the decomposition of urban transit systems.

d. The **Efficiency** of vehicles travelling on roads impacts how much energy is lost to urban developers by continuing to design auto-centric suburbs.

e. Along a 5 km stretch of road, assuming 9000 cars and 1000 trucks pass through, with respective efficiencies of 0.476 GJ/100km and 1.311 GJ/100km, the total primary **Power** exerted on the road over the life of the road (assumed 40 years on average) would be 4,090,800 GJ, or 280 GJ/day (or 24,192,000 GW).[5]

II. Thermodynamics of the Alternative

a. Work remains the same in principle, however the amount of energy as heat required to the work of pushing pistons in ICEs is greatly reduced if no new infrastructure is needed.

b. Densification of urban and extant suburban areas requires investing in public transit infrastructure rather than enlarging the street grid and adding more traffic lanes. One 5km stretch of steel-reinforced concrete road has an ultimate embodied energy (production, transportation, etc. as **Heat**) of 113,500 GJ.[6] In the example of Atlanta GA, the city increased in size from 105 km North/South to 177 km.[7] The additional embodied energy in that linear growth alone is 1,634,400 GJ.

c. The **Entropy** of dense urban centers is high. However, continued maintenance of degrading infrastructure is more feasible within a smaller area. Suburbs, being more spread out spatially, require more mobility on the part of city maintenance crews. As the economy declines, people are no longer able to afford homes in areas of sprawl, meaning that the spontaneous processes of decomposition increase entropy as homes and roads are abandoned, and city governments are unable to afford maintenance or infrastructural support.

d. Developing alternative public transportation routes, such as electric rail lines, would result in a higher overall **Efficiency** for several reasons. Firstly, many urban centers in the US have existing electric rail or city car lines running through them which have been paved over or simply discontinued. The infrastructure needed to bring electric light rail back into these areas would not need to be fabricated from 'scratch' in many cases. Secondly, the efficiency of electric power plants (based mainly off of fossil fuel combustion) is anywhere between 33-57%, the rest being lost as heat.[8] Suburbs have high energy and water consumption rates (larger houses, lawns, more personal vehicles), and much of that consumption could be avoided in denser communities with less personal vehicles.

e. Power relates to densification in that a reduction in the number of vehicles travelling on city streets would decrease the GJ/day exerted on said streets.

[1] L. Price et al (2001); *Energy Use and Carbon Dioxide Emissions from Steel Production in China*; accessed 10/9/2011; http://ies.lbl.gov/iespubs/47205.pdf

[2] *Embodied Energy Coefficients – Alphabetical* (9/20/2007); accessed 10/8/2011; http://www.victoria.ac.nz/cbpr/documents/pdfs/ee-coefficients.pdf

[3] Graham Treloar et al (Jan. 2004); *Hybrid Life-Cycle Inventory for Road Construction*; Journal of Construction Engineering and Management; accessed 10/9/2011; http://www.inference.phy.cam.ac.uk/sustainable/refs/lca/Treloar.pdf

[4] ibid

[5] ibid

[6] ibid

[7] *New Research on Population, Suburban Sprawl, and Smart Growth*; Sierra Club; accessed 10/9/2011; http://www.sierraclub.org/sprawl/whitepaper.asp

[8] Light Rail Now Project Team (Aug. 2007); *Transportation Energy Debate: How Many BTUs on the Head of a Pin?...er… Power Line?*; accessed 10/8/2011; http://www.lightrailnow.org/facts/fa_lrt_2007-08a.htm

Comments

Alexandra Rempel - Nov 14, 2011 10:06 PM

You have lots of great information here! Now...can it somehow be made more approachable? More of a story, emphasizing your efficiency points? A graph or diagram might help, showing the embodied energy of a compact urban center vs. a sprawling metropolis, or possibly just as importantly, showing the difference in vehicle miles traveled. The figure on page 17 of this article: http://www.smartgrowthamerica.org/sprawlindex/MeasuringSprawl.PDF shows some interesting data that could help with the vehicle miles traveled aspect.

Selected Links and Sources

Excellent Books on Suburban Development in the US:

Kenneth T. Jackson; *Crabgrass Frontier: The Suburbanization of the United States*. Oxford University Press; New York; 1985.

Robert A. Beauregard. *When America Became Suburban.* University of Minnesota Press; Minneapolis; 2006

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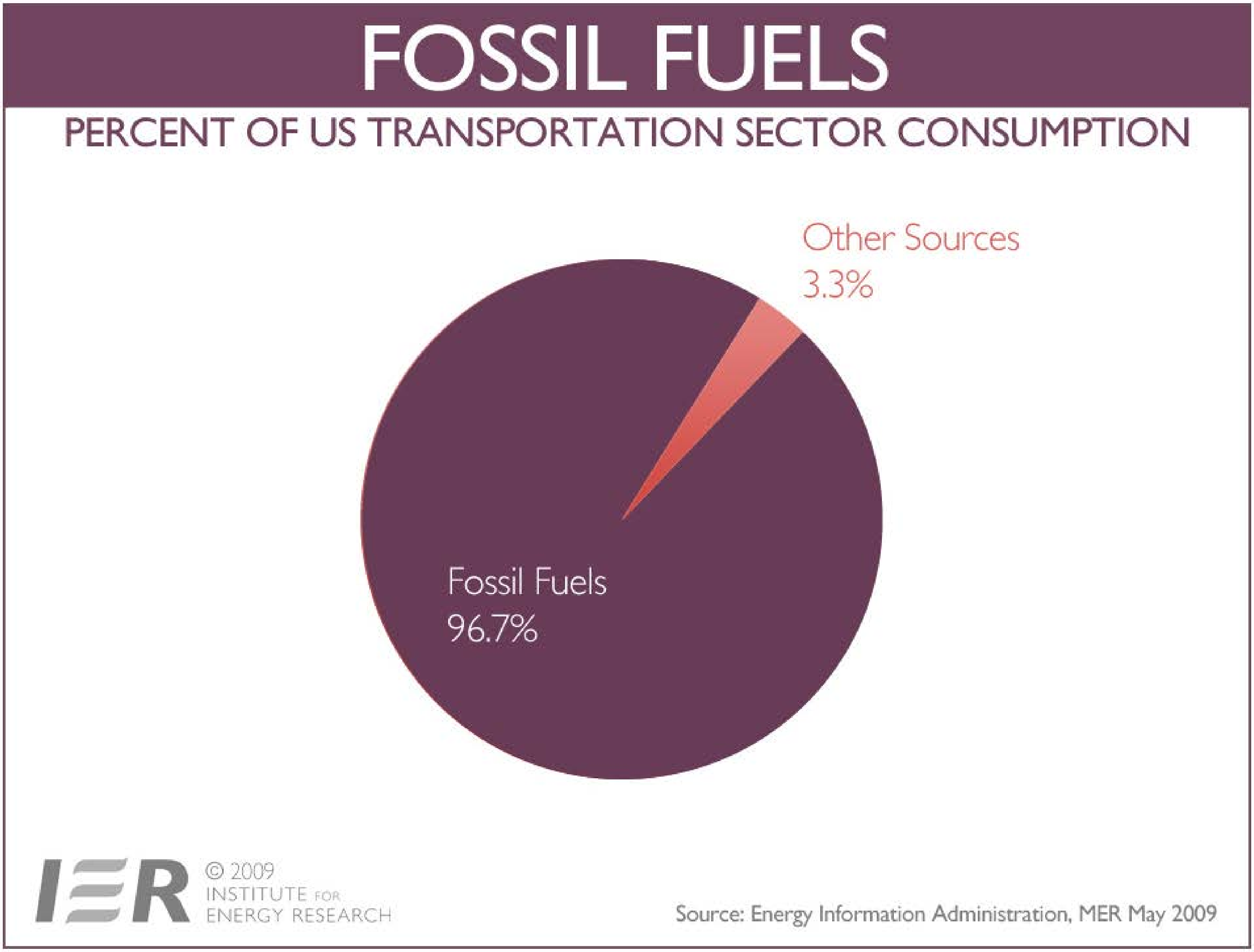
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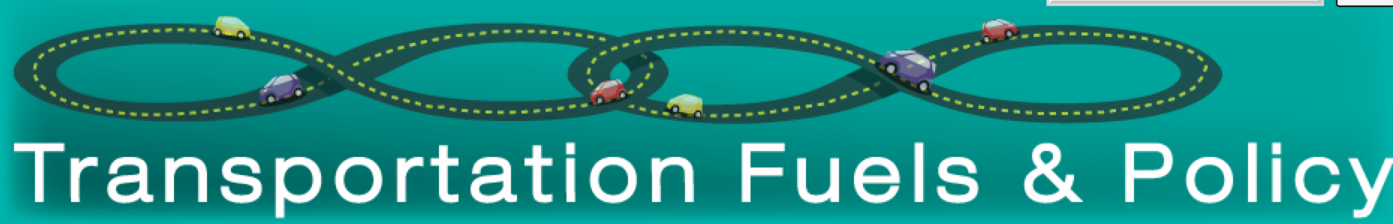

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