



World Nuclear Association Annual Symposium
4-6 September 2002 - London

Hydrogen Fuel and Electricity in Transportation

Dr. Geoffrey E.H. Ballard

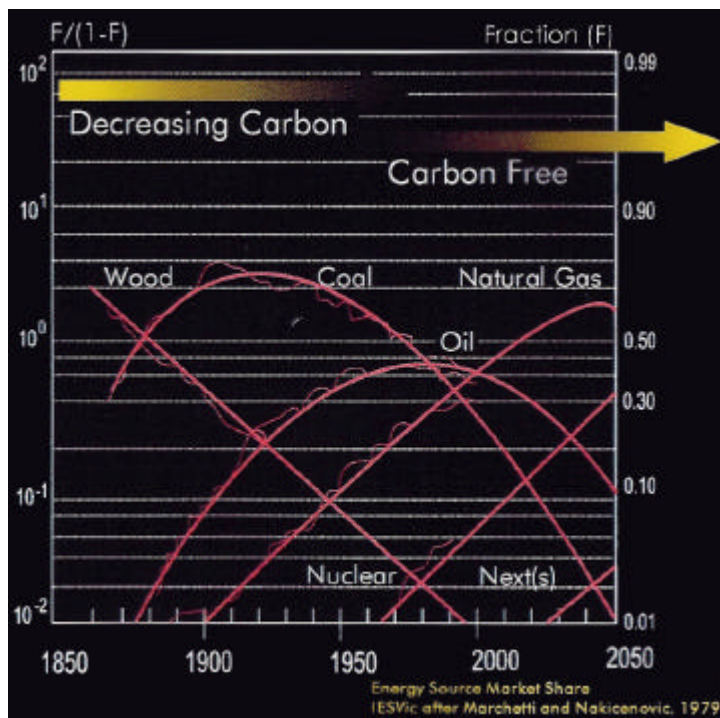
The overall theme for this talk is that, if the hydrogen economy emerges in the transportation sector as I believe it will, then nuclear power generation will have to play a paramount part in its evolution.

As I will explain, hydrogen is a 'currency' of an energy system, not a source of energy. To create the currency, hydrogen, primary power must be utilized. The most likely candidate to produce this power is nuclear.

I would like to start off with a general overview of the fuel cell. Our respective disciplines are so different that I think it would be a useful introduction.

Slide 1: Energy sources with time

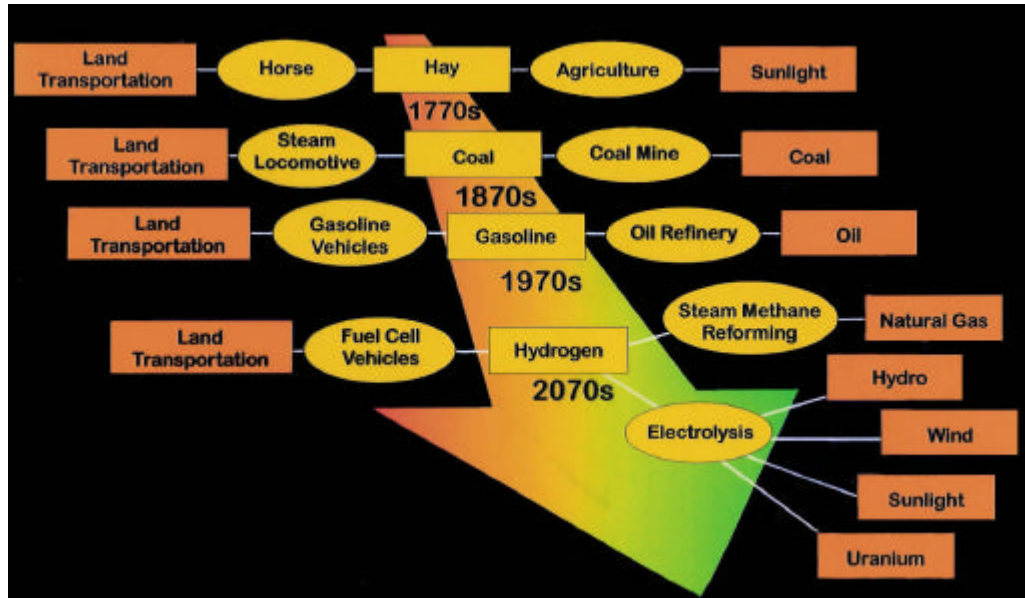
- Decreasing carbon with time
- World wide coal is on the decrease
- Nuclear is on the increase



- 'Nexts' are primarily academic but we must be aware there will be a NEXT.

Slide 4: Evolution of land transportation

- Before the hydrogen economy, all transportation systems were essentially dependent on a single energy source
- The gasoline economy is dependent on crude oil

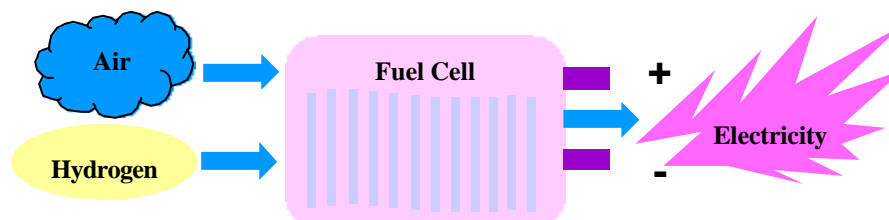


When hydrogen becomes the staple currency for transportation then any source can supply the energy to produce it. This contrasts with how, historically, the system restricted the choices to a single source: first sunlight, then coal, and today, crude oil. By using hydrogen as the transportation currency, all energy sources will have 'equal access' to supply hydrogen. In the fullness of time, any energy source will be able to energize transportation services.

An analogous situation exists today with electricity: any energy source can be used to generate electrical power and can, therefore, energize any service delivered by an electricity technology. By contrast, sunlight, nuclear energy and hydraulic power are effectively blocked from today's transportation sector.

Slide 5: How a fuel cell works

- Hydrogen and air in – electricity out



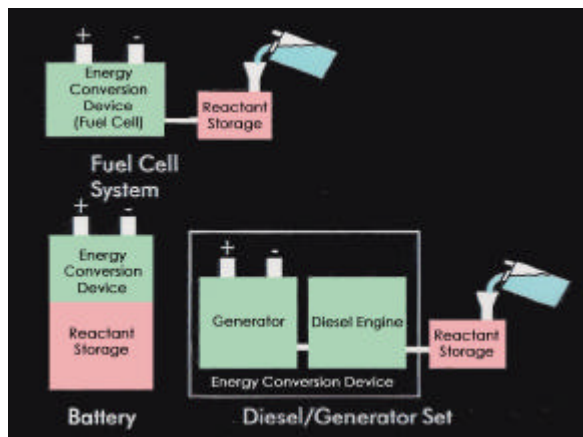
Slide 6: Fuel cell comparisons

- There are at least 6 basic fuel cells – each with different temperature and performance characteristics
- We chose PEM for transportation because it has a solid electrolyte and operates below the boiling point of water

	PAFC	AFC	PEM	MCFC	SOFC
Electrolyte	H ₃ PO ₄	KOH/H ₂ O	Polymer	Molten Salt	Ceramic
Operating Temperature	190°C	80/200°C	80°C	650°C	1000°C
Fuels	H ₂ /Reformate	H ₂	H ₂ /Reformate	H ₂ /Reformate	H ₂ /CO/Reformate
Reforming	External		External	External/Internal	External/Internal
Oxidant	O ₂ /Air	O ₂ /Air?	O ₂ /Air	CO ₂ ,O ₂ /Air	O ₂ /Air
Efficiency	40-50%	40-50%	40-50%	>60%	>60%
Scale	200 kW to 10 MW	0.1 to 20 kW	0.1kW to 20MW	>100MW	>100MW
Applications	Small Utility	Aerospace	Motive/Small Utility	Utility	Utility

Slide 7: Fuel cell technology

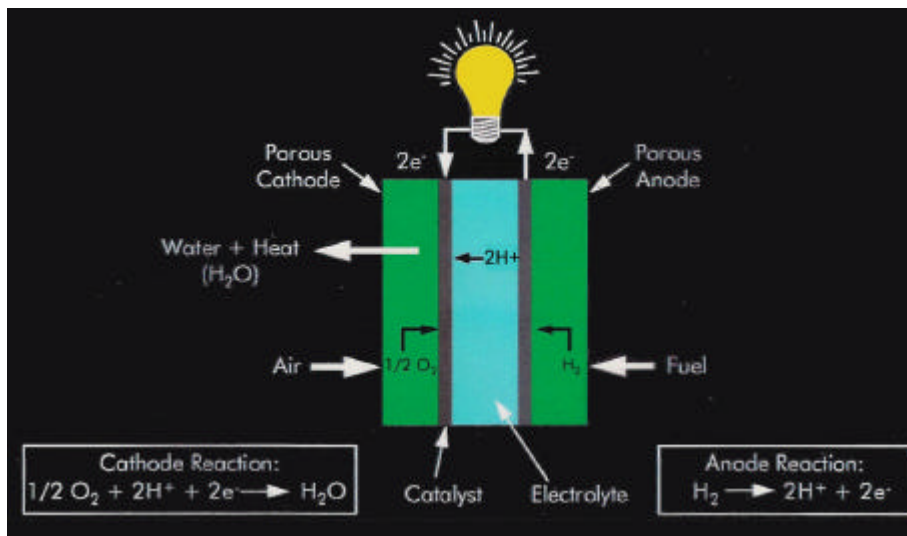
- Diesel generation set chosen to compare with common output
- Scale energy and power separately with ICE or FC but not with a battery



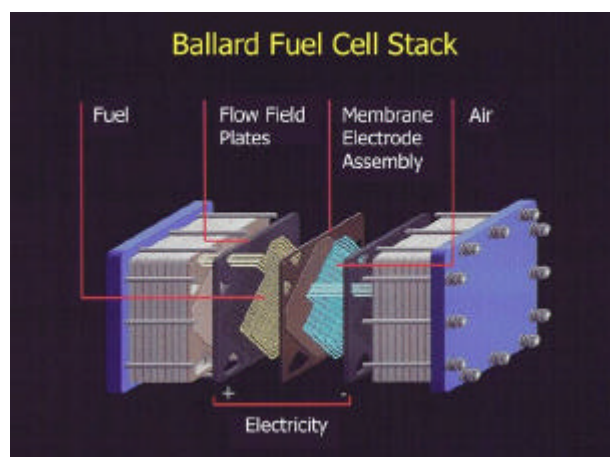
Advantages

- Electricity Without Combustion
- Continuous Production of Electricity as Long as Fuel Supplied
- Environmentally Clean
- High Efficiency
- Modular and Compact
- Use Available Fuels

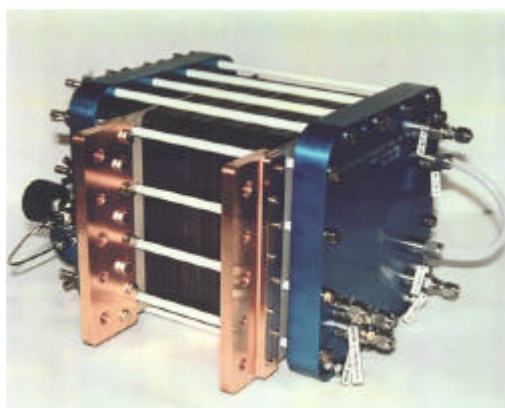
Slide 8: Proton Exchange Membrane FC



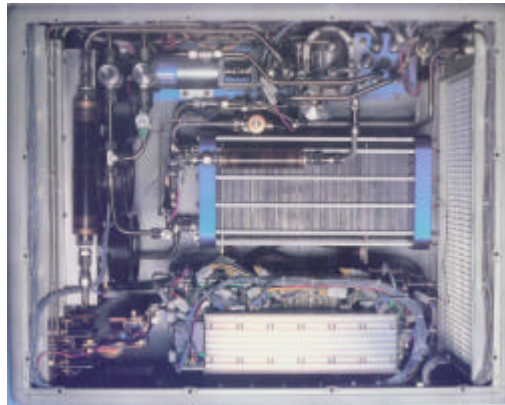
Slide 9: Typical Ballard Fuel Cell Stack



Slide 10: Early DB Stack



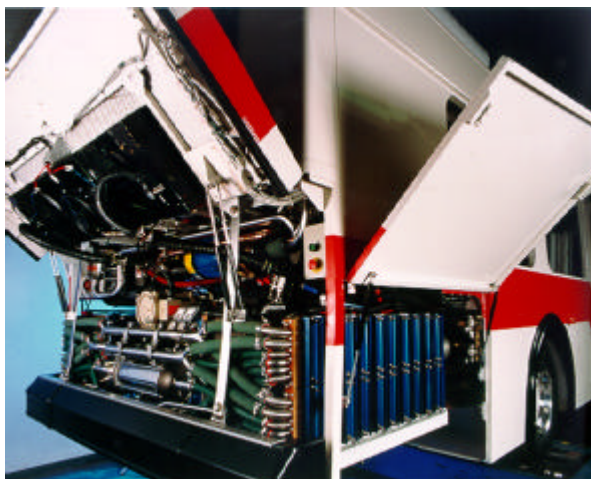
Slide 11: Globe 90 Demo



Slide 12: Stack Development



Slide 13: Early Ballard Bus



With the advent of an economic hydrogen fuel cell, for the first time electricity can be stored efficiently in large quantities. Prior to the hydrogen fuel cell, large amounts of electricity could not be stored economically, and hence energy systems were basically single-source dependent, and generating capacity had to be designed for peak loads rather than for average energy consumption.

The hydrogen fuel cell allows us to use any primary energy source to fuel our economy: geothermal, wind, solar, hydro, nuclear, coal and petroleum. *With the hydrogen economy we are at 'choice'*. Any primary energy source can be used to produce electricity. And electricity can produce hydrogen. Hydrogen can be stored, used and shipped to again make electricity. This interchangeability will ensure that electricity and hydrogen are our currencies of choice.

A number of recent studies in the United States and Europe start with a preamble that expresses concerns with the supply of petroleum. I hold no such fears. Studies by the International Atomic Energy Agency in Vienna clearly show that there is at least 200 years' supply of petroleum available even under very pessimistic circumstances. We should not be changing the energy system because of a fear of limited petroleum reserves. We should change the energy system because the current system militates against energy security, unacceptably destroys our earth's atmosphere, and makes our children sick with inner city pollution. Petroleum should be focused towards the petro-chemical industry, not towards energy supply.

The overall plan should be to move towards a hydrogen economy. To do this we must recognize that the primary energy source should be directed towards electrical production. The excess electrical production at any moment can be converted into hydrogen. **HYDROGEN INSTEAD OF GASOLINE CAN BE THE FOCUS OF OUR LAND TRANSPORTATION NEEDS.**

With this focus in mind, a nation's entire energy system can gradually shift away from dependence on oil and petroleum without a massive disruption of the economy. We can control the evolution of a nation's energy utilisation into directions and systems which are appropriate for each nation and least disruptive of our global ecology.

It must be noted, as I have stressed throughout this talk, that hydrogen is not an energy source. Hydrogen is only a currency, but it is a currency that makes all sources of energy available to the energy economy. It is the first truly reversible currency.

As the world progresses to the hydrogen economy, I believe hydrogen and electricity will become so indistinguishable from each other that they will be referred to as a joint currency called **HYDRICITY™**. The hydrogen economy will be realized in the transportation sector, because there it will clean up the inner-city, reduce greenhouse gas emissions and form the foundation for energy and homeland security. I believe that we will eventually emerge to the **HYDRICITY™ ECONOMY**.

There is much debate and worldwide concern about resurrecting the nuclear energy dream. Advocates of other systems point to wind and solar energy, but environmentally desirable as the non-carbon and non-nuclear sources of energy are, they are unlikely to provide the vast amounts of primary energy that social progress will demand.

If carbon-based energy sources must be set aside, and I believe that they must, then the only remaining viable source, at this stage in our development, is nuclear.

To put some numbers on the framework I am projecting for the transportation sector:

- If 4% of the automobiles in California were fuel cell vehicles, they would represent more generating capacity than the entire stationary generation capability of the state. In other words if all the automobiles in California had 100 kW fuel cell engines, they would represent 25 times the stationary generating capacity of California.
- An energy round trip using electricity from the grid to make hydrogen and then at a later time using a fuel cell to make electricity from the hydrogen to return to the grid, could be 30% efficient. Again, in other words, if you bought electricity off the grid to make hydrogen for 2 cents per kWh, you would have to sell the electricity you made from that hydrogen back to the grid for 6 cents per kWh in order to break even. Not a bad trade when peak-to-trough energy costs in California range from 2 cents to 35 cents per kWh.
- If the hydrogen economy were in place today for on-road transportation, then to provide the basic energy requirement that would replace the current use of gasoline would take 4500 GW of generating capability running at 100% capacity.

Two general themes have dominated my work for the last decade, cleaning up the inner city air and, on-road transportation vehicles as the key to our energy future.

Air pollution takes many adverse forms on earth, but the worst one, to my mind, is the foul atmosphere that we inflict on inhabitants of the inner city. This has been widely ignored in the environmental debates, where the arguments are directed to cleaning up the upper atmosphere, ozone holes and depletion, and warming trends that could inundate the coast.

Cleaning up the inner city, by cleaning up transportation, has the associated effect of making a major contribution to cleaning up the upper atmosphere of the greenhouse gases that have such a bad image in the public's imagination.

I think that many factors are aligning to bring about the hydrogen economy for transportation systems.

- Only 12% of the world's population has access to automobiles. When the other 88% of the world decides to drive, planet earth will not be able to survive the pollution that will be produced from extending the current gasoline economy.
- The automobile in the inner city is already wreaking devastation on the health of its inhabitants.
- Homeland security and energy security are greatly enhanced by a distributive source of generating capacity.
- We have a ready-made solution to the source of primary power, nuclear energy.
- Petroleum is a finite reserve that is better utilized in the petrochemical industry.

It will take a combined effort of academia, government and industry to bring about the change from a gasoline economy to a Hydrogen Economy. The forces are building and progress is being made. It is of major importance that a change of this magnitude is not forced on unwilling participants; but that all of us work for an economically viable path to change.