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# Calculating Hydrogen Production Costs

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Two of the most important question to be resolved in shifting to a hydrogen economy is what will the hydrogen be made from, and how much will it cost? Hydrogen can be made from any fossil fuel or nuclear facility, as well as any solar energy technology. In evaluating energy costs, cost per unit of heat, such as British Thermal Units (Btus), are used. This is because Btu numbers make comparative economic analysis of different energy systems easy because every energy resource can be measured on a Btu basis.

One Btu is the amount of energy needed to raise temperature of one pound of water by one degree F. Typically, a match has about one Btu. A kilowatt hour of electricity has 3,412 Btus, and a gallon of gasoline has about 120,000 Btus. A gallon of liquid hydrogen has about 30,000 Btus, which explains why a liquid hydrogen tank is approximately four times larger by volume than a gasoline tank. In spite of the larger liquid hydrogen fuel tanks, Lockheed engineers calculated that that takeoff weight of a typical commercial aircraft would be reduced by over 40% if liquid hydrogen was used instead of conventional aviation kerosene. This means much larger aircraft can be built, and it is why with hydrogen fuel systems, bigger is better.

## Current Hydrogen Production Costs

Since a gallon of gasoline has about 120,000 Btus, if its production cost is $1.00 a gallon, it is equivalent to $8.33 per million Btus (MMBtus). By contrast, hydrogen manufactured by coal will cost about $7.00 to $10.00/MMbtu. Most of the hydrogen that is used to make gasoline and other chemical products comes from natural gas. Although natural gas prices over the past decade have been in the range of $2.00/MMBtu, given supply problems, current natural gas prices are now in the range of $7.00/MMBtu. Moreover, natural gas prices are expected to continue increasing as the available reserves are exponentially consumed. As a rule, hydrogen costs from natural gas are about two or three times the cost of the feedstock, thus $7.00 feedstock gas would result in the hydrogen costing between $18 to $20.00/MMBtu, which is equivalent to gasoline costing about $2.40 a gallon.

## Wind Electric Systems

The cost of electricity is a major factor in hydrogen production costs. Although any solar energy option can generate the electricity needed for hydrogen production, the cost of electricity from photovoltaic solar cells is about 10-times more expensive than the electricity generated from megawatt-scale wind machines. State-of-the-art wind systems, which have an installed capital cost of approximately $1,000 per kW and a 35% capacity factor, are able to generate electricity for approximately 4-cents per kWh. If the wind systems are mass-produced like automobiles for large-scale hydrogen production, their capital costs will be expected to drop to well below $300/kW, which will reduce the cost of electricity to one or two-cents per kilowatt hour (kWh).

## Electrolyzers

Electrolyzers have been in commercial use for over 100 years, and they are the key technology that takes about 3 gallons of water and 60 kWh of electricity to manufacture the energy content of a gallon of gasoline in the form of gaseous hydrogen. Assuming the electricity costs 4-cents/kWh, the electricity costs alone would be approximately $20.00/MMBtu, which is equivalent to gasoline costing $2.40 per gallon. The capital cost and maintenance of the electrolyzer and related hydrogen storage and pumping system also needs to be factored into the equation. With conventional electrolyzers that are not in high-volume production, the installed capital costs are in the range of $600/kW, which adds an additional $4.00/MMBtu, thereby increasing the production cost of the gaseous hydrogen to about $24.00/MMBtu, which is equivalent to gasoline costing $3.00 per gallon. If the hydrogen is to be liquefied, an additional $4.00/MMBtus would be added, which would make the production cost of liquid hydrogen about $28.00/MMBtu, which is equivalent to gasoline costing $3.38 per gallon.

## Mass-Produced Wind Hydrogen Costs

Assuming the wind-powered electrolyzers are mass-produced on a scale to displace fossil and nuclear fuels, the electricity costs would be reduced to about one cent/kWh, and the electrolyzer costs would be reduced to less than $100/kW, which would reduce the gaseous hydrogen production cost to approximately $10.00/MMBtus. If the hydrogen is to be liquefied, an additional $3.00/MMBtus would be added, which would make the cost of liquid hydrogen about $13.00/MMBtu, which is equivalent to gasoline costing $1.56 per equivalent gallon.

However, additional cost per mile savings occur because hydrogen-fueled internal combustion engines are about 25% more fuel efficient than when they use gasoline, and they do not generate organic acids and carbon deposits, which contaminate the engine oil and reduce engine component life. These additional factors would reduce the price of liquid hydrogen to about $1.40 per equivalent gallon of gasoline. This cost does not include state or federal taxes, which typically add an additional $0.40 per gallon, bringing the total cost to approximately $1.80 per equivalent gallon of gasoline. It is important to note the cost of gasoline will always be getting more expensive in the future as global oil reserves are depleted, whereas the cost of solar hydrogen will always be getting less expensive in the future as more and more engineers optimize the technology.

## External Costs

External costs cost of fossil and nuclear energy systems include environmental damage and climate change, and the resulting billions of dollars in related health care costs that result from contaminating the ocean ecosystems and the millions of families who are forced to live their lives breathing unhealthy air and drinking contaminated water. Other external costs include the storage of radioactive wastes, corrosion to buildings and bridges, and the military costs of protecting the remaining oil reserves in the Middle East. If these costs were factored into fuel costs, the cost of gasoline would be easily increased by a factor of 2 or 3. Factoring carbon sequestration alone will increase the price of gallon of gasoline by 80-cents per gallon, based on CO2 sequestration costs of $100 per ton. Moreover, unlike wind hydrogen systems, which will always be less expensive in the future as more and more engineers refine the technology, gasoline and other hydrocarbon fuels will only get more expensive as the global fossil fuel reserves are exponentially depleted.

## The Fair Accounting Act

The "trigger mechanism" for this "transition of substance" to a solar hydrogen economy is the passage of Fair Accounting Act legislation by the U.S. Congress and state legislatures. This legislation would transfer the $150 billion a year in subsidies to fossil and nuclear fuel systems to renewable hydrogen systems, and factor in at least some of the external costs of using dirty energy sources. If a "fair" accounting system is used, taxes on a gallon of gasoline would be increased by at least a $1.00 a gallon, which would then make hydrogen competitive with gasoline and other hydrocarbon fuels. Moreover, the funds raised by the Fair Accounting Act could then be returned to the consumers in the form of a tax credit to defer the cost of modifying their existing vehicles to use hydrogen fuel. As the fossil fuels are phased-out, so will the carbon tax that would be imposed by the Fair Accounting Act. This underscores the fact *that tax policy profoundly impacts energy, economic, environmental and foreign policies.*

## The Phoenix Project

Because of the exponential nature of the interrelated global energy and environmental problems, *The Phoenix Project* calls for the U.S. to shift from fossil and nuclear fuels to wind-powered electrolytic systems with wartime speed. Approximately 10 million one-megawatt wind machines would be needed to generate all of the U.S. current energy requirements (i.e. 100 quadrillion Btus). Given that wind machines are similar to an automobile from a manufacturing perspective, and given that 17 million vehicles are manufactured each year in the U.S., the needed wind systems could be mass-produced and installed in less than 12 months once the tooling is in place. As such, it is possible for the U.S. to be energy independent with a pollution-free and inexhaustible energy resource within 5 or 10 years. That would include the development and deployment of a an interstate superconducting hydrogen pipeline system that would carry both electricity as well as hydrogen, as well as the modification of all of the automotive vehicles and power plants in the U.S. Such a transition of substance will have profound implications for the economy, the environment, and U.S. foreign policy.