Hydrogen: Reality and Policy

The challenge and the alternatives

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"Essentials" are published by TSAugust to bring essential information about the environment to people everywhere in the United States, especially students.

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Preface

Building the physical infrastructure to support the hydrogen economy is an immense task;

It also requires a huge financial investment.

In addition, the technologies are undeveloped; and, to some extent, unproven.

Despite these truths, hydrogen may yet be our best hope for decoupling our economy from oil…Sometime during the 21st century.

Donn Dears

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Introduction.

The TSAugust paper "Hydrogen Today" defined the parameters surrounding the development of a hydrogen economy. This paper addresses policy considerations and a reality check on the task confronting America in establishing a hydrogen economy.

"Hydrogen Today" categorized the technical and cost issues as follows:

- Production
- Delivery (Transporting of hydrogen.)
- Storage
- Usage (Conversion of hydrogen to useful work.)
- Safety

A first step in evaluating policy considerations is to examine alternative pathways for achieving a hydrogen economy. These are outlined in Figures I thru V in the Appendix.

A second step is to examine the alternatives in light of available resources. These reality checks shed light on the task ahead. Though the reality checks are based on estimates, they identify the magnitude of the task.

An important aspect of this analysis is that it identifies the additional or new infrastructure required for a hydrogen economy.

Alternative Pathways.

There are five basic alternative pathways to achieving a transportation economy based on hydrogen.

As can be seen from Figures I thru V(b) in the Appendix, the decision tree branches at the decision points depicted in Diagram 1.

1.0 Local **OR** Centralized production of hydrogen

1.1 For <u>local branch</u>; Electrolysis **OR** steam methane reforming

1.2 For <u>centralized branch</u>; electrolysis **OR** steam methane **OR** thermo (Nuclear) **OR** other technologies such as solar or biomass if they prove feasible.

1.2.1 For <u>next branch in centralized tree</u>, Compressed **OR** Liquefied hydrogen and

1.2.1.1 For <u>centralized compressed hydrogen branch</u>; dedicated pipeline **OR** trucking.

Diagram 1

Continued ⇒

(Alternative Pathways Cont.)

The following are significant comments pertaining to these alternatives:

1.2. Centralized branch comments:

- Electrolysis could use nuclear generating plants, or coal or gas powered generating plants for the electricity needed to produce hydrogen.
- The Steam Methane method could use coal rather than natural gas as its source of hydrogen. One approach is a coal gasification combined cycle system to produce electricity and hydrogen. This is a proven process.
    - There are ample reserves of coal in the US while natural gas in the US is limited in supply. Data is not currently available to compare the cost of producing hydrogen from coal with that of hydrogen from natural gas.
    - Using coal results in byproducts such as CO2. Sequestering of CO2 would add to cost but is feasible if deemed necessary.
- Direct thermo chemical processes are being developed for producing hydrogen from water using the high temperatures generated by nuclear reactors. This and other processes using nuclear energy are still in the research stage.
    - Using nuclear under any scenario will require the political will to overcome the objections of political environmentalists.
- Biomass is in the very early stages of determining whether the process is feasible on a large scale. Solar (Photo Voltaic) suffers from the same limitations as wind in that current technology requires too much space to produce the required amounts of electricity[1].

1.2.1 Compressed or liquefied branch comments:

- A dedicated hydrogen pipeline would probably be at a lower pressure than the ultimate fueling pressure of, for example, 10,000 psi. Natural gas pipelines, for example, typically operate at between 600 and 1400 psi.

  Compressing hydrogen to, say 10,000 psi, for local storage and fueling would probably be done at the local fueling station rather than at the centralized plant. Hydrogen pipelines may have additional problems in that hydrogen may be more susceptible to leakage while hydrogen can also embrittle some metals used for pipelines.
- A decision tree branch for Liquefied hydrogen showing a choice between trucking and dedicated pipelines has been omitted. (Trucking could be augmented by barges or coastal sea transport.) This is an arbitrary omission based on cost, in terms of energy lost plus the cost of refrigeration to maintain the hydrogen in liquid state over long distances. Separately, there has been a proposal for power generation and superconductivity for transmission that uses liquefied hydrogen as a coolant where liquefied hydrogen would be transported in pipelines encasing the super conducting cables[2].

For general reference, Figure VI (Appendix) depicts the various processes for producing hydrogen.

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Reality Checks

Before proceeding with a discussion of alternative policies it is wise to test key assumptions against known criteria or conditions. These reality checks put various alternatives into perspective.

1. If all of the hydrogen required to fuel all of the vehicles currently in use today was generated using electrolysis, it would be necessary to build new electric generating capacity nearly as large as is installed today in the United States. In addition, with local electrolyzers, sufficient transmission and distribution systems would also have to be built, nearly duplicating the transmission and distribution systems existing today.
2. If all of the hydrogen required to fuel all of the vehicles currently in use today was generated using the steam methane method with natural gas as the feedstock, it would be necessary to extract and distribute half again as much natural gas as is currently being used in the United States. In addition, sufficient new transmission and distribution capacity would also have to be built roughly increasing the size of the existing natural gas transmission and distribution systems by 50%. This is in addition to the 48% increase in production and 30% increase in distribution required by 2020 by economic growth, without using natural gas for the production of hydrogen[3].

In other words, we will (1); either have to nearly duplicate our existing power generating capacity **or** extract 50% more natural gas than is currently being used in the United State, under the above two scenarios:

And (2); we will need to substantially replicate the existing electric or gas transmission and distribution infrastructure unless production of hydrogen is done centrally in which case only hydrogen gas distribution pipelines will need to be built.

And what about cost?

- The United States currently has an installed generating capability of 903,000 MW.

  Using the BTU content of gasoline, the total BTU's consumed by automobiles in the United States in 1999 was approximately 15.8 Quads. At a conversion factor of .5 for converting water to hydrogen and assuming that Fuel Cell powered cars are twice as efficient as gasoline powered cars, the total new generating capacity that would have to be built is 661,105 MW. This could be reduced if off peak power was used for some production of hydrogen. It may also be reduced if the conversion factor and efficiency of the FC car are improved[4 & 5].
- The United States currently consumes 23.4 quads of natural gas each year.

  Using a conversion factor of .7 for the steam methane process for producing hydrogen and assuming that Fuel Cell powered cars are twice as efficient as gasoline powered cars, we would need to produce 11.3 quads of additional natural gas each year to generate the hydrogen needed to replace the gasoline consumed by the 132 million cars on the road in 1999[6].

Neither of these estimates include trucks or other users of gasoline or diesel fuel.

- The potential total cost for adding 661,105 MW of generating capacity and related transmission line capacity is $1.3 Trillion[7].
- The potential total cost for producing, transmitting and distributing the 11.3 additional quads of natural gas would be approximately $863 Billion[8].

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(Reality Checks Cont.)

(The major difference between these two cost estimates is in the cost of new transmission and distribution.)

Admittedly these calculations are rough but they do provide a glimpse at the magnitude of the challenge facing the US if it seriously wants to develop a hydrogen economy. These requirements are in addition to the new power generation and gas production facilities needed to meet the demand created by the increased population of 120 million Americans by 2050.

These numbers are mind boggling so relating them to more easily comprehended reference points may be useful.

Adding the extra generating capacity to produce the required hydrogen, means building over 2640 new power plants rated 250 MW[9] or 156 new such plants each year by 2020; if that is the target date for replacing all cars with fuel cell cars. This is in addition to the nearly 1000 additional 250 MW units needed by 2020 to merely accommodate normal growth without hydrogen.

This would be an aggressive but not impossible task, given that 55,114 MW of generating capacity were added in 2002. Total generating capacity needed by 2020 for normal growth plus growth to produce hydrogen is 904,000 MW. At the rate of 55,114 MW per year the required capacity could be added in just over 16 years. It should be noted however that the average increase in generating capacity for the preceding ten years was slightly over 11,000 MW, so 2002 was an unusual year[10]. Using 11,000 MW average for the past ten years it would require 82 years to add the required additional capacity.

Renewable energy such as wind cannot meet this need.[11]

Policy Considerations.

While at first blush it might seem logical to produce hydrogen locally, using either electrolysis or the steam methane method, it may not be the long term least costly approach.

For Example:

- A system of regional centralized electrolysis plants having a dedicated power generation facility co-located with the hydrogen generating plant could be more cost effective than local electrolysis. This centralized scheme would eliminate the need for additional costly electric transmission and distribution facilities. Dedicated hydrogen gas lines would be required but they may be less expensive than increasing the electric transmission and distribution infrastructure. Given the difficulty in siting new transmission lines, installing dedicated hydrogen pipelines may be the better approach.
- Similarly, a Thermo hydrogen generating plant using nuclear would eliminate the need for additional investment in natural gas production, transmission and distribution. Dedicated hydrogen gas lines may be less expensive than increasing the transmission and distribution pipelines for natural gas required under the local steam methane scenario.

All these alternatives raise the issue of whether public financial support is appropriate at the current stage of the development process.

Is it appropriate to use taxpayer money to stimulate the advancement of hydrogen as a fuel and to advance the introduction of fuel cell vehicles?

Should money be used for R&D or to encourage the use of hydrogen and fuel cell vehicles through financial incentives?

(Policy Considerations Cont.)

Should the government make a single big bet on a technology or should it make a number of smaller bets on many technologies?

At the next level, the issue becomes how best to intercede: By using tax breaks, subsidies, R&D contracts, loans or direct support, such as by mandating the purchase of fuel cell vehicles by government bodies.

The question of timing is of utmost importance when examining these issues. Acting prematurely could lock the economy into the wrong technology: Or waste tax dollars. For example, would initiating an Apollo type program today to build centralized hydrogen production facilities using coal as the feedstock with dedicated hydrogen pipelines for distribution be a good investment: Both in dollar terms and for national security?

Do we really know enough about the alternatives for centralized production to jump in that direction?

Or, would it be better to allow technology and market forces guide the direction of the development of a hydrogen economy? A fundamental difference between the Apollo program and the current H2 situation is that little attention was paid to the cost effectiveness of the Apollo rocket and moon landing system.

The cost effectiveness of the ultimate hydrogen economy is important and depends on choices for which there are currently few answers.

Governments have been singularly unsuccessful in making big bets and selecting winners. Japan tried a centralized approach to energy beginning in 1974 called the “Sunshine Project”. Later it became the “Moonlight Project.” And in 1993 the “International Clean Energy Network Using Hydrogen Conversion (the WE-NET) program” was initiated. In another example Canada and the EU tried to structure a program using Hydro power to produce liquid hydrogen and then transport it to Europe in ships. Similarly, Norway and Germany proposed a scheme using hydropower in Norway and transporting liquid hydrogen to Germany by ship[12].

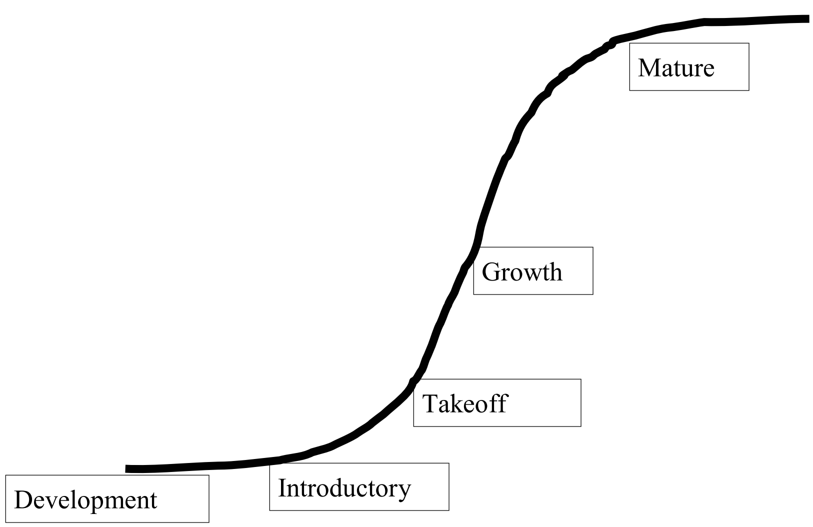

Diagram 2

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(Policy Considerations Cont.)

In each case there was a bureaucratic imprint on the proposal which is typical of grand schemes undertaken by governments. None of these proposals has advanced the hydrogen concept very far.

Examining the traditional "S" curve (Diagram 2) is useful when considering new technologies.

The "S" curve depicts the life cycle of a product or technology. At the root of the "S" curve is the development stage, followed by the introductory stage, then the take off and growth stages and ending with the mature stage as the technology and market becomes mature.

Hydrogen and fuel cells for transportation are clearly in the development stage. Fuel cells for stationary power generation may be entering the introductory stage; but not all fuel cells used for stationary power are suitable for use in vehicles, so support for stationary power fuel cells may not translate into advances for fuel cells used in vehicles.

During the development stage the emphasis should be on R&D and the establishment of demonstration sites. In fact, there are a multitude of technologies each with an "S" curve.

This is why Venture Capital firms place smaller bets on several different technologies, anticipating that at least one will be successful.

If government intervention is desirable at this stage, tax dollars could be spent on research and development: Placing multiple smaller bets to encourage different technologies rather than selecting one as the assumed winner.

R&D has a multiplying effect. VC's see this when their original investment is transformed into a large payoff from an IPO.

While the government doesn't see a large payoff from an IPO it can see more rapid development of technologies that are beneficial to its taxpayers through economic development and more jobs. The caveat is that decisions on using tax money for R&D should be based on scientific and business analysis, not politics.

The introductory stage presumes marketable, safe products. In the case of hydrogen it infers that suitable fueling stations have been developed and that first generation production models of fuel cell vehicles are available. By definition these products will be more expensive than commercially available alternatives. At this stage government intervention could take the form of tax incentives for purchasing fuel cell vehicles or for installing fueling stations.

Once the take off stage is reached market forces should begin to take over and government intervention, if desirable, could focus on accelerating the adoption of the new technologies. Also at this point the succeeding "S" curve should begin to emerge for the second generation of products. Here again government could use R&D to stimulate these new developments.

Another place where government could intercede is in the establishment of safety standards. There are a multitude of standards bodies and a myriad of government entities involved in this effort. Given the complexity of the issue Federal and State governments could establish an organization, similar to UL, for establishing safety standards with the understanding that states would accede to the standards established by this organization. This could be a private corporation with some government financial support which would avoid creating a new bureaucracy.

A fundamental policy issue is whether the shift to a hydrogen based transportation system is motivated by a desire to lower green

(Policy Considerations Cont.)

house gas (GHG) levels or to reduce or eliminate the use of imported oil from foreign sources.

While there are ten times as many scientists who believe that global warming is not being-caused by GHG (primarily CO2 and methane) the minority has generated a great deal of fear in the general public. Because of this fear, there is pressure to move to H2 for transportation no matter the cost.

Rationally, GHG should not drive such an enormous shift. Interestingly, a recent MIT study[13] indicates no advantage for a FCV over a hybrid ICE vehicle where GHG are concerned.

Eliminating the use of foreign oil has strategic implications that could warrant government assistance for R&D now and for assistance later to accelerate implementation.

Conclusions.

Good policy decisions will acknowledge the realities surrounding the task of transforming the transportation sector from an oil to hydrogen driven economy.

The first reality is that the job is enormous. The physical task of constructing the required infrastructure is an immense undertaking; especially if it is to be done in a short time frame. Building power plants and transmission and distribution systems; finding and then drilling and establishing new natural gas production facilities; obtaining regulatory approvals for nuclear or coal based or other controversial installations, and overcoming local resistance are daunting tasks.

The second reality is that the cost will be staggering.

The third reality is that the various technologies are at a very early stage of development with no clear indication as to which technology is superior.

Compounding these realities is the general concern that our economy depends on imported oil.

Reality would suggest a go slow policy; but the desire to uncouple our economy from imported oil would suggest a more aggressive policy.

Finding the right balance is the true challenge facing policy makers. Going too slow could subject our economy to oil disruptions. Going too fast could waste money and lock the economy into the wrong, inefficient technology; allowing other countries to leapfrog our technology, thereby making our economy uncompetitive on the world stage.

A moderately aggressive policy could take the following form

1. Support for R&D across the spectrum of hydrogen and fuel cell technologies relating to transportation.
    - This could include studies by industry for centralized production and distribution of hydrogen so that centralized production is well understood in time to evaluate it as an alternative to local production.
2. Support for demonstration projects for each technology that appears ready for implementation.
    - This could include FC vehicles that do not meet minimum distance and speed requirements required for daily use by the general public; plus, busses, fleet vehicles and taxi's.

(Conclusions Cont.)

3. Initially, support for localized production of hydrogen to establish a network of hydrogen fueling stations using either hydrolysis or steam reforming of natural gas
    - Hydrolysis could initially take advantage of off peak power thereby limiting its impact on generation and transmission facilities during this early implementation stage.
    - The current high price and limited supplies of natural gas could preclude this option unless new supplies are developed and transmission lines are constructed.
4. Encourage the introduction of modified internal combustion engines using hydrogen. This could help support the installation of hydrogen fueling stations and eliminate the chicken or egg problem inherent with this new technology. It could accelerate the transition to a hydrogen economy.
5. Support for an independent corporation, similar to UL, for establishing safety requirements.
6. Encourage market forces rather than government schemes for development of hydrogen economy.
7. Wait for fuel cell vehicles to achieve minimum distance and speed criteria before supporting the purchase of fuel cell vehicles by the general public. This would be at the takeoff stage of the technology cycle.

There is no guarantee that hydrogen will emerge as the transportation fuel within the next twenty years…Or even the next hundred years. Renewable's can fill no more than a niche when it comes to replacing fossil fuels.

Therefore, policies should also consider what will happen if hydrogen does not become viable as a transportation fuel.

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APPENDIX

Figures I thru V(b) depict the steps required for each hydrogen production alternative, from fueling, back to the well head or power plant.

I. Distributed Hydrogen generation, using local small **steam methane** reformers**.**

- Local steam methane reformer generating compressed hydrogen for fueling vehicles
  - o Gas distribution pipeline of natural gas (methane).
    - ◊ Gas transmission pipeline of natural gas (methane).
      - ∗ Gas processing plant (separate methane from propane etc.)
        - √ Gas well

Figure I

II. Distributed Hydrogen generation, using local **hydrolysis.**

- Local hydrolysis unit generating compressed hydrogen for fueling vehicles
  - o Electric distribution lines and transformers..
    - ◊ Electric transmission lines and substations..
      - ∗ Electric generating plant.

Figure II

APPENDIX (Continued)

III. (a) Centralized Hydrogen production using **electrolysis**; distributing **compressed hydrogen** for vehicles having tanks for compressed hydrogen**.**

- Local storage of compressed hydrogen at local station for fueling vehicles
  - Dedicated distribution pipeline for hydrogen **OR** Trucking of compressed hydrogen to local stations.
    - ◊ Centralized electrolysis plant producing hydrogen.
      - ∗ Dedicated electric generating plant at centralized plant **OR** power from grid.
      - ∗ If power from grid; Electric transmission lines and substations
        - ∇ Electric generating plant.

Figure III a

III. (b) Centralized Hydrogen production using **electrolysis**; distributing **liquefied hydrogen** for vehicles having tanks for liquefied hydrogen **.**

- Local storage of liquefied hydrogen at local station for fueling vehicles
  - Trucking of liquefied hydrogen to local stations
    - ◊ Liquefaction plant
      - ∗ Centralized electrolysis plant producing hydrogen.
        - √ Dedicated electric generating plant at centralized plant **OR** power from grid.
        - √ If power from grid; Electric transmission lines and substations
          - ∇ Electric generating plant.

Figure III b

APPENDIX (Continued)

IV. (a) Centralized Hydrogen production using **steam methane** process; distributing **compressed hydrogen** for vehicles having tanks for compressed hydrogen**.**

- Local storage of compressed hydrogen at local station for fueling vehicles
  - o Dedicated distribution pipeline for hydrogen **OR** Trucking of compressed hydrogen to local stations
    - ◊ Centralized steam methane process plant producing hydrogen.
      - ∗ Dedicated power plant at centralized plant, for steam**.**

Figure IV a

IV. (b) Centralized Hydrogen production using **steam methane** process; distributing **liquefied hydrogen** for vehicles having tanks for liquefied hydrogen **.**

- Local storage of liquefied hydrogen at local station for fueling vehicles
  - o Trucking of liquefied hydrogen to local stations
    - ◊ Liquefaction plant
      - ∗ Centralized steam methane process plant producing hydrogen.
        - √ Dedicated power plant at centralized plant, for steam**.**

Figure IV b

APPENDIX (Continued)

V. (a) Centralized Hydrogen production using **Thermo (nuclear)** process; distributing **compressed hydrogen** for vehicles having tanks for compressed hydrogen**.**

- Local storage of compressed hydrogen at local station for fueling vehicles.
  - o Dedicated distribution pipeline for hydrogen **OR** Trucking of compressed hydrogen to local stations.
    - ◊ Centralized thermo (nuclear) process plant producing hydrogen.
      - ∗ Dedicated nuclear power plant at centralized plant, for high temperatures necessary to produce hydrogen from water**.**

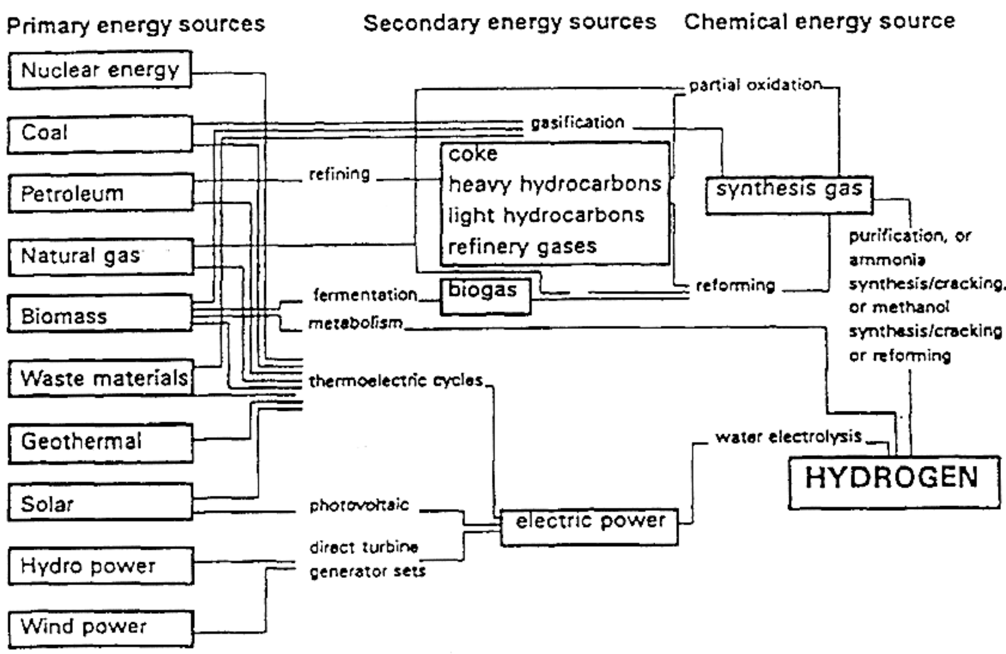
Figure V a

V. (b) Centralized Hydrogen production using **Thermo (nuclear)** process; distributing **liquefied hydrogen** for vehicles having tanks for liquefied hydrogen **.**

- Local storage of liquefied hydrogen at local station for fueling vehicles.
  - o Trucking of liquefied hydrogen to local stations.
    - ◊ Liquefaction plant.
      - ∗ Centralized thermo (nuclear) process plant producing hydrogen.
        - √ Dedicated nuclear power plant at centralized plant, for high temperatures necessary to produce hydrogen from water**.**

Figure V b

APPENDIX (Continued)



Alternative processes for producing hydrogen.[14]

Figure VI

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NOTES

1. For a discussion of other renewables see "The False Promise of Renewable Energy (for power generation)" obtainable from www.tsaugust.org.
2. There has been a proposal for power generation with superconductivity for transmission that uses liquefied hydrogen for maintaining the superconductivity of the cable. The liquefied hydrogen could be bled off the superconducting cable and used for transportation. The "Super City Grid" was proposed by Chauncey Starr President Emeritus of EPRI and Paul Grant EPRI Science Fellow. A recent conference on the subject indicated no known technical barriers and recommended research on the subject.
3. The natural gas infrastructure is in need of rapid expansion. By 2020, the Department of Energy predicts Americans will demand 48 percent more natural gas than today. To meet increased demand from all sectors, current gas pipeline transmission and distribution mileage must be increased 30 percent by 2020
4. This assumes that the power generating units operate at a capacity factor of 80%. Nuclear has a capacity factor of approximately 90%, steam and gas turbines roughly 60% and wind 30% or less. The best conversion factor for hydrolysis published thus far is .5. Theoretically 1 KwHr of electricity would produce about 3412 BTU of hydrogen. The calculations used here assumes 1700 BTU's.
5. The two key assumptions used in this calculation are that the conversion factor for converting water to hydrogen is 50% and that fuel cell powered automobiles are twice as efficient as gasoline powered cars. If the conversion factor for electricity to water increases to 70% and the fuel cell cars become three times as efficient as gasoline powered cars the resulting additional generating capacity needed to generate the necessary hydrogen would be 315,000 MW.
6. The key assumption used in these calculations is that fuel cell powered automobiles are twice as efficient as gasoline powered cars. If fuel cell cars become three times as efficient as gasoline powered cars the resulting additional gas consumption would be 7.5 quads.
7. The assumptions used are that it costs about $500 per KW for new coal plant, and about $1200/KW for a new nuclear plant. Construction time for nuclear is about 2-3 times longer than for a new coal power generating plant: And that it costs $6 million per mile to construct new transmission capabilities.
8. The data used for this assumption is from an Alliance for Energy estimate of the number of miles of pipelines needed to increase delivery capacity of existing system to accommodate normal growth prorated for growth required by hydrogen production. The cost for increased production was derived from EIA data while data on pipeline costs per mile came from FERC. An average cost for pipelines of 4 to 16 inches in diameter was used for estimating the cost of distribution pipelines; while the cost of 30 inch pipelines was used for the cost of transmission pipelines.

NOTES (Continued)

9. Only 22 plants were built in 2002 larger than 250 MW. Out of a total 55,114 MW added in 2002, the average size new power plant was 68 MW.

   It could be assumed that these new power plants would be centrally located using coal or nuclear in which case each plant could easily be rated around 1000 MW cutting the number of new power plants by 1/4, or 660 total new power plants with 39 new plants being built annually rated 1000MW.

   There are several possible variations of size and degree of centralization. For example, new pebble bed nuclear reactors rated 165 MW could be built regionally using high temperature thermal production of hydrogen which would reduce the need for transmission lines and, by being closer to the users of hydrogen, result in shorter hydrogen distribution lines.

10. Source EIA, chart “Electric Net Summer Capacity at Electricity-Only Plants: Electric Power Sector, 1949-2001”

11. An area of between 100,000 and 160,000 square miles, would be required for the 881,000 wind turbines required to produce the needed hydrogen. Theoretically 881,000 wind turbines could fit in an area of 100,000 square miles. The empirical data developed thus far indicates that wind turbines can only develop 5KW of power per acre which is considerably less than the theoretical amount based on spacing turbines at 7 times their rotor diameters. If the empirical data merely reflects the effect of topography then 160,000 square miles would be required: If it reflects a lower capacity factor for wind than 30%, then additional wind turbines would also be required.

12. Reference International Atomic Energy Agency, Vienna (Austria) IAEA-TECDOC--1085

13. ***“Considering the uncertainties of long range predictions and judging solely by lowest life-cycle energy use and greenhouse gas (GHG) releases, there is no current basis for preferring either fuel cell (FC) or internal combustion engine (ICE) hybrid power plants for mid-size automobiles over the next 20 years or so using fuels derived from petroleum or natural gas.”*** Comparative Assessment of Fuel Cell Cars February 2003, MIT Laboratory for Energy and the Environment, 77 Massachusetts Avenue, Cambridge MA 02139-4307

14. Reference International Atomic Energy Agency, Vienna (Austria) IAEA-TECDOC--1085