

HYDROGEN ICE FOR URBAN TRANSIT SYSTEM

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and,

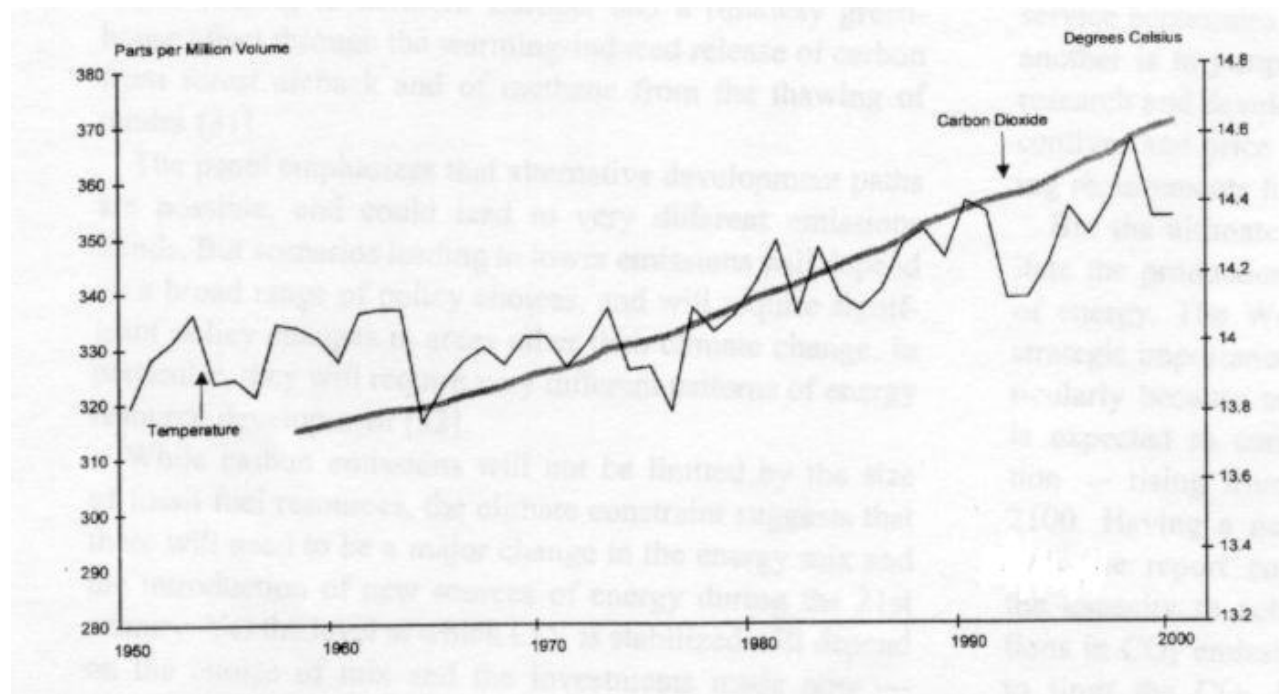
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Introduction

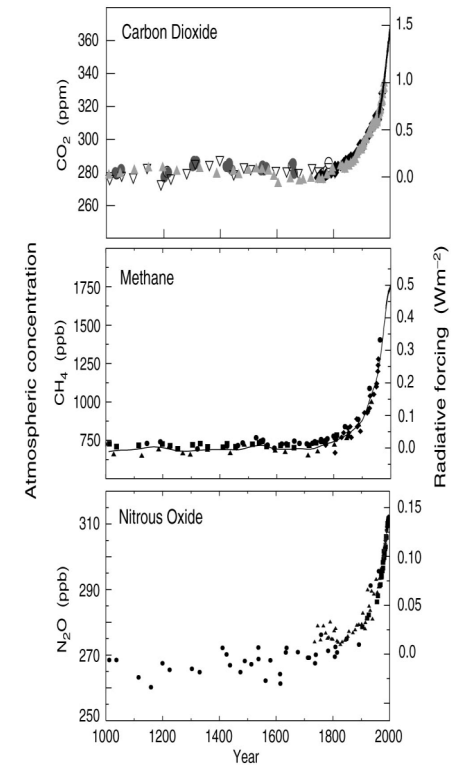
- Since the industrial revolution began fossil fuels in the form of coal, oil, and natural gas have powered the technology and transportation networks that drive society.

- But, these fossil fuels:
 - Cause a variety of environmental and health hazards;
 - Are unevently distributed;
 - will eventually be depleted.

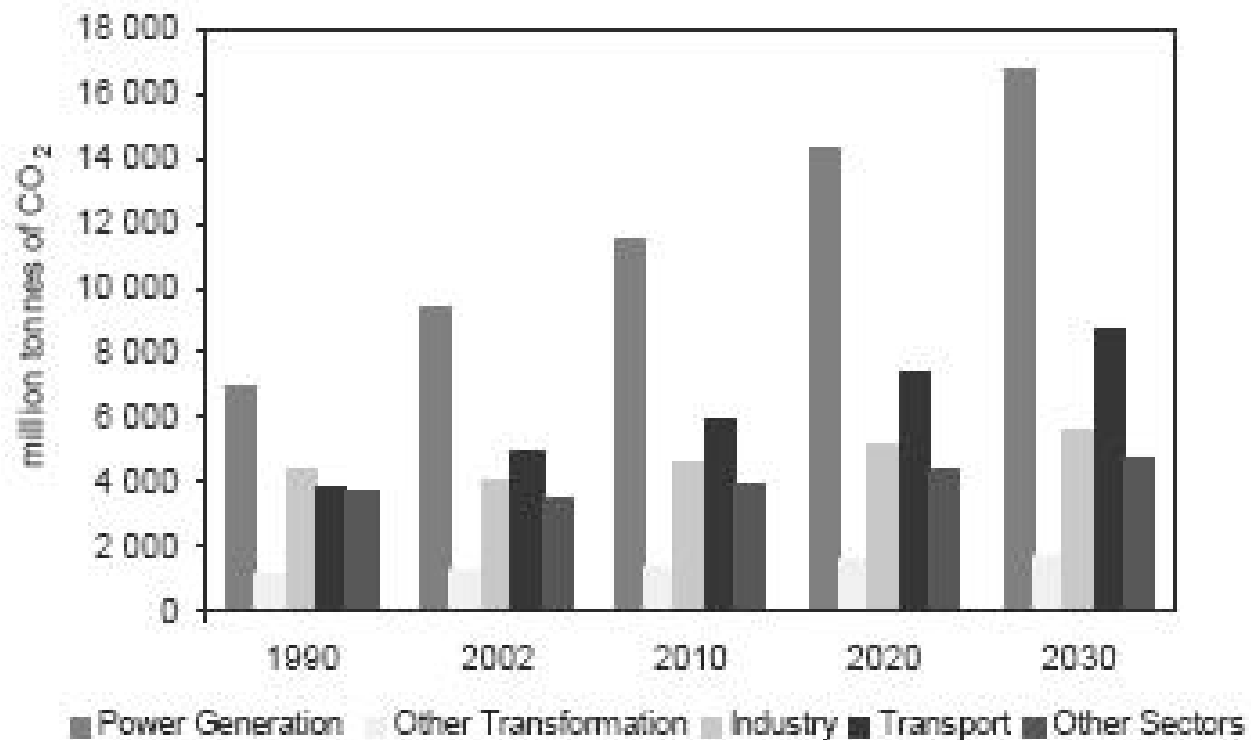
Air Pollution and Global Warming



(a) Global atmospheric concentrations of three well mixed greenhouse gases

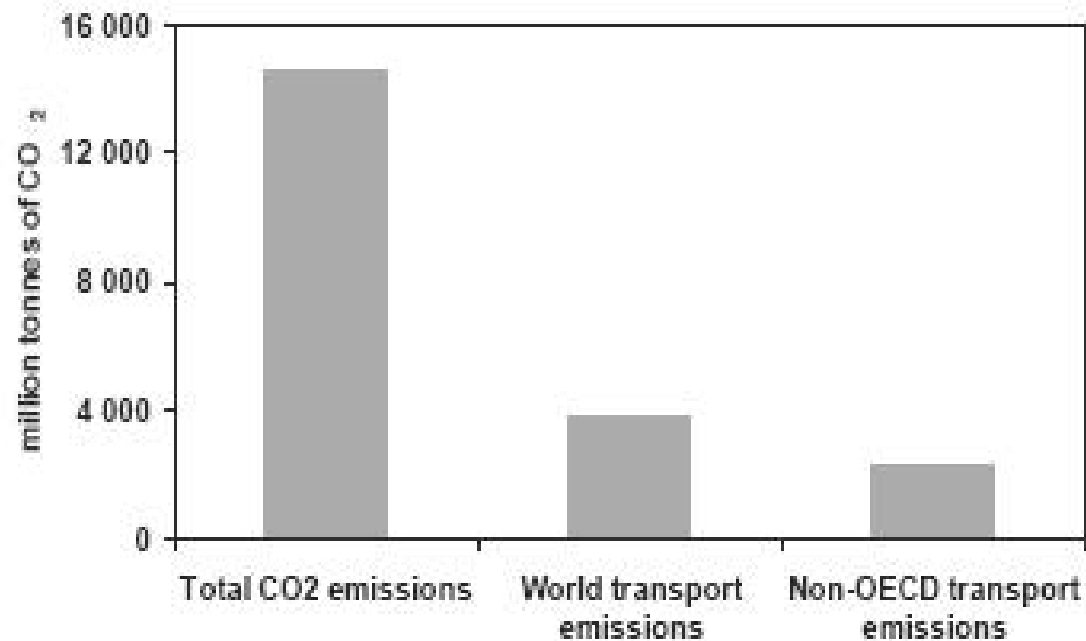


CO₂ EMISSIONS BY SECTOR 1990-2030



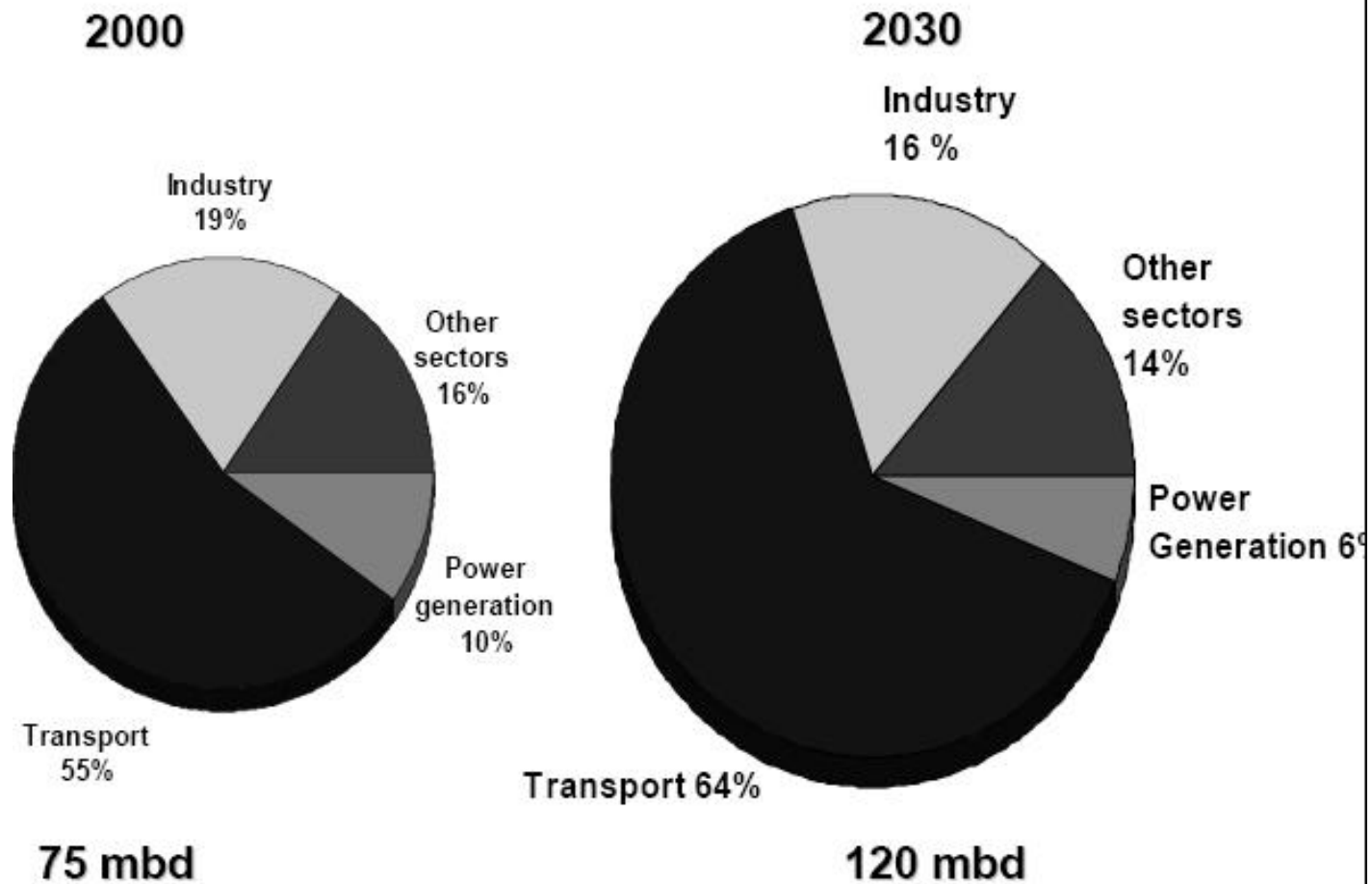
Source: World Energy Outlook 2004.

Incremental CO₂ emissions in the transport sector 2002-2030



Source: World Energy Outlook 2004.

World oil demand by sector



Source: World Energy Outlook 2002.

Reacting to climate change

- Reduction of atmospheric concentrations of CO₂ to acceptable levels will require significant global emission cuts (Kyoto):
 - Gains in energy efficiency;
 - Direct reduction of emissions by targeting most serious emitters of greenhouse gases;
 - Serious effort should be made to develop renewable sources around the world.

Global Energy Systems in Transition

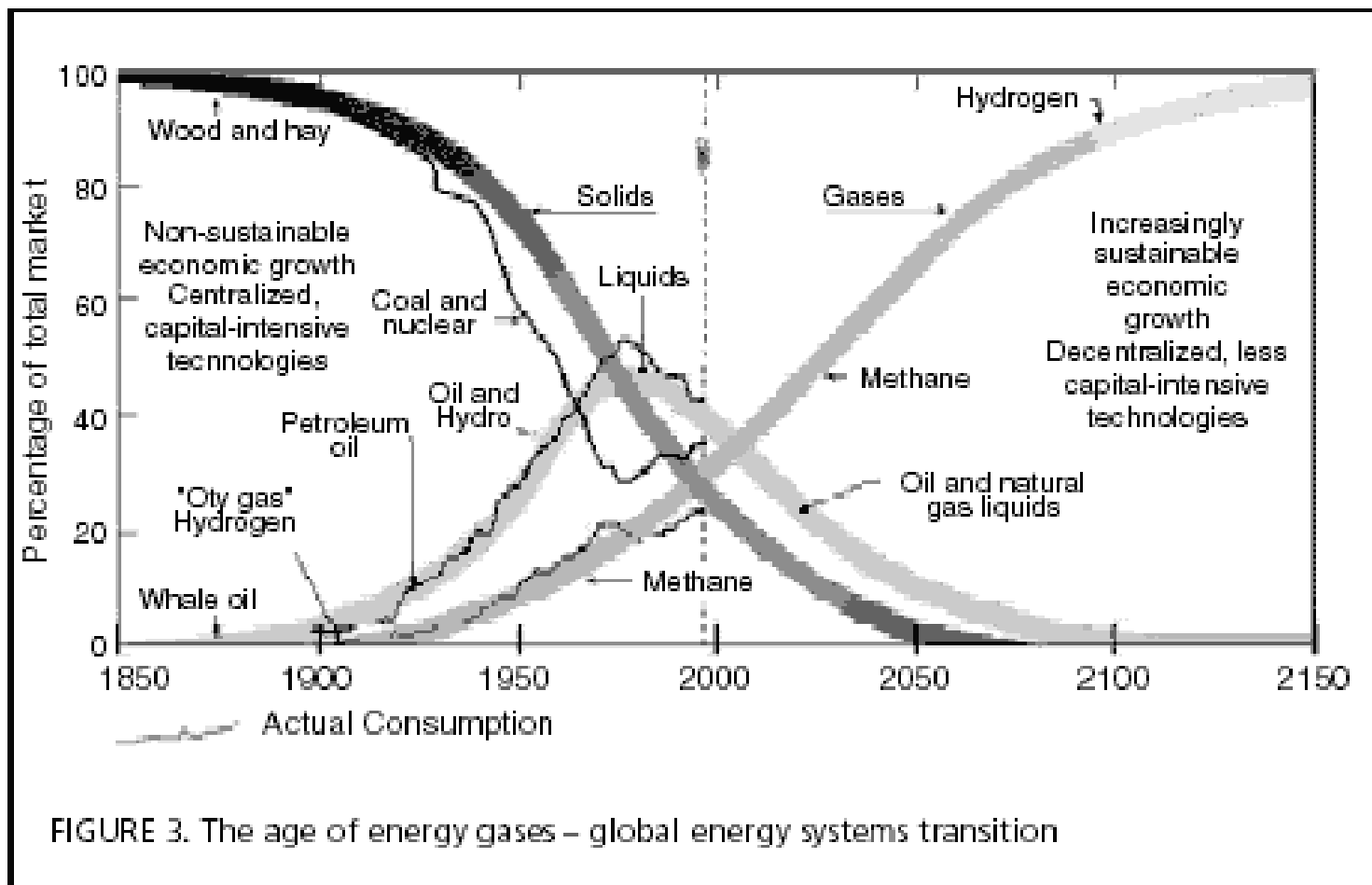


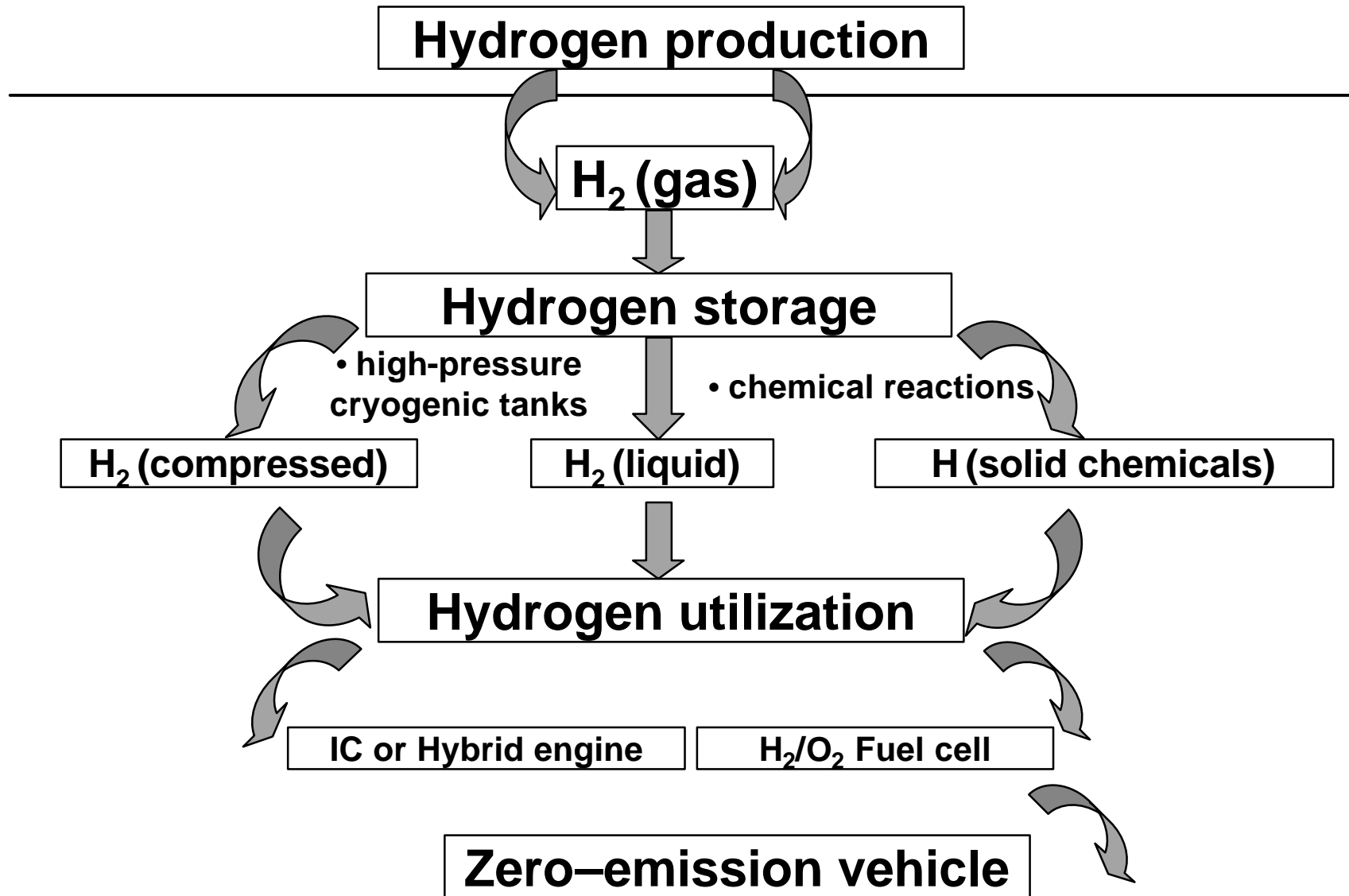
FIGURE 3. The age of energy gases – global energy systems transition

Hefner RA, GHK Company: The age of energy gases.

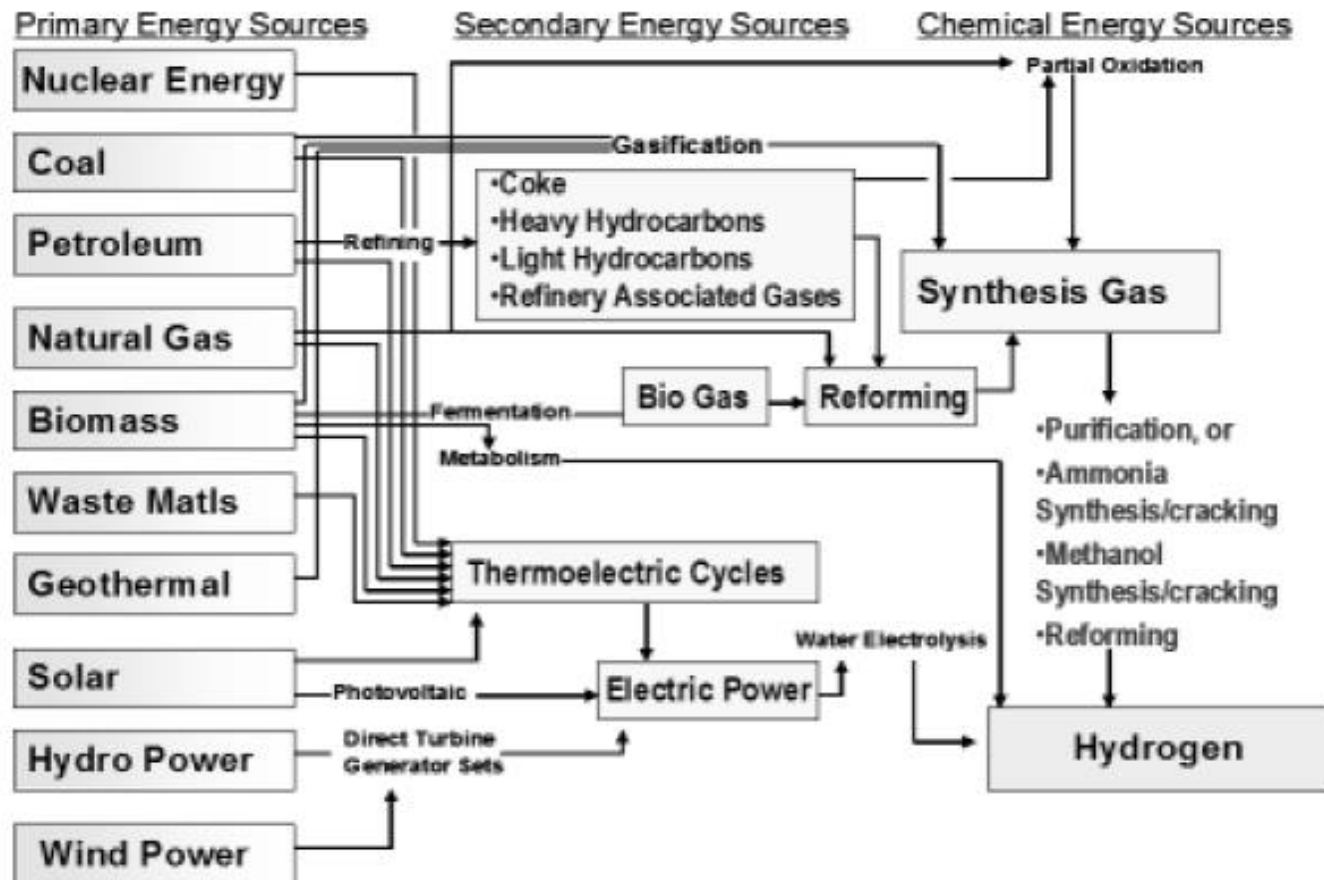
Hydrogen as an Energy Vector

- ❑ Hydrogen is the solution both for local air pollution and GHG emissions.
- ❑ Hydrogen is the most abundant element.
- ❑ Hydrogen is found in water, biomass, fossil fuels, all organic matter.
- ❑ The combustion of hydrogen yields three times more energy per unit mass than petrol and six times more than coal.

CLEAN HYDROGEN ECONOMY FOR THE FUTURE



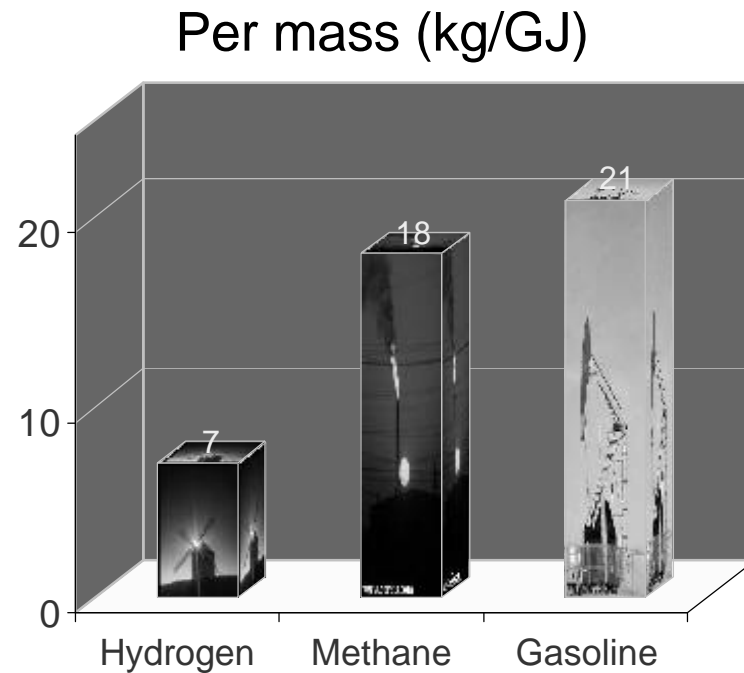
Hydrogen production sources



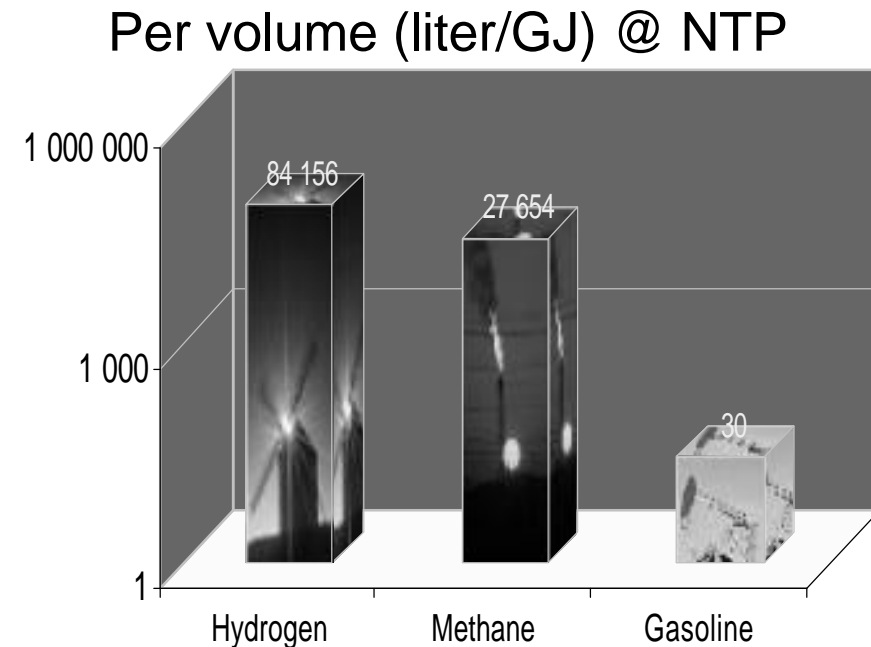
Hydrogen production -2-

- Hydrogen production by reforming fossil fuels reduce air pollution, but
 - It does not solve:
 - The greenhouse gas problem;
 - The depletion problem.
- Reforming fossil fuels (with carbon sequestration) to produce hydrogen should be taken as transitional step toward achieving the benefits of the hydrogen economy.
- Using heat and electricity produced from nuclear reaction could be a source for hydrogen production.
- Production of Hydrogen from renewable sources must be the final step for an effective hydrogen economy.

Hydrogen storage: energy density is critical



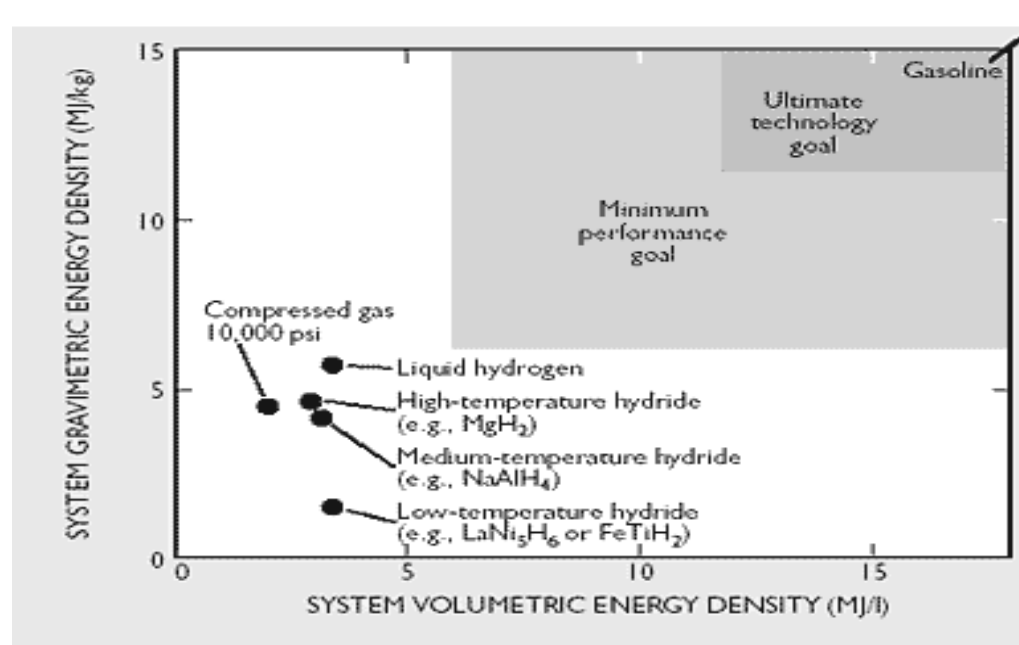
This property makes H_2 very desirable. It lessens the weight of the fuel required.



This dramatically reverses the picture, H_2 leads to heavier and bulkier systems.

Current situation of the energy densities of hydrogen fuels

To be attractive, storage capacity must be increased by a factor 4.



The dawn of a hydrogen economy for mainstream vehicles may well depend on breakthrough research to find new storage materials or innovative storage concepts.

From *The Industrial Physicist*, American Institute of Physics, February/March 2004.

Hydrogen storage reservoir size comparison

Volume Comparisons for 4 kg Vehicular H₂ Storage

Figure 1 Volume of 4 kg of hydrogen compacted in different ways, with size relative to the size of a car. (Image of car courtesy of Toyota press information, 33rd Tokyo Motor Show, 1999.)



Schlapbach & Züttel, Nature, November 15, 2001.

Hydrogen price at the service station based on the primary source and the production process

PRIMARY SOURCE	NATURAL GAS (steam-methane reforming)		COAL (gasification)	BIOMASS (gasification)	ELECTRICITY (electrolysis)
	without CO ₂ sequestration	with CO ₂ sequestration	without CO ₂ sequestration		
Price of the primary source (\$/GJ)	9,30		2,60	2,60	17,80
Cost of production (\$/GJ)	15,30	17,60	16,80	19,50	29,40
Storage (\$/GJ)	1,70	1,70	1,70	1,70	1,70
Transport (\$/GJ)	2,00	2,00	2,00	2,00	2,00
Distribution (\$/GJ)	15,70	15,70	15,70	15,70	15,70
Cost of H ₂ (\$/GJ)	34,70	37,00	36,20	28,90	48,80

Assuming a price of \$60/barrel for petrol, the price after refining is about \$18/GJ

Current obstacles

- In general, a transition to a pollution free hydrogen economy is possible but there are obstacles in the short term:
 - Renewable Hydrogen Cost;
 - Fuel Cell Cost;
 - Fuel Cell Durability.

Transition strategy

- Hydrogen from natural gas:
 -Transitioning to renewable hydrogen.
- Hydrogen Internal Combustion Engine and hybrid:
 - Transitioning to Fuel Cells.

- However, Natural Gas (relatively clean) infrastructure exists in many countries, and one of the ways to hydrogen pathways may be to use HCNG (mixture of NG and H₂) as a transition strategy.

Benefits of Natural Gas

- Emissions benefits of replacing conventional Diesel with CNG

Fuel	CO	NOx	PM (Particulate Matter)
Diesel	2.4 g/km	21 g/km	0.38 g/km
CNG	0.4 g/km	8.9 g/km	0.012 g/km
% Reduction	84	58	97

Natural Gas Infrastructure:

Top 10 countries in term of Natural Gas Vehicles in the World (2005)

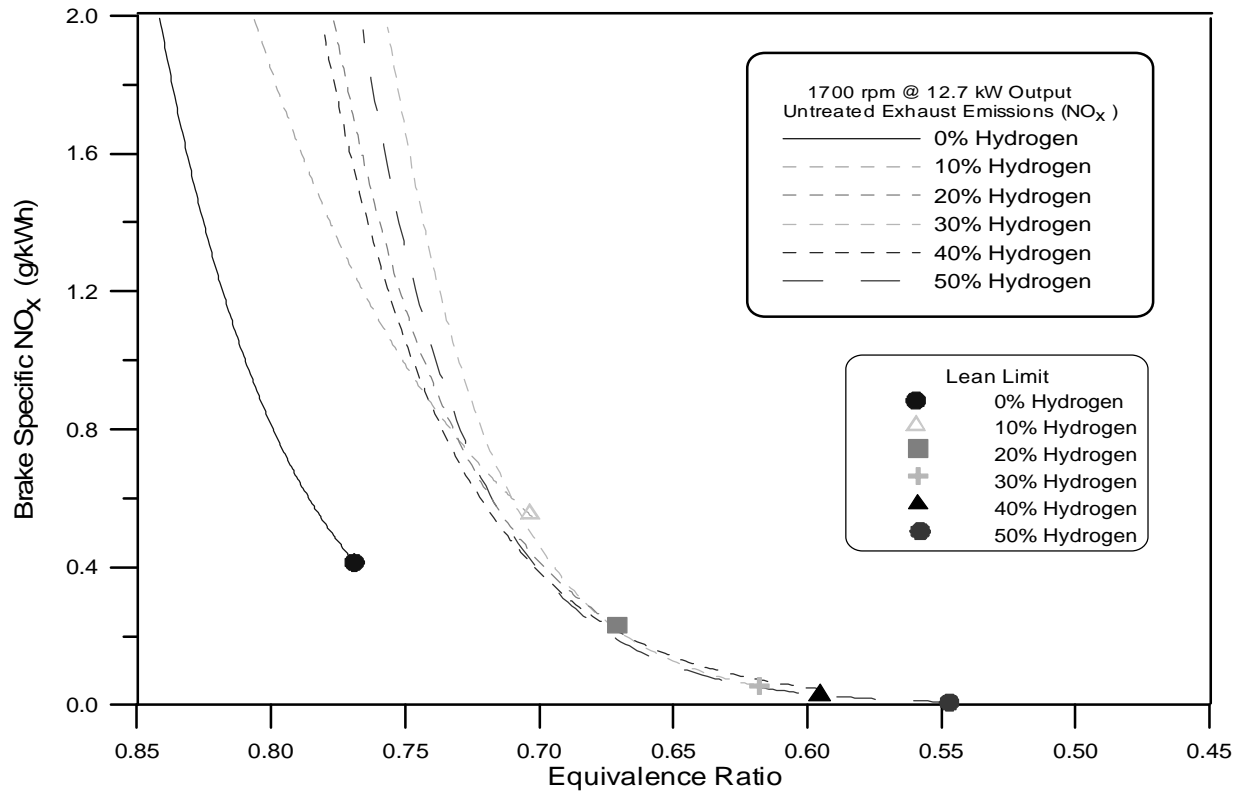
Country Rank	Vehicles (OEM and Converted)	Refuelling Stations
Argentina 1	1,459,236	1,400
Brazil 2	1,117,885	1,227
Pakistan 3	1,000,000	930
Italy 4	382,000	509
India 5	248,000	198
USA 6	130,000	1,340
Iran 7	115,479	137
China 8	97,200	355
Ukraine 9	67,000	147
Egypt 10	63,135	95
Canada 19	20,505	222

Source: Latest International NGV Statistics. International Association for Natural Gas Vehicles. www.iangv.org

Why HCNG?

- **Can utilize existing internal combustion engine technology:**
 - Current infrastructure for volume manufacturing;
 - Current infrastructure for maintenance;
 - Over 100 years of development and refinement.
- **Can utilize existing CNG infrastructure:**
 - Allows potentially lower cost refueling.
- **Hydrgen requirements are modest:**
 - 30 % Hydrogen by volume = ~ 8% by energy content.
- **Most importantly! Ultra-low exhaust emissions.**

Why HCNG?



Source: Collier Technologies.

Pathways toward the hydrogen economy

- The Westport-Cummins (a Vancouver based company) Hydrogen-CNG bus engine upgrade led to:
 - A reduction of nitrous oxide (NO_x) and non-methane hydrocarbon (nmHC) emissions by 50%.
 - In operation, this bus would produce 65% less NO_x, 80% less particulate matter (PM) and about 10 tonnes per year less greenhouse gases (GHG) versus a bus featuring the newest diesel engines certified to the 2002 emissions levels established by the US Environmental Protection Agency.

Pathways toward the hydrogen economy

□ Hydrogen and natural gas infrastructure:

- Vehicles with internal combustion engines burning hydrogen-natural gas blends require the same infrastructure as natural gas.
- Hydrogen and natural gas refueling facilities both require a large scale network of distribution and compression facilities.
- Distributed hydrogen production would be attractive especially in the early stages of a hydrogen economy. Hydrogen could be provided where it was needed, allowing supply to match demand.
- Taking advantage of the natural gas network, onsite production of hydrogen by steam methane reforming is the likely route to achieve cost-effectiveness.

Pathways toward the hydrogen economy

□ Stationary power generation:

- Electricity blackouts are a way of life in many cities around the world.
- Hydrogen-powered fuel cells and ICE generators can be used as a back up power units to provide on-site generation of electricity for residential buildings, and commercial and industrial sites.
- Fuel cells (1 to 2 kW PEM) as back up power for individual apartments or single dwelling. They are noiseless and non-polluting.
- HICE could be used as back up power for buildings, hospitals, fire stations, etc.
- Hydrogen will be provided by refuelling stations developed for the transportation sector.

Hydrogen Internal Combustion Engine

- ❑ **To reduce NOx hydrogen fuelled engines you must reduce the equivalence ratio (EQR) to .4 or lower:**
 - NOx emissions of less than 1 ppm can be achieved by proper engine design and engine controls.
- ❑ **Pre-ignition concerns:**
 - Hydrogen ignites very easily;
 - Don't run hydrogen in a « dirty » engine as the carbon deposits can act as ignition sources and cause pre-ignition.
- ❑ **Effects of ambient temperature:**
 - Hydrogen is almost unaffected by ambient temperatures. It is an excellent « starting » gas for engines on cold mornings;
 - Antarctica is not too cold for hydrogen to operate in.
- ❑ **Power from hydrogen:**
 - Hydrogen has a high octane rating and can be used in engines with 14.5:1 compression ratio;
 - This gives an increase of more than 4% in efficiency.

Emissions test results

□ HC	(ppm)	2.6
□ CO	(ppm)	0.0
□ NOx	(ppm)	7.1
□ O2	(%)	13.8
□ HC	(grams/hr)	1.4
□ CO	(grams/hr)	0.0
□ NOx	(grams/hr)	5.3

Hydrogen ICE-Hybrid

- ❑ Hybrid electric vehicles are well suited to “stop-and-go” city transit operation.
- ❑ The hybrid-electric design allows considerable increase in efficiency (compared to conventional drive vehicles) due to energy recovery by use of regenerative braking.
- ❑ The fuel efficiency of the high-compression hydrogen ICE hybrid could approach that of the diesel hybrid.
- ❑ Gasoline ICE hybrid gives 52 miles/ gallon for a compact car.
 - It is expected that the mileage and efficiency of the hydrogen ICE hybrid would be considerably better.

Conclusion

- ❑ An elegant solution to the storage problem of H₂ is one of the most important issue.
- ❑ Renewable hydrogen must be pursued as a long-term strategy.
- ❑ Hydrogen ICE and hybrid technologies may play a commercial role in the near term. Hydrogen FCVs are believed to be the long-term solution
- ❑ The green future will not be based on the hydrogen economy alone but certainly on a sustainable energy economy with a broad clean energy sources portfolio.