

Matt Sprague
Directed Study in Scientific Research
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The Current State of Our Energy Economy

Background: It is estimated that, given current levels of consumption, the world's oil supply will run out sometime shortly after the year 2040. This is simply a prediction, but it is known for sure that our oil supply will not last forever. Keeping this in mind, alternative sources of energy must be found. The current energy breakdown for the United States is as follows – Coal 50%, Natural Gas 18%, Petroleum 3%, Nuclear Power 20%, and Renewable Energy (Including Hydro, Solar, Wind, etc.) 9%. It is good to see that 29% of the US's energy is provided by relatively clean energy sources (Nuclear and renewable), but for the sake of energy independence and environmental friendliness this percentage should be increased. Unfortunately, most of the new power plants constructed in the 90's were petroleum and natural gas powered, given the low cost of oil and gas during that decade. Doubly unfortunately, most power plants slated for construction during this decade are coal burning plants, due to the rising prices of natural gas and petroleum. The good news is that modern coal plants incorporate technology that removes much of the pollution associated with this form of energy.

Cleaning Up Coal Plants: One proposition that could help reduce CO₂ emissions is to store CO₂ produced from coal power plants deep in the Earth. The advantages of this process, called sequestrations, would be almost no CO₂ emissions, but a potential catastrophic leak of CO₂ all at once due to a shifting of tectonic plates could cause significantly greater environmental problems than if the CO₂ had not been stored at all. Advanced coal plants would first put coal through a gasification cycle, in which hydrogen could be produced and harmful chemicals removed, leaving a cleaner burning coal behind. Currently, the US is planning to build FutureGen, a "zero-emissions" advanced coal plant, slated to finish construction in 10 years. In this innovative project, many pollution reducing proposals that will dramatically reduce carbon monoxide and nitrogenous wastes will be implemented in a beta advanced coal power plant.

Nuclear? : Nuclear fusion has the potential to produce 10 million times more energy per kilogram than fossil fuels. ITER, the International Thermonuclear Experimental Reactor is being built in France as we speak, and will hopefully prove that fusion is both possible and feasible. Nuclear fission is still in the picture, especially since natural gas and petroleum reactors are no longer profitable. However, strict government regulation has hampered any efforts to build a new nuclear power plant for 20 years. Breeder reactors, which would take spent radioactive nuclear fuel from fission reactions and further process it to decrease radioactivity is being pursued internationally, though not so much in the United States because of government regulation. There are signs that regulations are being relaxed to allow nuclear fission plants to become profitable again, and the hopes of many are that fission plants will be built instead of the planned advanced coal plants.

Solar Energy: If every sun-facing roof in America was solar-paneled, 25-33% of America's energy would be taken care of. The high costs of energy are making solar projects feasible. Multiple techniques of harnessing solar energy: Solar dishes, solar

panels, mirror heating systems, etc. Right now, solar panels are about 20% efficient, but already experimental panels can capture up to 30% of sun energy.

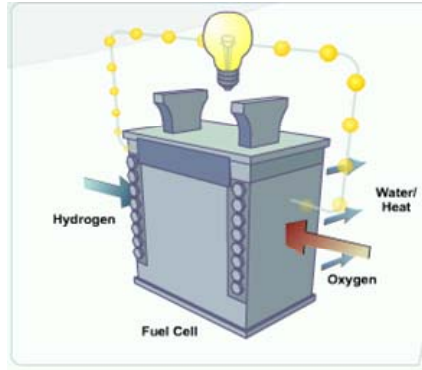


Here are some of the different ways that solar power can be harnessed: (Clockwise from top left) mirror focusing light onto a hydrogen expansion engine, typical solar panel, rows of mirrors focusing light on a water pipe to create steams and power a turbine, diffraction glass capturing light energy.

Ethanol: Ethanol, a cleaner burning fuel than gasoline, can be produced domestically in a variety of different ways; currently, people are fixating on ethanol production from corn, but more practical methods include synthesizing it from agricultural wastes. The problem is that if conventional corn is used to generate ethanol, then the pollution associated with farming (a rather intensive process) will partially neutralize the gains of ethanol, a cleaner burning fuel. Although the cost of a barrel of ethanol can be \$120 compared to around \$70 for oil, the ethanol industry is an decreasing cost industry and if the rate of price hikes remain the same for gasoline, it will be no time at all until ethanol is an attractive alternative. Currently, cars can handle up to a 10% blend of ethanol in fuel, and new “Flex-Fuel” vehicles work on 85% blends of ethanol. The country of Brazil provides for most of their car fuel by harvesting vast tracts of sugar cane and converting it into ethanol. Ethanol is not zero-emissions, simply a way to decrease oil-dependence. There is research investigating ethanol’s potential use in hydrogen fuel cells, which will be discussed later.

Biodiesel: Biodiesel is an attractive fueling choice for any cars that run on diesel, and is a clean-burning fuel that can ensure longer engine life. From a cost perspective, it is rather expensive compared to petroleum-diesel, but as production of it increases it is expected that its price should go down. Biodiesel can be derived from vegetable oils, and is both biodegradable and non-toxic. Immense tracts of land would be required to produce enough biodiesel to power all US car, unfortunately. Lately, there has been research in algae's capability to produce oils that are suitable for biodiesel – some benefits of this process are that ideal locations for algae oil farms would be in deserts, with the most solar exposure, and smaller amounts of land would have to be used. Once again, biodiesel is not a zero-emissions fuel, but is cleaner burning and would further America's energy independence. There are alternative biodiesels that are not standardized but are readily available: for instance, it is possible (with less than \$200 in modifications to a traditional diesel engine), to run a diesel car or truck on kitchen grease wastes. Though only an oddity at this point, a fanatic group of followers are starting up companies to provide these grease wastes in different cities (obtained from fast food restaurants and such).

Hydrogen Fuel Cells: Hydrogen Fuel Cells acquire energy from the exothermic reaction between O_2 and H_2 to form water. The H_2 and O_2 are fed into a polymer electrolytic membrane (PEM), electron exchange takes place. The only emission from this reaction is water, however to obtain the hydrogen required for the reaction chemical processes may emit non water waste. There are many different types of fuel cells being developed – the main problem is that hydrogen is an especially difficult gas to store, so methanol, ethanol, laundry detergent, platinum and many other methods are proposed for hydrogen storage. The different methods of storage require different temperatures and conditions, as well as different PEM's. On the whole, this is a rather pricey process, and the US economy is several years away from being able to distribute and use hydrogen as an energy source. There are several flavors of hydrogen fuel cell: Polymer Electrolyte Membrane (PEM), Direct Methanol, Alkaline, Phosphoric Acid, Molten Carbonate, Solid Oxide, and Regenerative fuel cells. They all work by the same basic principal. A porous anode and cathode are separated by a porous membrane. Hydrogen is injected into the negatively charged anode, and with the help of a catalyst (usually platinum) the hydrogen atoms have their electrons removed and are now simply H^+ protons. These electrons cannot travel through the membrane towards the positively charge cathode, so they travel in a circuit creating a current – this is where the electricity is generated. These electrons are combined with oxygen at the cathode end of the cell, and the electronegative oxygen ions absorb these electrons. The charged oxygen and hydrogen permeate through the membrane and combine to form H_2O , or water.



<http://www.eere.energy.gov/>

Comparison of Fuel Cell Technologies

Fuel Cell Type	Electrolyte	Operating Temperature	Applications	Advantages	Disadvantages
Polymer Electrolyte membrane (PEM)	Solid organic polymer polyperfluorosulfonic acid	60–100°C 140–212°F	• electric utility • portable power • transportation	• Solid electrolyte reduces corrosion & management problems • Low temperature • Quick start-up	• Low temperature requires expensive catalysts • High sensitivity to fuel impurities
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90–100°C 194–212°F	• military • space	• Cathode reaction faster in alkaline electrolyte so high performance	• Expensive removal of CO ₂ from fuel and air streams required
Phosphoric Acid (PAFC)	Liquid phosphoric acid soaked in a matrix	175–200°C 347–392°F	• electric utility • transportation	• Up to 85% efficiency in cogeneration of electricity and heat • Can use impure H ₂ as fuel	• Requires platinum catalyst • Low current and power • Large size/weight
Molten Carbonate (MCFC)	Liquid solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	600–1000°C 1112–1832°F	• electric utility	• High efficiency • Fuel flexibility • Can use a variety of catalysts	• High temperature enhances corrosion and breakdown of cell components
Solid Oxide (SOFC)	Solid zirconium oxide to which a small amount of yttria is added	600–1000°C 1112–1832°F	• electric utility	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte reduces	• High temperature enhances breakdown of cell components

http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/pdfs/fc_comparison_chart.pdf

One of the challenges confronting hydrogen fuel cells is the source of fuel. Where and how will the hydrogen that powers these devices be produced? Many of the current methods for producing hydrogen produce significant emissions, thus making the entire process not so “emissions free”. There are many solutions out there, but one of the most promising and seemingly infinite sources is electrolysis of water by photoelectric panels. In this system, solar panels convert sunlight to energy and split water molecules as following – $\text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2$.

Conclusion: It seems the United States is attempting to juggle two problems – energy independence and lower emissions. The automotive industry in America will be greatly benefited by the rise of ethanol and biodiesel, produced domestically, and these two

industries will become prominent over the next decade. In terms of providing power to American homes, over the next decade it seems that advanced coal plants and nuclear fission will be the primary new energy sources, the latter being preferable in terms of lower emissions. Solar power and fuel cells have a long while to go before they become mainstream, but they promise some of the cleanest technological pathways and should not be dismissed.