THE hydrogen ECONOMY

Energy Transformations: A Look Back

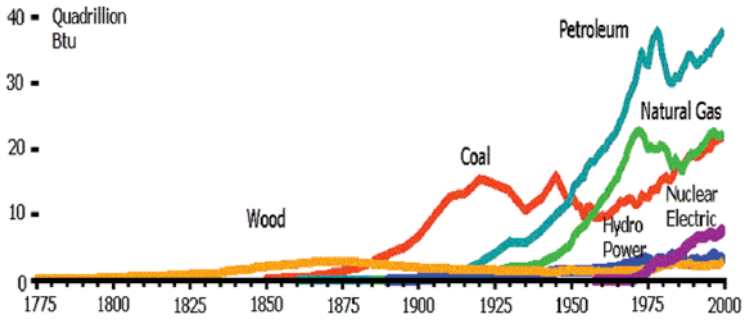
The transition to a hydrogen economy - though it may sound implausible - isn't unprecedented. Up until the last half of the 19th century, the United States had an energy system based on animals for transportation and wood for heating and cooking. Today, energy in the form of transportation fuels and electricity has become so ubiquitous it is difficult to separate it from the function of modern society.

In the span of less than 150 years, the U.S. and much of the developed world, has successfully transitioned from wood to coal, to increasing contributions from natural gas, petroleum, hydro, nuclear energy (see Figure 1) and, most recently, renewables. The later transitions are more reflective of a diversification of energy resources than actual transitions. The entry of new energy resources has been driven in large part by environmental concerns, technological advances, demand and economic forces.

Until the end of the 20th century, the U.S. produced nearly all of the energy it needed. In the 1980's consumption of natural gas began to outpace domestic production so the U.S. turned to Canadian imports to make up the difference. Starting in 1994, the U.S. imported more petroleum than it produced, mostly to meet transportation demands. For electricity generation, abundant coal remains the dominant, domestic primary energy resource.

Access to energy has had unparalleled consequences socially, economically and environmentally. The industrial revolution and indeed the technological revolution would not have been possible without a reliable energy supply. But the principal energy resources of the fossil fuel economy are finite, and they produce emissions that are harmful to the environment when we use these resources to provide lighting, cooking, heating and mobility. These factors will likely be among the main drivers to bring about the next energy transition.

Figure 1: Energy Consumption in the United States, 1775-1999



Source: U.S. Department of Energy, Energy Information Administration "Milestones in the History of Energy and its Uses". www.eia.doe.gov/kids/milestones

The Next Energy Transition

Right now we may be standing on the brink of the next big energy transition, or diversification. The international community recognizes hydrogen as a key component to a clean, sustainable energy system. This future hydrogen economy features hydrogen as an energy carrier in the stationary power, transportation, industrial, residential and commercial sectors. As technology matures, hydrogen will be produced mainly using clean technologies like electrolysis from renewables and nuclear, or reformation of fossil feedstocks with carbon sequestration. It may be stored, transported by truck or pipeline, and used in a fuel cell, turbine or engine to generate an electric current with water as the principal by-product.

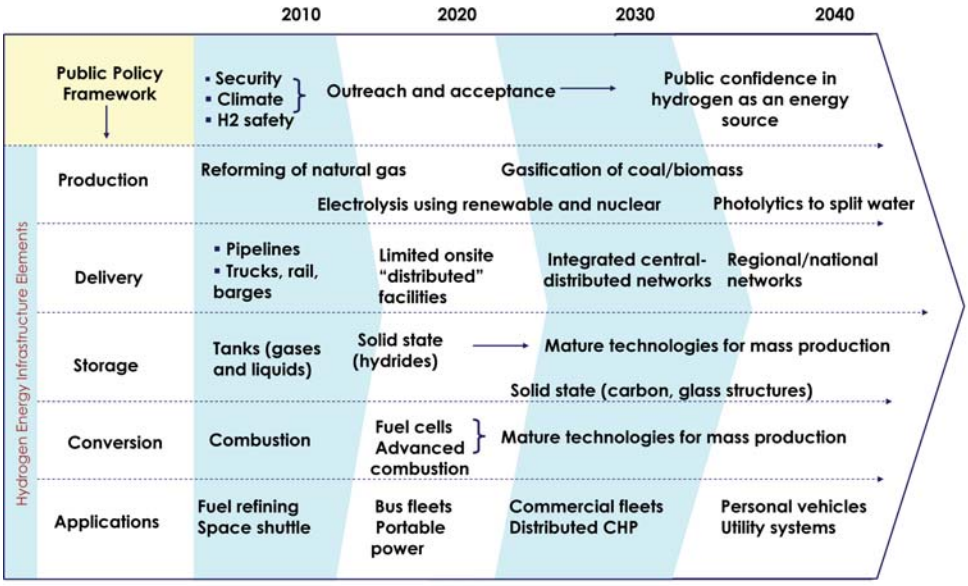
To reach that point, hydrogen will be introduced into small market segments as these technologies become market-ready. The chemical and refining industries have safely produced, stored and transported hydrogen for industrial purposes for decades. The technologies used by those industries to produce hydrogen are a logical starting point to catalyze more widespread use of hydrogen as an energy carrier (see Figure 2).

> "The Stone Age did not end because we ran out of stones, and the Oil Age will not end because we run out of oil."
>
> *Don Huberts, Shell Hydrogen*

Hydrogen Production

In the near- to mid-term, hydrogen will likely be produced by steam reforming natural gas, a well-understood and time-tested technology, and by water electrolysis using electricity from conventional energy resources. In the mid- to long-term, the hydrogen production technologies currently under development --renewables via electrolysis, direct renewables (photobiological, photoelectrochemical, etc.), high temperature nuclear chemical cycles, clean coal and natural gas--will become more cost effective and contribute to a diversification of domestic hydrogen production. One of hydrogen's great strengths is its ability to be produced from a wide variety of resources. Each region may use a different combination of resources to produce hydrogen.

Figure 2: Transition to Hydrogen Economy



Source: U.S. Department of Energy, Hydrogen Posture Plan

Hydrogen Distribution

A reliable and low-cost hydrogen distribution network will not be built overnight. Limited hydrogen pipeline networks exist in certain regions of the U.S. to supply hydrogen to the refining industry. Gas production plants also frequently transport hydrogen by tanker truck to industrial users. As hydrogen demand grows, industry will respond by building or expanding the hydrogen delivery and distribution network using current and advanced technologies for pipeline construction, hydrogen storage and delivery.

Hydrogen Utilization

The fuel cell is one of several conversion technologies that can be fueled by hydrogen. Basically, hydrogen fuel cells operate like electrolysis in reverse: Hydrogen gas and oxygen from the air combine in a catalyzed electrochemical reaction to produce an electric current, heat and water, pure enough to drink. Aside from being pollution-free, fuel cells are quiet, and can achieve efficiencies that are two- to three-times greater than internal combustion engines. The scalability of fuel cells makes them ideal for a wide variety of applications – including laptops (50-100 Watts) and central power generation (1-200 MW). Although fuel cells have the potential to serve all sectors of the economy, today they are relatively expensive to build compared to our internal combustion engines. They will need further development to increase durability and bring down cost so they can compete economically.

CARBON SEQUESTRATION

The use of fossil resources (natural gas, coal, petroleum) to produce hydrogen emits some carbon dioxide (CO_2), a greenhouse gas. Technologies to capture and sequester (store) CO_2 are under development. We will need these technologies before large-scale hydrogen production from fossil resources contributes to the transition to a sustainable hydrogen economy.

We can use hydrogen in internal combustion engines (ICEs), similar to the engines we have in our cars today, with slight modifications. Hydrogen burns much cleaner and more efficiently than gasoline which makes hydrogen ICEs a realistic near-term transition technology. However, fuel cells, with higher efficiencies and zero emissions will likely be a more popular utilization technology in the longer term.

Reciprocating engines and combustion turbines are also under development to combust hydrogen in place of traditional fuels to efficiently generate electricity and thermal power with zero emissions. Once mature, these technologies can also find use for on-site power applications in homes, offices and industrial facilities.

Getting There

As with all energy transitions, the transition to a hydrogen economy will take time and occur in phases. Technological advances and market acceptance are expected to define the phases. In addition, a corresponding education effort in hydrogen safety will ensure public readiness as hydrogen becomes increasingly available.

Government, industry and the public will all play vital roles. Government will be a major supporter of technology research and development as well as the development of codes and standards for the safe use of hydrogen. Governments also can use policy to stimulate the marketplace and to encourage "early adoption" of hydrogen energy technologies. Industry's role is to determine when technologies are ready to transition to the marketplace and in establishing the manufacturing base to supply the component technologies. Together, industry and the public will define consumer requirements and market acceptance of the technologies.

Hydrogen presents a significant economic opportunity for U.S. industry. By taking an aggressive position in hydrogen energy technology development, the U.S. is well-positioned to supply hydrogen technologies worldwide. The transition will require significant effort and investment. But the outcome will be a reliable and sustainable economy that uses domestically available, renewable resources to provide clean electricity and fuels to meet our energy demands.

For more information on hydrogen and to view the electronic version of this fact sheet, please visit www.HydrogenAssociation.org or www.eere.energy.gov/hydrogenandfuelcells/