DOES A HYDROGEN ECONOMY MAKE SENSE?

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Abstract

A sustainable energy world will be based on renewable energy sources. With the exception of biomass, all natural energy contributions will be harvested as electricity. Electric power will replace fossil carriers as the "lead currency" in the energy market. Today, coal, oil and natural gas are upgraded to electricity in thermal power plants or fuel cells. In the future, the base energy will already be high-grade electricity. It can be distributed with high efficiency and zero pollution by existing transmission systems and proven technology. Hydrogen will be manufactured from electric power by electrolysis. It then has to be packaged by compression or liquefaction to make it marketable. The transport of the packaged energy carrier will also consume energy and so does its transfer and storage. Because of the high energy losses (about 50%) the consumer has to pay about twice as much for hydrogen as for power from the grid. Even with the best fuel cells only 50% of the hydrogen energy can be converted into electricity. Consequently, electricity from hydrogen will be generated with only 25% overall efficiency and be about four times as expensive as grid power. The consumer will prefer electric heat pumps to hydrogen furnaces and electric cars to hydrogen vehicles. Hydrogen cannot become a dominating energy carrier because it always has to compete with the original energy: electricity. There is no room for hydrogen in a sustainable energy economy.

Keywords: *renewable energy sources, hydrogen, hydrogen economy*

1. Preface

The establishment of a sustainable energy future is a major step in the history of mankind. It must be taken with due and honest consideration of the laws of physics and be based on proven technology and experience whenever possible. Advice of „visionaries", neglect or distortion of physics, short-sighted lobbying, superficial journalism, political programs etc. cannot establish a base for a secure energy future. Recognize the future and go for it! Do not extrapolate (too much) from the presence.

2. A Sustainable Energy Future

No oil, no gas, no coal, no nuclear All energy comes from renewable sources

Onset and speed of transition to sustainability depend on:.
- local availability of fossil resources,
- availability of hydropower and geothermal heat,
- climatic conditions for harvesting solar, wind and ocean energy,
- local availability of biomass,
- established standards and practices of energy use,
- political leadership with sound visions.

Countries with no fossil resources like Switzerland are already on the road to sustainability. Countries with vast fossil deposits like Saudi Arabia, US or Russia are just beginning to recognize the problem.

There is no global road map to energy sustainability.

The answers to the topic question are presented in the Fig. 1-15.

SUSTAINABLE ENERGY

Solar energy	photovoltaic	DC electricity
	thermal	hot water, space heating etc.
		AC electricity
Wind energy		AC electricity
Hydropower		AC electricity
Ocean energy	waves	AC electricity
	tides	AC electricity
Geothermal	heat	hot water, space heating etc.
		AC electricity
Biomass		synthetic liquid fuels
	heat	hot water, space heating etc.
		AC electricity
Organic waste		synthetic liquid fuels
	heat	hot water, space heating etc.
		AC electricity
Perhaps: nuclear		AC electricity

Most renewable energy becomes available as electricity

INVERSION OF ENERGY SYSTEM

Today:
Energy system is dominated (80%) by chemical energy: coal, oil, gas
- -electrical and motion energy derived from chemical energy
- -thermal power plants, engines, fuel cells

Sustainable future:
Energy system is dominated (80%) by electrical energy:
- -chemical energy must be derived from electricity
- -electrolysis of water

Significant change of energy system:
- -end of chemical energy conversion technologies
  - -coal, oil, gas fired power plants
  - -IC engines, fuel cells
- -end of Carnot or Nernst losses

Extremely efficient energy system based on electricity

ENERGY STRATEGY OPTIONS

Continue with Dominance of Chemical Energy:

-Substitute oil and gas by hydrogen
-Develop or improve hydrogen energy technologies
-production, packaging, transportation, storage, transfer
-Build a hydrogen infrastructure
-Secure business interests of prominent players (oil and car companies)
This can be done!

But efficiency of energy system is lowered. Consumer pay more for energy

Controlled Transition to Electrical Energy:

-Replace furnaces by electric heat pumps or heater (plus insulation)
-Electric cars for commuting
-Biomass-derived synthetic liquid fuels for distant transport
-Extension of power grid
This can be done!

But efficiency of energy system is raised. Consumer pay less for energy

ELECTRICITY OR HYDROGEN?

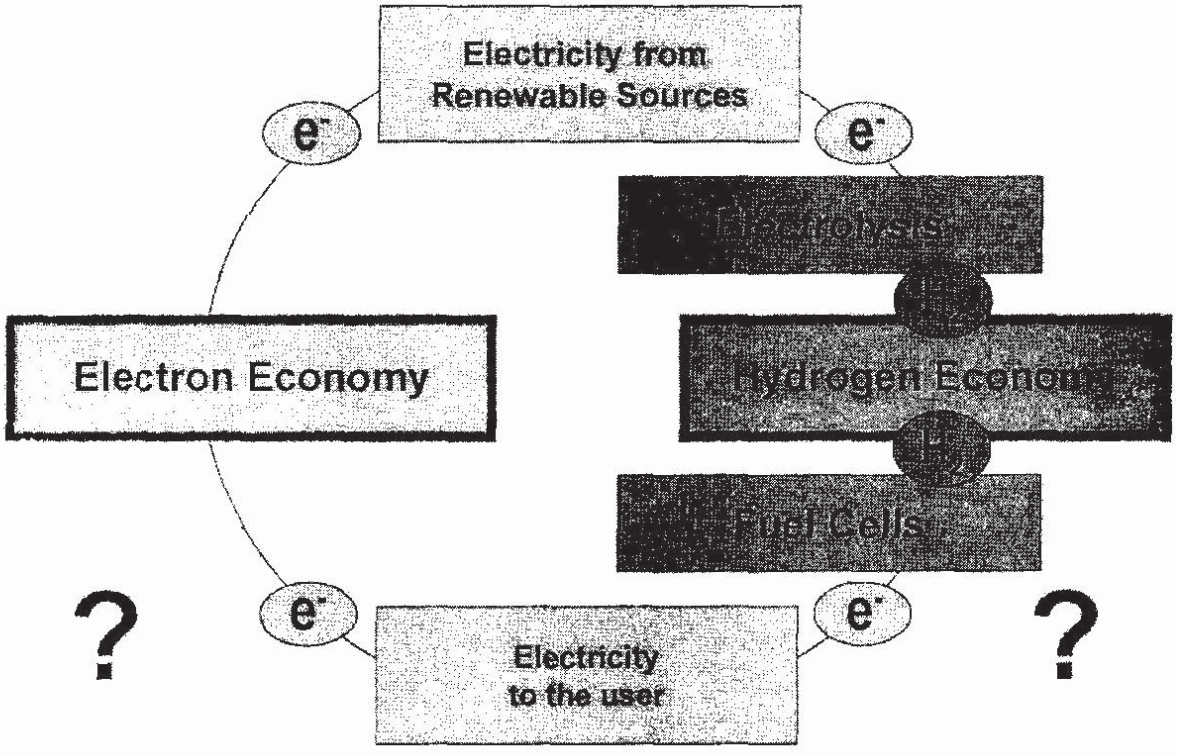


Fig. 1. Renewable Electricity to the User

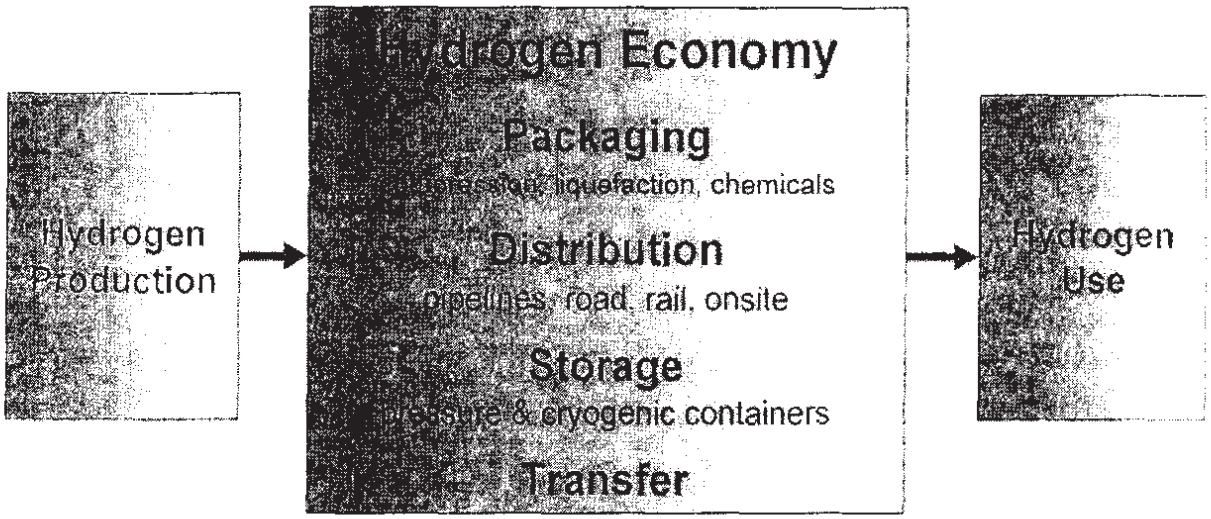


Fig. 2. Basic Elements of a Hydrogen Economy

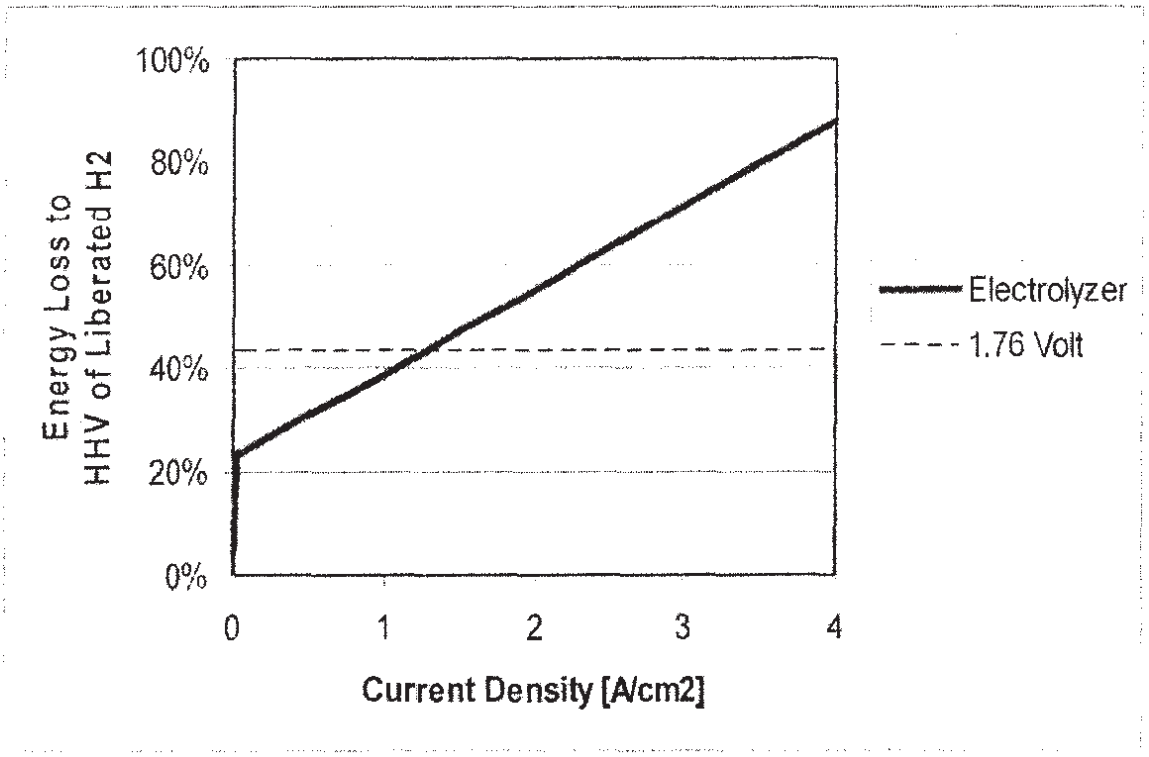
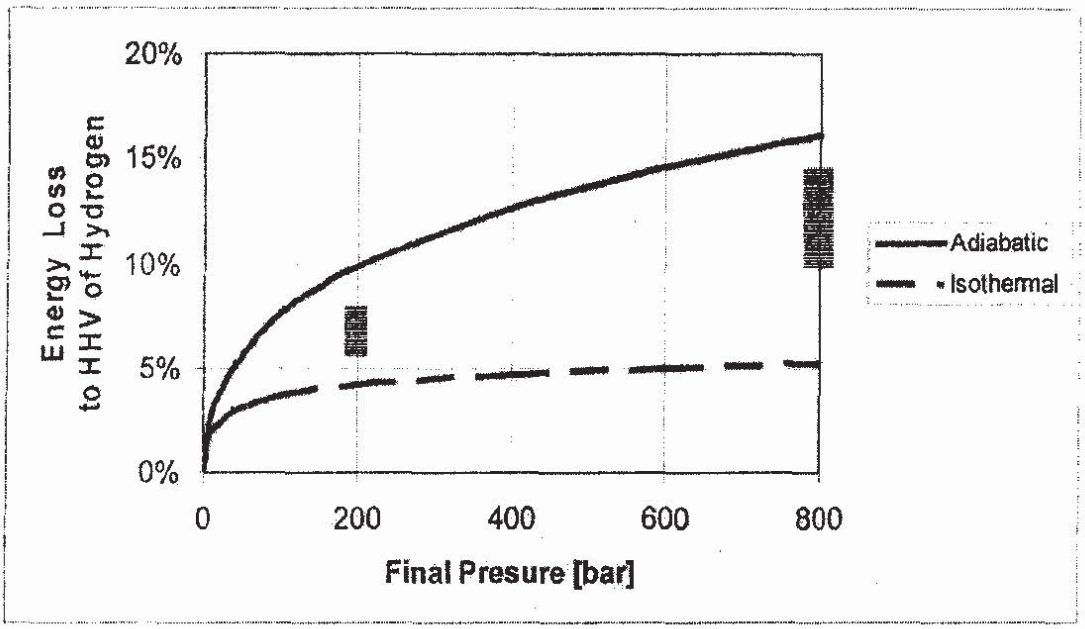


Fig. 3. Water Electrolysis: Energy Loss in HHV--% of Generated H_2



Compression energy CE of H_2 = 8 x CE of natural gas or 15 x CE of air

Fig. 4. Adiabatic and Isothermal Compression: Compression Energy in HHV -- % of H_2

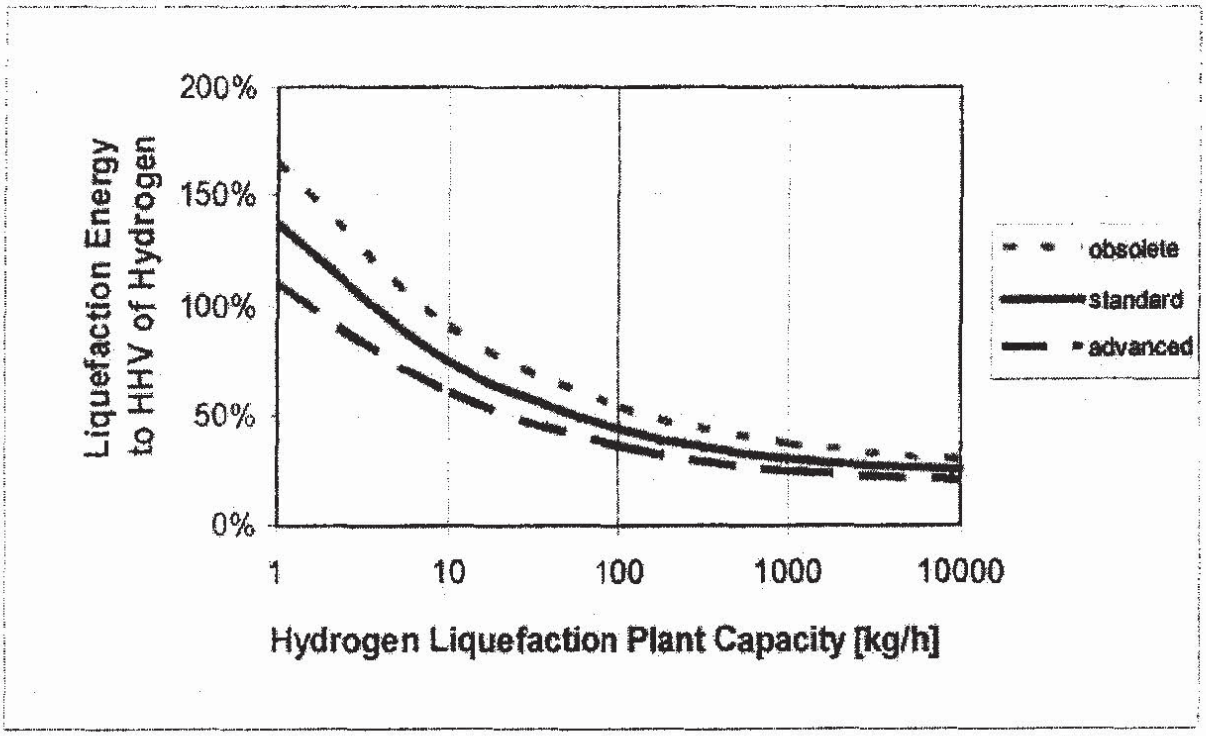


Fig. 5. Liquefaction of Hydrogen: Liquefaction Energy in HHV--% of H_2

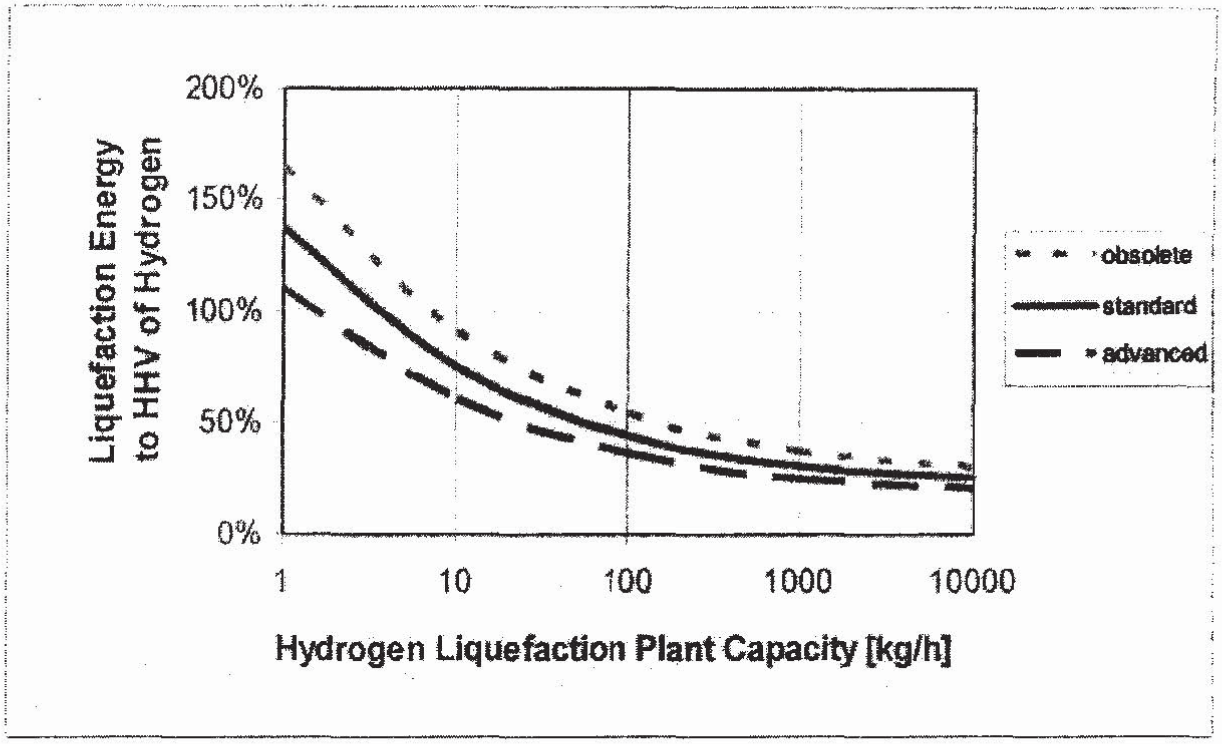
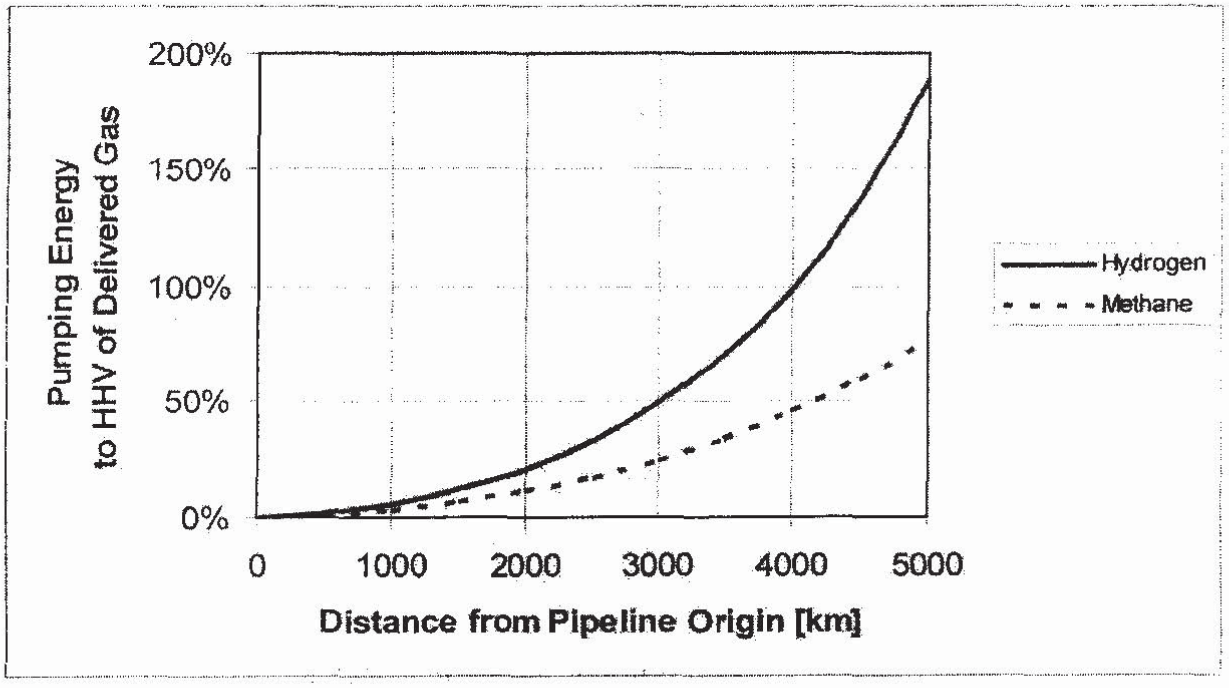


Fig. 6. Road Delivery of Energy: Fuel Energy in HHV--% of Delivered Energy



Pipeline transport of hydrogen over long distances „impractical".
Also: Natural Gas pipelines cannot be used for hydrogen!

Fig. 7. Hydrogen Pipeline Pumping Requirement in HHV --% of Delivered Energy

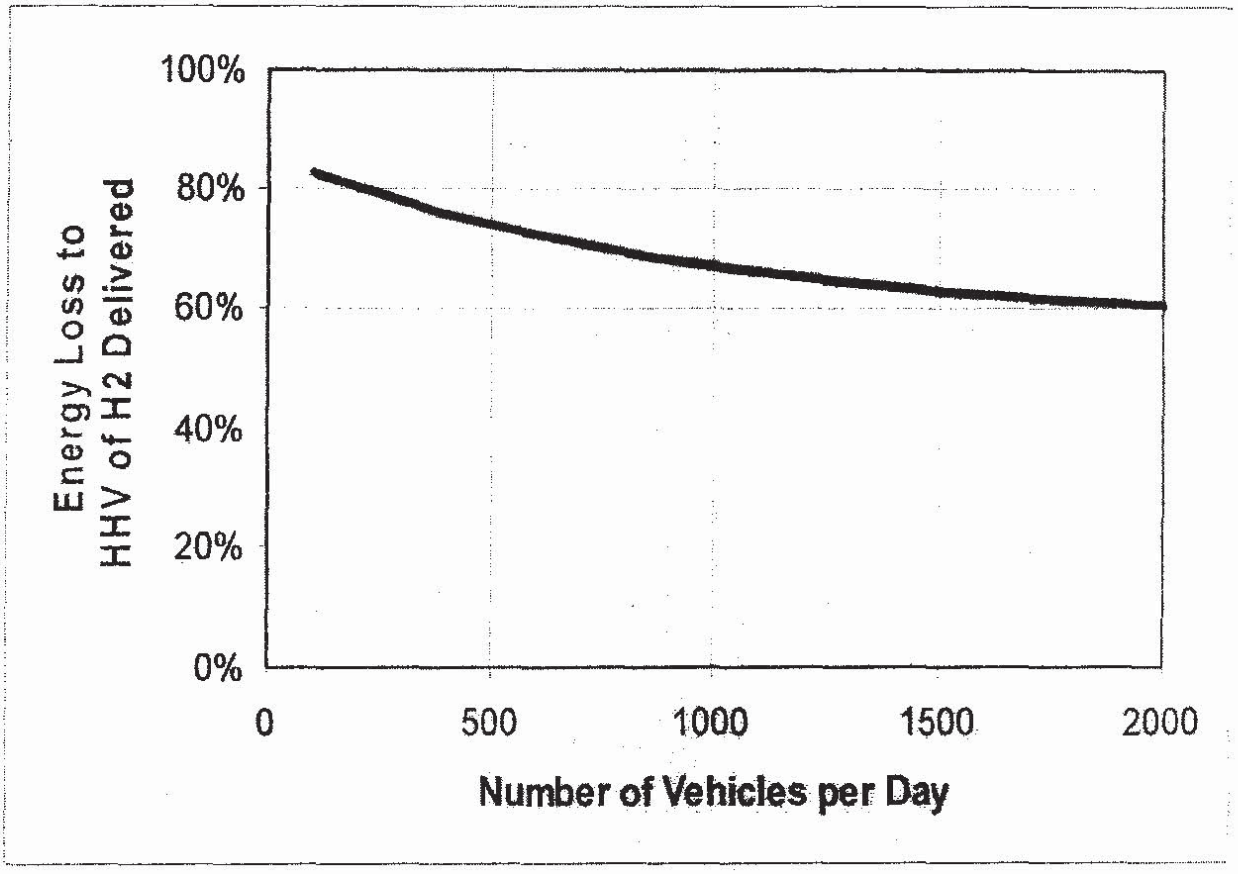


Fig. 8. Hydrogen by Electrolysis at Filling Stations: Energy Loss in HHV % of Delivered H_2

ENERGY NEEDS OF A HYDROGEN ECONOMY

Energy (mostly electrical) consumed in HHV-% of delivered hydrogen

Representative numbers:		
Hydrogen from **electricity** and **water**		40%
Compression	200 bar	8%
	800 bar	13%
Liquefaction	small plants	50%
	large plants	30%
Chemical hydrides		60%
200 km road delivery (Diesel)	200 bar	13%
	liquid	3%
2000 km pipeline		20%
Onsite generation (electrolysis)		50%
Transfer from 100 bar storage to 700 bar tank		8%
Re-conversion to **electricity** and **water** by fuel cells		50%

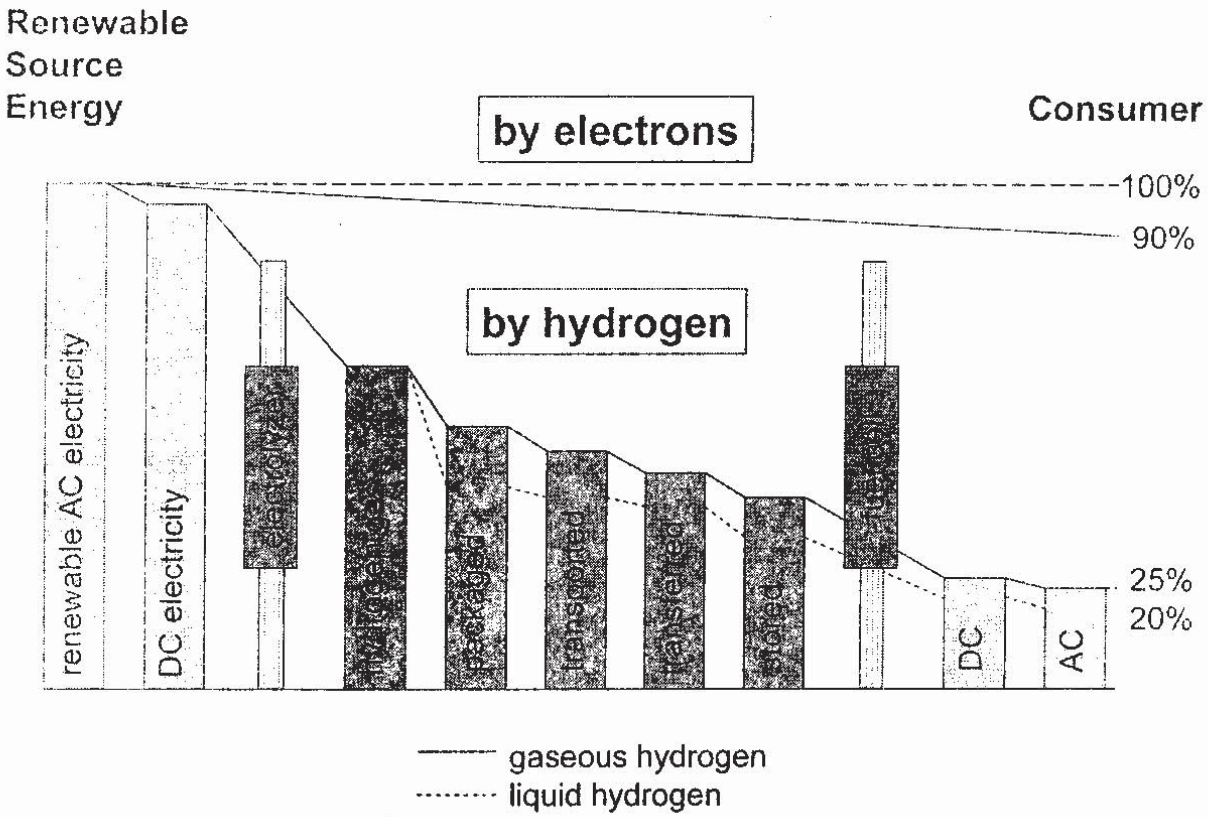


Fig. 9. Electricity Transport

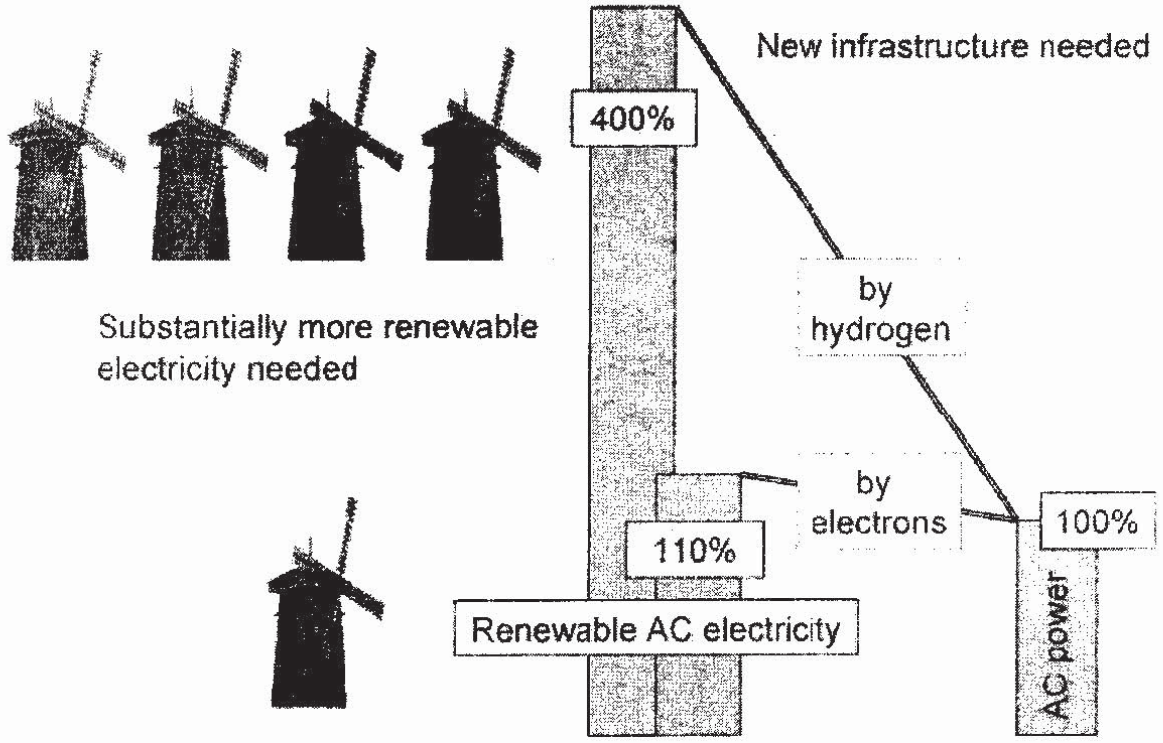


Fig. 10. Electricity transport by electrans or by hygrogen?

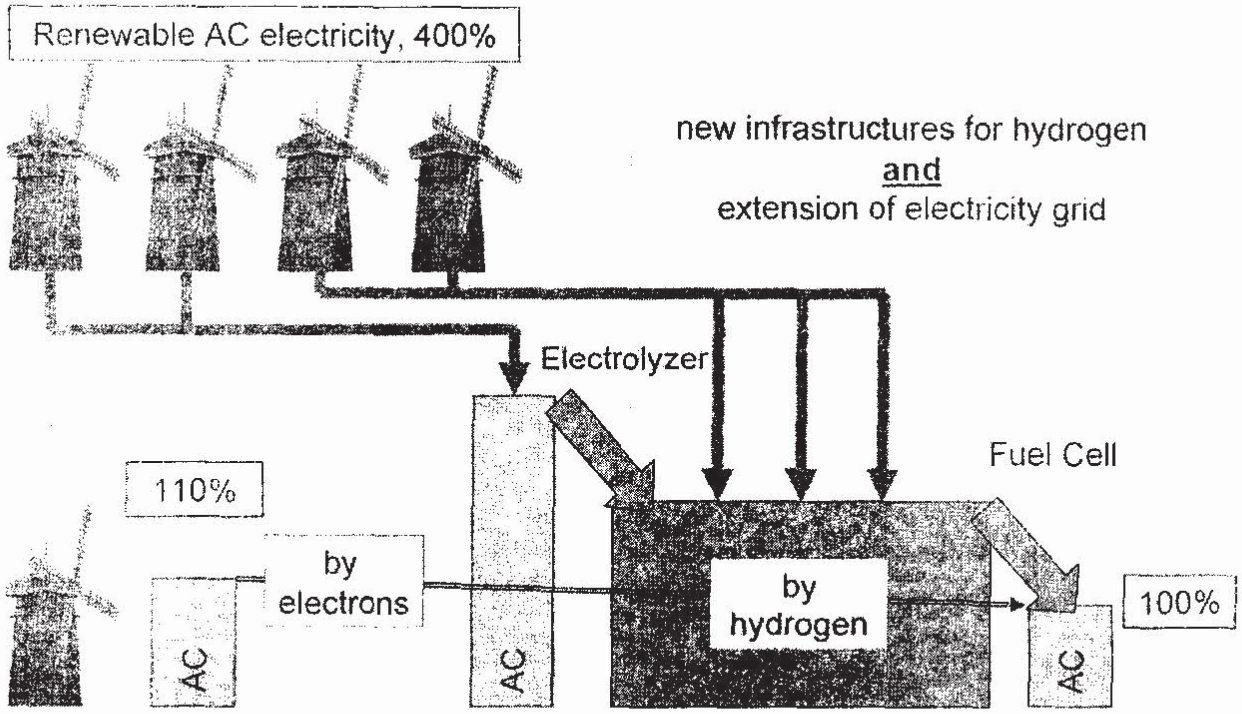


Fig. 11. Infrastructure for energy transport by electrons or by hydrogen?

CONSUMER COST OF ENERGY

Assumption: As today, energy losses will be charged to the customer. Therefore by laws of physics:

Likely consumer prices for energy:

Hydrogen energy will be **at least twice** as expensive as electrical energy

Electricity derived from hydrogen with fuel cells will be **at least four times** more expensive than power from the grid

The consumer will opt for the low-cost solution:

Home remodeling with improved thermal insulation and electric heaters or heat pump rather than replacing natural gas by hydrogen

Electric cars for commuting, not hydrogen fuel cell vehicles

Liquid synthetic fuels from biomass for long distance driving, trucks and air transport rather than hydrogen

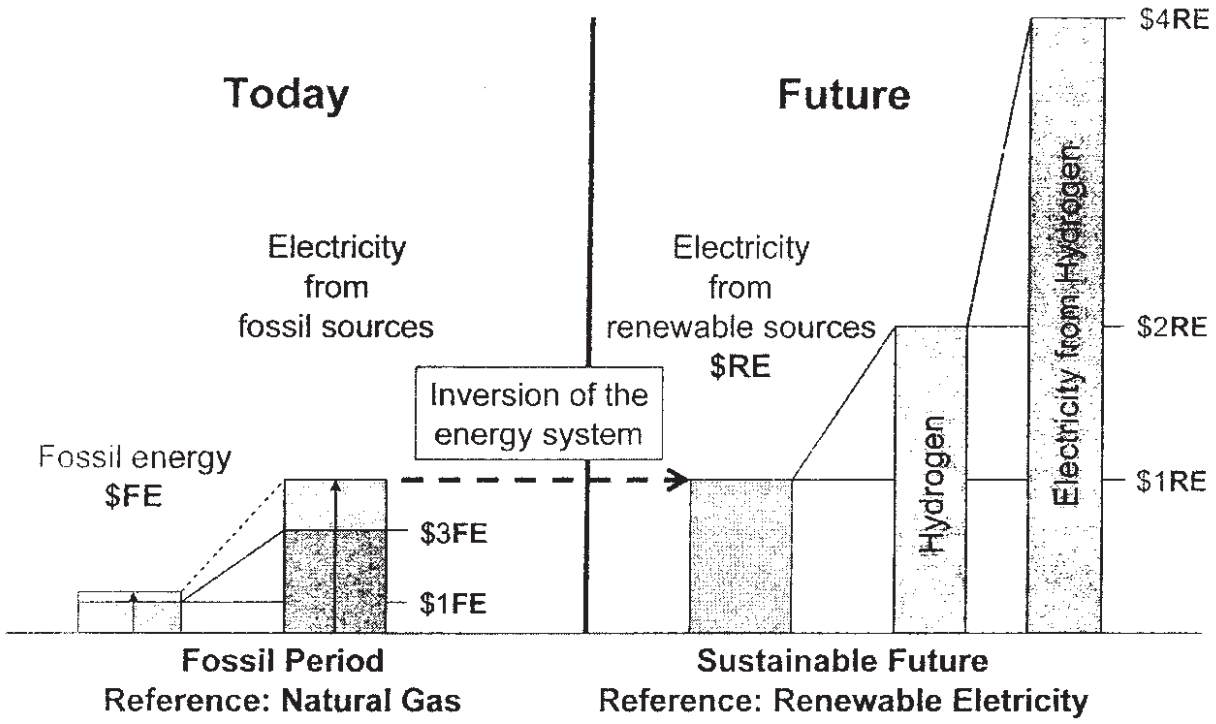


Fig. 12. Energy costs for Energy Users

TRENDS BETWEEN NOW AND HYDROGEN

Depletion of Fossil Resources:

- **Rising energy prices**
  - Stationary sector:
    - Improved thermal insulation and more efficient HVAC appliances
    - Substitution of natural gas and heating oil by electricity
  - Mobile sector -Improved efficiency of IC engines
    - Hybrid electric vehicles and small electric commuting cars
    - Substitution of fossil fuels by synthetic hydrocarbons and electricity
- **Higher efficiency of energy distribution system**
  - More direct electricity, fewer energy conversion steps
- **More electricity from renewable sources**
  - Constant cost of renewable electricity at rising oil and gas prices
- **Rising awareness and change in consumer behavior**

Transition to electricity already in progress. „Hydrogen Economy" cannot catch up with „Electron Economy"

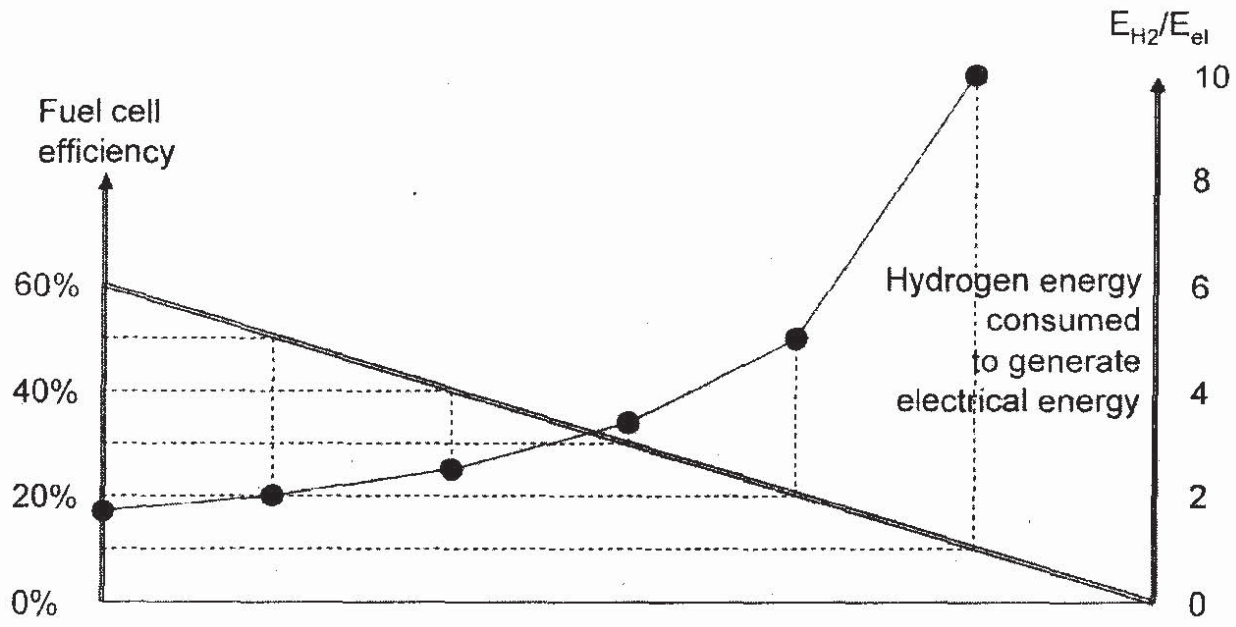


Fig. 13. Fuel Cell Efficiency and Hydrogen Consumption

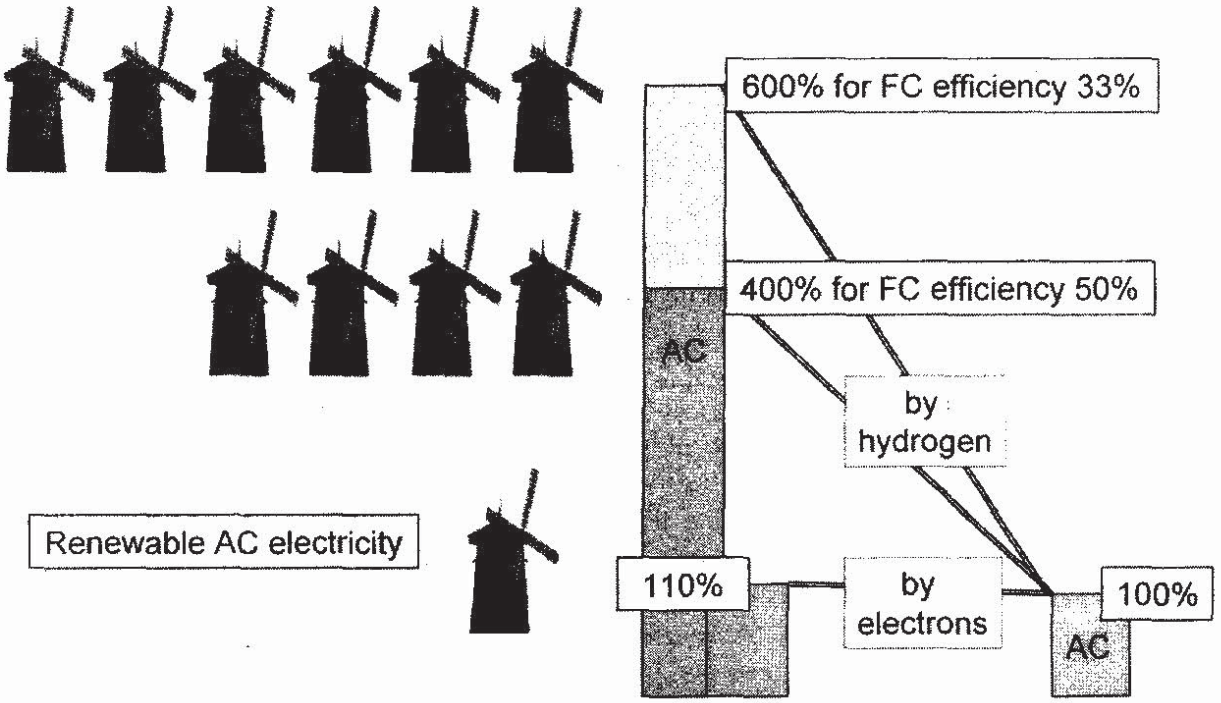


Fig. 14. Fuel Cell Efficiency and Electric Power Needs

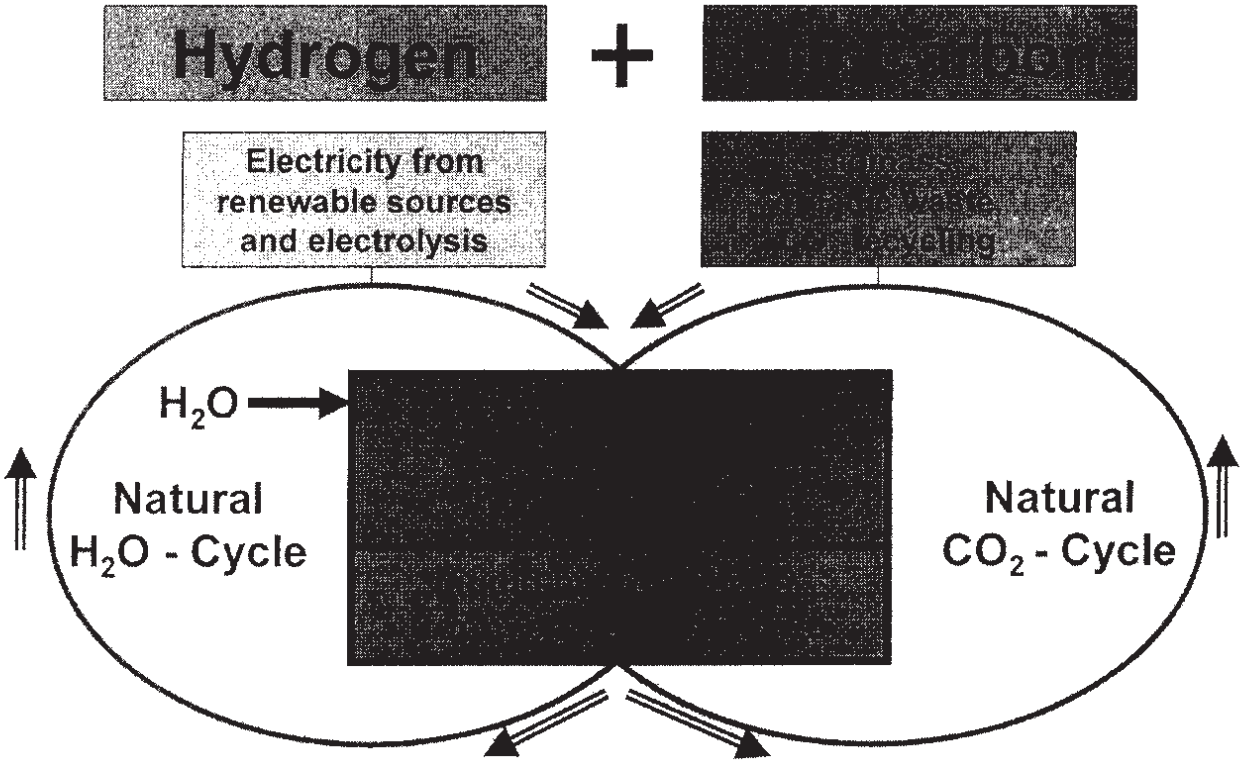


Fig. 15. Synthetic Liquid Hydrocarbon Fuels for Transportation

3. Conclusions

1. Technology for a Hydrogen Economy exists or can be developed Hydrogen must be fabricated from fossil fuels or electricity.
2. By laws of physics energy is lost in the process.
3. Hydrogen always carries less energy than the source energy.
4. Hydrogen can compete with the source energy, only if distribution and use are much more efficient than that of the source energy.
5. But parasitic energy consumption is extremely high in a Hydrogen Economy.
6. Consequently, hydrogen can never compete with its source energy.
7. Hydrogen cannot compete with its own source.
8. Therefore, a Hydrogen Economy has no future.
9. In fact, the hasty establishment of a Hydrogen Economy may block the establishment of a sustainable energy future based on electricity from renewable sources.
10. The question was: Does a Hydrogen Economy Make Sense?
11. The answer is: no.