

The Evolution: Electric Vehicles and the End of Oil Addiction

By Cory Donahue

A PROJECT

Submitted to
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In Partial Fulfillment of
The Requirements for the
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The world is currently using an unsustainable system of meeting its transportation needs with oil. This system is taking a toll on the world environment and on global politics. The physical availability of oil is the system's most immediate problem and will most likely bring about a transition away from oil dependency. As a solution, the world should replace oil with electricity by replacing cars that use gasoline with cars that use electricity from a battery. Other alternatives, namely ethanol and hydrogen, present a step down from petroleum in terms of sustainability. While electric cars present challenges that can be addressed, their improvements over gas cars justify a very optimistic outlook for the future of transportation. The transition to electric cars has started to occur and will accelerate in the immediate future.

Key Words: Oil, Sustainability, Electric Cars

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The Evolution: Electric Cars and the End of Oil Addiction

Chapter 1: Introduction

Liquid Conflict Diamonds

“ My son was supposed to finish school this year, but yesterday I had to peel off his blood-soaked clothes, and today I buried him, ’ said an elderly man who broke down in tears on top of a grave site. He didn’t give his name.”

–From an article in *The Oregonian*, November 8, 2007, after an attack on a school in Afghanistan.

“Our problems stem from our acceptance of this filthy, rotten system.”

– Dorothy Day

I have no intention of debating whether or not Iraq was a just war, nor whether or not the United States started the war for access to more oil. While these may be important issues, they are not necessary to connect the war to oil. During the Oil-for-Food Program (1996-2002), the Government Accountability Office estimated that Saddam Hussein’s regime illegally took in \$10.1 billion in oil revenues.¹ For comparison, the CIA estimated that Iraq’s official government revenue from 1995 to 2001 was \$2.0 billion.² Without its oil resources and the accompanying revenues, Saddam’s regime would have been broke and harmless, making it invisible to American military interests.

¹ <http://www.gao.gov/new.items/d04651t.pdf>

² http://www.foia.cia.gov/duelfer/Iraqs_WMD_Vol1.pdf, page 150.

When US forces first set ground in Iraq, much was made of the Saddam's brutal repression of the Kurdish minority, killing 5,000 of them with chemical weapons.³ Yet if Iraq had no oil, or if oil had no relevance, their lives would be just as irrelevant to American interests as the 300,000 lives that have been lost in the conflict in Darfur.⁴ Yet, as it is, when someone in the Middle East sneezes, America says "bless you."

As of this writing, the war in Iraq is winding down. But Iraq's main significance is as a distinct expression of a systemic problem, a symptom of an untreated disorder. We will continue to harvest the rotten fruits of war and instability as long as the world economy is addicted to oil. When Saddam invaded Kuwait (104 billion barrels of oil reserves)⁵ in 1991; when Russia invaded two territories of Georgia (the ones that contain an oil pipeline that transport one million barrels per day)⁶ in 2008; when China threatens to veto any action to stop the genocide in Darfur (Sudan supplies China with ¾ million barrels of oil per day)⁷ – when these events happen, one constant cord connects all of them: oil is essential. Oil supplies cannot take a back seat to smaller issues like human rights or national sovereignty.

The main significance of the events mentioned above is that they stem from a system that is rooted in oil. The problematic system I am referring to is the arrangement in which under-developed countries supply the raw material (oil) for developed countries, which are completely dependent on these imports for their societies to function. The economies of developed countries rely on value-added processes, including refining most of the world's oil into gasoline, which poorer countries in turn must import. In the 16th Century, this system

³ http://news.bbc.co.uk/onthisday/hi/dates/stories/march/16/newsid_4304000/4304853.stm

⁴ http://www.cnn.com/2008/WORLD/africa/04/22/darfur.holmes/index.html?eref=rss_topstories

⁵ <http://www.eia.doe.gov/emeu/international/reserves.html>

⁶ <http://www.timesonline.co.uk/tol/news/world/europe/article4484849.ece>

⁷ http://www.ensec.org/index.php?option=com_content&view=article&id=197:chinas-oil-supply-dependence&catid=96:content&Itemid=345

was called mercantilism. The closest manifestation of mercantilism today is the global oil trade. Of the world's 66.2 million barrels of oil exports per day, 49.3% comes from just the top ten countries.⁸ The difficulty with profiting from commodities is that suppliers cannot differentiate their product and therefore can compete only on price. To overcome this disadvantage, in 1960 a handful of oil suppliers formed the oil cartel known as the Organization of Petroleum Exporting Countries (OPEC). OPEC today provides 40% of the world's oil exports.⁹ OPEC exists to control the price of oil.

If oil were governed by free market principles, market mechanisms would have kicked in to lower the price. In 2008, Saudi Arabia exported 8.7 million barrels of oil per day at an average price of \$91.48.^{10,11} Saudi Arabia has the cheapest oil in the world; some estimates for the cost for Saudi Arabia to develop one barrel of oil are \$4-\$6 per barrel.¹² Furthermore, the country currently has 266.7 billion barrels of proven reserves (enough to satisfy their current rate of production for roughly 70 years).¹³ Accordingly, they should have no objection to ramping up production and selling even more oil at a lower price for more total revenue. Producers could continue profitably undercutting each other until the revenue from each barrel declined enough to equal the cost of each barrel. At this point, the cheapest oil would be used up first, and only then would the price of oil increase enough to encourage developing more expensive oil wells. This clearly has not happened, due to the careful planning of OPEC. These countries, led by Saudi Arabia, collaborate to decide the desired output for ensuring adequate revenues at a favorable price. In the free market, the

⁸ http://www.photius.com/rankings/economy/oil_exports_2009_0.html

⁹ <http://www.nytimes.com/2008/10/25/business/worldbusiness/25oil.html>

¹⁰ <https://www.cia.gov/library/publications/the-world-factbook/geos/sa.html>

¹¹ http://www.inflationdata.com/inflation/Inflation_Rate/Historical_Oil_Prices_Table.asp

¹² <http://www.reuters.com/article/idUSLS12407420090728>

¹³ <https://www.cia.gov/library/publications/the-world-factbook/geos/sa.html>

key difference is that private companies would never intentionally decide that they have made *enough* money. Unfortunately, private oil companies control only 10% of the world's oil and will not convince public oil companies to undercut each other on prices anytime soon.¹⁴ So oil trades on the free market, after the price has been voted on.

Not surprisingly, this quasi-free market process is anathema for economic efficiency. In economic terms, the problem is externalities. In other words, the true costs of the decisions are not felt by the decision makers. No one pays for pollution's cost to the environment unless the government intervenes. No one pays for the human cost of political oppression that petrodictators can afford with their oil revenues. No one pays for the punishment to currency exchange rates that trade imbalances cause. There is also the hidden cost of the de-industrialization that occurs in petroleum-exporting countries. Furthermore, the steady flood of government revenue is fostering generous patronage systems, which are major inhibitors of economic development. If we added all of these costs onto the price of oil, we would find the real cost of oil to be prohibitively high.

However, "no one pays" is not a fair statement about the modern world's petroleum-based economy. Perhaps a more accurate statement is "everyone pays." We all have to live in this environment. Would anyone argue that a global climate change would not affect their part of the world? More tangibly, the United States military interests are so heavily wrapped around the Middle East that American taxpayers foot the bill for a colossal amount of military spending every year. Furthermore, the petroleum-exporting countries do not have the moderating effect of a middle class, so that democracy in the Middle East could actually be dangerous. The invisible hands of the free market are handcuffed by these externalities so that these problems are not going to take care of themselves.

¹⁴ *The Independent Financial Review*, "Oil Giants Losing Their Grip," April 4, 2007

Another potential crisis in the making is that oil production cannot continue indefinitely. To be fair, doomsday predictions about the end of oil have been around for decades and so far have always been wrong. The main reason peak oil predictions keep passing unfulfilled is that oil extraction technology is improving and has allowed hard-to-reach oil to become economically recoverable. However, the truth is that oil will eventually run out. More immediately, the crisis will happen when the rate of production fails to keep pace with increasing demand. Peak oil is such a predictable crisis that making the transition to a crisis-free system would certainly cost less than failing to read the writing on the wall.

Another difficulty in addressing these problems is that the costs will fall heaviest on future generations. Oil's status as a finite resource will eventually bring itself to bear on society, but the convenience of neglecting the problem appeals to most decision makers. Furthermore, oil consumption inescapably puts more carbon in the air, contributing to the greenhouse effect. Future generations will inherit a world that is getting hotter and will therefore face increased droughts, flooding, and habitat destruction. Just as deficit spending is more popular than increased taxation, using natural resources for our immediate self-interests is firmly entrenched in our mindsets.

Faced with an unsustainable oil-based system, we have seen socially responsible consumers change markets before. After the movie *Blood Diamond* came out, grossing \$171 million,¹⁵ “conflict diamonds” became the rallying cry for conscientious consumers that refused to fund rebel groups with their jewelry purchases. Conflict diamonds were the fuel of the resistance during the 27-year civil war in Angola. It was originally a Cold War conflict with US and USSR supporting their ideological counterparts, but the war was able to continue after the Cold War by replacing foreign assistance with diamond sales. Between

¹⁵ <http://www.the-numbers.com/movies/2006/BDMND.php>

1992 and 1998, UNITA (the anti-communist side) made an estimated \$3.72 billion from diamond sales.¹⁶ Due to widespread awareness, establishing the conflict-free origins of diamonds on the market became a marketing necessity and a consumer requirement. Fortunately, 99% of diamonds are completely conflict-free.¹⁷

On the other hand, oil and its associated conflicts seem inescapable in the current system. Oil production in the United States has had a solid downward trend since 1970 with a corresponding increased reliance on imports.¹⁸ We cannot choose to consume less oil because there is currently not a single alternative liquid fuel that can economically replace gasoline.

From a global perspective, oil dependence is so universal that the talk of replacing oil sounds unrealistic at best. Much of the hype concerning oil independence ignores the global market for commodities. Oil is traded internationally. If the United States produced all of its own oil, there would still be an international price for oil. Oil is like a pool; exporters fill the pool and importers suck out an equal amount. We cannot choose to disconnect Middle Eastern oil from the pool. In order to drive down the revenues of petrodictators in the Middle East, the total global demand for oil must decrease. Oil must become obsolete.

Faced with such a daunting task, it should come as no surprise that the government has not been able to pull off a miracle here. Rather, government actions constantly remind me of the maxim, “If you think the problems are bad, wait until you see the government’s solutions.” The current combination of embargos, taxes, mandates, and subsidies resembles a drunken walk. The drunken walk analogy is very fitting, since alcohol is definitely involved. Ethanol is just another ingredient in the government’s scattergun method of

¹⁶ Arnold, Guy (2000). *The New South Africa*. p. 131.

¹⁷ <http://diamondfacts.org/>

¹⁸ http://www.eia.doe.gov/pub/oil_gas/petroleum/presentations/2000/long_term_supply/sld007.htm

meeting America's energy needs. The only commonality of these niche solutions is that they are always profitable for the special interest groups that support them. Ethanol production is of course extremely popular in ethanol-producing states. Politicians are merely listening to their constituents. The drawback of our democracy is that we get the government we deserve.

The "solutions" to our oil dependency and their costs are just another reason we urgently need to find a real solution. Ridiculous subsidies to grow food for fuel cost around \$9 billion annually.¹⁹ The artificial demand for corn helped catalyze a 400% increase in the price of corn flour in the spring of 2007.²⁰ The increase in food prices is one reason the United Nations called the United States' food-for-fuel strategy a "crime against humanity."²¹ The best way to make biofuels sound practical is to compare them to hydrogen fuel cells. The government has also funded \$1.2 billion in for researching hydrogen fuel cells.²² According to the National Research Council, fuel-cell cars might become commercially viable after by 2023 after \$200 billion in development.²³ It might cost less to buy an oil-producing country.

So why has every strategy for energy independence been so feckless? Many of the books on oil politics focus on corruption and conspiracies. Their argument is simple. Oil is power. Power corrupts. Not only that, but since oil has monopoly power as the only liquid fuel that meets the needs of the world's transportation sector, this absolute power corrupts absolutely. However, every country and company is simply acting in its own best interest. I

¹⁹ <http://www.eia.doe.gov/oiaf/analysispaper/biomass.html>

²⁰ <http://www.independent.co.uk/news/world/americas/how-the-rising-price-of-corn-made-mexicans-take-to-streets-454260.html>

²¹ <http://news.opb.org/article/645-un-calls-converting-food-crops-fuel-crime-against-humanity/>

²² <http://www.whitehouse.gov/omb/rewrite/budget/fy2009/energy.html>

²³ <http://www.globalsubsidies.org/en/subsidy-watch/studies/massive-public-subsidies-required-hydrogen-vehicles-are-competitive-say-us->

do not believe there is anything wrong with that. More importantly, whether right or wrong, that is not likely to change. No company will volunteer to reduce profits, nor will any country subvert its own priorities in the interest of pure altruism.

Fortunately, the automotive industry is at a turning point in its evolution. Charles Darwin's 1859 book *The Origin of Species* proposed a mechanism for change known as phyletic gradualism. This is the traditional view of evolutionary change, in which mutations alter living things at a rate that is too subtle to notice without the hindsight of millions of years. However, this does not perfectly match what we see in the fossil record. We do see closely related species but never a gradual slide connecting different species. As a solution, Stephen Jay Gould and Niles Eldredge proposed a theory called punctuated equilibrium, in which mutations build up over time before expressing themselves. Accordingly, we fail to see evolution in the fossil record not because it is too slow but because it is too fast.

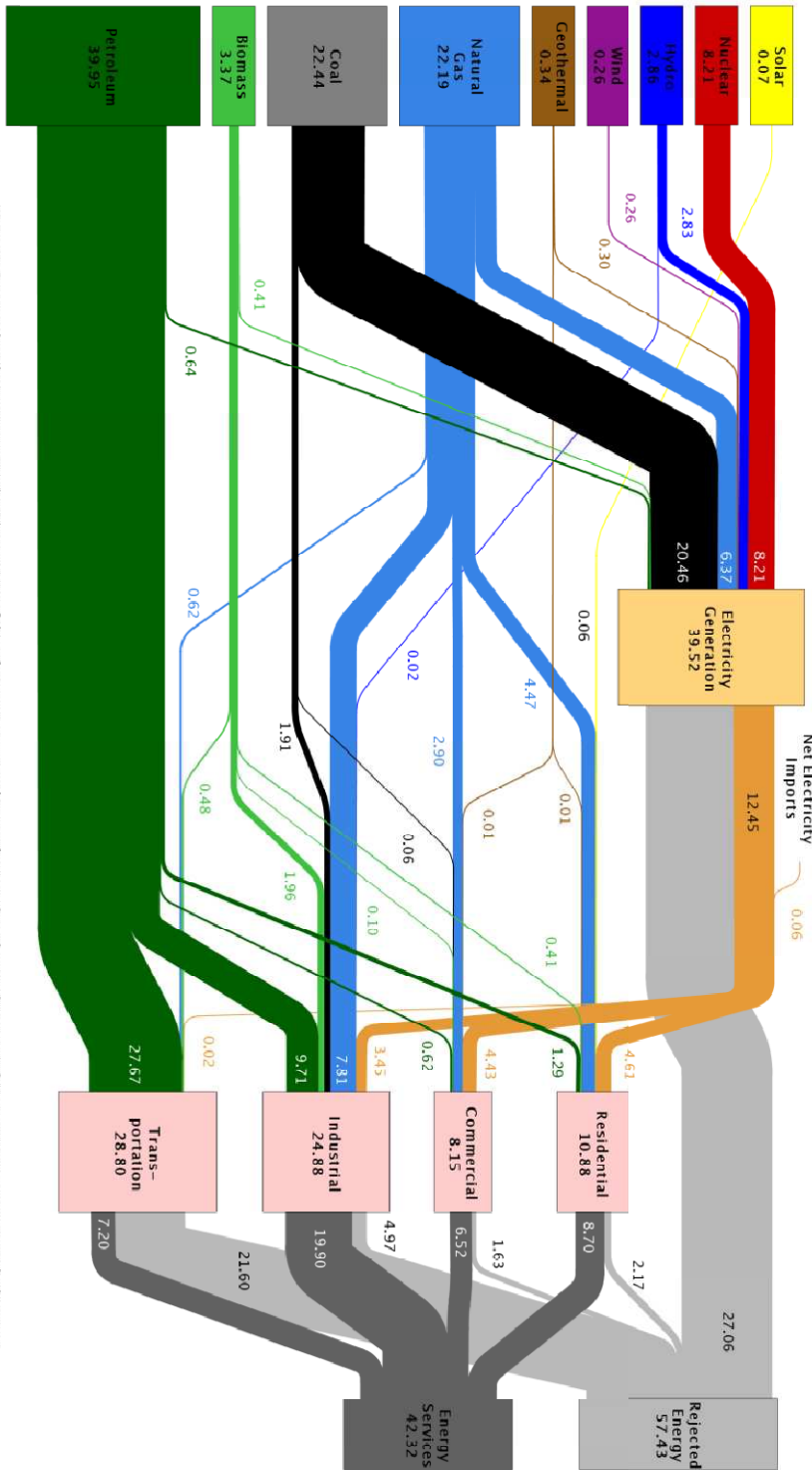
If the automotive industry's evolution were described in biological terms, its mechanism of change would certainly best be compared to punctuated equilibrium. Advances in electric vehicle technology have built up over time and are currently reaching a turning point where they are finally making themselves felt. The natural selection of the free market will see to it that electric cars will cannibalize their primitive ancestors that bleed oil and spew exhaust. Electricity will replace gasoline in vehicles that will offer superior comfort, convenience, and performance at a lower price. Because of this turning point, the automotive industry will clean up its act in the same way diamonds have, without the idealistic request that humans evolve above self-interest. With the proper blame for the country's continued oil dependency placed on the limitations of today's technology, it becomes clear that tomorrow's technology will lead the way towards energy resilience.

Technology in this sense is simply continuing its pattern of averting the so-called Malthusian catastrophe. Two hundred years ago, Thomas Malthus believed a catastrophe was coming because he believed that the means of sustaining the human population increased linearly while the population increased exponentially. Malthusian thinking continues to show up in books on peak oil, climate change, and energy shortages. The reason that doomsday scenarios have so often failed to materialize is that technology actually increases our ability to meet our needs, and technology has always advanced exponentially. A skeptic of this optimism may point to the few millennia of stagnant technological growth, but slow initial growth is just the subtle phase of exponential growth. Once the exponential curve turns the corner, the curve looks almost as vertical as it looked horizontal before the turning point.

A quick look at the relevant numbers shows that cars are the culprit in America's energy problems. In the United States, 70% of oil is destined to be used in the transportation sector.²⁴ Accordingly, if the transportation sector became oil-free, it would displace more oil consumption than the amount of oil we currently import. If cars use electricity, then at no point in the supply chain does oil ever appear, because the United States does not generate electricity from oil, as shown in Figure 2 below. While this switch would not immediately eliminate carbon emissions from the transportation industry, electricity generation does have the potential to be carbon-free. An overview of the current state of energy production and consumption is shown in the flow chart below. Notice that the large green bar for petroleum shows that oil is the only source of energy for transportation.

²⁴ <http://www.instituteforenergyresearch.org/energy-overview/petroleum-oil/>

Estimated U.S. Energy Use in 2006: ~99.8 Quads

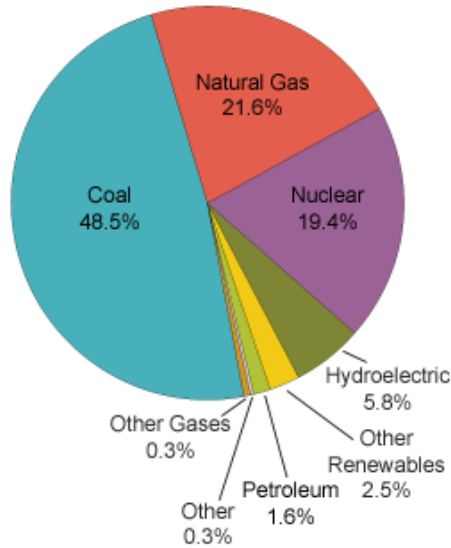


Source: LLNL 2008. Data is based on DOE/EIA-0384(2007), June 2008. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electrical production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Figure 1 - Energy Flow Chart²⁵

²⁵ https://publicaffairs.llnl.gov/news/energy/content/energy/energy_archive/energy_flow_2006/LLNL_US_Energy_2006.png

U.S. Electric Power Industry Net Generation, 2007
Total = 4,157 billion kilowatthours



Sources: EIA, Form EIA-923, "Power Plant Operations Report" and predecessor form(s) including Form EIA-906, "Power Plant Report;" and Form EIA-920, "Combined Heat and Power Plant Report."

Figure 2 - Sources of US Electricity²⁶

Not only are cars the problem, they are a rapidly escalating problem that has already reached a colossal level. There are *one billion* cars on the road today, a quarter of which are in the United States.²⁷ Approximately 52 million cars were produced in 2009.²⁸ Cars account for one fourth of world CO₂ emissions and one third of US CO₂ emissions.^{29,30} Cars are so tightly integrated into our lives that becoming car-free is not currently possible or desirable. Instead, we simply need to make cars oil-free and emissions-free.

Electric cars can be the cure to our addiction to foreign oil. Their progenitors, hybrid cars, have seen exponential growth in the last five years and are expected to continue this trend for the foreseeable future. Following their lead, the next phase in the evolution of

²⁶ http://tonto.eia.doe.gov/energyexplained/index.cfm?page=electricity_in_the_united_states

²⁷ <http://www.plunkettresearch.com/Industries/AutomobilesTrucks/AutomobileTrends/tabid/89/Default.aspx>

²⁸ <http://oica.net/category/production-statistics/>

²⁹ http://www.earth-policy.org/index.php?/indicators/C52/carbon_emissions_2002

³⁰ http://www1.eere.energy.gov/vehiclesandfuels/facts/2007_fcvt_fotw464.html

automotives will be explosive growth in all-electric and plug-in hybrid vehicles. Fifty years from now, I predict that more new cars will be powered by a battery than by an internal combustion engine. One hundred years from now, they will no longer be known as “green cars,” but rather, simply “cars,” and gas-powered cars will be “alternative vehicles.”

To accelerate this revolution, consumers, producers, and politicians need a healthy dose of facts. First, the context needs to be outlined, so that we can see how beneficial and necessary this revolution will be. The societal ills introduced in this chapter will be discussed at length in the next chapter. Furthermore, I will examine “the other side” of the story, meaning the perspective that we should stick with the status quo.

Next, the following chapter is aimed at correcting the misdirection that is distracting us from pursuing the real solutions to the problems we are facing. Growing corn to produce alcohol to use as a fuel is a perfect example of an exercise in futility. The main rival example of futility is hydrogen-powered cars. Corn ethanol requires an unsustainable level of energy, water, and government subsidies to produce. Hydrogen requires an outrageous, expensive amount of energy to produce, contain, distribute, and use. However, the greatest cost from both of these initiatives may be the opportunity costs of resources that could have been used to advance electric vehicles.

Finally, and most enjoyably, the second half of this book will cover the forefront of the revolution, the companies and products that will define the future of personal transportation. Every major automaker is producing hybrids and is racing to produce plug-in vehicles. Plug-ins include pure electric cars and plug-in hybrid electric cars – anything that has an all-electric mode and thus has the possibility of being petroleum-free. The section

will also address criticisms of electric cars such as their effect on the electric grid and the state of battery technology.

Chapter 2: America's Addiction to Oil

A Troubling Diagnosis

*“Keeping America competitive requires affordable energy. And here we have a serious problem: **America is addicted to oil**, which is often imported from unstable parts of the world.”*

-President George W. Bush, 2006 State of the Union Address

A world that runs on oil is a relatively new phase in the grand scheme of human history. Using oil from the ground was a solution to the crisis of “peak whale oil” due to the overconsumption of whales. The first time a drill was used to get oil was in 1859 in Pennsylvania.³¹ Gasoline and diesel were waste products after oil was refined to make kerosene for lamps. An even newer technology, automobiles, which were first mass-produced by Henry Ford in 1914, stimulated the first demand for these waste products. For the last hundred years, oil has greased the wheels of extraordinary economic growth by providing quick, affordable transportation in the form of planes, trains and automobiles. While petroleum has had such a beneficent effect on the human experience for the last hundred years, the bad news is that the same cannot be said about the next hundred years. This chapter will explain why the current system is unsustainable. That is to say, it will not be physically, environmentally, or economically possible to continue the status quo for the next hundred years.

³¹ Downey, Morgan. *Oil 101*. Page1. 2009

Environmentally

The planet is getting warmer. The average global surface temperature currently stands at about 58°F.³² This value represents an increase of 1.4°F since 1750 (most of which occurred in the last 30 years).³³ The ten hottest years ever recorded all occurred after 1997.³⁴ While it is true that the planet's average temperature does vary from day to day, year to year, and decade to decade, etc., the most significant point about today's temperatures is that they have had a steady upward trend since the Industrial Revolution, as shown in Figure 3 below.

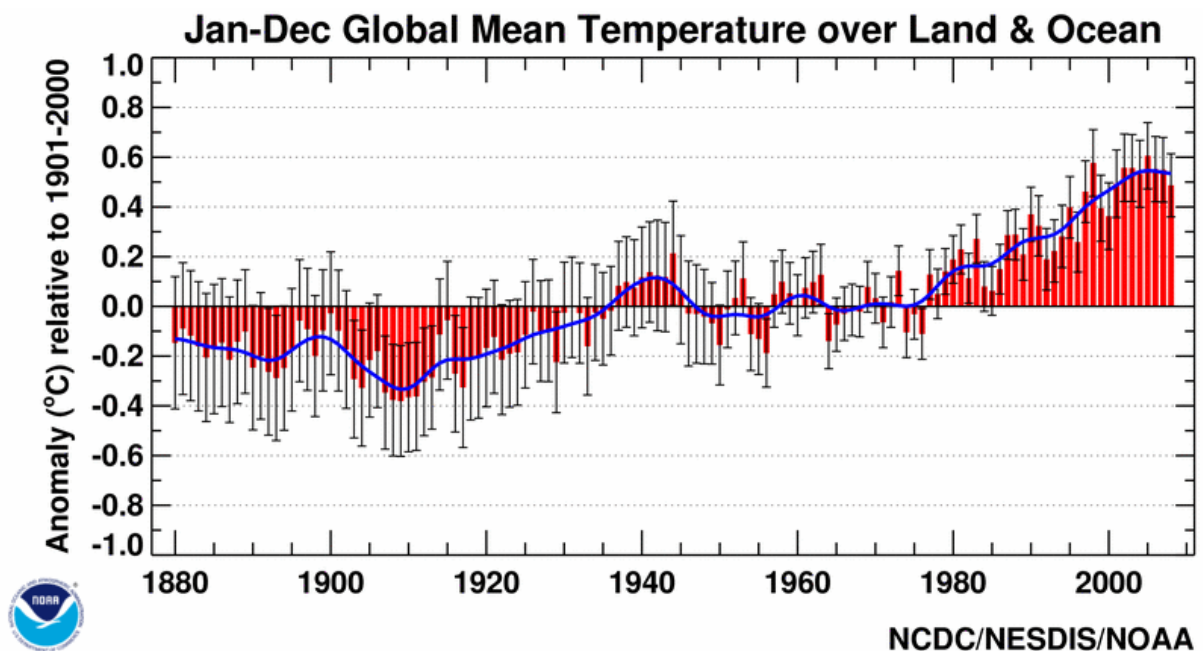


Figure 3 - Average Global Surface Temperature³⁵

Understanding this trend requires understanding the planet's heating system. The sun's radiation travels through the earth's atmosphere in a few different routes. Only half of the sun's heat is absorbed by the earth's surface. Of the other half, the radiation is almost evenly split between being reflected away by clouds and being absorbed by the atmosphere.

³² <http://www.earth-policy.org/index.php?indicators/C51/>

³³ Friedman, Thomas. (2008). *Hot, Flat, and Crowded*. New York: Farrar, Straus and Giroux. Page 36.

³⁴ <http://www.earth-policy.org/index.php?indicators/C51/>

³⁵ <http://www.scams.gov.uk/environment/lowcarbon/climate/lcl002.htm>

The heat that is absorbed by the surface causes the surface to give off infrared radiation. Infrared radiation is often confused with thermal radiation, even though thermal radiation can just easily include radiation in the visible and ultra-violet range of the electromagnetic spectrum. Clouds and greenhouse gases trap this infrared radiation. Without these gases, the temperature of the earth would be about 60°F lower.³⁶ The different possibilities for sunlight hitting the earth are shown in the picture below.³⁷

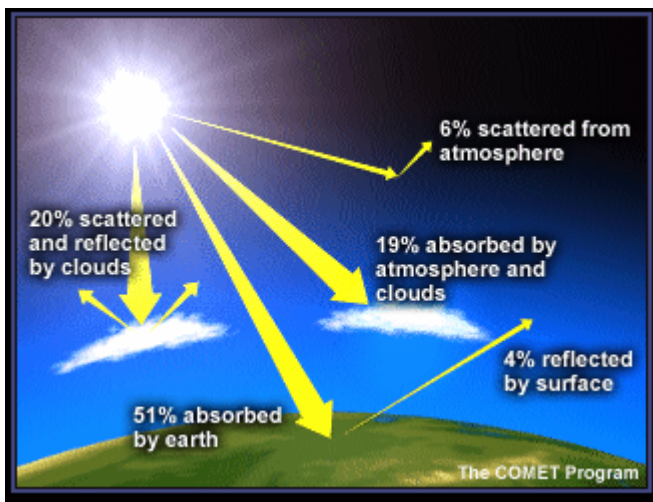


Figure 4 - Average Distributions of Sunlight

The extent to which the atmosphere traps thermal radiation depends on the atmosphere's composition. The atmosphere is made of 78% nitrogen, 21% oxygen and 1% other gases, with a much more detailed description given in Table 1 below. The entries that contain an asterisk are gases

that trap heat (i.e. are greenhouse gases): water vapor, carbon dioxide, methane, nitrous oxide and ozone. The ability of these gases to absorb infrared radiation and their cumulative effect on the atmosphere are shown in Figure 5.

³⁶ Friedman, Thomas. (2008). *Hot, Flat, and Crowded*. New York: Farrar, Straus and Giroux. Page 36.

³⁷ http://www.windows.ucar.edu/tour/link=/earth/climate/greenhouse_effect_gases.html

Gas Name	Chemical Formula	Percent Volume
Nitrogen	N ₂	78.08%
Oxygen	O ₂	20.95%
*Water	H ₂ O	0 to 4%
Argon	Ar	0.93%
*Carbon Dioxide	CO ₂	0.0360%
Neon	Ne	0.0018%
Helium	He	0.0005%
*Methane	CH ₄	0.00017%
Hydrogen	H ₂	0.00005%
*Nitrous Oxide	N ₂ O	0.00003%
*Ozone	O ₃	0.000004%

Table 1 - Composition of Earth's Atmosphere³⁸

³⁸ <http://www.physicalgeography.net/fundamentals/7a.html>

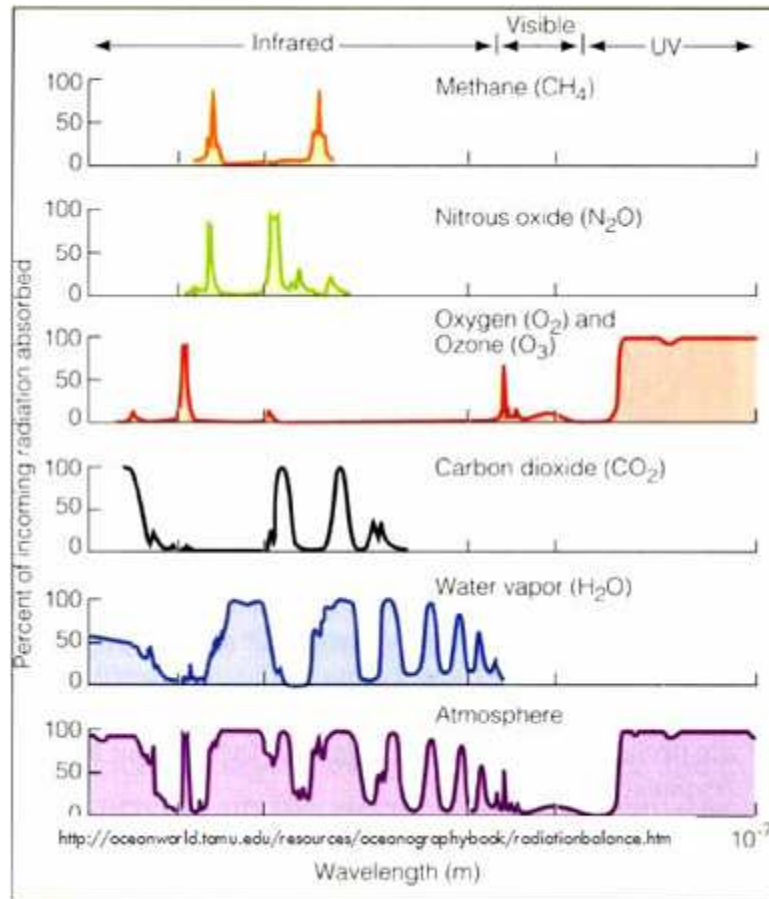


Figure 5 - Response to Radiation of Greenhouse Gases³⁹

Even though the seven gases at the bottom of Table 1 each account for less 0.1% of the atmosphere, their greenhouse effect is still significant. How well they capture heat can be described with the metric known as Global Warming Potential (GWP). GWP measures how many times more potent than carbon dioxide a gas is at causing the greenhouse effect. Carbon dioxide provides an effective baseline because it is the least potent but most abundant greenhouse gas, not including water vapor. For example, the atmosphere contains over 210 times as much carbon dioxide as methane, yet because methane is 72 times more effective at trapping heat, carbon dioxide is responsible for only 3 times as much greenhouse warming as

³⁹ http://www.columbia.edu/~fhz2102/kyotofuture/greenhouse_effect.html

methane. GWP's are given in more detail in Table 2 below. Following Table 2, Table 3 shows the total effect of each greenhouse gas.

Greenhouse Gas	Lifetime (years)	GWP time horizon		
		20 years	100 years	500 years
Carbon Dioxide		1	1	1
Methane	12	72	25	7.6
Nitrous oxide	114	289	298	153
HFC-23 (hydrofluorocarbon)	270	12000	14800	12200
HFC-134a (hydrofluorocarbon)	14	3830	1430	435
Sulfur Hexafluoride	3200	16300	22800	32600

Table 2 - GWP of Selected Greenhouse Gases⁴⁰

Major Greenhouse Gas	% of Greenhouse Effect
Water vapor	36% to 66%
Water vapor & Cloud droplets	66% to 85%
Carbon dioxide	9% to 26%
Methane	4% to 9%
Ozone	3% to 7%

Table 3 - Greenhouse Contribution of Individual Gases⁴¹

While water vapor and clouds are responsible for most of the greenhouse effect, their effect is innocuous because they are simply part of a system of homeostasis that the earth has maintained in its current climate for thousands of years. Similarly, most atmospheric carbon dioxide is a natural byproduct of the lifecycle of plants. However, carbon dioxide also comes from anthropogenic sources such as combustion, cement production, and other industrial processes. The pre-industrial level of carbon dioxide in the atmosphere was 280 parts per

⁴⁰ http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/248.htm

⁴¹ http://www.windows.ucar.edu/tour/link=/earth/climate/greenhouse_effect_gases.html

million (ppm), or 0.028%.⁴² We know this from measuring the composition of air in air bubbles trapped in ice layers in Antarctica. As shown in the two charts below, the level of atmospheric carbon dioxide has been steadily increasing and is currently at 385 ppm.⁴³

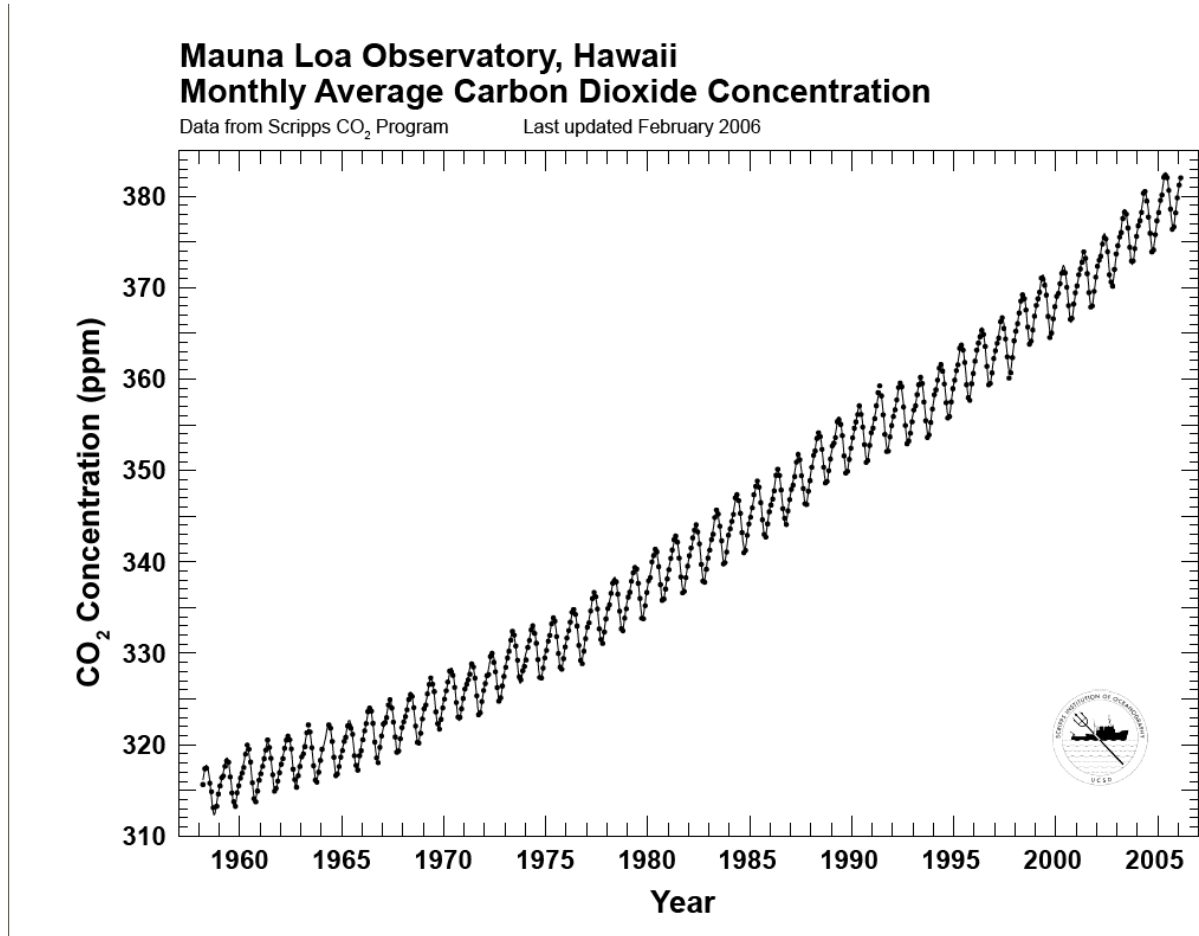


Figure 6 - Direct Measurements of Atmospheric Carbon Dioxide⁴⁴

⁴² <http://www.friendsofscience.org/assets/documents/FoS%20Pre-industrial%20CO2.pdf>

⁴³ <http://www.friendsofscience.org/assets/documents/FoS%20Pre-industrial%20CO2.pdf>

⁴⁴ http://www.esrl.noaa.gov/gmd/obop/mlo/programs/coop/scripps/img/img_scripps_co2_record.gif

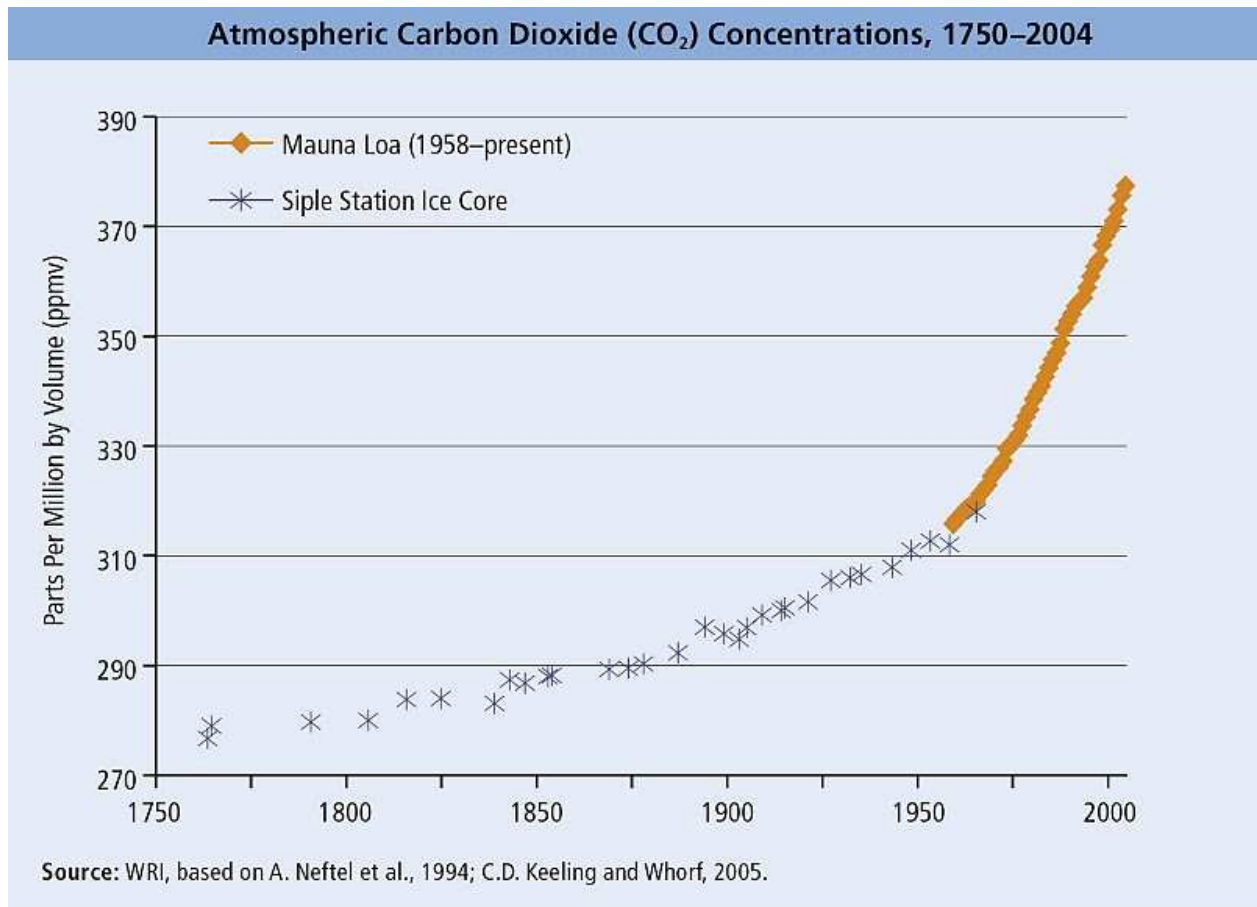


Figure 7 - Atmospheric Carbon Dioxide, Larger View⁴⁵

Complications

Up to this point in the chapter, this description has been a basic review of the science behind today’s global warming. Presented with the undisputed principles of the greenhouse effect, most people in the developed world have been won over by the direct observations of increasing global temperatures and of skyrocketing carbon dioxide. However, as President Barack Obama said during his 2010 State of the Union Address, “I know that there are those who disagree with the overwhelming scientific evidence on climate change.”⁴⁶ A March 2009 Gallup poll found that this skeptical camp has been growing in the United States for the last four years, as shown below.

⁴⁵ <http://earthtrendsdelivered.org/node/38>

⁴⁶ <http://www.whitehouse.gov/the-press-office/remarks-president-state-union-address>

Thinking about what is said in the news, in your view is the seriousness of global warming -- [generally exaggerated, generally correct, or is it generally underestimated]?

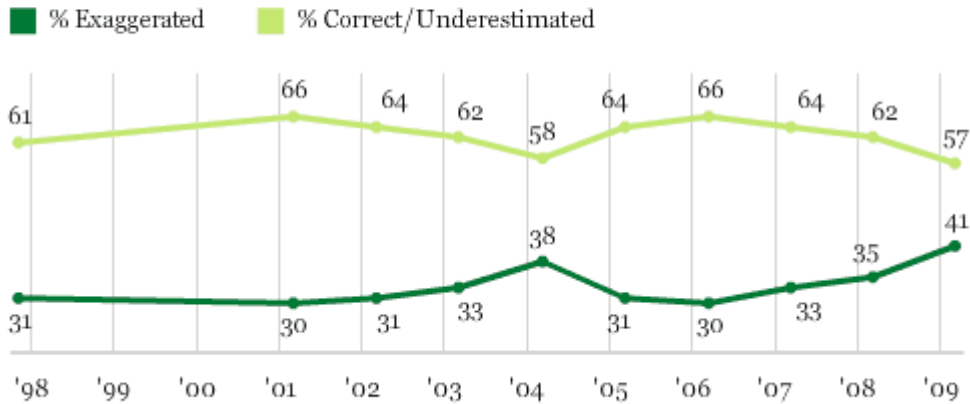


Figure 8 - Gallup Poll Showing American Skepticism Concerning Global Warming⁴⁷

Many of the rebuttals from global warming skeptics stem from the complexity of general climate science. There are several factors that affect the climate and could potentially pass the buck away from humans. Besides anthropogenic greenhouse gases, there are also cycles of solar activity, variations in planetary motion and varying carbon outputs from oceans, plants and animals. Furthermore, these factors often affect each other, sometimes reinforcing and sometimes counteracting shifts in the global climate. While selective information about the factors can be used to confuse the issue, putting these into perspective should help mobilize reasonable efforts to prevent further global warming.

One of the most clearly established causes of global climate change is the effect of Milankovitch cycles. In 1920, Serbian geophysicist Milutin Milankovitch published his work on three cyclic changes to the earth's relationship to the sun: eccentricity, obliquity, and precession. The eccentricity of earth's orbit changes, meaning that the orbit varies between being more circular and more elliptical every 100,000 years, due to the effect of other planets

⁴⁷ <http://www.gallup.com/poll/116590/Increased-Number-Think-Global-Warming-Exaggerated.aspx>

in the solar system. Secondly, the tilt of Earth's axis varies from 22.1° to 24.5° in a 41,000 year cycle. Lastly, in the process known as precession, Earth's axis is wobbling so that the solstices happen at different points in Earth's orbit, coming full circle every 11,000 years.⁴⁸ While these cycles dramatically change the Earth's climate, they are on a time scale that makes them irrelevant to the recent acceleration of warming.

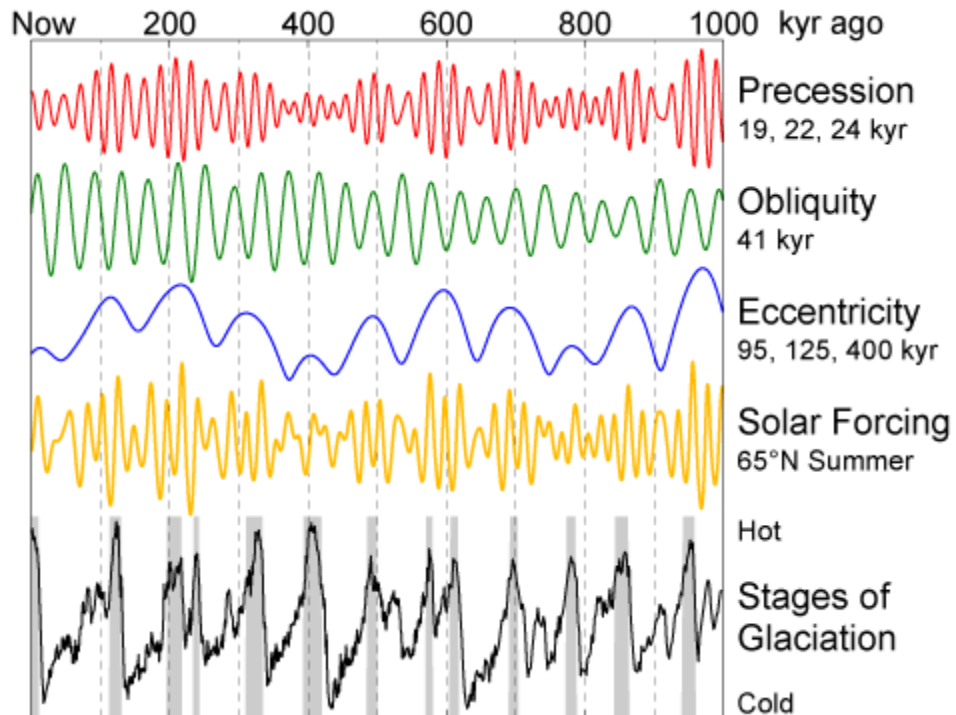


Figure 9 – Milankovitch Cycles⁴⁹

Perhaps the most common excuse for dismissing the human element of global warming comes from blaming solar activity. The sun is an active body, producing sunspots, solar flares and coronal mass ejections. Sunspots are areas with a strong magnetic field that blocks convection so that the spots remain cooler than the surrounding surface. Because heat builds up in the area surrounding a sunspot, sunspots actually correlate with a higher overall flux of solar radiation. Astronomers have observed the sun since Galileo Galilei made

⁴⁸ <http://ags.ou.edu/~jgriggs/intro2.htm>

⁴⁹ http://en.wikipedia.org/wiki/Milutin_Milanković

improvements to the telescope in 1609.⁵⁰ This allows us to match solar activity with past periods of warming and cooling, which are depicted in Figure 11. According to a recent report from NASA says that only 0.1°C of the last 0.5° of warming is due to solar activity.⁵¹ While this argument may be the closest one to a reasonable argument against blaming the greenhouse effect, it is still incomplete.

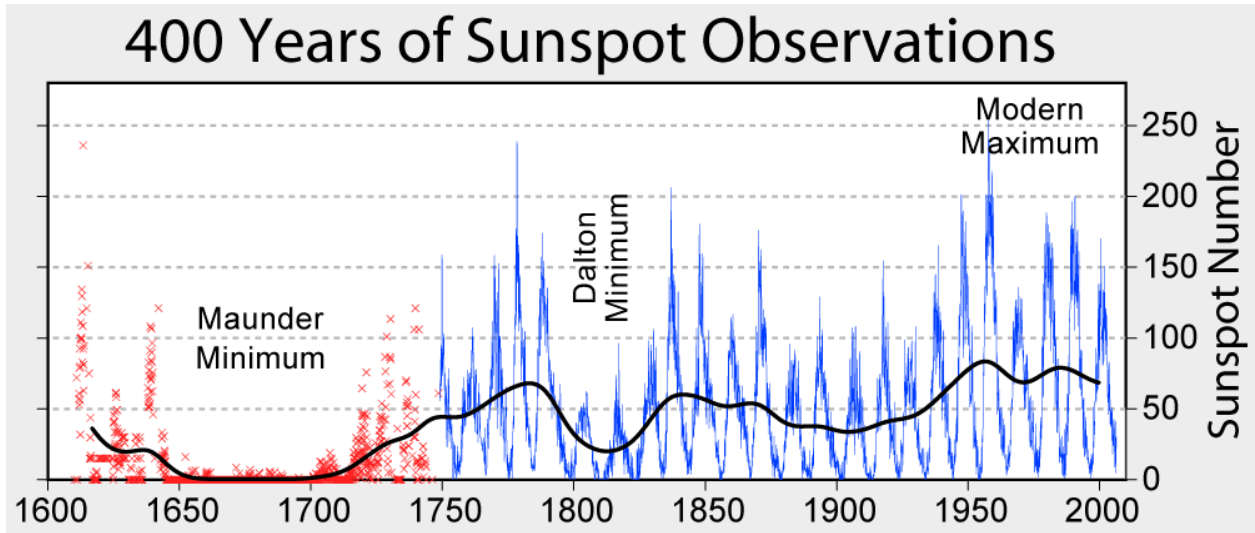


Figure 10 - Increasing Solar Activity⁵²

⁵⁰ http://galileo.rice.edu/bio/narrative_6.html

⁵¹

<http://www.dailytech.com/NASA+Study+Acknowledges+Solar+Cycle+Not+Man+Responsible+for+Past+Warming/article15310.htm#>

⁵² http://www.globalwarmingart.com/wiki/File:Sunspot_Numbers_png

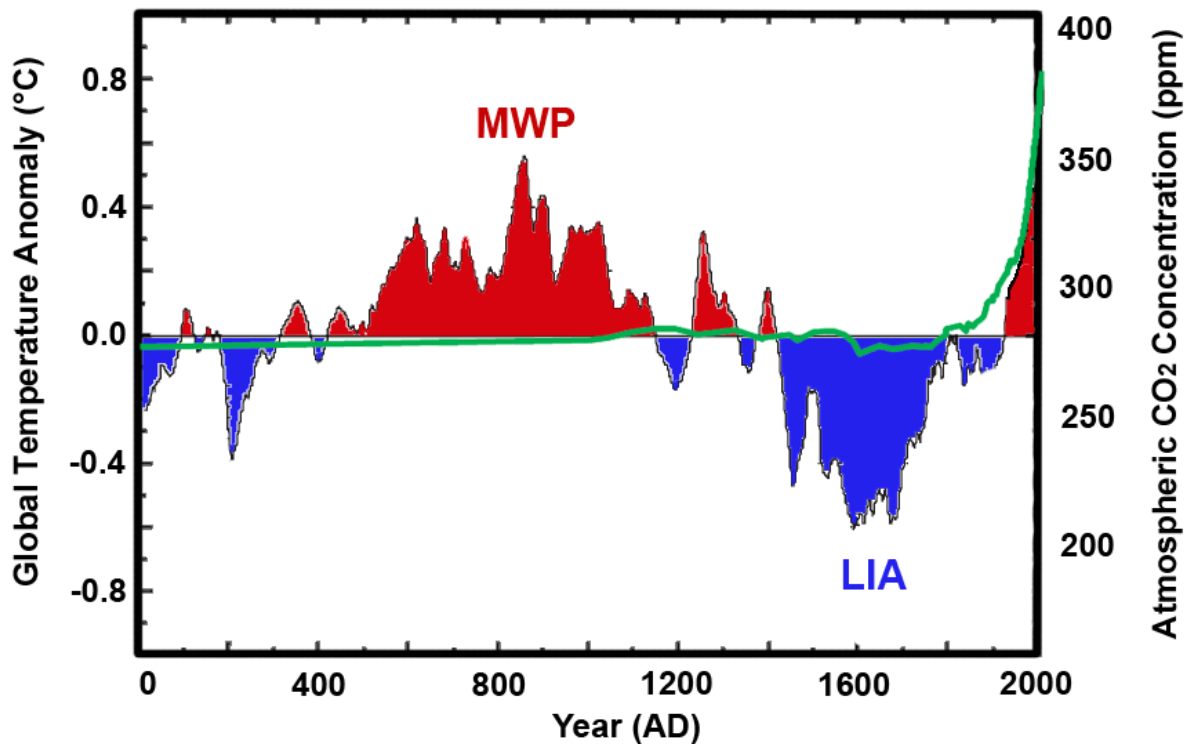


Figure 11 - Global Climate Changes in Years A.D.⁵³

Another method of “debunking” anthropogenic global warming is to try to throw doubt on the relationship between global temperatures and atmospheric carbon dioxide. There is indeed an 800 year lag between temperature and atmospheric carbon dioxide. Warm water holds less carbon dioxide and therefore releases it into the atmosphere; this slow process happens on a large enough time scale to explain the lag. However, imagine a house with a central heating system that was thoughtlessly programmed to turn on after the temperature had already been raised to a certain point. Forcing the heating system to turn on apart from its default programming will still warm the house. In the same way, it is totally reasonable to say that past climate changes caused increased CO₂ concentrations and that skyrocketing CO₂ concentrations are causing global warming today.

⁵³ <http://www.co2science.org/articles/V12/N10/EDIT.php>

At first, a couple degrees Fahrenheit might seem like a difference that could be doubted or ignored. However, as global warming advocates say, the earth is running a fever. Just as a couple extra degrees of body temperature means that a person is under the weather, an increasing global temperature can lead to progressively worse symptoms. While people squabble about the causes and effects of global warming, it is easy to forget the scientific reasoning that encourages us to limit greenhouse gases. The fact that carbon dioxide traps heat is not an interpretation of historical or pre-historical data, but rather is an observable, repeatable property we know from physics. We cannot afford to continue flooding the atmosphere with carbon dioxide at exponentially increasing rates. Examining the repercussions of runaway global warming should make it apparent that the costs of prevention are preferable to the costs of an increasingly feverish climate.

An expansion in the world's oceans is probably the greatest threat posed by global warming. The global sea level has been rising at an average of 1.7 mm per year since 1870.⁵⁴ The threatening aspect of this is that approximately 42% of the world's population lives along the coast, as does half of the population of the United States.^{55,56} Rising sea levels comes from both the thermal expansion of existing waters and the melting of land-based ice sheets. As is true of all materials, water expands as its temperature increases. If all of the ice on Greenland went into the ocean, it would raise the sea level 7 meters.⁵⁷ For Antarctica, the number is 61 meters.⁵⁸ While the floating ice caps in the Arctic do not contribute to rising sea levels (ice cubes that are melting in a glass of water were already displacing the water), the shrinking Arctic ice cap is one of the most visible signs of global warming. The Arctic

⁵⁴ <http://www.agu.org/pubs/crossref/2006/2005GL024826.shtml>

⁵⁵ http://www.livescience.com/environment/060718_map_settle.html

⁵⁶ <http://oceanservice.noaa.gov/facts/population.html>

⁵⁷ http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/412.htm#tab113

⁵⁸ http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/412.htm#tab113

ice caps have shrunk to 31% less than the average of the last thirty years.⁵⁹ The total recorded sea level changes are shown in Figure 12.

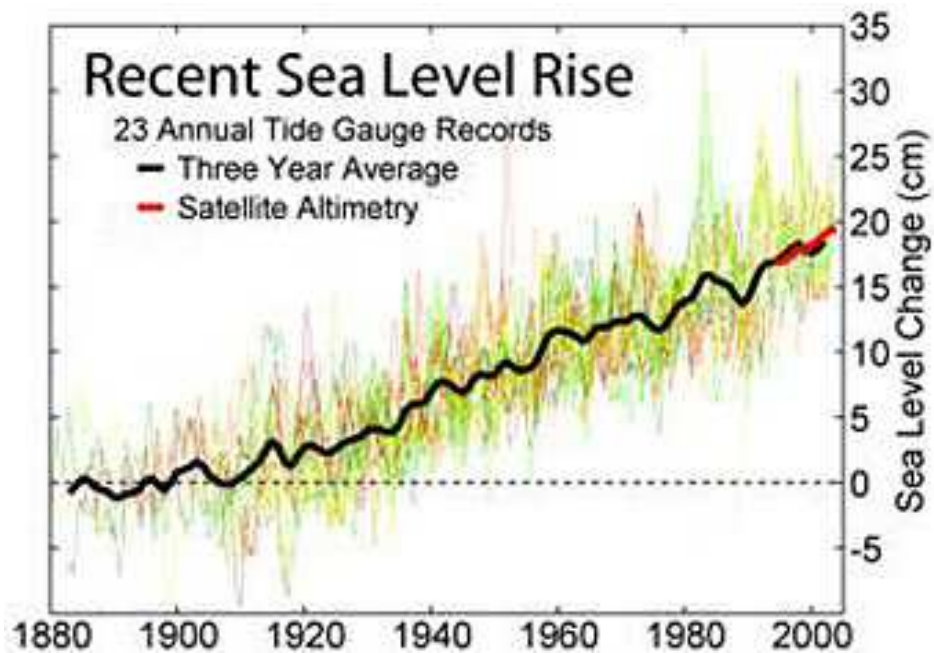


Figure 12 – Historical Sea Level Rise⁶⁰

⁵⁹ <http://www.sciencedaily.com/releases/2007/10/071001160655.htm>

⁶⁰ http://rst.gsfc.nasa.gov/Sect16/300px-Recent_Sea_Level_Rise.jpg

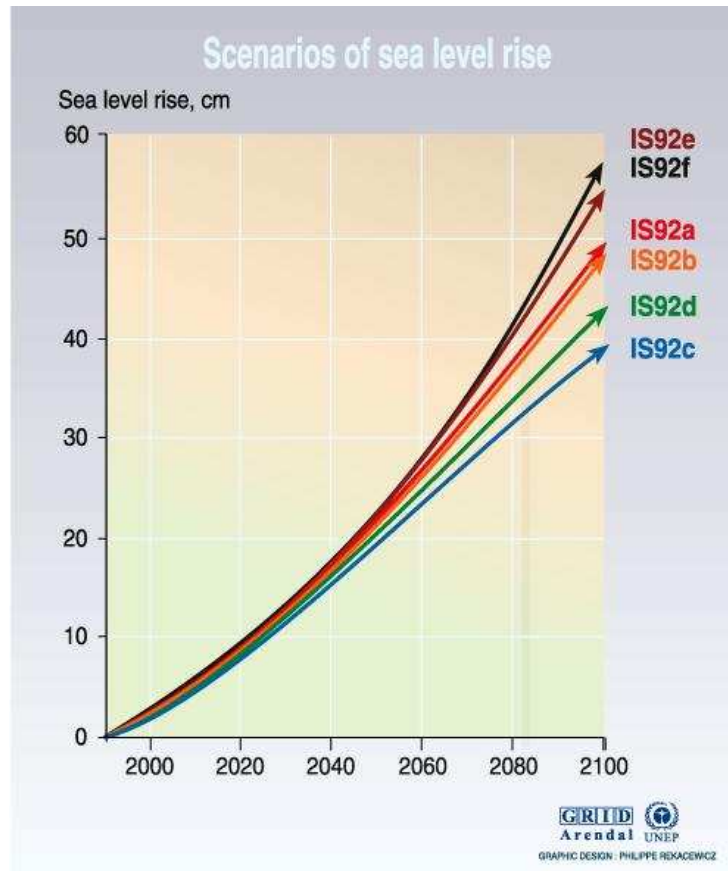


Figure 13 – Projections of Rising Sea Levels by the IPCC⁶¹

The “documentary” *An Inconvenient Truth* was stronger on scare tactics than technical accuracy, especially during the part where Florida is pictured under water. One of the strongest arguments that Al Gore may have been exaggerating is that he bought a condo on the San Francisco waterfront for an estimated \$2 million, though the movie claimed that the property would soon be under water.⁶² However, as shown in Figure 13, the sea level is projected to rise half a meter by 2100. Because the rate is accelerating, the total increase of the sea level will hit one meter well before 2200. If that happens, the picture below shows that many of the most valuable coastal properties will be underwater.

⁶¹ http://www.bdix.net/sdnbd_org/world_env_day/2004/seasoceans/climate_change/activity/climate_change/climate_sealevel_rise.htm

⁶² <http://www.prweb.com/releases/2005/12/prweb326327.htm>



Figure 14 - Florida's Coast Under Water⁶³

To avoid damaging the environment and Floridian coastal real estate, we ought to attack the biggest sources of greenhouse gases. The flow chart below illustrates both the major activities that cause greenhouse gases and the percentages of anthropogenic global warming that each gas is responsible for (similar to Table 3, with water vapor's contribution removed). The main activities, in order, are electricity and heat generation (24.6%), land use change (18.2%), agriculture (13.5%), and transportation (13.5%). Land use could use reform and gets an excellent treatment in the books *Economic Analysis of Land Use in Global Climate Change Policy* and *Land Use and the Causes of Global Warming* by Neil Adger and Katrina Brown. As far as agriculture is concerned, if we are asked to forego meat and dairy in order to eliminate methane-producing cattle, we have to wonder why we would still want

⁶³ <http://www.roperld.com/science/SeaLevelVsTemperature.htm>

to save the planet. In contrast, if technology advances make electricity generation and transportation environmentally benign, then no sacrifices will be required on our part.

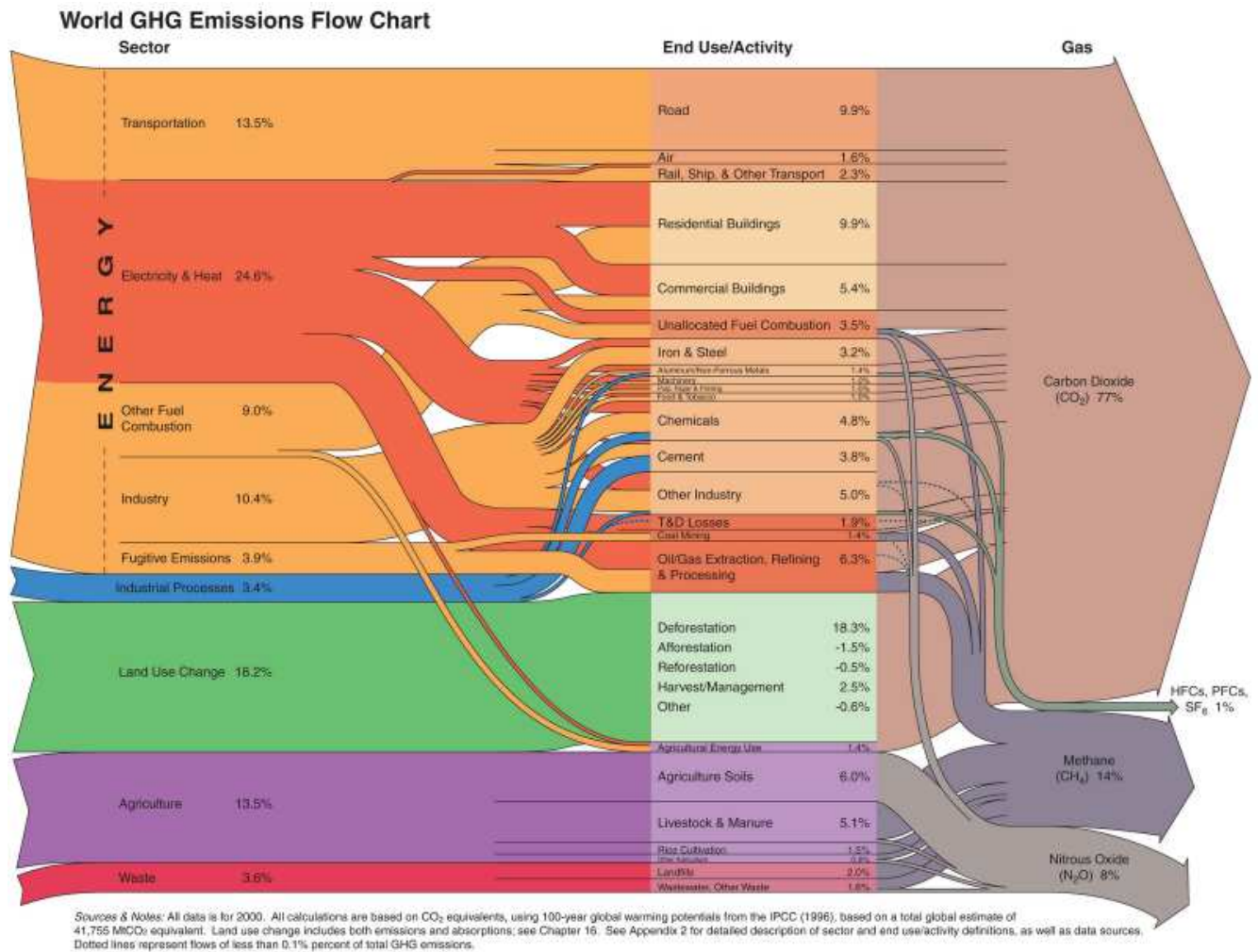


Figure 15 - Greenhouse Gas Flow Chart⁶⁴

On a global scale, one fourth of all carbon emissions come from transportation.⁶⁵ In contrast, operating an electric vehicle produces zero carbon emissions. However, the electricity to charge the battery often comes from burning fossil fuels. A holistic strategy for switching to electric vehicles would require switching to carbon-free electricity generation. The development of this strategy will be discussed later in this book.

⁶⁴ <http://cait.wri.org/figures.php?page=/US-FlowChart>

⁶⁵ Sperling. *Two Billion Cars*. Page 4

Physically

Oil is a finite resource. Because we consume oil and the planet's production is effectually nothing, the world will eventually run out of oil. Furthermore, because the rate of oil consumption is globally increasing, this eventuality is becoming more earth-shattering all the time. However, more relevant than the point at which the world runs out of oil is the point at which production slows down and fails to keep up with consumption. When the world has little enough remaining oil, we will not be able to extract oil at the same rate we have in the past. This event, peak oil, has the potential to create a global crisis, crippling transportation, shocking the global economy, and disrupting political stability.

The scientific endeavor to predict peak oil first started with American geophysicist M. King Hubbert (1903-1989). In 1956, he correctly predicted that American oil production would peak in the early 1970's. His basic premise was to assume that oil production follows a normal distribution, or bell curve. He also predicted that global oil production would peak around 2004.⁶⁶ One of the offsets for this prediction is that oil production has not followed a normal distribution. After peaking, oil production declines more slowly than his model predicts because extracting technology has continued advancing and has made unconventional oil more extractable.

⁶⁶ <http://press.princeton.edu/chapters/s7121.html>

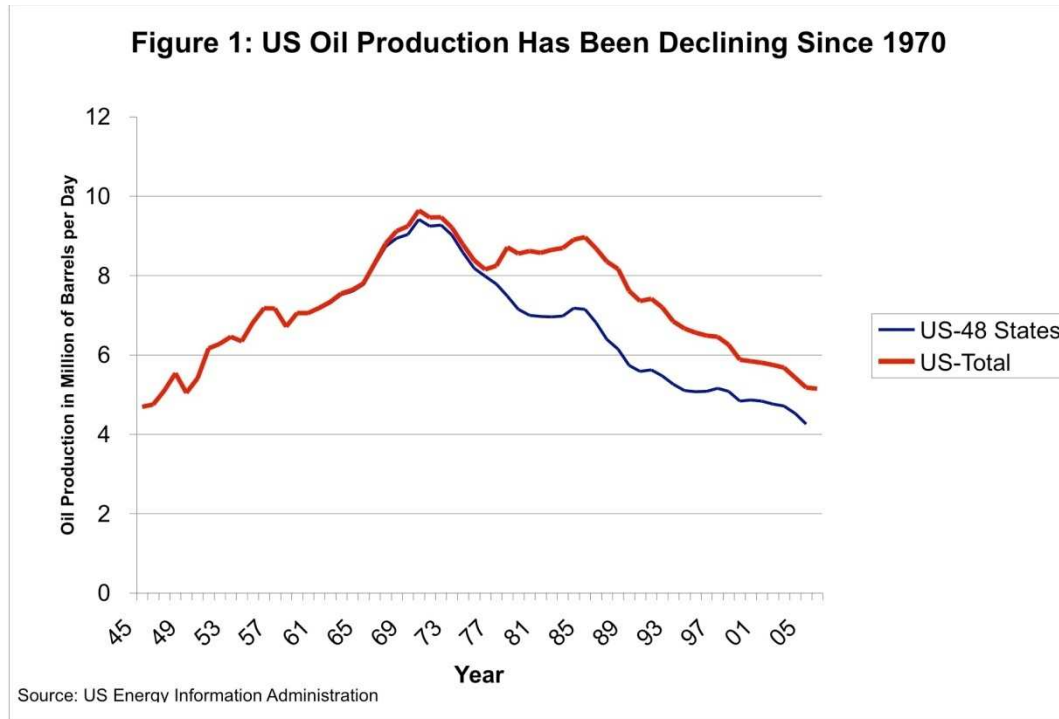


Figure 16 - Peak Domestic Oil⁶⁷

One of the inputs for Hubbert's analysis was the rate of discoveries of new oil fields. Discoveries of oil fields in the lower 48 states of the United States peaked in the early 1930's.⁶⁸ The time lag between peak discoveries and peak production depends on the size of the discoveries to date and the rate at which those discoveries are being depleted. As shown in Figure 17, global discoveries of crude oil peaked in the early 1960's. If the prediction from Hubbert's model describes the world as accurately as it predicted peak oil in the United States, peak oil on a global scale will occur between 2005 and 2015.⁶⁹ Figure 18 below reproduces a well known projection by The Association for the Study of Peak Oil.

⁶⁷ <http://gailtheactuary.files.wordpress.com/2007/03/us-production.jpeg>

⁶⁸ Downey, Morgan. *Oil 101*. Page 299. 2009

⁶⁹ Downey, Morgan. *Oil 101*. Page 299. 2009

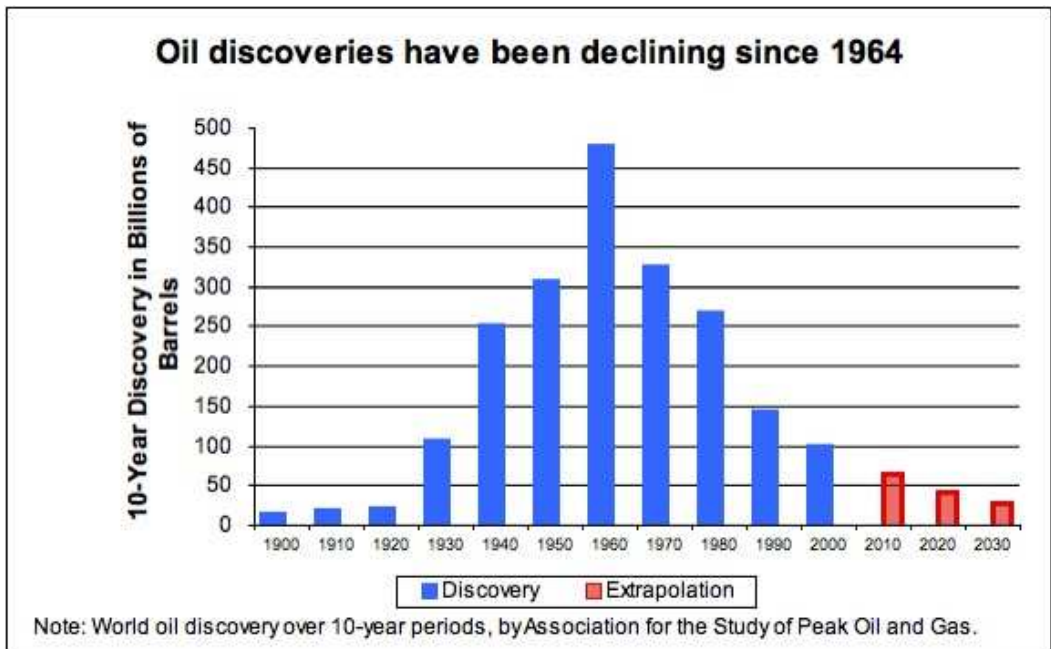


Figure 17 - Peak Discoveries⁷⁰

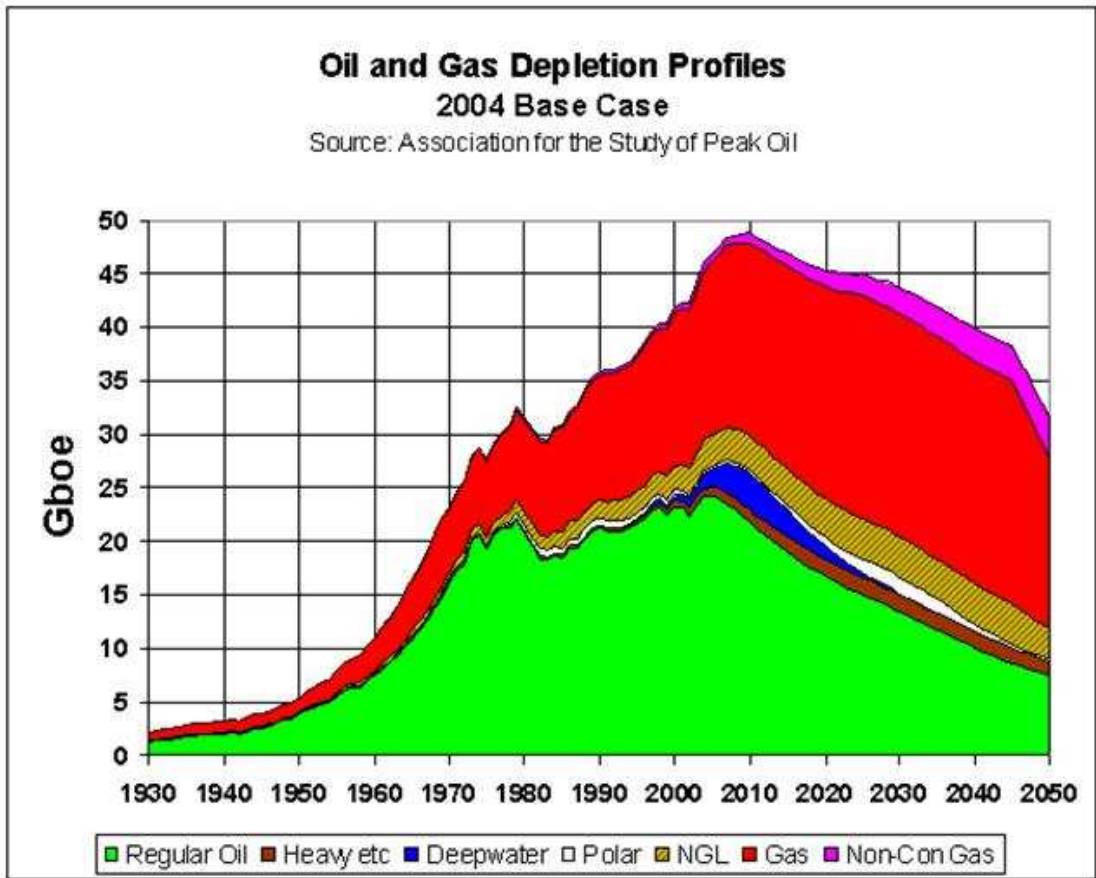


Figure 18 - ASPO Projection⁷¹

⁷⁰ <http://transitionbarrie.org/peakoil/peakoilprimer/>

Peak oil can be narrowed into a more relevant focus on peak conventional oil. There are hundreds of kinds of oil, categorized according to density, sulfur content, chemical composition and extractability. The main split is between conventional oil and unconventional oil. The split is significant because conventional oil is easy to economically extract and refine, whereas unconventional oil, such as oil shale and offshore oil, requires higher costs, energy and expertise to extract. Oil extractors always find it in their best interest to extract the less costly conventional oil first. Peak conventional oil is universally expected within the next 15 years. Much of the debate between optimism and pessimism depends on how effectively unconventional oil will be able to make up the gap. While unconventional oil may be physically recoverable, it is always expensive enough to extract that oil companies will not develop these resources unless the price justifies doing so. This price floor for future oil resources will prevent the presence of the affordable oil on which our economy currently depends.

Economically

What will happen at the peak? When increasing demand faces a decreasing supply, it can only mean one thing as far as price is concerned: exploding gasoline prices. We received a preview in 2008 when production was struggling to keep up with demand. On July 2008, the price of oil hit an all-time high of \$147.30 per barrel, up 223% from the monthly average price twelve months earlier (\$65.96).⁷¹ The price of gasoline went to a national average of \$4.03 at its highest point, as shown in Figure 19. Fortunately, there was a global financial crisis, and recession throughout 2009 reduced the demand for oil, pushing the impending oil shortage below the surface of our attention.

⁷¹ <http://www.optimumpopulation.org/opt.more.energy.html>

⁷² http://inflationdata.com/inflation/inflation_Rate/Historical_Oil_Prices_Table.asp

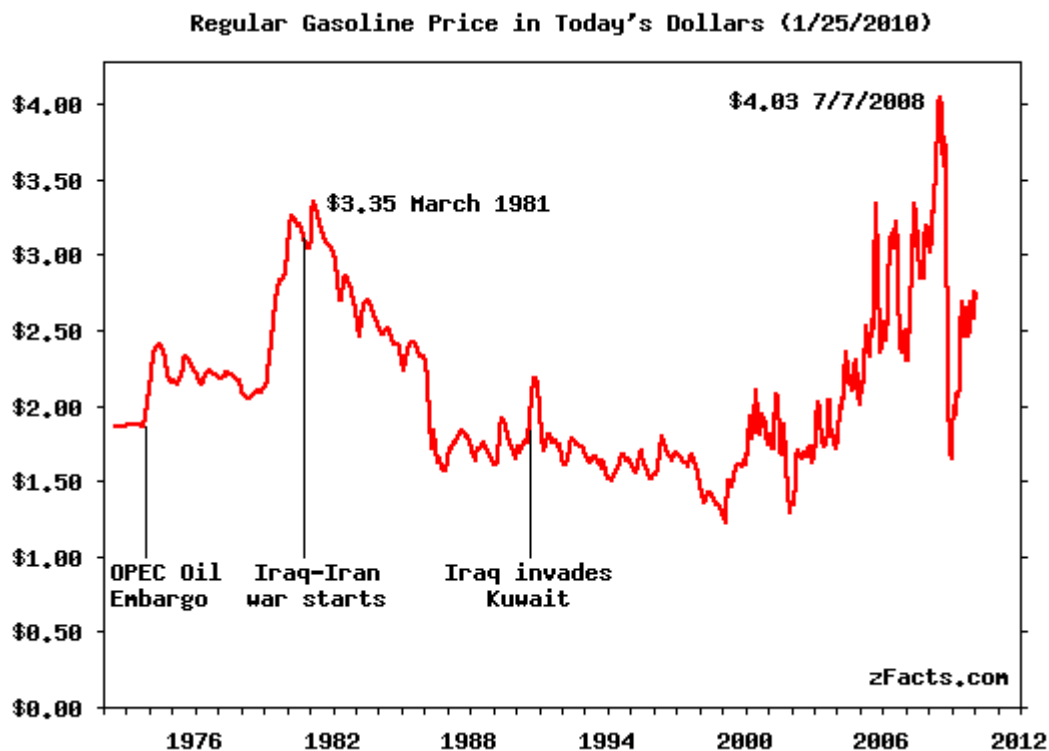


Figure 19 - Gasoline Prices Hitting New Peaks⁷³

Because oil is the only practical liquid energy source in the world today, we will have no choice but to swallow the bill. There are alternative liquid fuels, but they will only become practical once the price of oil has already reached record-breaking heights. In economic terms, oil has an extremely low price elasticity of demand. In other words, even if the price sky-rocket, we almost still consume just as much. The first and second oil crises in the 1970's have given us the historical data to prove this monopoly behavior. However, those events were brought about by temporary political circumstances, whereas the impending crisis is due to the permanently limited supply of conventional oil in the world.

The standard of living of American commuters cannot be sustained in our current arrangement. Rising gas prices and correspondingly higher costs for public transportation will hurt the lower class more because non-discretionary spending (such as gasoline and bus

⁷³ <http://zfacts.com/p/35.html>

fare) represent a greater part of their budget. Our best option is to face reality and recognize the need to bring prices down for carbon-free, oil-free transportation, as will be discussed in later chapters.

Conclusion

The United States and the rest of the world cannot continue our current system. Our current paradigm for organizing a car-centric society and global economy uses unlimited cheap oil as its foundation. That option will not be available to us in the near future. One option is to do nothing and let a crisis develop that will hit both the global economy and the global environment. A step up from this is to make sacrifices to adapt our way of life more sustainable. However, the best option, which most discussions on this topic have ignored, is investing enough into technological change to make our current way of life sustainable. What follows is a discussion of making our energy generation and consumption evolve so our cars will face natural selection rather than letting the blow fall to human life.

Chapter 3: Alternative Fuels

Hydrogen and Ethanol

Hydrogen fuel cells are permanently a generation away, and biofuels are always a generation behind.

Hydrogen and ethanol are two commonly suggested alternative automotive fuels. Both are said to be able to potentially replace oil in a post-oil world. Just as oil comes with its drawbacks, these two fuels have problems with their sustainability. There are more types of fuel cells than just hydrogen fuel cells, and there are more types of biofuels than just ethanol. However, these two fuels have been chosen because they are the most commonly suggested alternatives and are largely believed to be the closest to viability. Unfortunately, they fail to offer significant improvements over the main drawbacks of oil. This chapter will explain why they make compete well with each other for the title of the most foolish alternative fuel.

Hydrogen

Hydrogen fuel cell cars are marketed as a complete transformation from internal combustion cars. A fuel cell is a battery without the electrodes. The fuel of a fuel cell acts as an electrode to complete the batteries. There are other chemistries of fuel cells, just as there are different battery chemistries. In hydrogen fuel cells, onboard hydrogen reacts with air inside a fuel cell to produce power and water, completely emissions-free. It sounds too good to be true, and unfortunately, the hype is a lot of hot air.

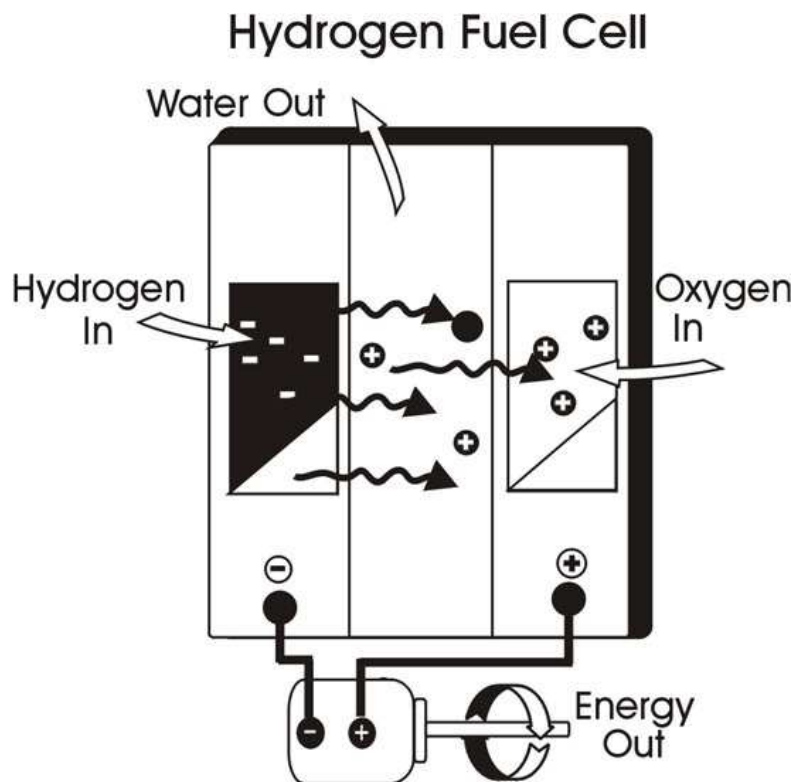


Figure 20 - Fuel Cell Operation⁷⁴

The hype can be at least partially blamed on the aspirations of oil companies and automakers. Vertically integrated oil companies already produce hydrogen to use in other refinery processes. The appeal for automotive companies is that fuel cell cars are more similar to gas cars than electric cars are in that fuel cell cars are potentially more powerful, may have longer ranges, use similar designs, quickly refuel, and would refuel at stations similar to gas stations. On the other hand, the case against using hydrogen fuel cells comes from a scientific understanding of the barriers to hydrogen's viability.

The first thing to make clear is that hydrogen is not a source of energy. It is a carrier of energy. Hydrogen does not exist in nature as H_2 . Generating usable hydrogen requires energy. The most practical method of producing hydrogen today is to use steam reformation to separate hydrogen from natural gas. The more idealistic, less economic method is to use

⁷⁴ <http://www.alternative-energy-news.info/technology/hydrogen-fuel/>

electrolysis to separate hydrogen from water. Commercial-grade hydrogen from electrolysis costs about \$100 per kilogram.⁷⁵ For comparison, one kilogram of hydrogen provides the same amount of energy as one gallon of gasoline. The electricity could have been more economically used by charging an electric vehicle's battery.

Over 95% of hydrogen produced today comes from natural gas.⁷⁶ Natural gas is mostly methane and includes other light hydrocarbon gases such as ethane and propane, which are normally removed. Methane (CH₄) is subjected to high-pressure steam to remove the hydrogen atoms from the carbon atom. As such, the process is not carbon neutral unless the carbon is sequestered. As author and energy trader Morgan Downey points out, "One has to wonder why one would bother expending energy converting the natural gas to hydrogen, when one can simply burn the natural gas in an automobile using existing technology. Natural gas as a source of hydrogen is not the solution."⁷⁷

After hydrogen has been produced, it would need to be distributed to fueling stations. A steel tank able carry hydrogen that has been compressed to 5000 psi will weigh about 65 times more than the hydrogen being carried, so that transporting 100 kg of hydrogen requires a truck that can haul 7 tons.⁷⁸ A pipeline would make more sense, except that hydrogen often diffuses through materials, embrittling them and making the maintenance of any distribution system prohibitively expensive.

Fuel station development is also faces an economic conundrum. Hydrogen cars will not become viable without fueling stations, and fueling stations would not appear without cars that they can service. For electric vehicles, home electrical outlets can meet the needs of

⁷⁵ Zubrin, Robert. *Energy Victory*. Page 116.

⁷⁶ Downey, Morgan. *Oil 101*. Page 317.

⁷⁷ Downey, Morgan. *Oil 101*. Page 317.

⁷⁸ Zubrin, Robert. *Energy Victory*. Page 118.

enough potential EV drivers that quick-charging stations may one day become universal, but houses do not already have home hydrogen outlets.

Once a hydrogen car has been refueled, on-board storage must become possible. If hydrogen remains on board as a liquid, it has to be very heavily insulated and will have one tenth the volumetric energy density of gasoline.⁷⁹ Even worse, hydrogen gas has a lower energy density. Such a heavy, voluminous tank still only allows for a driving range inferior to gas cars. On board hydrogen is also dangerous in that it is highly flammable.⁸⁰

One debate concerning hydrogen fuel is whether liquid hydrogen or compressed hydrogen gas will work better. Liquid hydrogen has a greater volumetric energy density than compressed hydrogen gas, but it requires energy-intensive refrigeration. As a liquid, the energy required for refrigeration is as much as 40% of the hydrogen's energy.⁸¹ For comparison, the energy for compressing hydrogen gas wastes only about 20% of the energy being stored.⁸² However, the steel tank required to contain this hydrogen would run into the same weight problems mentioned in the paragraph on transporting hydrogen. It is difficult to describe one as being more practical than the other since neither are close to being feasible.

Totally aside from the difficulties associated with hydrogen fuel, the fuel cells themselves face insurmountable hurdles to economic viability. One fuel vehicle costs approximately \$1 million.⁸³ Fuel cell stack includes a platinum (more expensive than gold) catalyst that puts a floor on how much extra fuel cells cars will cost. The other major cost is the heavy hydrogen tank. The pressure requirements for storing enough hydrogen to have a practical range are enormous.

⁷⁹ <http://www-formal.stanford.edu/jmc/progress/hydrogen.html>

⁸⁰ Downey, Morgan. *Oil 101*. Page 317.

⁸¹ Zubrin, Robert. *Energy Victory*. Page 117.

⁸² Zubrin, Robert. *Energy Victory*. Page 118.

⁸³ http://www.bloomberg.com/apps/news?pid=20601087&sid=az48qD9Cl_kQ

Even if all of these hurdles were overcome, the feasibility of hydrogen cars would require that hydrogen cars improve more than competing car technologies. This is the nail in the coffin for hydrogen cars. Technology in general will never stop advancing, so hydrogen cars in the future may work as well as today's gas cars today. However, what really matters is that they must work better in the future than the other cars of the future. Competing technologies are already better, and hydrogen cars will have to catch up in a race that they have been losing at every point so far.

Ethanol

Ethanol is similar to hydrogen in many respects. The idea of being able to grow the liquid energy we need would remove any worries about depleting our liquid energy resources.

Domestic ethanol production has been skyrocketing for the last two decades, as seen in Figure 21.⁸⁴ As we will see, however, ethanol can live up to its promise about as well as hydrogen can.

Ethanol, or ethyl alcohol, is the same kind of alcohol in alcoholic drinks. As of 2007, it accounted for 3.4% of fuel consumption in the United States, mostly in the form of low-level blends.⁸⁵ Ethanol has 67% of the energy density of gasoline.⁸⁶ Unlike

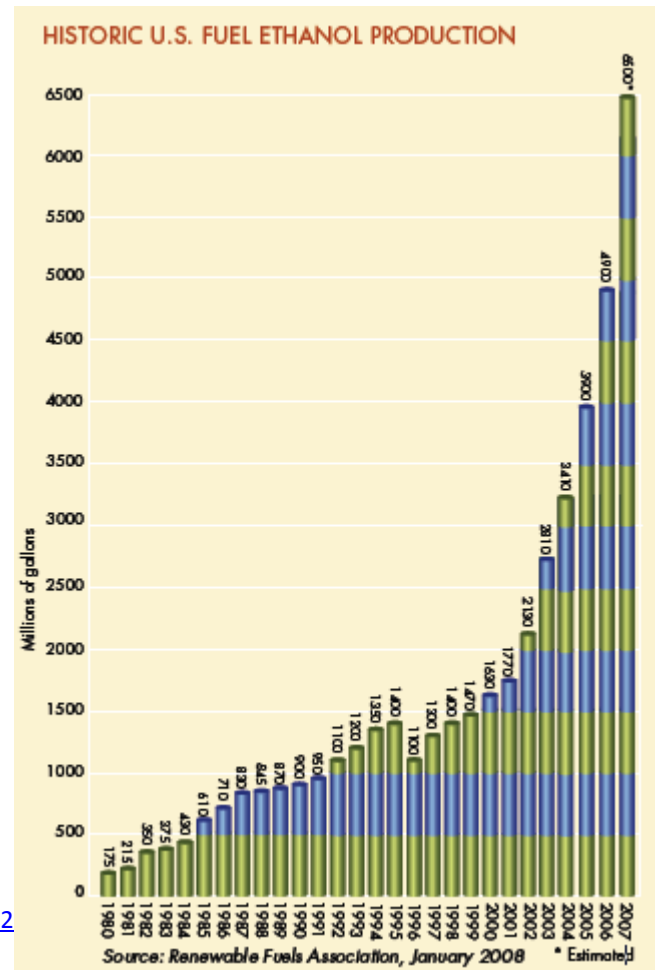


Figure 21 - US Ethanol Production

⁸⁴ <http://www.researchrecap.com/wp-content/uploads/2008/02>

⁸⁵ <http://www.afdc.energy.gov/afdc/ethanol/market.html>

⁸⁶ Downey, Morgan. *Oil 101*. Page 192

oil, it mixes with water, which makes alcohol harder to store and transport than oil and prevents ethanol from using oil's distribution system.

The most significant point to make about corn ethanol is that it is practically impossible to scale up to the level required to significantly displace oil consumption. At present, approximately one quarter of all corn grown in the United States is destined to be turned into ethanol.⁸⁷ As mentioned earlier, this amounts to only 3.4% of fuel consumption. If the entirety of US corn were converted to ethanol, it would produce as much energy as 13% of the energy of gasoline in the country, which is itself only half of all finished oil products in the US.⁸⁸ While ethanol production cannot add up to solution, we will see that this is not due to a lack of trying.

If ethanol cannot compete with oil, why does it so consistently persist in the discussion of energy independence? Using ethanol is a government idea, as opposed to a good idea. It benefits a very focused, very influential group of constituents. The political and economic background provides the key context for understanding how political decision-making is under the influence of alcohol.

As a maturely developed economy, the United States economy has been in a process of evolving towards a stronger service sector and away from domestic agriculture and manufacturing. Currently, 2% of Americans earn their living from farming.⁸⁹ Developing nations are more dependent on agriculture, exporting low-cost goods to the lucrative American market. However, government intervention has consistently protected domestic agriculture from this competition. Without the support of government subsidies and

⁸⁷ Downey, Morgan. *Oil 101*. Page 193

⁸⁸ Downey, Morgan. *Oil 101*. Page 193

⁸⁹ <http://www.csrees.usda.gov/qlinks/extension.html>

protective tariffs, market forces would lower the price of agricultural goods for consumers and squeeze out more producers.

More specifically, the US Midwest is the heartland of agricultural protectionism. Iowa holds the first primary in every Presidential election. Iowa produces about one third of the nation's ethanol.⁹⁰ According to a poll conducted in January 2007, 92% of Iowans feel that ethanol is very important to Iowa's economic well-being.⁹¹ It is very hard to get elected and tell the truth about ethanol at the same time. John McCain pulled an about-face concerning his former criticism of ethanol by the time the 2008 Presidential campaign started.⁹² Similarly, Hillary Clinton, who voted against pro-ethanol legislation 17 times a New York senator, touted her commitment on the side of Iowa's ethanol producers.⁹³

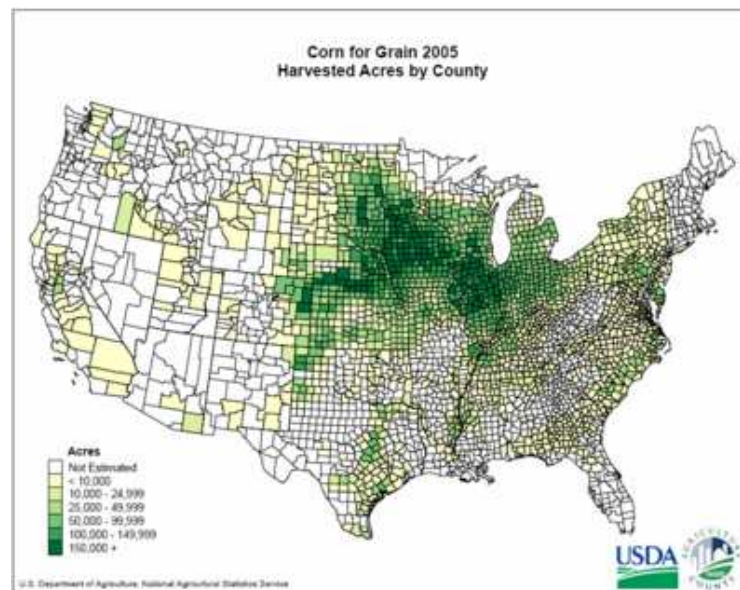


Figure 22 – Midwest / US Corn Belt⁹⁴

The most supported agricultural product in the United States is corn. On top of subsidies for corn in general, the government encourages corn to be turned into ethanol.

⁹⁰ Bryce, Robert. *Gusher of Lies*. Page 156.

⁹¹ Bryce, Robert. *Gusher of Lies*. Page 158.

⁹² Bryce, Robert. *Gusher of Lies*. Page 156.

⁹³ Bryce, Robert. *Gusher of Lies*. Page 157.

⁹⁴ http://www.wikinvest.com/images/thumb/7/7b/Corn_by_county.png/400px-Corn_by_county.png

According to a 2006 report from the Global Subsidies Initiative, the subsidies for ethanol added up to between \$1.05 and \$1.38 per gallon.⁹⁵ Despite all of the subsidies for ethanol, it still has never been competitive with gasoline, as shown in Figure 23.

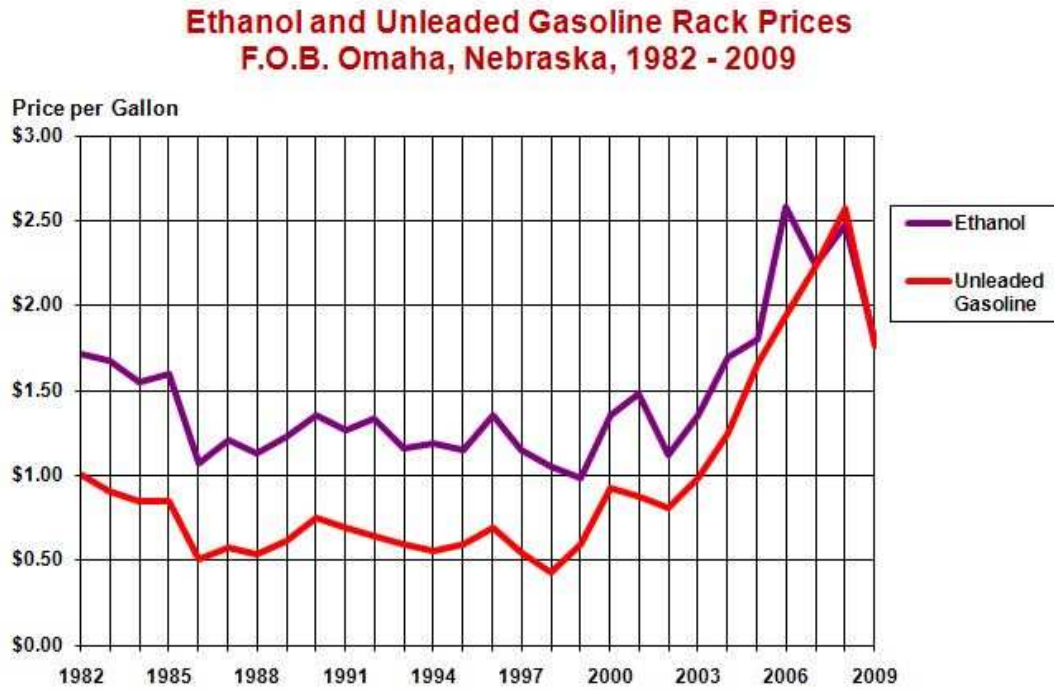
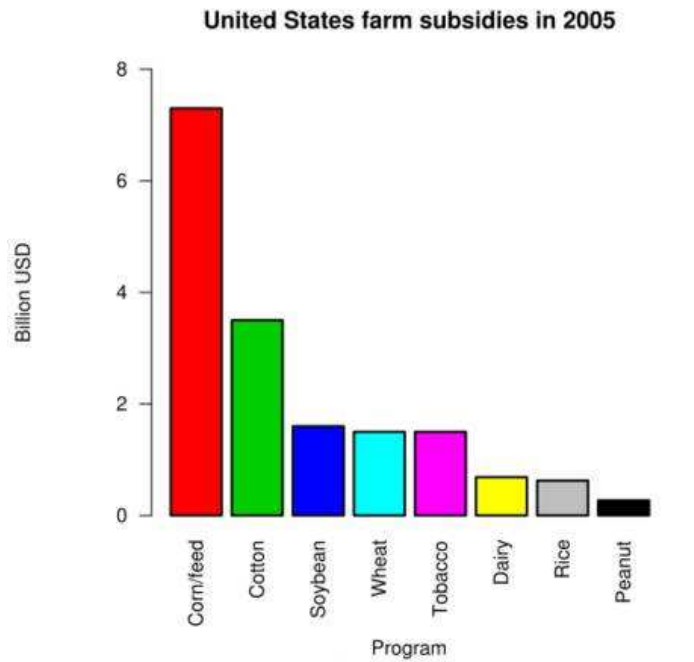


Figure 23 - Ethanol Not Competitive with Gasoline⁹⁶

⁹⁵ Bryce, Robert. *Gusher of Lies*. Page 149.

⁹⁶ <http://www.neo.ne.gov/statshtml/66.html>



Source: Congressional Budget Office (via the Associated Press)
 Figure 24 - Money Given to Farmers, in Billions⁹⁷

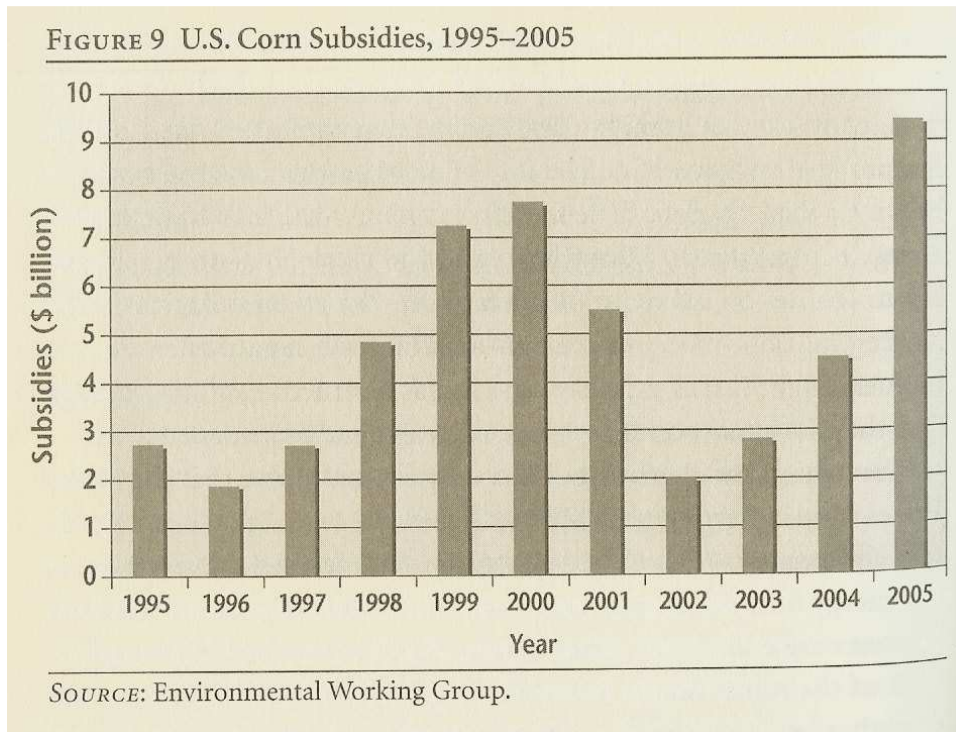


Figure 25 - Alcohol, the Great Money Guzzler⁹⁸

⁹⁷ http://wapedia.mobi/en/Agricultural_subsidy

⁹⁸ Bryce, Robert. *Gusher of Lies*. Page 148

Despite the overzealous government support for ethanol, its benefits are marginal. The reduction of greenhouse gases is given in Figure 26. This is partially explained by the low energy balance of corn ethanol. It requires energy to plant, fertilize, water, harvest, transport and ferment corn. The most famous studies on the energy returned are those of David Pimentel, who popularized the idea that corn ethanol uses more energy than it produces. However, most studies are more accurate and find that corn ethanol has a positive energy balance of 1.3, as shown Figure 27.

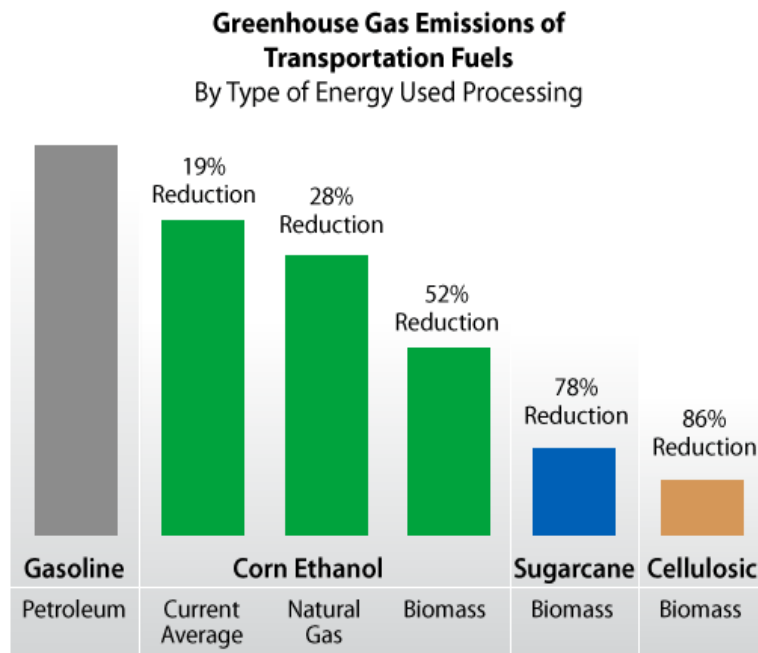


Figure 26 - Limited Benefits of Ethanol⁹⁹

⁹⁹ http://www.afdc.energy.gov/afdc/ethanol/images/greenhouse_gas_emiss_trans.gif

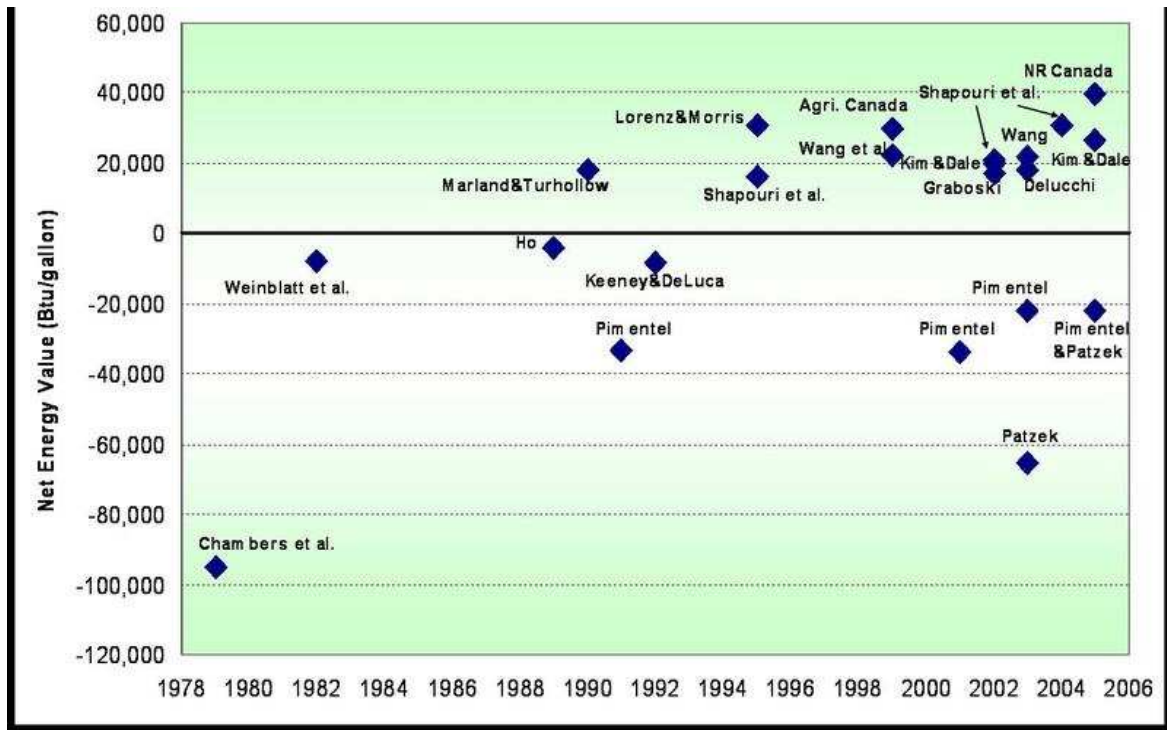


Figure 27 - Energy Balance of Corn Ethanol¹⁰⁰

When ethanol is fermented, it is the starch that ferments. So the sweeter the plant is, the more it yields ethanol (the most sugary plant being *sugar cane*). Corn is a whole-fiber fruit, making it a good food but not a good fuel. Sugar, on the other hand, has the best hopes of providing sustainable ethanol. It is not a major crop in the United States because it grows best in tropical climates. As such, domestic sugar producers have sought the protection of the federal government, which shelters domestic sugar producers from international competition. Because of this, Americans pay between two to three times the world price of sugar.¹⁰¹ Commodity trader Jim Rogers has the following advice concerning the government's support for sugar producers:

"I would advise a solution that I have often offered in public to the economic absurdities of the roughly \$5 billion a year that the U.S. government hands over to the nation's 5,000 or so American producers (about \$1 million per grower). According to the Rogers Plan, we should instead offer them \$100,000 a year for life, a condo at the beach, and a

¹⁰⁰ http://thefraserdomain.typepad.com/photos/uncategorized/ethanol_net_energy_balance.jpg

¹⁰¹ Rogers, Jim. *Hot Commodities*. Page 179.

Porsche, the only stipulation being that they can never plant sugar again. It would be a much better investment of \$5 billion, and we ordinary American citizens would all come out way ahead over tie."¹⁰²

The Brazil Story

If any country in the world can succeed with ethanol, it is Brazil. Brazil has the perfect physical environment for growing the best biofuel crop, sugarcane. Brazil also has approximately 12% as many cars as the United States.¹⁰³ However, not even Brazil owes its oil independence to ethanol. Overall, ethanol plays a very small role in meeting Brazil's energy needs, as shown in Figure 28. Since ethanol production has not been able to scale up to the level of petroleum production in Brazil, its chances of becoming significant in the United States is as negligible as the benefits of ethanol.

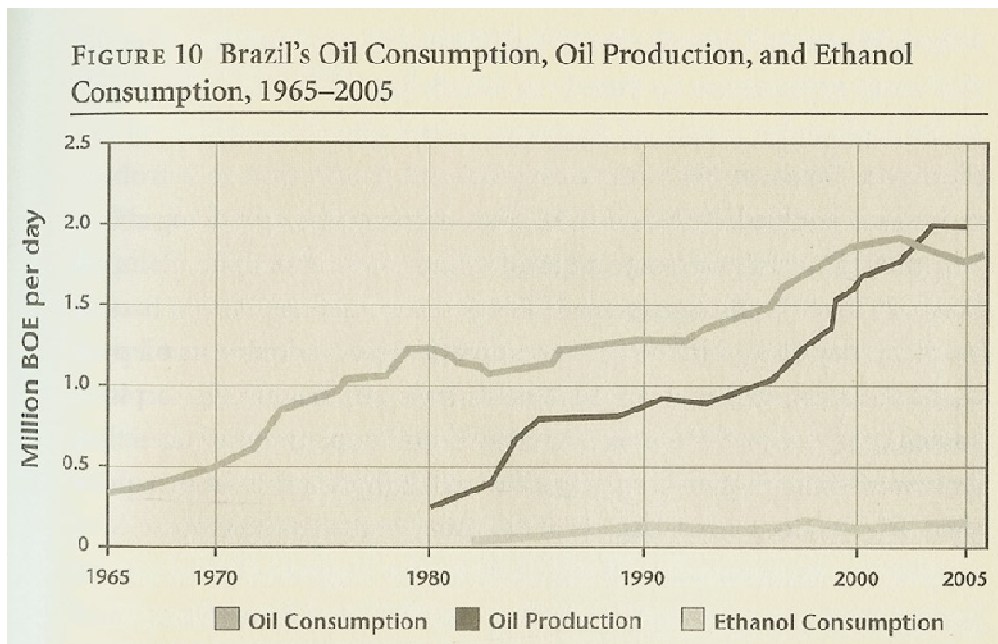


Figure 28 - Marginal Ethanol Consumption

¹⁰² Rogers, Jim. *Hot Commodities*. Page 193-194.

¹⁰³ <http://www.energybulletin.net/node/21064>

Conclusion

Marginalized fuels are often pushed into the margins for good reason. Their feasibility meets barriers in every step of the product's life cycle. Like many government solutions, they offer marginal benefits for sizable costs. Hydrogen will never happen, and alcohol never has a good influence on decision making. It is never responsible to mix alcohol and driving. They are a tax on national resources, yet their greatest method of impeding sustainability is their role as a distraction. Now that they have been addressed, it is best to ignore them and to move on to the future of the automotive technology.

Chapter 4: Green Cars

A Case Study in Gradualism

“This is no time to engage in the luxury of cooling off or to take the tranquilizing drug of gradualism.”

-Dr. Martin Luther King Jr., *I Have a Dream* Speech

I hesitate to use a quote from Dr. King and to hijack his call for justice in a book about technological evolution. So with great reverence to the noble purpose he stood for, I simply wish to make an analogy. Just as the safety and simplicity of the gradualist stance appealed to moderates during the Civil Rights Era, the gradualist approach has an appeal to people who think we should content ourselves with conventional fuel-efficient cars instead of pushing for any revolutionary changes to today’s automotive technology.

At first, fuel-efficient cars would seem to be a reasonable part of a strategy for sustainability. However, upon learning about the meager magnitude of the impact of efficiency gains, the main theme that emerges is that such changes would have very limited benefits. Below, Figure 29 shows that according to the National Renewable Energy Laboratory, even if 100% of new cars were fuel-efficient hybrids, it would only be enough to prevent further increases in our oil consumption. The feeble impact comes from several mitigating factors that slow down our ability to clean up the transportation sector.

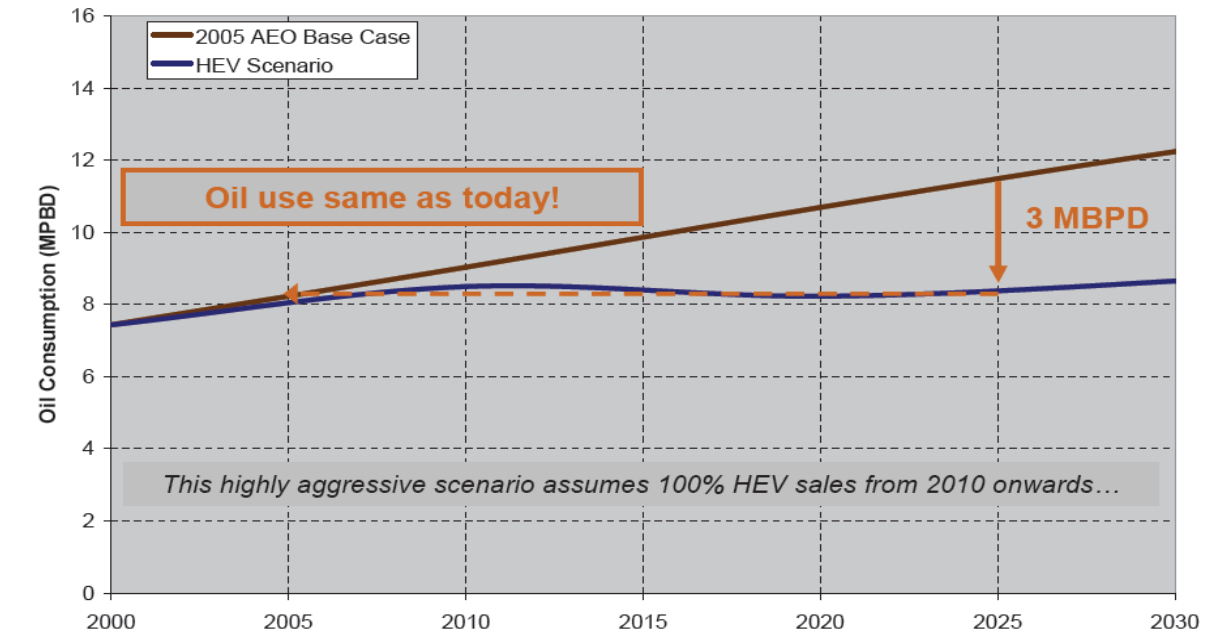


Figure 29 - If 100% of New Cars Were Conventional Hybrids¹⁰⁴

The first mitigating factor is that only around 5% of cars on the road in the United States are new each year.¹⁰⁵ The average car in the United States stays on the road for 8.9 years, and that number has been increasing for the last ten years.¹⁰⁶ It is expected to increase as manufacturers focus on quality improvements and market the longevity of their cars. Making new cars more efficient is really just scratching at the heels of the problem. Even though the fuel economy of *new* passenger cars was 27.5 miles per gallon in 2008, altogether there are already 254 million registered vehicles in the United States, and their average fuel economy is only 17.2 miles per gallon.¹⁰⁷

Furthermore, the environmental quality of new cars has a very weak relationship to total automotive pollution. This is because most of the pollution comes from a small fraction

¹⁰⁴ <http://www.nrel.gov/docs/fy06osti/40239.pdf>

¹⁰⁵

<http://www.plunkettresearch.com/Industries/AutomobilesTrucks/AutomobileTrends/tabid/89/Default.aspx>

¹⁰⁶ http://www.bts.gov/publications/national_transportation_statistics/2005/html/table_01_25.html

¹⁰⁷ http://www.bts.gov/publications/national_transportation_statistics/html/table_04_23m.html

http://www.bts.gov/publications/national_transportation_statistics/html/table_04_09.html

of the cars on the road today. According to the Center for American Progress, cars that are 13 years old or more are responsible for 75% of automotive emissions, even though they account for 25% of the automotive miles driven.¹⁰⁸ In Denver, 55% of all pollution from car use comes from just 5% of the cars on the road.¹⁰⁹ Old cars, or newer cars with high mileage, will have a declining performance when it comes to pollution. Old cars may even have their emissions-controlling technology fail so that even the state-of-the-art changes fail to last. New cars are already so clean that as air quality standards tighten, squeezing every gram of hydrocarbons out of the exhaust is making a smaller and smaller difference.

Technical Background

Even with ideal conditions, internal combustion engines (ICEs) are facing the limitations of the Second Law of Thermodynamics. Basically, the Second Law states that 100% energy conversions can never actually happen; the usability of energy can only ever decrease. For ICEs, the chemical energy of the gasoline is converted into the thermal energy of combustion, which forces the linear motion of the piston, which in turn becomes the rotary motion of the crankshaft. All automotive ICE's today use a four-stroke cycle to accomplish this. Combustion happens during the ICE's power stroke, as shown in Figure 2 below. As the fuel-air mixtures combusts, the temperature of the mixture spikes upward, expanding the volume it occupies and pushing down the piston in the power stroke.

¹⁰⁸ http://www.americanprogress.org/issues/2009/03/cash_for_clunkers.html

¹⁰⁹ Gladwell, Malcolm. *What the Dog Saw*. "Million Dollar Murray." Page 193. February 13, 2006.

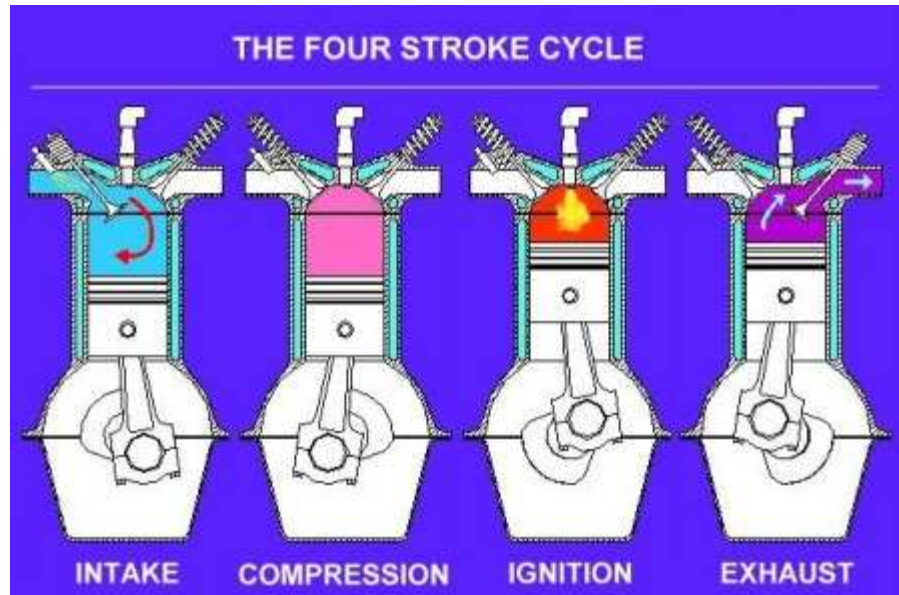


Figure 30 - Four Stroke Stages¹¹⁰

Thermal energy, the energy of heat, is actually the energy from rotational, vibrational, and translational motion of the molecules. In other words, heat energy is an inherently disorganized form of energy; in a more technical wording, converting to heat energy increases entropy. Cooling down the engine to deal with all this heat takes up 60% of an engine's energy. Together with other efficiency loss, the average ICE is 20% efficient.¹¹¹ The maximum theoretical efficiency a steel engine can achieve is 37%.¹¹²

As the air/fuel mixture goes through the four strokes, its pressure and volume are changing. These changes are shown in the figure **Error! Reference source not found.** to the right.¹¹³ The purpose of the diagram is to show the inherent inefficiency of any

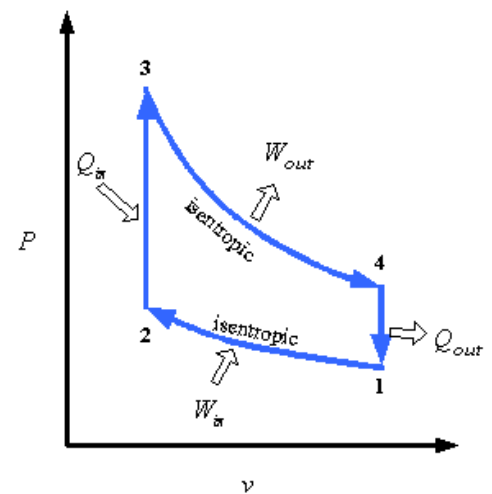


Figure 31 - The Otto Cycle

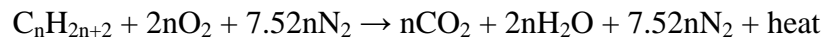
¹¹⁰ http://www.ict4us.com/r.kuijt/images/en_strokeengine.jpg

¹¹¹ <http://courses.washington.edu/me341/oct22v2.htm>

¹¹² <http://www.fags.org/patents/app/20080314350>

¹¹³ <http://www.qrg.northwestern.edu/thermo/design-library/otto/otto.html>

thermodynamic cycle. The area under the lower line (2-1) is energy wasted. The only way that an engine would be 100% would be for the exhaust gases to have gotten rid of all of their thermal energy and thus be at absolute 0 (-460° F), which is not physically possible. This is the limitation that all turbine-driven power plants work with.



Equation 1 – Fossil Fuel Combustion

The above equation gives the ideal chemical reaction inside an internal combustion engine. Ideally, there is 14.7 times as much air as there is gasoline when combustion happens. The result of perfect combustion includes carbon dioxide; no matter how many miles per gallon a car gets, one gallon of gasoline inevitably puts 19.4 pounds of carbon dioxide into the air. This is possible even though a gallon of gasoline weighs only around 6.3 pounds because the 5.5 pounds of carbon from gasoline joins the 13.9 pounds of oxygen in the air to form carbon dioxide.¹¹⁴ However, most of the time, engines do not even achieve the ideal ratio. To compensate for the difficulties of running a cold engine, engines run richer (extra fuel) when starting. That is why short trips are bad for fuel efficiency.

Commercial Realities

On top of the limits of theoretical efficiency and the real-life deviations from these limits, market realities are also hampering our ability to reduce greenhouse-gas emissions. The demand for better fuel economy has only been strong in the 1970's during the oil crises and in recent years as the world runs out of oil. Until recent years, fuel economy has grown less important at least in part due to the fact that from 1975 to 2005, the cost of gasoline dropped from 33.4% of the total costs of car ownership to 18.2%.¹¹⁵ Aside from special

¹¹⁴ <http://www.fueleconomy.gov/Feg/co2.shtml>

¹¹⁵ Bryce, Robert. *Gusher of Lies*. Page 256. 2008.

circumstances, the default consumer mode is to ignore fuel economy and to be won over by more powerful cars. Even though efficiency gains have continued increasing, they have translated into increased power instead of increased fuel economy.

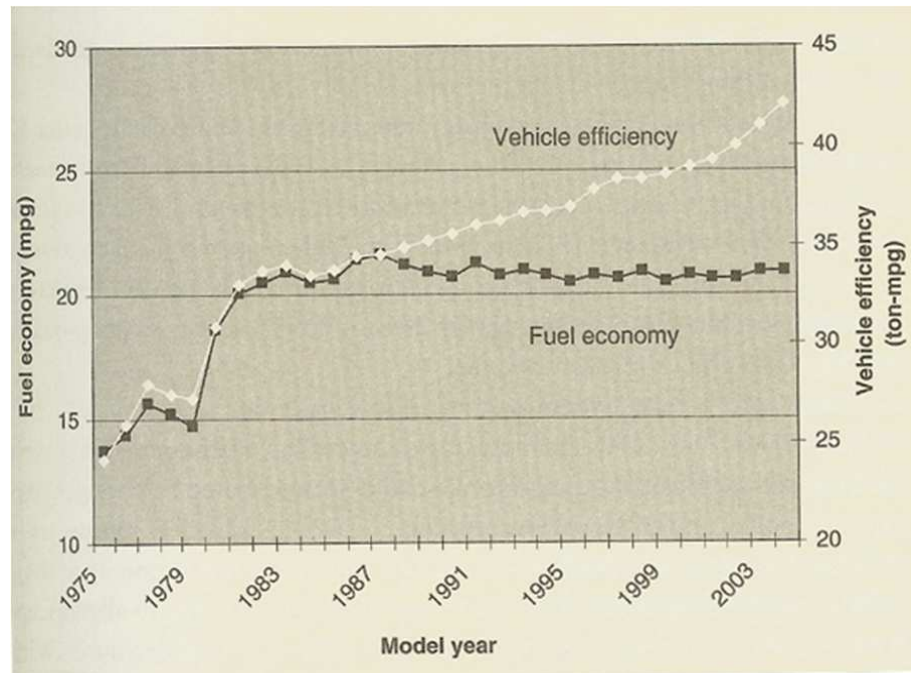


Figure 32 - Energy Efficiency Gains Spent on Power¹¹⁶

Automakers have been more than happy to meet these demands. Producers have been pushing SUV's and heavier cars during the last two decades of relatively low gas prices. At present, SUV's and light trucks

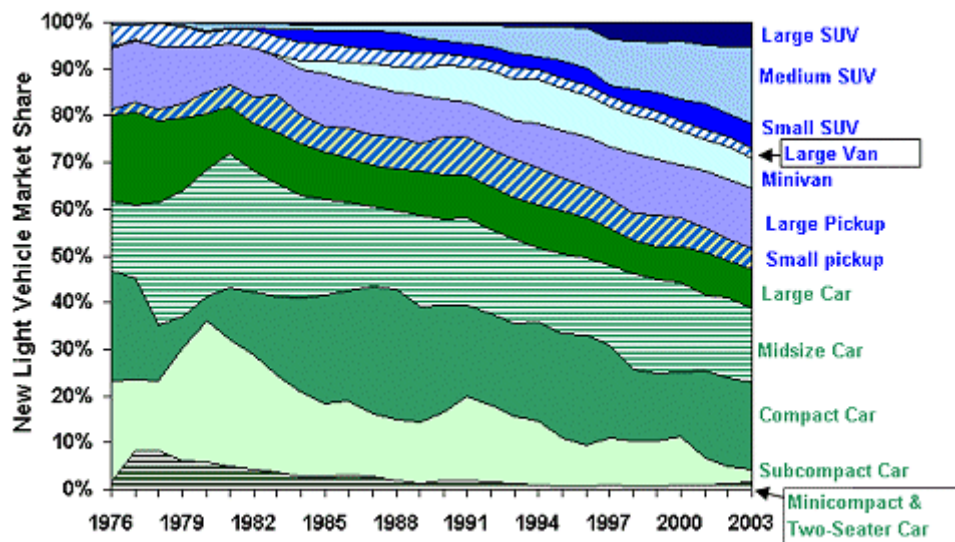


Figure 33 - US Market Composition Getting Heavier

¹¹⁶ Sperling, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 21. 2009

account for just over half of the vehicles on the road today.¹¹⁷ Larger cars offer automakers much larger profit margins than smaller cars. Even Honda, the world's greenest automaker (see

Figure 34) has been growing its Accord to stay with this trend, as shown in Table 4.

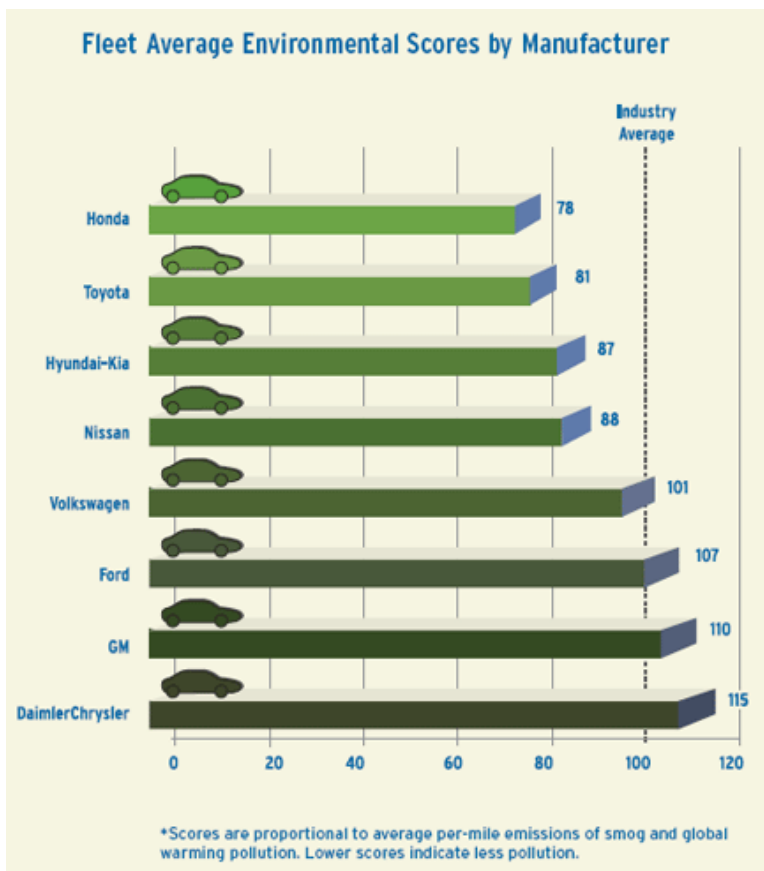


Figure 34 - Average Fleet Pollution¹¹⁹

Specifications	1976 Accord (1st generation)	2008 Accord (7th generation)
Weight (lbs)	2000	3567
Horsepower (hp)	68	268
Engine size (liters)	1.6	3.5
Cylinders (#)	4	6
Fuel economy (mpg)	32 city 46 highway	19 city 29 highway
Transmission	Automatic 2-speed	Automatic 5-speed
Price (constant 2008 \$)	\$15,380	\$25,960
Annual U.S. sales	18,643	400,000+ (est.)

Source: Edmunds.com, *Insideline*.

Table 4 - Honda Accords, Then and Now¹¹⁸

¹¹⁷ http://www1.eere.energy.gov/vehiclesandfuels/facts/2004/fcvt_fotw332.html

¹¹⁸ Sperling, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 19. 2009

¹¹⁹ http://www.ucsusa.org/clean_vehicles/vehicle_impacts/cars_pickups_and_suvs/automaker-rankings-2007.html

Nonsolutions

There are many Americans who have at least their hearts in the right place when they suggest injurious sacrifices that would hamper our lifestyles but would not fix the problem. For example, there is commonly a proposal that we reduce gasoline consumption by increasing the cost of driving. We can increase costs by increasing the gasoline tax from its current level of \$0.39/gallons, by charging more to register cars, or by instituting fees for entering cities.¹²⁰

First of all, making gasoline expensive does not solve the problem of expensive gas. It does even not significantly reduce consumption. Even in Europe, where punitive measures for driving and car ownership have been introduced, cars account for 80% of travel.¹²¹ High prices are only useful in that they encourage technological innovation so that producers can meet the needs of consumers, who want to maintain their behavior without it costing more.

The good news is that price of gasoline is already high enough to encourage innovation and is expected to remain so. Ali Al-Naimi, the Saudi Arabian Oil Minister, has repeatedly said that \$75/barrel is a good price for Saudi Arabia to choose when it comes to fixing the price of oil.^{122,123,124} So it seems a fair assumption that the people pulling the levers will not let the price of oil fall anytime soon and that gasoline will not get cheaper in the foreseeable future. As previously mentioned, this alone does not decrease gasoline consumption. It does, however, create a propitious environment for green cars and their producers.

¹²⁰ Downey, Morgan. *Oil 101*. Page 323. 2009

¹²¹ Sperling, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 14. 2009

¹²² http://www.pbs.org/nbr/site/onair/gharib/ali_al_naimi_saudi_oil_minister_090925/

¹²³ <http://www.petroleumworld.com/storyt10012602.htm>

¹²⁴ <http://www.reuters.com/article/idUSL0245799820080302>

Enter Hybrids

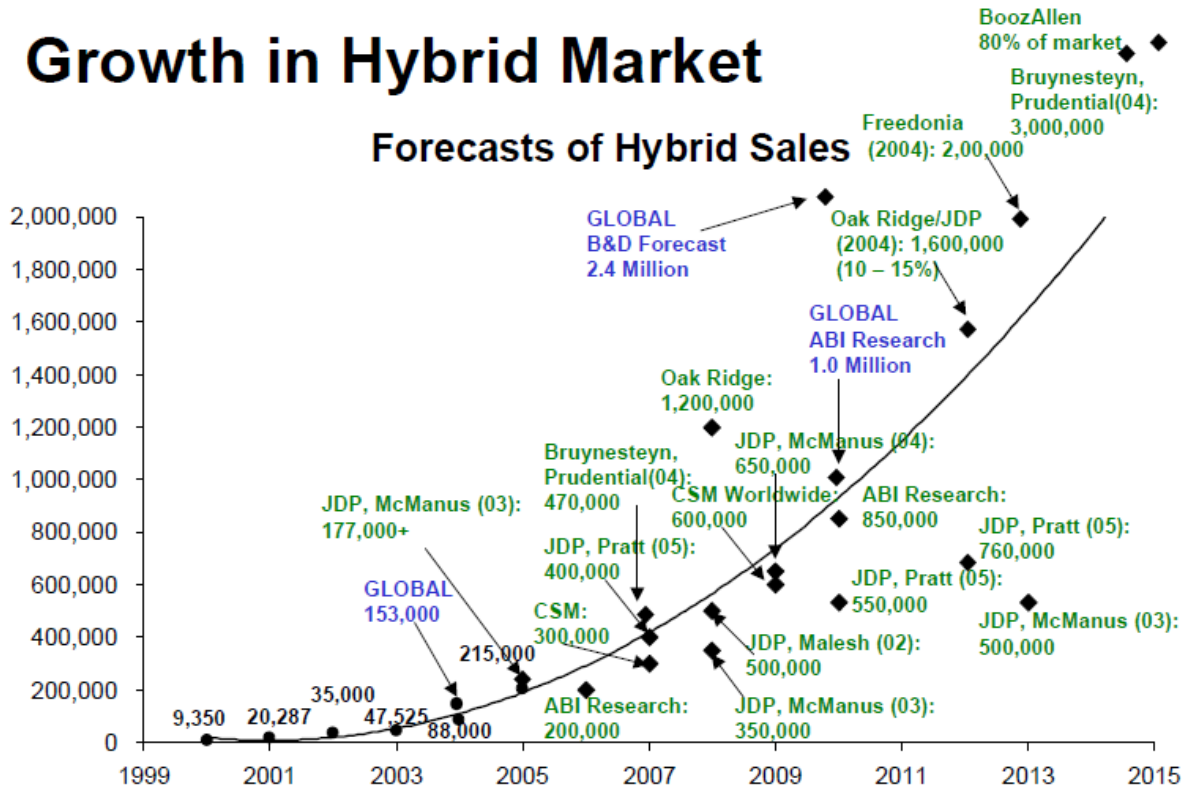
The “green car” movement has somewhat undefined terminology. “Green car” is an umbrella term that covers any car with low emissions, be it a hybrid, a super-efficient diesel, or a car that runs on vegetable oil. In theory, a hybrid is any car that uses more than one source of energy. For our purposes, hybrids will refer to cars that use both gasoline and electricity from a battery. Hybrids have a small market share but represent the largest growth opportunity in the global automotive market today. Hybrids account for 2.5% of new vehicle sales in 2009.¹²⁵ In 2004, they were only 0.5%.¹²⁶ JP Morgan recently predicted that hybrid sales will account for 19.4% of the market by 2020.¹²⁷ Other estimates for hybrids are shown in the chart below.

¹²⁵ <http://www.hybridcars.com/2009-hybrid-cars>

¹²⁶ <http://www.iags.org/n011504t1.htm>

¹²⁷ <http://www.hybridcarblog.com/2009/05/20-percent-hybrid-by-2020.html>

Growth in Hybrid Market



hybridCARS.com

Figure 35 - Exponential Growth of Hybrids¹²⁸

Hybrids can be categorized according to how much the car depends on the battery. “Mild” hybrids offer a slight increase to fuel economy by using regenerative braking and by evening out the fuel map so that the gas engine can work more efficiently. In full hybrids, the electric motor plays a more active role in driving, whether providing all of the propelling force for the wheels or propelling the wheels along with the engine. Plug-in Hybrids (PHEVs) can recharge through the electric grid and normally have an electric-only mode. Pure electric vehicles make no use of gasoline. The last two types are covered under the term “plug-in cars” and are discussed in the next chapter. The remainder of this chapter focuses on the lesser types of hybrids.

¹²⁸ <http://www.hybridcars.com/files/hybrid-forecast-graph.pdf>

Hybrids minimize the inherent inefficiencies of ICE cars. Using battery power allows cars to have smaller engines. Smaller engines are inherently more efficient because smaller engines weigh less. It takes less fuel to get the engine moving and less fuel to carry the engine. In ICE cars, braking is accomplished by squeezing the rotors with brake pads. As friction slows down the wheels, the car's kinetic energy (the energy of motion) is transferred to thermal energy so that the brake pads get very hot. In hybrids, the kinetic energy is returned to the battery to be used again for acceleration. Lastly, car's engine normally idles when the car is stopped, wasting gas. In hybrids, on the other hand, the engine turns off, and the more powerful battery simply starts the engine when the car returns to speeds that require the engine's input. Unless it is a full hybrid, the battery is nothing but dead weight when the car is cruising at high speeds on the freeway. For this reason, hybrids often get better gas mileage in city driving than in highway driving. In view of these advantages, hybrid marketing is best targeted towards urban environments that struggle with traffic and with air quality problems. Accordingly, hybrids have been selling well in big cities, as shown in Figure 36.



SOURCE: R. L. POLK & CO.

Figure 36 - Niche Markets for Hybrids

At first glance, rational consumers would not seem to be the target market for hybrids because the extra cost of a hybrid (i.e. the hybrid premium) is much more than savings on gasoline. Compare economy cars such as the 2010 Toyota Yaris and the 2010 Honda Fit to the ground-up hybrids the 2010 Toyota Prius and 2010 Honda Insight. The Prius costs almost double the Yaris. The Insight is a better bargain at only \$5,000 more than Honda's most affordable offering, the Fit. Next, compare the flagship sedans of Toyota, Honda and

Ford to hybrid versions of the same cars. A buyer would have to pay roughly \$7,000-\$8,000 more for a hybrid version of an already fuel-efficient car. In the table below, the annual cost of gas is estimated assuming an average distance of 10,000 miles per year at \$2.70 per gallon of gasoline. These numbers do not result in the thousands of dollars of savings that would make a hybrid purchase qualify as rational in the technical sense; that is, marginal utility (added fuel savings) is less than marginal cost (the hybrid premium).

Company	Car	Size	MSRP	MPG	Cost of Gas	Hybrid Premium	Annual Savings
Toyota	Yaris	Subcompact	\$12,605	32	\$844	\$10,195	\$304
Toyota	Prius	Midsize	\$22,800	50	\$540		
Toyota	Camry	Midsize	\$19,350	26	\$1,038		
Toyota	Camry Hybrid	Midsize	\$26,150	33	\$818	\$6,800	\$220
Honda	Fit	Subcompact	\$14,900	30	\$900	\$4,900	\$241
Honda	Insight	Compact	\$19,800	41	\$659		
Honda	Civic	Compact	\$15,455	29	\$931		
Honda	Civic Hybrid	Compact	\$23,800	42	\$643	\$8,345	\$288
Ford	Fusion	Midsize	\$19,695	27	\$1,000	\$8,255	\$308
Ford	Fusion Hybrid	Midsize	\$27,950	39	\$692		

Table 5 - The Hybrid Premium¹²⁹

To be fair, *all* new cars are outside the scope of strictly rational purchasing decisions. A new car is one of the few things people can spend money on that depreciates so quickly. For the truly thrifty consumer, used cars offer much more value per dollar spent. The average new car currently costs \$28,715 while the average used car sells for \$8,000.¹³⁰ Most consumers recognize this more reasonable route to car ownership; in 2005, used car sales outnumbered new car sales three to one.¹³¹ The chart below uses Edmunds.com’s “true

¹²⁹ Numbers are from the perspective company websites: <http://www.toyota.com/>, <http://automobiles.honda.com/>, <http://www.fordvehicles.com/?glbcmp=ford|vehicles|fordvehicles>

¹³⁰ http://www.carbuyersnotebook.com/archives/2008/02/average_new_vehicle_cost_1.htm;

Sperling, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 154

¹³¹ Sperling, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 154

market values” to show the selling price of select used-car models. Purchasing a 2007 model of one of the American cars costs half as much as a 2010 model. The Accord and Camry hold their value much better, always moving in lockstep with one another in every aspect, including design changes, marketing strategy, and price.

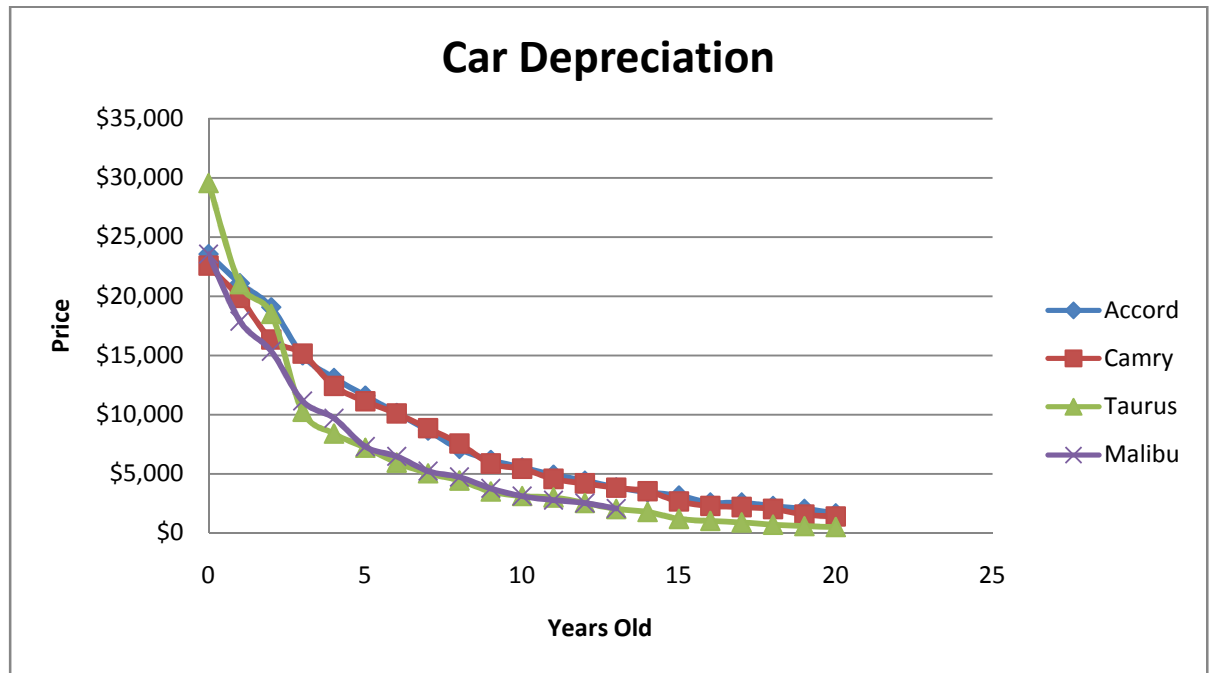


Figure 37 - Average Selling Price According to Edmunds.com¹³²

At this point, the power of effective marketing helps to explain the appeal of hybrids. Small economy cars have the stigma of serving cheap consumers that are forced to spend less. Hybrid cars represent conscientious drivers who are choosing to spend less. Additionally, consumer surveys have found that stopping for gas is viewed as an unpleasant experience, especially among females.¹³³ As such, hybrids have the appeal of requiring fewer refueling interruptions. Most importantly, these consumers are paying for the image of

¹³² <http://www.edmunds.com/chevrolet/impala/review.html>;
<http://www.edmunds.com/toyota/camry/review.html>;
<http://www.edmunds.com/honda/accord/review.html>;
<http://www.edmunds.com/ford/focus/review.html>

¹³³ Sperling, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 22. 2009

a conscientious consumer who takes sustainability seriously. Accordingly, the cities with highest rate of hybrids per household in the country, Portland, Oregon (10.394 per 1000) and San Francisco (7.453 per 1000) are famously green cities.¹³⁴ The power of green marketing has clearly been an ingredient in the recent wave of hybrid offerings from automakers.

The extent to which hybrids are an example of “greenwashing,” as opposed to offering a real environmental benefit, depends on the power of the hybrid system. There are different types of hybrid drive systems: parallel, series, and series-parallel (a hybrid hybrid system). The first hybrid sold in the United States was a parallel hybrid – the Honda Insight. Most parallel hybrids do not allow electric-only propulsion. The series-parallel hybrid drivetrain, popularized by the Toyota Prius, combines the two designs, allowing the gasoline engine to drive the wheels or be disconnected temporarily so that only the electric motor drives the wheels. Toyota leadership on hybrid drive systems has had a trickle-down effect on the way the rest of the industry is trying to catch up.

Toyota

Toyota became the world’s largest automaker in 2008. Toyota has inspired several popular books about the company’s excellence, including *The Toyota Production System* by Taiichi Ohno, *The Toyota Way* by Jeffrey Liker, and *How Toyota Became #1* by David Magee. One of its practices for encouraging innovation is that it does not include research and development costs in its accounting of a model’s profitability.¹³⁵ This definitely would have made the initial business model for the Prius look better on paper, given the enormous R&D expenses that resulted in Toyota’s Hybrid Synergy Drive system.

¹³⁴ <http://www.hybridcars.com/hybrid-market-dashboard/november-2008-dashboard-25328.html>

¹³⁵ Sperlberg, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 71. 2009

Altogether, Toyota and its luxury brand, Lexus, currently offer seven hybrid models. While the Prius is a dedicated hybrid, the Camry and the Highlander were retrofitted with the hybrid drive train. Similarly, Lexus offers hybrid versions of the GS sedan, LS sedan, and the RX SUV and added its first dedicated hybrid, the HS Hybrid, in 2009. With these models, Toyota sells three fourths of the world's hybrids.¹³⁶ However, perhaps the most telling evidence of Toyota's leadership in hybrids was its announcement that it plans to offer a hybrid version of every one of its vehicles by 2020.¹³⁷

Any discussion of hybrid models on the market today needs to start with the Toyota Prius. Three fourths of the hybrids that Toyota sold in the United States 2009 are Priuses.¹³⁸ The Toyota Prius has an astronomically high 98% driver satisfaction rate.¹³⁹ While its success is clear today, its prospects were very uncertain in its early days. Continuing the stereotypical trend of new technologies, it was in Japan for a few years before making its way to the US. The Prius was first released in Japan in 1997 and in the US in 2000.¹⁴⁰

The first-generation Prius did not do well in the United States. Toyota decided to double down its sizable investment in the Prius by going through an elaborate model change for the second generation. The company added power and size for the second-generation Prius, introduced in 2004. Toyota's gamble to make the Prius the flagship vehicle of the green vehicle movement paid off. The Prius became one of the top-selling cars in the United States and in the world, reaching number 8 in the nation for the first half of 2007.¹⁴¹

¹³⁶ <http://www.hybridcarblog.com/2009/12/us-hybrid-sales-cant-top-3-percent.html>

¹³⁷ http://www.toyotamonitor.com/blog/1014213_toyota-going-all-hybrid-by-2020

¹³⁸ <http://detnews.com/article/20100111/AUTO04/1110391/Toyota-hybrid-concept-belongs-to-coming-Prius-family>

¹³⁹ <http://www.hybridcars.com/compacts-sedans/toyota-prius-overview.html>

¹⁴⁰ Boschert, Sherry. *Plug-In Hybrids*. Page 32.

¹⁴¹ Sperleng, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 27. 2009

To recover more of the R&D expenses that went into making Toyota's Hybrid Synergy Drive system, it is being shared with other Toyota models. Most notably, this includes Toyota's best-selling model, the Toyota Camry. While the fuel economy for highway driving will be basically unchanged, the hybrid version of the Camry offers 33 mpg in city driving compared to 22 mpg for the non-hybrid. Toyota expects that the hybrid version will account for 15% of Camry sales.¹⁴²

The Toyota Highlander Hybrid is another showcase of Toyota's head start on hybrids. It was first revealed in at the 2004 North American Auto Show.¹⁴³ Combining the same Highlander engine with the HSD technology, the car earned a SULEV emission rating from California. It gets 27_{city}/25_{highway} mpg, compared to the non-hybrid's 20_{city}/27_{highway} mpg.¹⁴⁴

Lexus

The Lexus RX Hybrid is another hybrid first that Toyota can claim, being the first luxury hybrid.¹⁴⁵ While it uses the same HSD technology, the technology is labeled Lexus Hybrid Drive when marketed in Lexus models. The development of the hybrid Lexus lineup follows a path parallel to the Toyota nameplate in that after introducing a ground-up hybrid like the Prius, Toyota has expanded hybrids in the Lexus nameplate by offering hybrid versions of their standard models.

Like the Prius, Toyota has decided to design another vehicle from the ground up as a hybrid for the Lexus lineup, the Lexus HS. The Lexus HS could be summarized as a luxury Prius, with similar styling and fuel economy in a more luxurious

¹⁴² <http://www.hybridcars.com/compacts-sedans/toyota-camry-hybrid-overview.html>

¹⁴³ <http://www.edmunds.com/news/autoshow/articles/100916/article.html>

¹⁴⁴ <http://www.toyota.com/>

¹⁴⁵ http://www.dailynews.com/search/cj_3076458

package.¹⁴⁶ http://en.wikipedia.org/wiki/Lexus_HS_-_cite_note-jal-0 After being debuted at the North American International Auto Show in January 2009, the HS 250h entered the Japanese market in July 2009 and the American market only one month later.

Honda

It has been a much bumpier road for Honda as it tries to figure out hybrids as well as Toyota has. While the Prius is the most famous, it was actually the Honda Insight that can claim the title of being the first hybrid to reach the American market. It went on sale in December 1999 for \$20,000, two months ahead of the Prius.¹⁴⁷ The Honda Insight was not a success on its first run. The Insight was taken off production from 2000 to 2007. Part of the difference is that the Insight was a two-seater, whereas the Prius seated five people and could therefore meet the needs of more consumers.

The Honda Accord hybrid also did not do well commercially. As mentioned in Table 2, the numbers alone often fail to make a hybrid seem like a rational purchasing decision. A major weakness of the Accord hybrid is that it looked exactly like the non-hybrid version. The Prius, on the other hand, has a distinctive hatchback style, so that the Prius comes with the clear image of being environmentally responsible. Another fault was that Honda decided to use the boost from the battery to give the car more power instead more fuel efficiency. The Accord hybrid registered 25 mpg city and 34 mpg highway.¹⁴⁸ Its price, \$31,685, was not competitive with the Prius's price of \$22,795 or the Camry Hybrid's price of \$26,820.¹⁴⁹

¹⁴⁶ <http://jalopnik.com/5128655/lexus-hs-250h-a-prius-for-the-country-club>

¹⁴⁷ Boschert, Sherry. *Plug-In Hybrids*. Page 118.

¹⁴⁸ http://en.wikipedia.org/wiki/Honda_Accord_Hybrid

¹⁴⁹ <http://www.accessmylibrary.com/article-1G1-164569894/honda-dropping-accord-hybrid.html>

It was even the most expensive on the market until the Lexus RX 400h hit the market.¹⁵⁰

After being consistently beat in both fuel economy and price, the program ended in 2007.

Honda is trying again with green cars. Honda is aiming to be more successful; that is, more like Toyota. It seems that the theme for the revamped Insight is to be more like the Prius. Like the Prius, the new Insight is a hatchback that seats five. Additionally, the Insight is closer to matching the Prius in that it has been made larger than the first generation Insight and focuses less on fuel economy (1st generation mpg = 70 mpg; 2nd gen = 41).¹⁵¹ The new Honda Insight aims also to compete with the Prius on price, (\$20,000 compared to the Prius's +\$22,000).¹⁵² The Insight started selling in Japan in February 2009 and in North America in March 2009. It is currently the lowest-priced hybrid in North America.¹⁵³

Unlike the Accord, the Civic Hybrid has remained in the lineup since first introduced in 2002. Perhaps since the Civic is already more fuel-efficient than the Accord, the Civic Hybrid better appeals to the anti-gasoline target market than the Accord hybrid. The Civic Hybrid is far and away Honda's best selling hybrid, as shown in Table 6 below.

¹⁵⁰ http://www.dailynews.com/search/ci_3076458

¹⁵¹ http://en.wikipedia.org/wiki/Honda_Insight

¹⁵² http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=12375

¹⁵³ http://www.blackamericaweb.com/?q=articles/life_style/automotive_life_style/14251

Model	Region	Start of Sales	Cumulative Unit Sales
Insight	Japan	Nov. 1999	2,340
	North America	Dec. 1999	14,288
	Europe	Mar. 2000	392
	Total		17,020
Civic Hybrid	Japan	Dec. 2001	22,899
	North America	Mar. 2002	191,493
	Europe	May. 2003	34,757
	Asia/Oceania	Feb. 2004	5,514
	China	Nov. 2007	280
	Others	May. 2006	306
	Total		255,249
Accord Hybrid	North America	Dec. 2004	28,471
	Total		28,471
Total Unit Sales of Honda Hybrid Models			300,740

Table 6 - Honda Hybrid Sales¹⁵⁴

Ford

Ford has been built on a successful start for its hybrid program and continues to make progress. Ford claims that it developed its hybrid technology independently and that when engineers realized that some components were similar to Toyota's patented hybrid technology, they decided to acquire licenses to avoid patent infringement.

Ford's first hybrid was also the first hybrid SUV, the Ford Escape Hybrid. Introduced in 2004, the Escape was followed one year later by its more expensive twin, the Mercury Mariner. Mechanically, both cars are identical, though the Mariner has a nicer trim, a luxury brand name, and a slightly higher sticker price (\$30,105 vs. \$29,860). The vehicle websites for both vehicles say that the Escape/Mariner is "the most fuel-efficient SUV on the planet." The Escape Hybrid's fuel economy rivals that of fuel-efficient sedans: 34 mpg-city and 31 mpg-highway.¹⁵⁵ According to Autoblog.com, Ford Hybrids first became profitable in 2008 after achieving a 30% cost reduction in manufacturing the Escape.

¹⁵⁴ <http://world.honda.com/news/2009/4090218Hybrid-Vehicles/>

¹⁵⁵ <http://www.fordvehicles.com/suvs/escapehybrid/?searchid=426441|28124909|205370178>

In 2005, Ford announced its next hybrid: the Fusion Hybrid. Four years later, it started offering a hybrid version of the Ford Fusion in March 2009 as a 2010 model. The same is true for “the other Fusion,” sold under the Mercury brand name, the Mercury Milan Hybrid. The four years of development paid off, with features that easily justify the fact that it won the North American Car of the Year Award at the 2010 North American International Auto Show in Detroit.¹⁵⁶ The Fusion Hybrid’s fuel economy beats every other hybrid but the Prius with 41 miles per US gallon for city driving and 36 miles per US gallon for highway driving.¹⁵⁷ In city driving, a full tank delivers 700 miles.¹⁵⁸ Lastly, the car has an electric-only mode that can last up to 2 miles.¹⁵⁹

Conclusion

As was mentioned at the beginning of the chapter, hybrids have the potential to merely slow the increase of our oil consumption. However, their true value is as a stepping stone. The truth is that hybrids are bringing us closer to electric cars in part because they are becoming more and more like electric cars. Hybrids will become plug-in hybrids with a farther electric range, as the case will be under current plans for the Prius. As the electric range increases, the fuel tank may eventually become unnecessary.

Hybrids lend themselves well to another analogy of evolution. One of the common arguments against evolution is that irreducibly complex structures could never have been gradually assembled, because natural selection would have eliminated and certainly not favored any partially complete structure, such as lungs. The hurdle seems insurmountable;

¹⁵⁶ <http://www.fordvehicles.com/cars/fusion/reviews/award-details/?id=229&searchid=426441|28115785|205351588>

¹⁵⁷ <http://www.nytimes.com/2008/12/31/business/31ford.html?scp=2&sq=Prius%20Fusion%20Hybrid&st=cse>

¹⁵⁸ <http://www.nytimes.com/2008/12/31/business/31ford.html?scp=2&sq=Prius%20Fusion%20Hybrid&st=cse>

¹⁵⁹ <http://www.hybridcars.com/vehicle/ford-fusion-hybrid.html>

any fish that suddenly evolved lungs would drown in the water. Similarly, any car that does not use gasoline might get left high and dry if it runs out of charge away from a charging station.

However, the lungfish provides a perfect case study here. The Australian lungfish has one working lung and can also respire through its gills. Clearing the evolutionary hurdle from water to land would simply require that gills downsize as lungs become more and more functional. In the same way, hybrids are leading to shrinking engines and are developing stronger batteries. Batteries need to develop a large energy capacity just as lung capacity had to expand to support land-based movement. Plug-in hybrids are a step up from conventional hybrids in the evolutionary ladder, followed by pure electric vehicles. The question will be whether the gradual change can happen on a short enough time scale to avert a crisis caused by either too much carbon or too little oil.

Chapter 5: Electric Cars

Post Priora

“So how would you run a whole country without oil?... If you could convert your entire country to electric cars in a way that is convenient and affordable, you could get to a solution.”

-Shai Agassai, Better Place CEO, 2009 TED Speech

Toyota’s capacity for vision is best evidenced in their chosen name for their flagship hybrid. “Prius” is Latin for “prior” (“priora” is the grammatically correct plural form of “prius”). Toyota’s executive said that the Prius would be the predecessor for the cars of the future. Automakers will eventually upgrade their conventional hybrids into plug-in hybrids. While that may be just a prediction for other cases, it is already happening to the Prius. In 2009, Toyota announced plans to start production of the plug-in Prius in 2010.¹⁶⁰

There is another way that hybrids are encouraging the development of EVs. Automakers are pursuing strategies for the green market than can be simplified into two categories: investing in hybrids or trying to leapfrog hybrids with all-electric cars. Toyota has the most invested in hybrids and the least invested in EVs. Nissan is not much of a player in the hybrid market, yet they are in the lead with electric cars. Honda is right the middle with a mild commitment to both. The American car companies have a parallel pattern. Chrysler is asleep about hybrids yet has produced the most domestic electric cars. GM has chosen to go with mild hybrids and one strong plug-in hybrid (the Chevy Volt). Lastly, Ford is aiming to beat its American counterparts in both categories.

While hybrids can use energy more efficiently than ICE cars, electric cars take everything a step further. Electric cars always use regenerative braking, idle without

¹⁶⁰ http://www.nytimes.com/2009/12/15/business/global/15toyota.html?_r=2

consuming energy, and completely eliminate all moving parts under the hood, except for the motor, driveshaft and wheels. Most importantly, plug-ins, whether all-electric or plug-in hybrids, have the potential actually turn the tide and decrease America's oil consumption, as shown in the figure below.

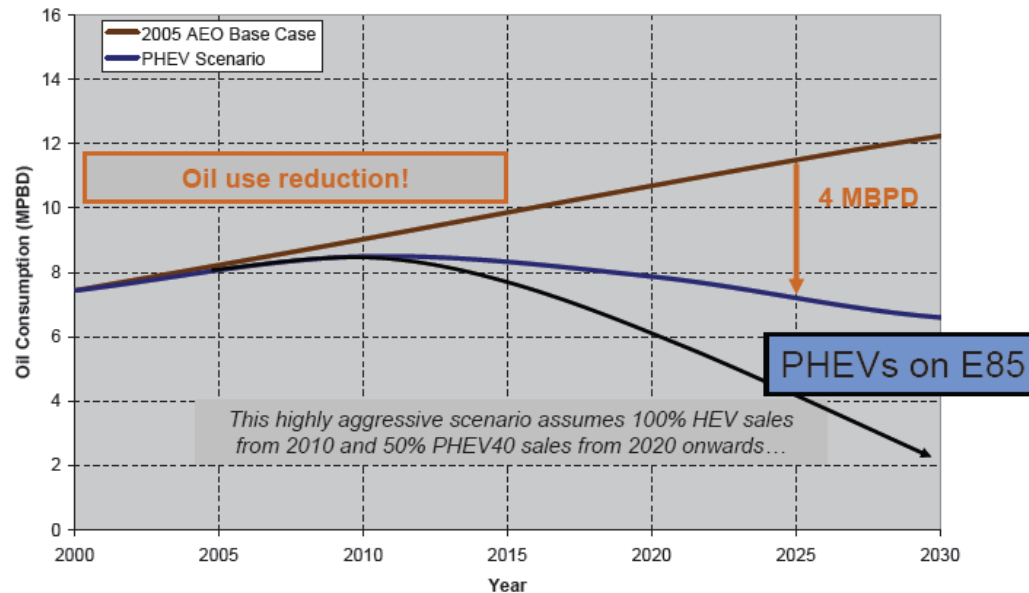


Figure 38 - Oil Consumption to Zero¹⁶¹

Another key performance advantage of EVs is instantaneous torque. For an internal combustion engine, power is the product of torque and engine speed (in RPM). While a flat torque curve is ideal, engines actually produce very low torque at low RPM, which is why cars normally require transmission systems that allow the engine speed to approach the best RPMs for producing ideal torque at different vehicle speeds. Electric cars on the other hand, have a perfectly flat torque curve, as shown in the chart below. This feature of electric cars can be felt if the driver decides to show off with a jolt of acceleration from 0 to whatever speed limit has been built into the electronic controller.

¹⁶¹ <http://www.nrel.gov/docs/fy06osti/40239.pdf>

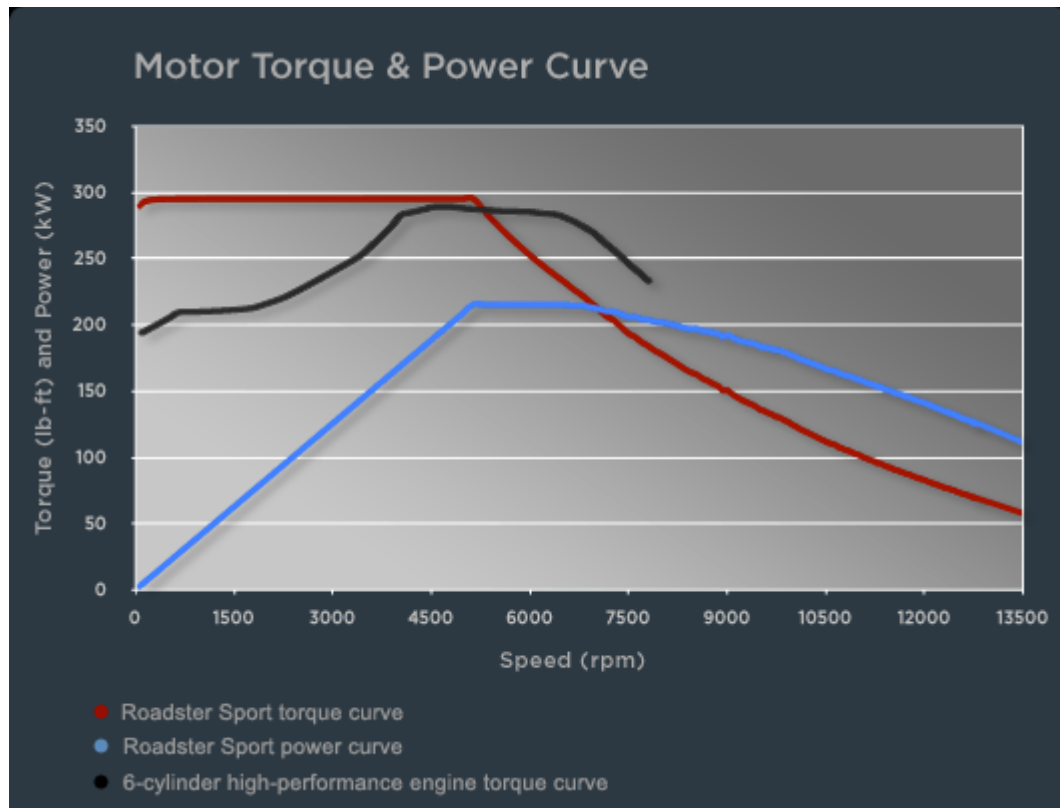


Figure 39 - Torque Curve from Tesla Motors¹⁶²

New technologies tend to follow an S-shaped curve for market penetration. The slow initial growth happens as only the early adopters and mavericks dare to experiment with the new, expensive technology. As the market size increases, new technologies take on a mainstream feel so that even cautious consumers join the market. Finally, the market penetration reaches a limit when it has already spread to most users. Electric cars are currently attracting early adopters, so the turning point of explosive growth will hopefully only be a few years away.

Everything is coming together auspiciously for the future of electric cars. High gas prices, maturing lithium-ion battery technology, a favorable political climate, and a frenzy among automakers to not miss out on the next big thing, put all together, means that the country will most likely experience what California experienced in the 1990's.

¹⁶² http://www.teslamotors.com/performance/acceleration_and_torque.php

The ZEV Mandate

While the air quality in Los Angeles has improved over the last decade, it still ranks as the worst city in the country for ozone pollution and ranks among the worst in most other categories of air quality.¹⁶³ Part of the problem is that Los Angeles, the second largest city in the United States, has 1.8 cars per person, the highest metropolitan rate in the world.¹⁶⁴ Furthermore, residents of the Los Angeles area have more traffic delays than any of other area of the country.¹⁶⁵ In short, cars are a big problem in Los Angeles.

With this context in view, GM CEO Roger Smith demonstrated the Impact, an all-electric prototype at the Los Angeles Auto Show in 1990.¹⁶⁶ California's Air Resources Board (CARB) took notice of this. Partially inspired by GM's proof of concept, CARB issued the Low-Emission Vehicle Program in 1990.¹⁶⁷ The most famous part of this order was the ZEV Mandate, demanding that automakers sell zero-emissions vehicles (ZEV) as 2% of their total sales by 1998, increasing to 5% in 2001 and 10% in 2003.¹⁶⁸ Basically, CARB ordered automakers to start making EVs.

Chief among the new electric vehicles was GM's EV1. The car was initially named the Impact, which "robbed the homely Edsel and hapless Studebaker of their distinctions as the worst names in the history of automobiles."¹⁶⁹ The Saturn EV1 became iconic to the electric vehicle movement and was the main feature of the movie *Who Killed the Electric Car?* The EV1 is pictured below.

¹⁶³ <http://www.msnbc.msn.com/id/30476335/>

¹⁶⁴ http://wikitravel.org/en/Driving_in_Los_Angeles_County#Los_Angeles_Car_Culture

¹⁶⁵

<http://www.dallasindicators.org/Transportation/EfficientTransportationWithintheMetroplex/Timespentintraffic/tabid/1053/language/en-US/Default.aspx>

¹⁶⁶ Schnayerson, Michael. *The Car That Could*. Page 26

¹⁶⁷ Sperling, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 189.

¹⁶⁸ Sperling, Daniel and Gordon, Deborah. *Two Billion Cars*. Page 189.

¹⁶⁹ Schnayerson, Michael. *The Car That Could*. Page 26



Figure 40 - An Electric Coupe From 20 Years Ago¹⁷⁰

Unfortunately for EV fanatics, the car was a stretch for commercial viability. The car replaced a gas tank with 843 pounds of lead-acid batteries.¹⁷¹ The batteries were expected to last for a maximum of 1,000 cycles, or about 3 years.¹⁷² It cut weight in every way it could, including the use of an aluminum frame and by holding parts together with glue instead of rivets.¹⁷³ GM leased out the EV1 in limited numbers while the ZEV mandate was alive but did not come close to recuperating the R&D costs of the program.

Meanwhile, the oil companies and automakers never took a moment's rest from fighting the mandate. The automakers filed a lawsuit to overturn the mandate. The Bush administration broke precedent by involving itself in CARB's actions and supported the car companies in the lawsuit. In March of 1996, CARB eliminated the 1998 ZEV mandate,

¹⁷⁰ http://jetube.files.wordpress.com/2009/08/gm_ev1.jpg

¹⁷¹ Schnayerson, Michael. *The Car That Could*. Page 9

¹⁷² Schnayerson, Michael. *The Car That Could*. Page 75

¹⁷³ Schnayerson, Michael. *The Car That Could*. Page 62

replacing it with the voluntary goal of producing 3,750 EVs by the year 2008.¹⁷⁴ GM bought the Hummer brand in 1998 one month before deciding to discontinue producing the EV1.¹⁷⁵ The assembly lines for the EV1 were shut down permanently in 1999.¹⁷⁶

Today's Market

Japanese Automakers

Toyota has the most to gain from hybrids because they have invested the most into hybrid powertrains. If hybrids remain the dominant green cars, Toyota will have more time to profit off their R&D investments. They have licensed out this technology to Ford, Nissan and Mazda. They are at least introducing a plug-in version of the Prius and are aiming to start full retail sales by late 2011.¹⁷⁷

The Prius has used nickel-metal hydride (NiMH) batteries since 2000, but is expected to switch to lithium-ion batteries for the plug-in version. Some plug-in cars offer radically different designs that look like futuristic race cars or odd golf carts. The marketing strategy for Toyota, however, was to offer a car very similar to an all-gas car, except better. In 2011, Toyota will start producing its plug-in version with an all-electric range of 12-19 miles and a combined fuel economy rating of 65 mpg.¹⁷⁸

Honda is in the early stages of developing a pure EV car with their EV sports car, the Honda FC Sport. It debuted at the 2009 Tokyo Motor Show, and will also be at the Detroit Auto Show in 2010.^{179,180} It is a 2-seater coupe. It is scheduled to enter production by the

¹⁷⁴ Schnayerson, Michael. *The Car That Could*. Page 252

¹⁷⁵ Boschert, Sherry. *Plug-In Hybrids*. Page 16.

¹⁷⁶ Boschert, Sherry. *Plug-In Hybrids*. Page 16.

¹⁷⁷ <http://green.autoblog.com/2009/12/14/toyota-officially-launches-plug-in-prius-program-retail-sales-i/>

¹⁷⁸ [http://www.mixedpower.com/toyota-prius/2010-phev-plug-in-prius-getting-65-mpg/;](http://www.mixedpower.com/toyota-prius/2010-phev-plug-in-prius-getting-65-mpg/)

<http://www.wired.com/autopia/2009/07/plug-in-prius-2/>

¹⁷⁹ <http://blogs.internetautoguide.com/6546730/auto-news/2015-honda-electric-vehicle-prototype-to-debut-at-the-2009-tokyo-auto-show/index.html>

¹⁸⁰ <http://www.autoblog.com/2009/10/25/honda-design-boss-discusses-changes-to-production-cr-z/>

end of 2015.¹⁸¹ As such, there is very little that known about the car, and all discussion about price, range, and even market entry dates are rather speculative.

Nissan is also well positioned for the electric car race. The Nissan Leaf is sometimes formatted as the “LEAF” because the name originated as the acronym “Leading, Environmentally friendly, Affordable, Family car.”¹⁸² *Time* magazine even ranked the Leaf as the 25th best invention of 2009.¹⁸³ Nissan is seeking to make potential buyers as comfortable as possible with its mere 100 mile range by including an on-board navigation system that continuously displays the maximum driving radius that the car can reach given its current charge.¹⁸⁴ The battery can be charged in 30 minutes with a 440-volt direct-current charger.¹⁸⁵ Another noteworthy point about the LEAF is that it aims to be competitively priced with high-end sedans in the range of \$25,000-\$33,000. Nissan claims that the LEAF will reach its first customers in North America, Europe, and Japan in 2010.¹⁸⁶

Mitsubishi deserves special mention as the only Japanese automaker that is currently producing all-electric cars. The car is named i-MiEV, from the acronym “Mitsubishi In-wheel motor Electric Vehicle.” As of September 2009, 536 of these four-door, four-seat cars have been delivered to Japanese consumers.¹⁸⁷ The first concept car in this program was the Mitsubishi Colt EV, exhibited in 2005, though it is not currently in production yet.¹⁸⁸ With the model i-MiEV, Mitsubishi decided to start their North American test run in Oregon,

¹⁸¹ <http://www.egmcartech.com/2009/08/24/honda-to-offer-electric-car-in-the-us-by-2015-concept-coming-in-oct/>

¹⁸² <http://www.careny.ca/2009/08/nissans-leaf-blowing-our-way-in-2012/>

¹⁸³ <http://www.time.com/time/specials/packages/completelist/0,29569,1934027,00.html>

¹⁸⁴ <http://www.autoblog.com/2009/07/27/nissan-shows-off-new-versa-based-electric-vehicle-prototype/>

¹⁸⁵ http://www.nissan-global.com/EN/NEWS/2009/_STORY/090802-02-e.html

¹⁸⁶ <http://www.autoblog.com/2009/08/01/2010-nissan-leaf-electric-car-in-person-in-depth-and-u-s-b/>

¹⁸⁷ Yamaguchi, Jack. *Automotive Engineering International*. “Tokyo Electrifies,” pg 11. December 2009

¹⁸⁸ <http://media.mitsubishi-motors.com/pressrelease/e/corporate/detail1269.html>

making it available to fleet customers in April 2009.¹⁸⁹ The production i-MiEV actually has one central motor instead of the in-wheel motors that the earlier concept cars had.¹⁹⁰ It currently has a 100 mile range.¹⁹¹ The car is scheduled to enter the markets in Hong Kong and Japan by March 2010 and to be gradually introduced into the global market.¹⁹²

American Automakers

Chevy Volt is the most ambitious American PHEV to date. It debuted at the 2007 North American International Auto Show, but was also featured at the 2008 Australian International Motor Show and 2009 Tokyo Motor Show.¹⁹³ The Volt is extremely significant to GM in that it features the Voltec drivetrain, which GM plans to use as its standard platform for all future PHEV and possible EV programs.¹⁹⁴ The Volt can go 40 miles without any help from gasoline and can go 400 miles on a full charge and tank.¹⁹⁵ It is yet to be seen if the market will find these features worth the estimated \$40,000 price tag.¹⁹⁶ To date, the car is on schedule to enter showrooms in North America by the end of 2010.¹⁹⁷

Ford plans to include an all-electric version of its third-generation Ford Focus. Ford's strategy is to save costs for the EV model by adapting the electric drivetrain onto an existing model instead of having to design an electric vehicle from the ground up. As for its second-generation Focus, the *Wall Street Journal* estimated that the program is losing the company one billion dollars per year.¹⁹⁸ So it is a low bar for the third generation as it enters

¹⁸⁹ http://www.oregonlive.com/business/index.ssf/2009/04/another_zappy_car_for_oregon.html

¹⁹⁰ http://en.wikipedia.org/wiki/MiEV#Production_version_of_Mitsubishi_i_MiEV_.282009.29

¹⁹¹ http://www.oregonlive.com/business/index.ssf/2009/04/another_zappy_car_for_oregon.html

¹⁹² <http://www.news.gov.hk/en/category/environment/090921/html/090921en04001.htm>

¹⁹³ http://en.wikipedia.org/wiki/Chevrolet_Volt

¹⁹⁴ http://en.wikipedia.org/wiki/GM_Voltec_platform

¹⁹⁵ http://en.wikipedia.org/wiki/Chevrolet_Volt

¹⁹⁶ <http://www.hybridcars.com/vehicle/ford-focus-ev.html>

¹⁹⁷ <http://www.reuters.com/article/idUSN037009220080603>

¹⁹⁸ <http://online.wsj.com/article/SB124156986367389899.html?mg=com-wsj>

production in late 2010. The Focus EV has an anticipated range of 100 miles.¹⁹⁹ It is expected to start selling in late 2011.²⁰⁰

Global Electric Motorcars (GEM cars) is a wholly-owned subsidiary of Chrysler. The subsidiary makes neighborhood electric vehicles (NEVs). NEVs closely resemble golf carts in both their vehicle design and top speed; they are only intended for intra-city use, such as for downtown pizza delivery cars. GEM cars include six different models, which can be described as six different versions of one platform. For example, the GEM e2 NEV seats two people, the e4 seats four; the e6 seats six.²⁰¹ The remaining three models are utility vehicles with more cargo capacity. GEM has produced 40,000 vehicles in its 11-year history and currently makes only 2,000 per year.^{202,203}

Start Ups

Volume has always been on the side of the major automakers. Research and development costs for a model can be distributed over more units per model for the larger companies. The only hope that entrepreneurs have in the auto industry is to meet some unmet need, to capitalize on a hole in the market. Those are the aspirations of a number of automotive startups in the United States. These gambles have frequently come to the brink of failing, but they have a strong fan base that is rooting for their success.

The Tesla Roadster is the poster child of the electric car movement. By producing a cool electric sports car, it does wonders for the image of electric cars. It has transferred the stereotype of electric cars from *always* being too slow to being *either* too slow *or* too expensive. As an electric car supporter, it would be great have more positive things to say

¹⁹⁹ <http://www.hybridcars.com/vehicle/ford-focus-ev.html>

²⁰⁰ <http://www.hybridcars.com/vehicle/ford-focus-ev.html>

²⁰¹ http://en.wikipedia.org/wiki/Global_Electric_Motorcars

²⁰² http://en.wikipedia.org/wiki/Global_Electric_Motorcars

²⁰³ Sperl, Daniel and Gordon, Deborah. *Two Billion Cars*. 2009

about Tesla Motors. However, they have only delivered 900 cars to date.²⁰⁴ After receiving a \$465 million dollar loan, the overwhelming majority of their funding comes from the government.²⁰⁵ While Tesla makes a great icon for electric cars, their overall impact is marginal compared to the actions of the major automakers.



Figure 41 - The Tesla Roadster²⁰⁶

Conclusion

Both 2010 and 2011 will be very big years for plug in vehicles. This round of EVs is more historic and more promising than the set of EVs that were released in the 1990's because this round is not being forced by government regulation. Rather, free market forces

²⁰⁴ http://www.motortrend.com/roadtests/alternative/112_0912_2010_tesla_roadster_sport_test/specs.html

²⁰⁵ http://www.motortrend.com/roadtests/alternative/112_0912_2010_tesla_roadster_sport_test/specs.html

²⁰⁶ <http://www.teslamotors.com/design/gallery-body.php>

are pushing automakers towards EVs, instead of having automakers push against EVs. Now that the supply is making a comeback, if demand is as strong as expected, then EVs will be able to survive on their own and continue to gain momentum.

It is possible that the next two years will not be a successful turning point for EVs. Sales may be hurt by the limited range. Gas prices might sink so low that gas-guzzlers enjoy the same prominence they did in the 1990's. Perhaps this recent trend of green vehicles is nothing more than herd mentality among lemming-like automakers. However, even if this latest round of plug-ins fails, the underlying technology will continue to improve. Every time that green vehicles become popular, their chances of forcing a more permanent evolution on the auto market improves. Because electric cars hold greater promise for sustainability, it appears inevitable that given enough time they will eventually dominate the auto market.

Chapter 6: EV Issues

A Critical Look

Are we trading tailpipes for smokestacks and an oil shortage for an electricity shortage?

The central idea of this book is that we should transition to a model of transportation that is responsible and beneficial to society, even for the long run. The main question is, “Is this something we can continue doing forever?” Hence, the term “sustainability.” Today’s petroleum-based system simply needs to go. However, it is essential to evaluate the alternatives with the same level of scrutiny. As such, in this chapter we will evaluate meeting the demand for electricity, physical supplies, environmental impact and feasibility for meeting consumers’ needs.

Generating Electricity

The most common issue that people raise concerning electric cars is the problems that might arise from all of the electricity that electric cars would use. To grasp the massive scale of our current oil consumption, consider the following: if all of the energy from today’s oil consumption were instantly replaced with energy from nuclear power plants, it would require building an additional 4,000 1.5 gigawatt (GW) reactors. For comparison, there are approximately 440 nuclear reactors in the world today, with a combined capacity of only of 6% that amount. Furthermore, if this happened, the world’s uranium reserves would be depleted in 10 years.²⁰⁷

First of all, it should be pointed that electric cars are projected to grow at a rate that is nowhere near enough to actually strain the electric grid. As mentioned in the previous

²⁰⁷ Downey, Morgan. *Oil 101*. Page 26-27.

chapter, conventional hybrids currently account for around 2.5% of new cars sold, and plug-ins are a very small portion of that number. According to Wally Rippel, an engineer with the electric car company AeroVironment, the electricity consumption of 200 million electric cars would be equal to 20% of the electricity being generated today.²⁰⁸

Secondly, the current shape of daily electricity production is perfect for accommodating electric cars. Electricity generation and consumption is much higher during the day than it is at night, as shown in the typical load curve below. Most electric cars would charge overnight, when electricity usage is lowest. According to the US Department of Energy, running power plants at their current capacity instead of ramping them down at night would produce enough energy to meet the needs of 43 million electric vehicles.²⁰⁹

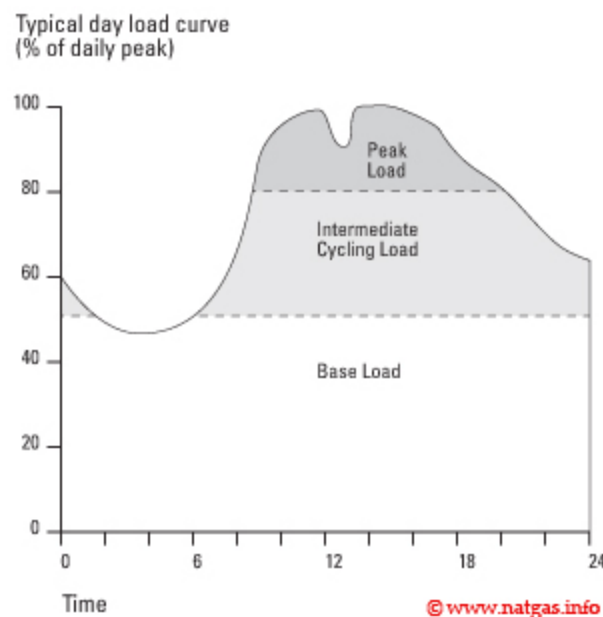


Figure 42 - Typical Daily Load²¹⁰

²⁰⁸ Boschert, Sherry. *Plug In Hybrids*. Page 116.

²⁰⁹ Boschert, Sherry. *Plug In Hybrids*. Page 116.

²¹⁰ <http://www.natgas.info/html/gasusage.html>

The Smart Grid

America's way of doing electricity was designed and implemented over a century ago, before the invention of computers or any modern communications technology. Unfortunately, the current system has not changed since it was first implemented. Free-market capitalism has brought numerous technologies to extinction, including telegraphs, the horse and buggy, record albums and video cassettes, all the while power plants that burn fossil fuels have continued their basic mode of operation. Similarly, business models have come and gone, such as daily milkman deliveries and clerk-based grocery stores (vs. self-service stores pioneered by Clarence Saunders and Fred G. Meyer), yet the basic business model for electricity has not changed. While most other industries exemplify natural selection due to brutal competition, electric utilities are not governed by free market principles. As Alan Greenspan said in *The Age of Turbulence*, "a key difference between a centrally planned society and a capitalist one [is] there was no creative destruction, no impetus to build better tools."²¹¹

Utilities follow a more stable business environment than the industries without government involvement. Traditionally, electric utilities negotiate with utility commissions, which are appointed by local governments, to determine how much money they are allowed to charge for a kilowatt-hour of electricity. Utilities and commissions do their best to project demand and operating costs in order to arrive at a rate the commission deems fair. This system does not use continuous feedback like today's financial markets or even periodic feedback to adjust prices according to retail sales reports. With only limited data to track demand, utilities are forced to estimate how much to supply. Furthermore, they are

²¹¹ Greenspan, Alan. *The Age of Turbulence*. Page 172.

mandated to always meet supply so they always have to overproduce to error on the side of caution.

Trying to fulfill this mandate while flying blind is a killing point for alternative energy. Wind turbines and solar panels have variable outputs because the wind does not always blow and the sun does not always shine. Therefore, utilities are required to have a dependable fossil-fuel power plant in order fulfill their mandate. This limits how much of their energy utilities can generate from alternative energy.

At this point, enter the smart grid. A smart grid could be described as an “Energy Internet,” a flexible, back-and-forth transfer of energy using real-time data to coordinate supply and demand.²¹² Changes would need to be made in distribution and consumption of electricity. For consumption, mechanical meters need to be replaced with electronic meters that can provide real-time data to utilities to tell them how much electricity they are using and when. Going even further, appliances could become programmable to only turn on when it becomes economically advantageous to do so. This would allow utilities to arrange costs so that electricity consumption during peak demand costs more and electricity costs less during less times of less demand.

A smart grid not only deals with the disadvantages of renewable energy sources but also creates a niche role for them. A smart grid encourages local installation of solar panels and microturbines by enabling consumers to sell electricity to the grid. Solar panels create electricity during the day, when demand is highest and electricity would be more expensive. Wind turbines tend to be most productive during the evening and morning, when changing temperatures generate wind currents. A smart grid allows the two-way transfer of energy so that this energy can be stored for when it is needed more.

²¹² Friedman, Thomas. *Hot, Flat, and Crowded*. Page 217

Electric cars would add another incentive for switching to a smart grid. Plug-ins could charge up during off-peak hours when electricity costs less and sell it back during the day. The significant energy storage requirements of electric car batteries means that electric cars could play a big role in transferring energy to and from the grid. Under this arrangement, energy providers could provide a steadier load of electricity. Producers would benefit, and consumers who are selling back more expensive electricity could potentially generate a profit from buying low and selling high, using a powerful car battery as storage in the meanwhile.

Environmental Impact

After concerns about electricity, the next greatest concern is probably whether electric cars simply displace and possibly increase pollution. When the car is fueled by electricity, the buck for sustainability passes to electricity generation. In regions with cleaner energy production, EVs are certainly a boon. However, there are 11 states that get more than 80% of their electricity from coal.²¹³ In 1994, the Union of Concerned Scientists found that when comparing electric cars to cars with in the CARB category of ultra-low emissions vehicles (ULEV), EV's generate 99% less carbon monoxide and volatile organic compounds, 60%-64% less nitrogen oxides, and 56% less particulate matter, even after accounting for the emissions during electricity production.²¹⁴ Furthermore, transferring pollution without reducing would still be beneficial to cities that struggle with air quality because most electricity production happens away from cities.

However, a holistic look would require looking at well-to-wheel efficiency. For ICE cars, this means also looking at the energy required to extract and refine oil and to distribute

²¹³ Boschert, Sherry. *Plug-In Hybrids*. Page 118.

²¹⁴ Boschert, Sherry. *Plug-In Hybrids*. Page 112.

gasoline. In the case of EVs that use electricity from fossil fuels, the starting point would be recovering and transporting the fossil fuels, running them through their thermodynamic cycle, transmitting that electricity to the charging point, and then the efficiency of charging and discharging, in addition to energy lost “on the shelf.” According to Tesla Motors, electric cars outcompete with even the most fuel-efficient vehicles, as shown in the figure below. While the numbers in these comparisons are frequently debated, EVs have the potential to side step this debate because any electricity production that is carbon-free would mean that EV use is carbon-free.

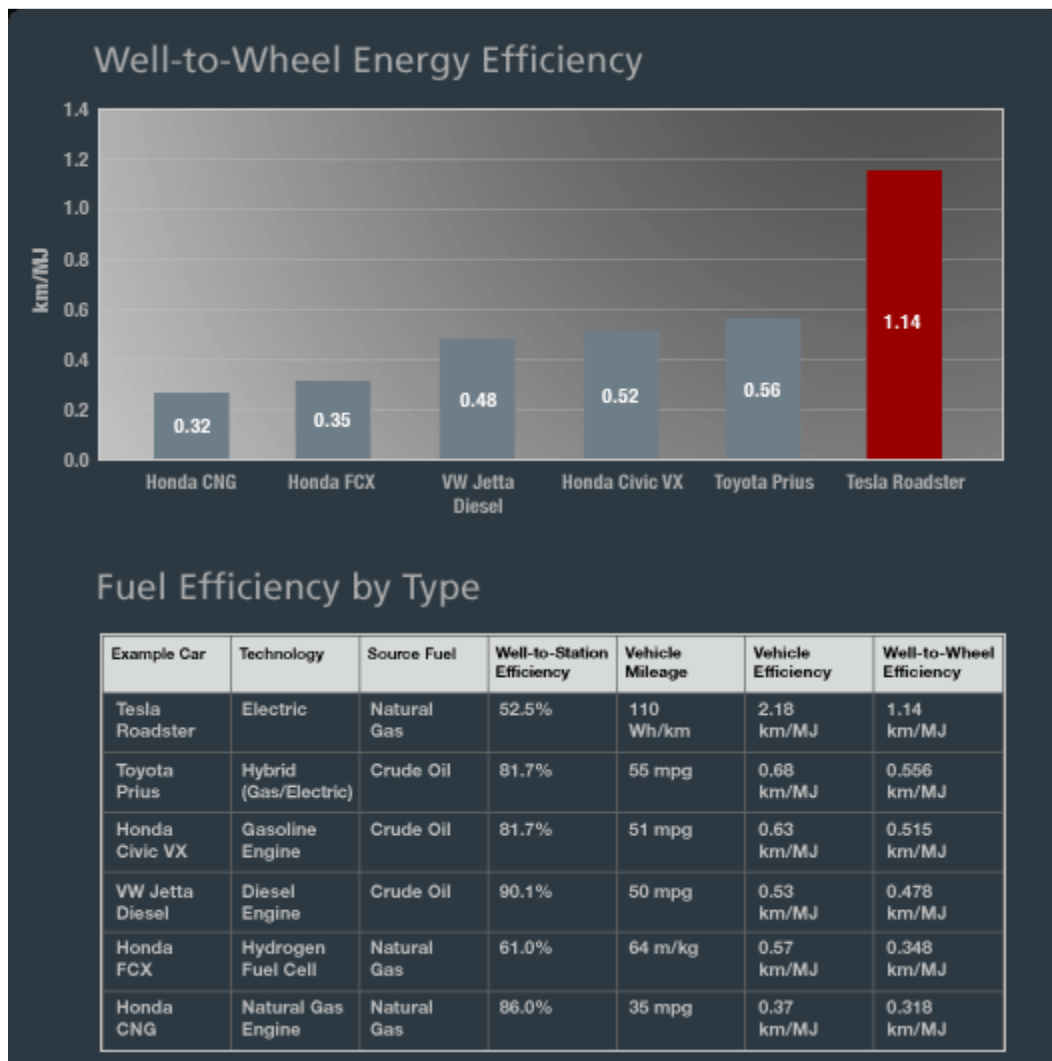


Figure 43 - Tesla Says the Tesla Roadster is Good

Range



Figure 1 - Cumulative Distribution of Daily Driving Distances²¹⁵

Range is frequently mentioned as the Achilles heel of electric vehicles. However, as the graph above shows, half of all cars on the road drive only 25 miles per day. Three quarters drive 45 miles. Most of the electric cars in this paper have an anticipated range of one hundred miles, which is needed less than 10% of the time. The issue with these numbers is that even though cars only occasionally need over a hundred miles, an electric car with a hundred mile range could never meet that need. The first reason for optimism about this issue is that only early adapters drivers would need to rely on home chargers; eventually, charging stations will be in high enough demand to appear in cities. Chargers themselves will need to mature so that recharging time will be on par with refueling times for gas cars. The second reason for optimism is that a few electric cars are able to go 300 miles. These are very expensive, but the point is that the technology is possible and simply needs to grow more affordable.

²¹⁵ <http://www.green-metroplex.com/EVs/Index.html>

PHEVs often have a range in excess of gas cars. The key is that it is possible for them to be carbon-free and oil-free during short trips. Only if a longer drive becomes necessary would PHEVs have to use a limited amount of gasoline. PHEVs do not need to be marketed as a household's ideal second car. In this way, PHEVs can be seen both as a tremendous improvement over gas cars and as the intermediate technology until EVs improve.

Material Dependency

The push to wean ourselves off of oil comes in large part from the physical reality that the world will someday run out of oil, just as the original idea to use "rock oil" came from the scarcity of whale oil to use for lighting. We must then ask the question if we are simply switching one temporary physical dependency with another.

Fortunately, the answer is that we have lithium to last hundreds of years. Lithium is one of the most abundant elements in Earth's crust. According to the Gerson Lehrman Group, a New York consulting firm, 500,000 cars powered by lithium-ion batteries would use less than 10% of last year's global lithium output. Chris Richter, an auto analyst with CLSA Asia-Pacific Markets in Tokyo, once said, "Of all the various problems with this technology, running out of lithium is not one of them."²¹⁶

In addition to concerns about physical supply, we must evaluate the distribution of resources around the world. If the world's lithium deposits were in the hands of unstable dictators, then foreign lithium dependency would not really be much of an upgrade. Even splitting our dependency between petrodictators and lithodictators would deny monopoly

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http://www.lexisnexis.com.proxy.library.oregonstate.edu/us/lnacademic/results/docview/docview.do?docLinkId=true&risb=21_T8084604310&format=GNBFI&sort=RELEVANCE&startDocNo=1&resultsUrlKey=29_T8084588401&cisb=22_T8084604323&treeMax=true&treeWidth=0&csi=6928&docNo=3 "Enough lithium for hybrid boom? Most say yes", September 21, 2009, Hans Greimel, Lexis Nexis Academic

status to either material. Fortunately, lithium well dispersed around the world. The numbers for reserves of the major relevant countries are given below.

Country	Mine Production		Reserves
	2008	2009e	
United States	Withheld	Withheld	38,000
Brazil	160	110	190,000
Zimbabwe	500	350	23,000
Canada	690	480	180,000
Portugal	700	490	NA
Argentina	3,170	2,200	800,000
China	3,290	2,300	540,000
Australia	6,280	4,400	580,000
Chile	10,600	7,400	7,500,000
World Total	325,400	318,000	9,900,000

Table 7 - World Lithium Production and Reserves²¹⁷

Conclusion

Many of the concerns about electric cars raise legitimate points of contention. The difference between electric cars and other alternatives are that electric vehicles still represent a great leap forward towards sustainability. They are not perfect, but their disadvantages can be handled and will eventually decrease as the technology improves.

²¹⁷ <http://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2010-lithi.pdf>

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