On the Way to a Sustainable Energy Future

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Presenting **physics,** not **philosophy**

That's me:

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Dipl. Ing., ETH Zürich, Switzerland (1961)
Mechanical Engineering: Aerodynamics, Thermodynamics
Ph.D., University of California, Berkeley (1968)
Rarefied Gas Dynamics, Molecular Beams
Assistant Professor, Syracuse University (1968-1970)
Mechanical and Aerospace Engineering
Group Leader, DFVLR, Göttingen, Germany (1970-1986)
Free molecular flow studies (space aerodynamics)
Founder and Manager of SOLENTEC, a consulting firm for
renewable energy and energy conservation (1978)
Fuel Cell Project Manager, ABB Baden, Switzerland (1986-1990)
Manager of ABB's fuel cell activities in Europe and US
Fuel Cell Consultant and Developer (1990-to date)
Siemens, Mitsubishi, Statoil, Eniricerche, EPRI, Novem
European Fuel Cell Forum (1994 to date)
International Fuel Cell Conferences
Lucerne FUEL CELL FORUM 2006 (July 3 – 7, 2006)
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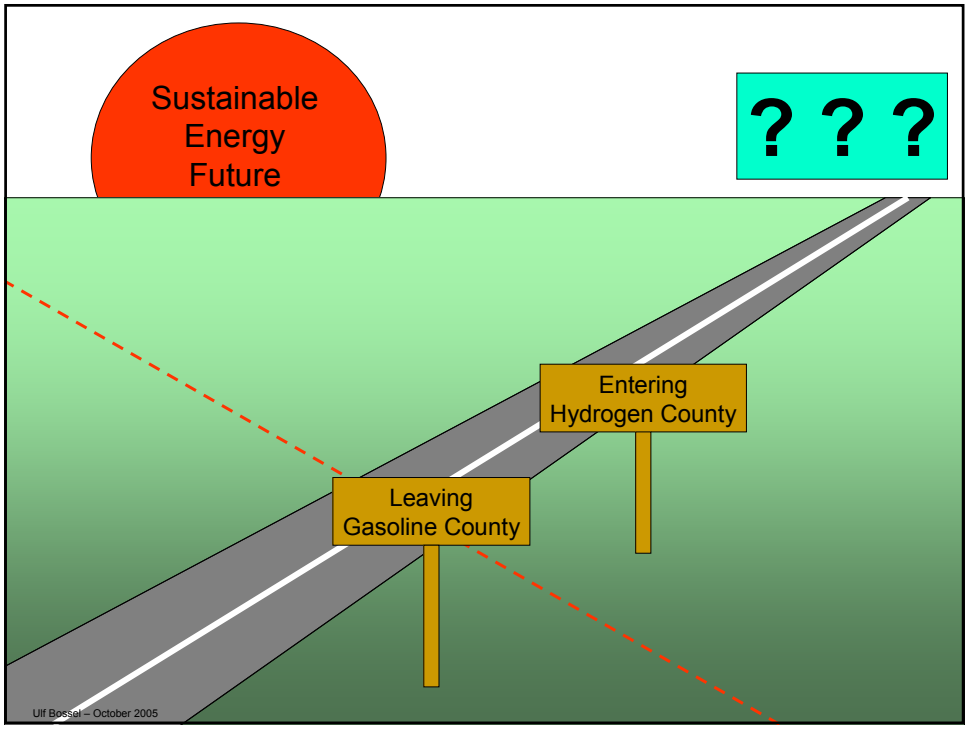


Dimension of Energy Problem

(just one "shocking" example)

Frankfurt Airport (2004)

520 jet departures per day, 50 Jumbo Jets (Boeing 747)
130 t of kerosene per Jumbo = 50 t of liquid hydrogen

For 50 Jumbo Jets per day:

(2,500 t LH_2/day, 36,000 m^3 LH_2/day, need 22,500 m^3 water/day)

Continuous output of eight 1-GW power plants needed for electrolysis, liquefaction, transport, transfer of LH_2!

At least 25 nuclear power plants plus the entire water consumption of Frankfurt needed to serve all 520 jet aircrafts per day at Frankfurt Airport

Energy problem cannot be solved by switching from fossil fuels to hydrogen

"Creation" of "Hydrogen Energy" (1)

1. From water by electrolysis

$$H_2O \Rightarrow H_2 + \tfrac{1}{2} O_2$$

Species balance

2 hydrogen atoms = 2 hydrogen atoms
1 oxygen atom = 1 oxygen atom

2. From natural gas by reforming

$$CH_4 + 2\ H_2O \Rightarrow 4\ H_2 + CO_2$$

Species balance

1 carbon atom = 1 carbon atom
8 hydrogen atoms = 8 hydrogen atoms
2 oxygen atoms = 2 oxygen atoms

Simple equations, friendly elements H, O and C
Hydrogen promoters are happy!
Even politicians can follow and initiate hydrogen programs

"Creation" of "Hydrogen Energy" (2)

1. From water by electrolysis

$$H_2O \Rightarrow H_2 + \tfrac{1}{2} O_2$$

Mass balance

18 kg H_2O = 2 kg H_2 + 16 kg O_2
9 kg H_2O = 1 kg H_2 + 8 kg O_2

2. From natural gas by reforming

$$CH_4 + 2\ H_2O \Rightarrow 4\ H_2 + CO_2$$

Mass balance

16 kg CH_4 + 36 kg H_2O = 8 kg H_2 + 44 kg CO_2
2 kg CH_4 + 4.5 kg H_2O = 1 kg H_2 + 5.5 kg CO_2

1 kg hydrogen replaces 1 Gallon or 4 Liters of gasoline

Clean water availability may limit hydrogen production
Mass handling not trivial. Carbon sequestration???

"Creation" of "Hydrogen Energy" (3)

1. From water by electrolysis

$$H_2O \Rightarrow H_2 + ½\ O_2$$

Energy balance

electrical energy = energy in H_2
286 kJ/mol = 286 kJ/mol

Reality: 130% energy input = 100% energy in H_2 + 30% energy loss

2. From natural gas by reforming

$$CH_4 + 2\ H_2O \Rightarrow 4\ H_2 + CO_2$$

Energy balance

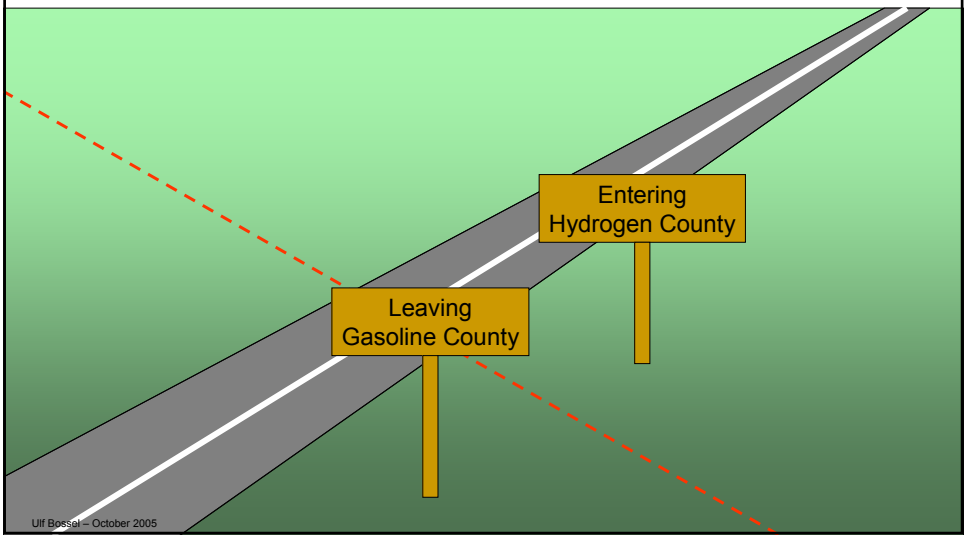
Methane energy + heat = energy in H_2
890 kJ/mol + 254 kJ/mol = (4 x 286 kJ/mol =) 1,144 kJ/mol

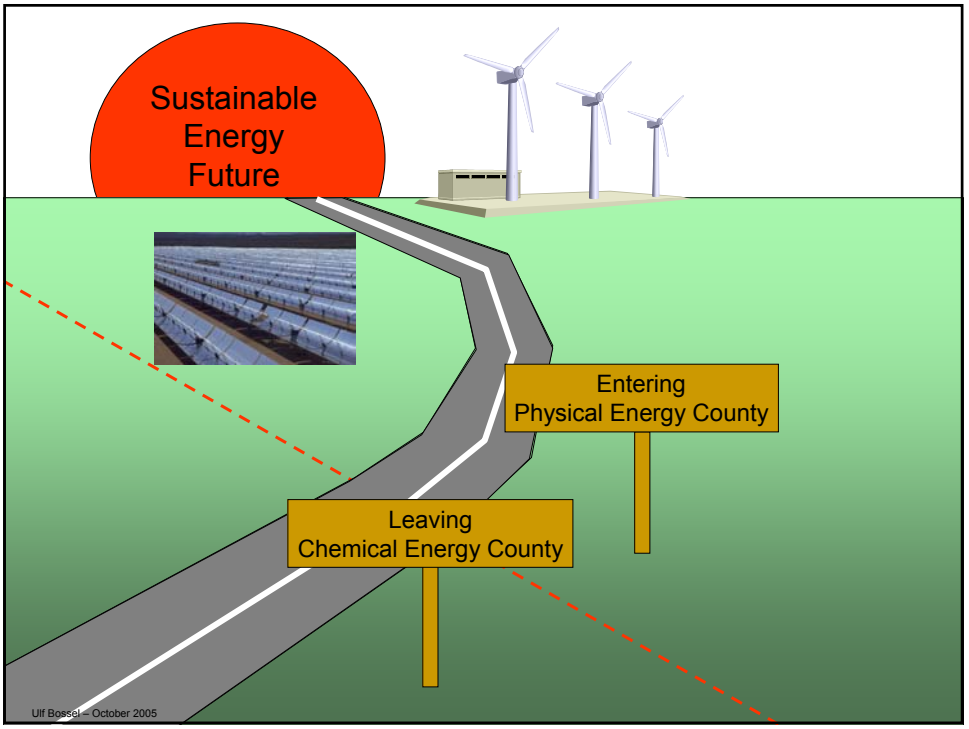
Reality: 110% energy input = 100% energy in H_2 + 10% energy loss

Add 100% for hydrogen distribution to customers

Where does the energy come from to make and distribute hydrogen?
We need to solve energy problems, not chemical problems!

primary energy consumption increased
more coal, more nuclear energy
more CO_2 and radioactive waste
time wasted
global catastrophe





Common Goal:
Sustainable Energy Future

Only two conditions must be satisfied:

1.
Energy source, sink, handling and use must be sustainable

2.
Energy must be distributed and used with highest efficiency

Need to re-organize the entire energy system for a sustainable energy future

Sustainable Energy

Oil, natural gas, coal or nuclear are not sustainable!

Energy from sustainably managed renewable sources:

Solar energy	photovoltaic	DC **electricity**
	thermal	AC **electricity**, hot water, space heating etc.
Wind energy		AC **electricity**
Hydropower		AC **electricity**
Ocean energy	waves, tides	AC **electricity**
Geothermal	heat	AC **electricity**, hot water, space heating etc.
Biomass and organic waste		heat, organic fuels
	heat	AC **electricity**, hot water, space heating etc.

Most renewable energy is "harvested" as electricity

Energy carriers like water, hydrogen, electrons etc.
obey the laws of species conservation.
Energy carriers cannot be classified as „sustainable"

Solar Energy Availability

Solar energy received by red area exceeds World energy consumption

In addition: wind, waves, geothermal, biomass, organic waste etc.

Energy Challenge

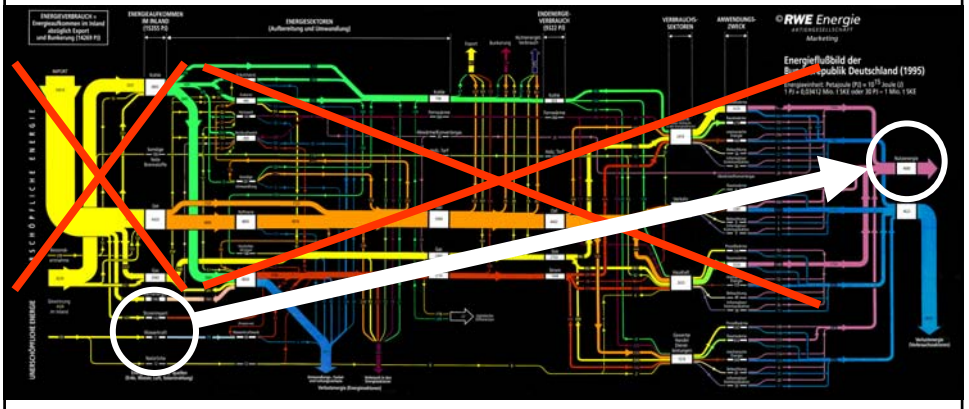
With the exception of biomass **nature provides physical energy**
- kinetic energy of wind, water, waves
- solar radiation
- heat form geothermal sources

With the exception of food **people need physical energy**
- motion
- communication
- lighting
- heating and cooling (space conditioning and cooking)
- industrial processes

The challenge is the direct transfer of physical energy from source to service

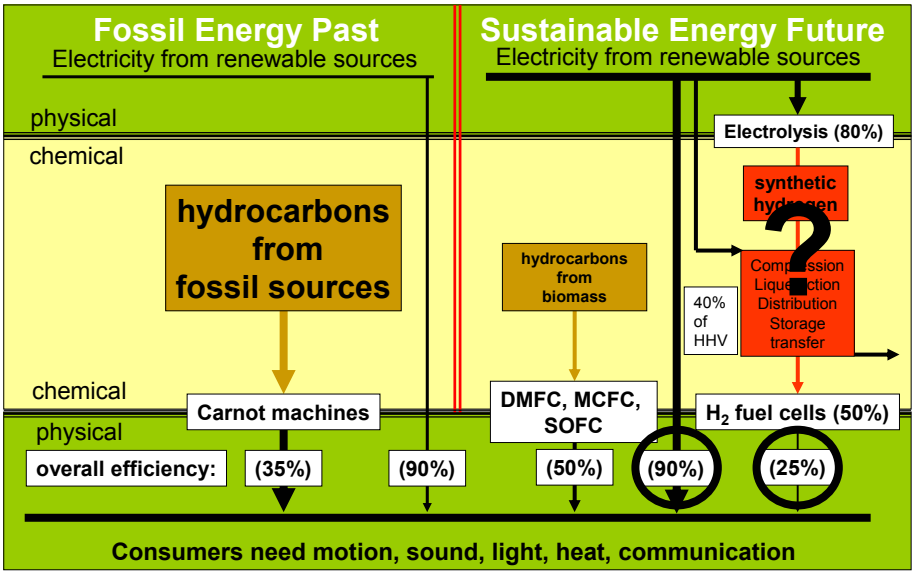
Whenever possible, avoid conversions across the chemical -|- physical energy boundary

Energy Flux Diagram of Germany (1995)

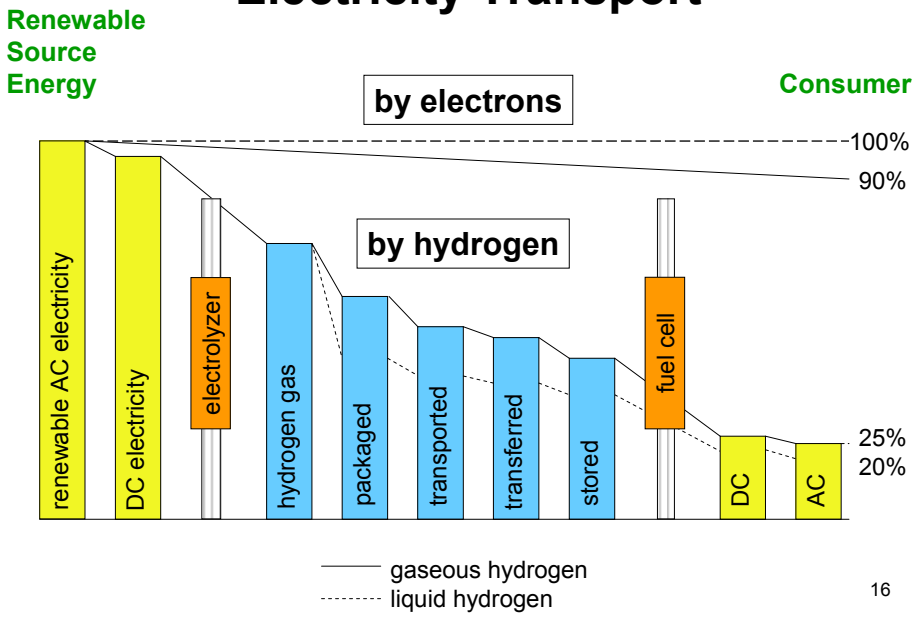


yellow: primary energy
blue: energy losses
purple: useful energy

Fossil Past and Sustainable Future



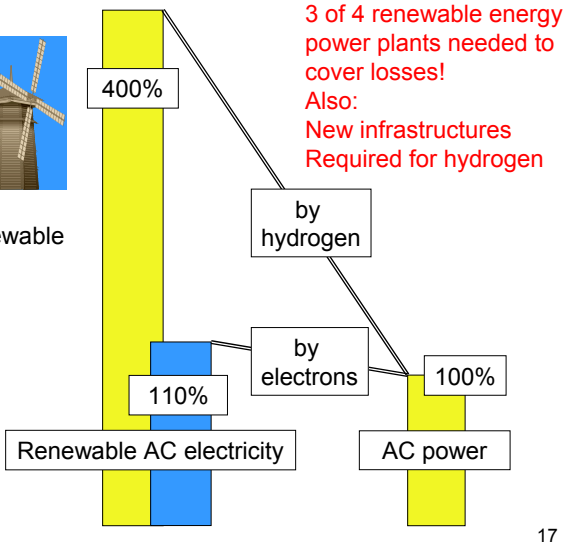
Electricity Transport



Renewable Energy Power Plants

and energy transport by electrons or hydrogen

Substantially more renewable electricity needed



3 of 4 renewable energy power plants needed to cover losses!
Also:
New infrastructures Required for hydrogen

Consumer Cost of Energy

Assumption: As today, energy losses will be charged to the customer.

Therefore by laws of physics:

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 choose the low-cost solution:

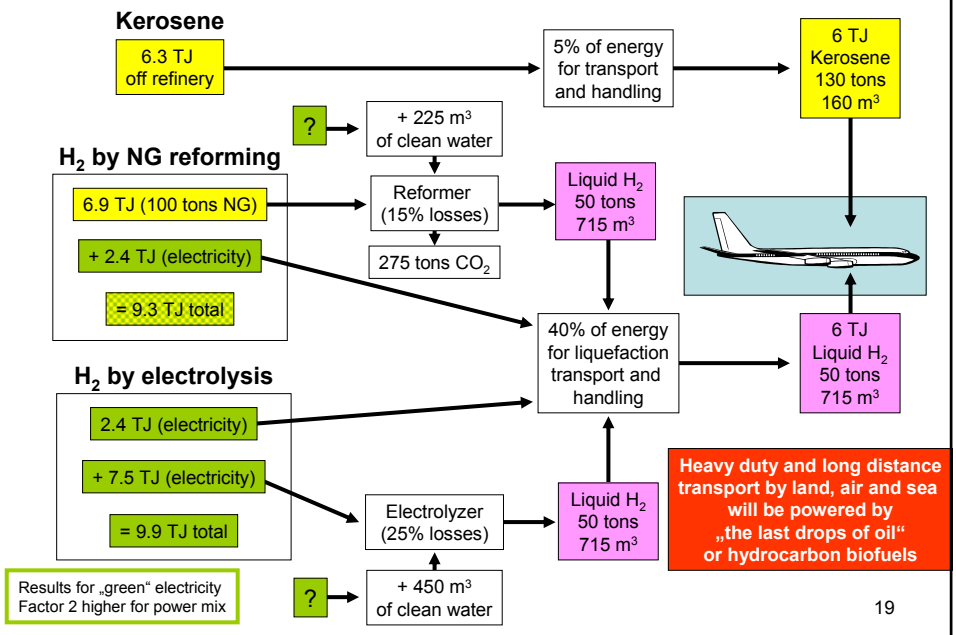
Electric heaters or heat pumps rather than hydrogen for heating

Electric cars for commuting, not hydrogen fuel cell vehicles

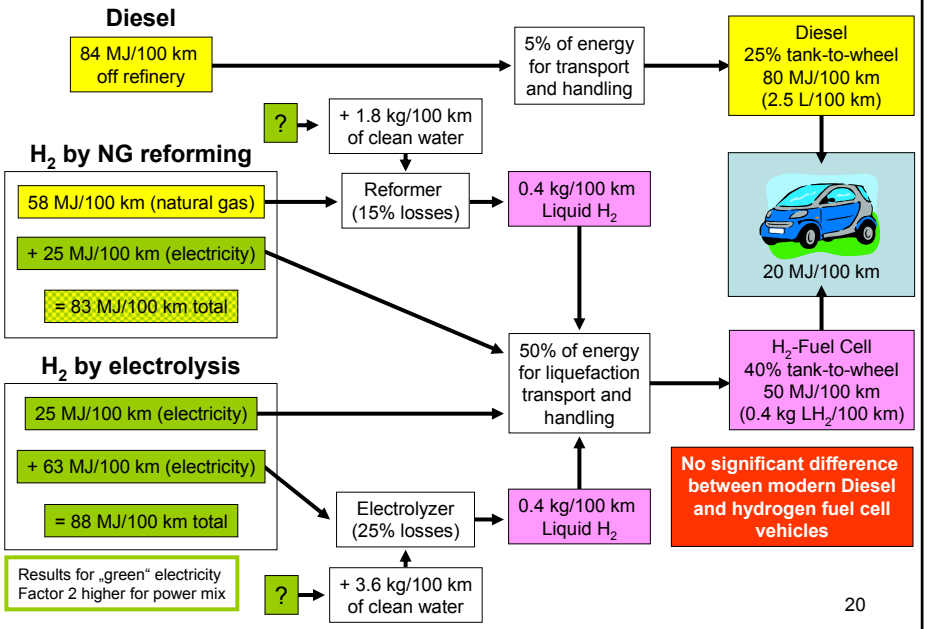
The last drops of oil and liquid fuels from biomass will be used for long distance driving, trucks and air transport

Hydrogen has to compete with its own energy source. Therefore, it will always be an expensive fuel

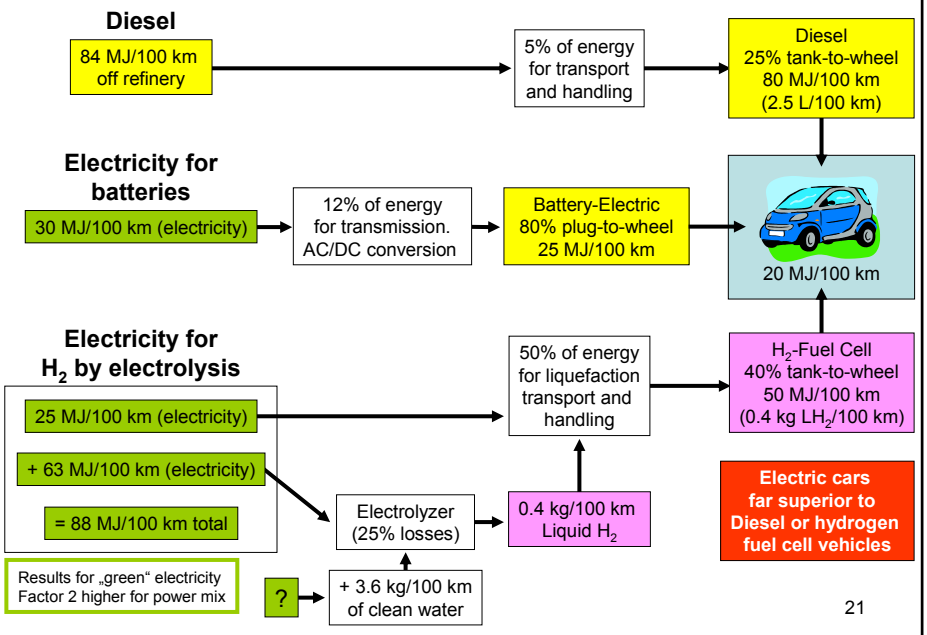
Energy Options for a Jumbo Jet



Energy Options: Diesel vs. H_2-Fuel Cell Cars

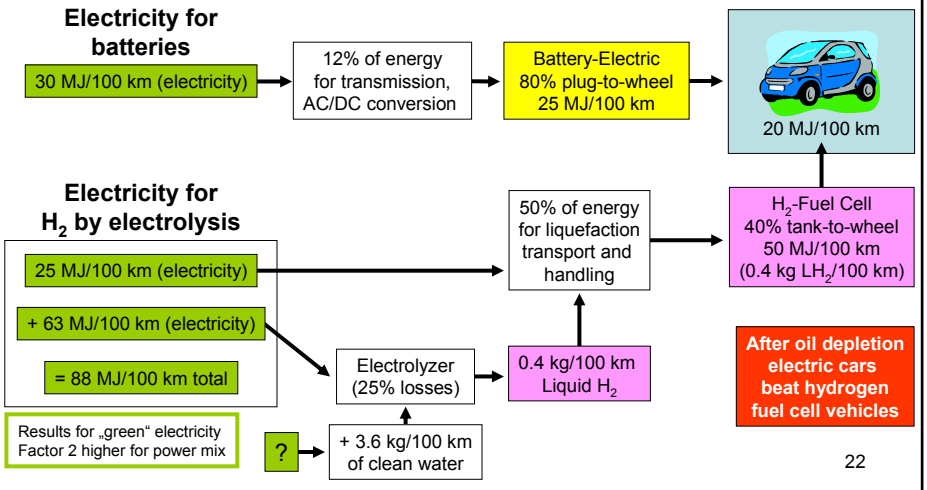


Energy Options: Diesel vs. Electricity for Cars



Sustainable Energy Options for Passenger Cars

In a sustainable future electricity will be the main energy source. Electric cars will be preferred to hydrogen fuel cell vehicles!



Transportation

Status of electric cars with Li-ion Batteries (China):

Range: 350 km on one battery charge.
Battery recharging in minutes. Lifetime 10 years.
Driving costs much less than for IC engine cars,
much less than for hydrogen fuel cell vehicles

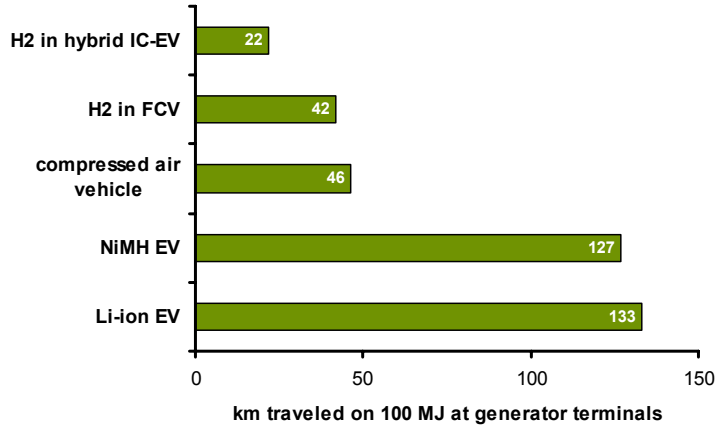
Other options for commuter cars using physical energy:
Compressed air, liquid Nitrogen

Electric cars make much better use of electricity than hydrogen fuel cell vehicles

Technology for a Hydrogen Fuel Cell Vehicles exists or can be developed
But hydrogen infrastructure may never be established:
Who wants to buy hydrogen? Electricity costs much less!
Who wants to invest in a hydrogen infrastructure? Uncertain business!

Wind Electricity for Transportation

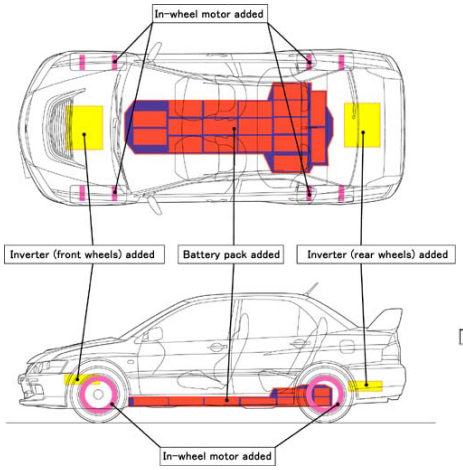
Wind-to-Wheel Energy Assessment
by Patrick Mazza and Roel Hammerschlag
(Lucerne Fuel Cell Forum 2005, corrected)

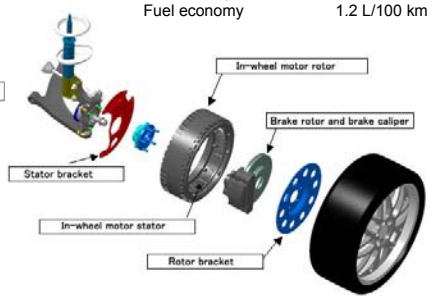


Electric Cars are Coming

Mitsubishi Lancer Evolution MIEV:

Length	4490 mm
Width	1770 mm
Curb weight	1590 kg
Seating	5
Max. Power	4 x 50 = 200 kW
Max. speed	180 km/h
Range/charge	250 km
Lithium-ion	90Ah at 14.8 V
No. of batteries	24
Max. energy stored	32 kWh
Gasoline equivalent	3 Liters
Fuel economy	1.2 L/100 km





Source: Mitsubishi Corporate Press Release of August 24, 2005

Trends towards Electricity

Driven by source depletion and global warming:

- **Rising energy prices**
  - **Stationary:** Improved thermal insulation and more efficient HVAC appliances
    Substitution of natural gas and heating oil by electricity
  - **Mobile::** 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 conversion steps, use of waste energy
- **More electricity from renewable sources**
  Constant cost of renewable electricity at rising oil and gas prices
- **Change in consumer behavior**

Transition to electricity is already in progress.
Hydrogen cannot catch up with electrons

Need Electrical Energy Storage

Storage economy depends on service life, cycle efficiency, initial and operational costs etc.

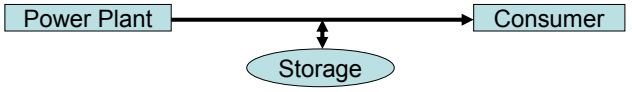
	Service cycles	Efficiency
Hydrogen	1,000?	45%
Lead acid batteries	1,000?	70%
Compressed air	>100,000	75%
Hydro	>100,000	75%
Sodium-Sulfur batteries	2,000?	80%
Flywheels	>100,000	85%
Li ion "batteries"	>100,000	90%
Super capacitors	>100,000	95%

Physical energy storage offers superior solutions

Need Dispersed Electricity Storage

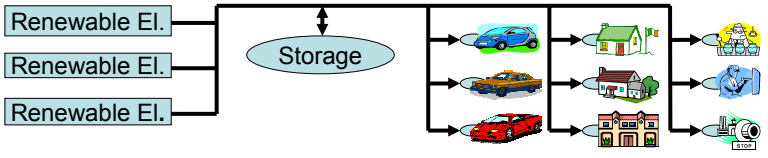
Today:

Two-way storage in few large centralized facilities near power plans



Sustainable future:

In addition to large centralized two-way storage facilities
One-way storage in many small dispersed appliance-connected storage units



In a sustainable energy future dispersed one-way storage will augment centralized two-way storage systems

Need Electricity Storage Management

Dispersed one-way storage units are grid-connected

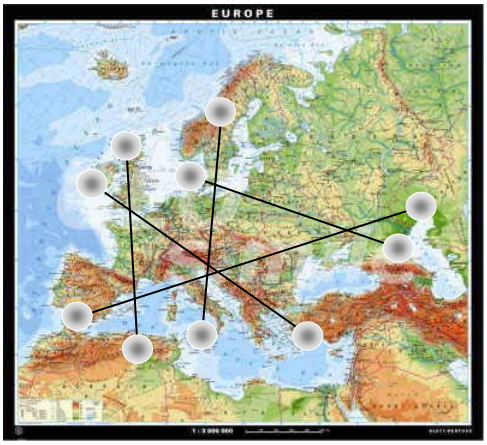
They are charged by electric power utility
to 80% whenever recharging is needed
to 100% when excess power is available
at times when surplus power is inexpensive
etc.

Electric cars stay grid-connected when not driven

Charging conditions as above.
Need automatic charge transfer platforms in garages and parking lots.
Electricity received is metered on-board or by HF-signals
and charged to the car owner by the end of each month

Dispersed one-way electricity storage units could be managed by electric utilities, not by home or car owners

Need New Electric Power Links



wind-wind
hydro-solar
waves-solar
wind-solar
biomass-wind
time difference
etc.

Autonomous renewable energy areas connected by long-distance high-voltage DC power lines

Not a Question of Money

The "2nd Oil War" has already cost the tax payer $300 billion

How much wind energy capacity could have obtained for this sum?

Assumptions:
$1 Mio/$MW_{peak}$ or $3 Mio per $MW_{average}$ for advanced wind generators
$2 Mio/MW from private investors
$1 Mio/MW from government

$1 million support could trigger investment in 1 MW continuous wind power
$300 billion could lead to 300 GW continuous wind generating capacity.

Harvested wind energy sufficient to power
260 million electric commuter cars for 36,000 km per year each
Forever!

Need 0.65% of US landmass, but farming can continue under wind generators

Conclusions

A sustainable energy future is possible when based on energy from renewable sources and highest efficiency!

Energy base must be changed from chemical to physical

Physics is eternal and cannot be changed by governments. Therefore by laws of physics:
Hydrogen can never compete with its own energy source.
A "Hydrogen Economy" has no past, no present and no future

Prepare for an "Electron Economy"

We need:
Energy strategies based on physics, not fantasies
Investments in sustainable technology, not research
True political leadership