Centre for Energy and Environmental Markets

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Prospects for Fuel Cells and Hydrogen

With an emphasis on transport applications

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Inaugural Meeting of the Hong Kong IAEE Affiliate, 19 December 2005

Hydrogen fuel cell car

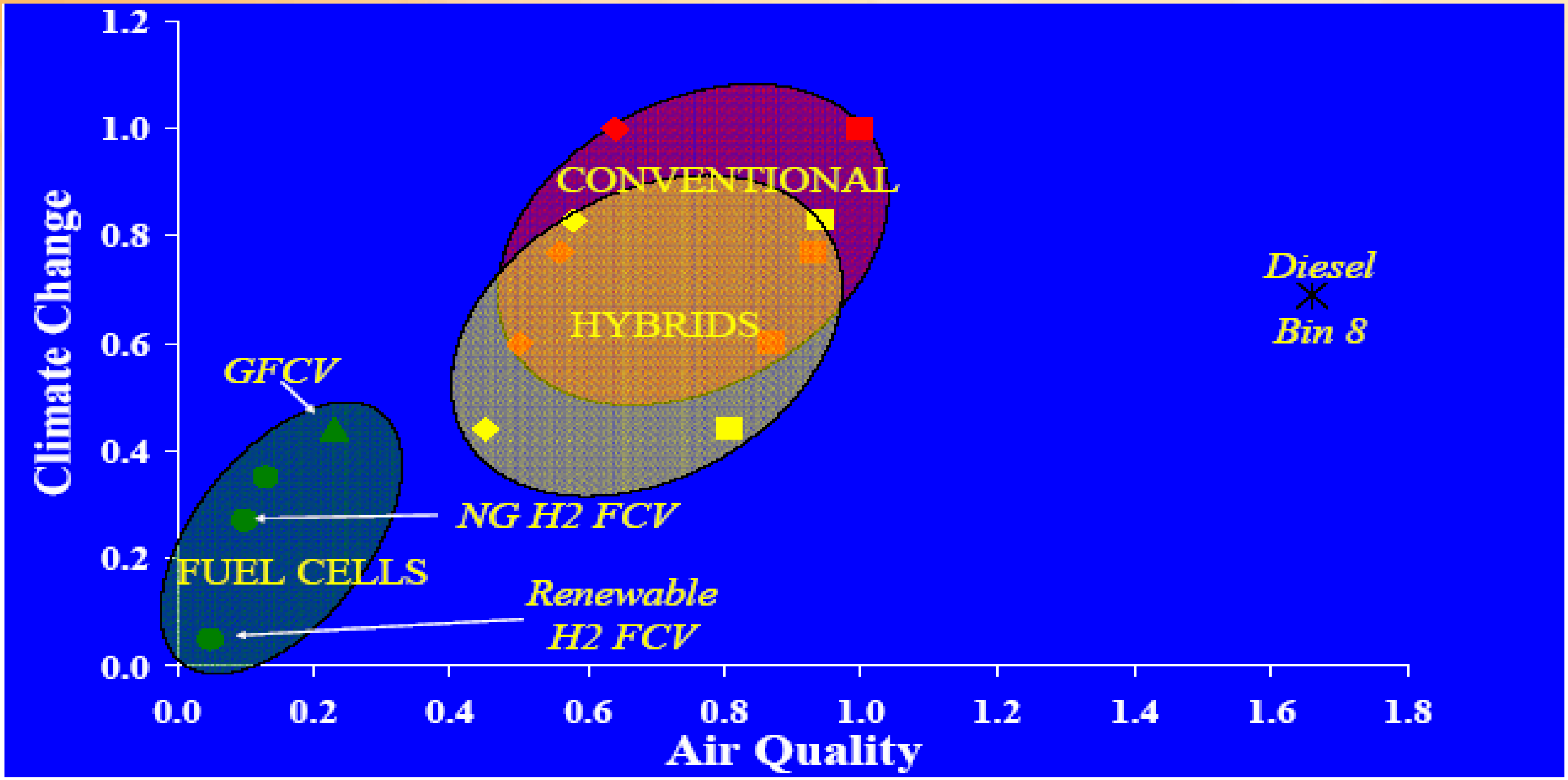
Hydrogen fuel cell bus

Why fuel cells and hydrogen?

1. Environmental impact of combustion of fossil fuels:
   - Global – Climate change
   - Local – Air pollution

2. Energy (and specifically oil) security and price volatility

Environmental footprint
Passenger cars and trucks



What’s a fuel cell?

A fuel cell is an electrochemical device that produces electricity by combining stored hydrogen and oxygen from the atmosphere. The only emission is water vapour.

A fuel cell vehicle is an electric vehicle that uses a fuel cell rather than a battery to provide electricity for power.

A FCV could also use methanol, natural gas, or gasoline but would require on-board conversion to hydrogen gas

Advantages and disadvantages of fuel cells

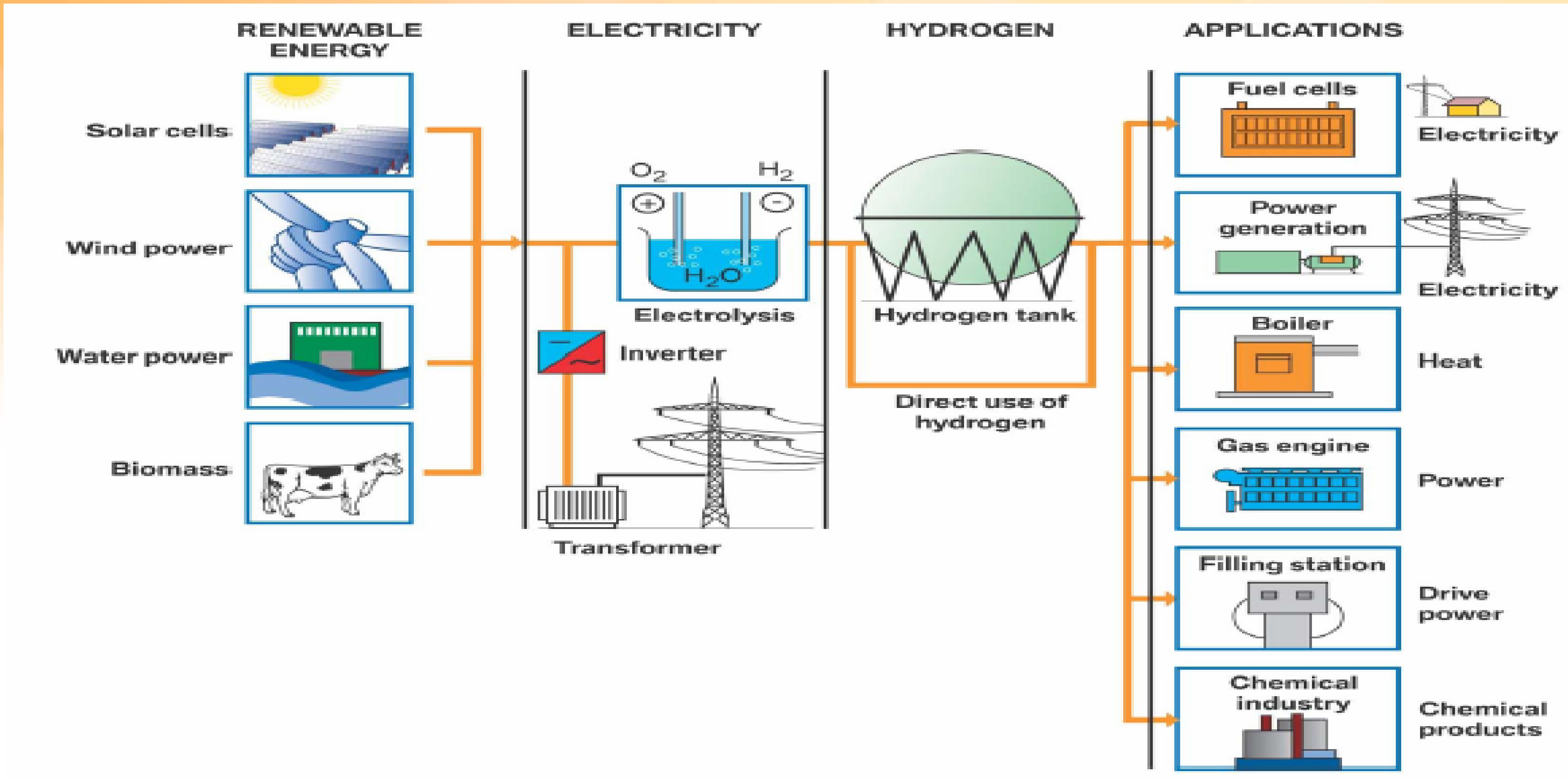
Advantages

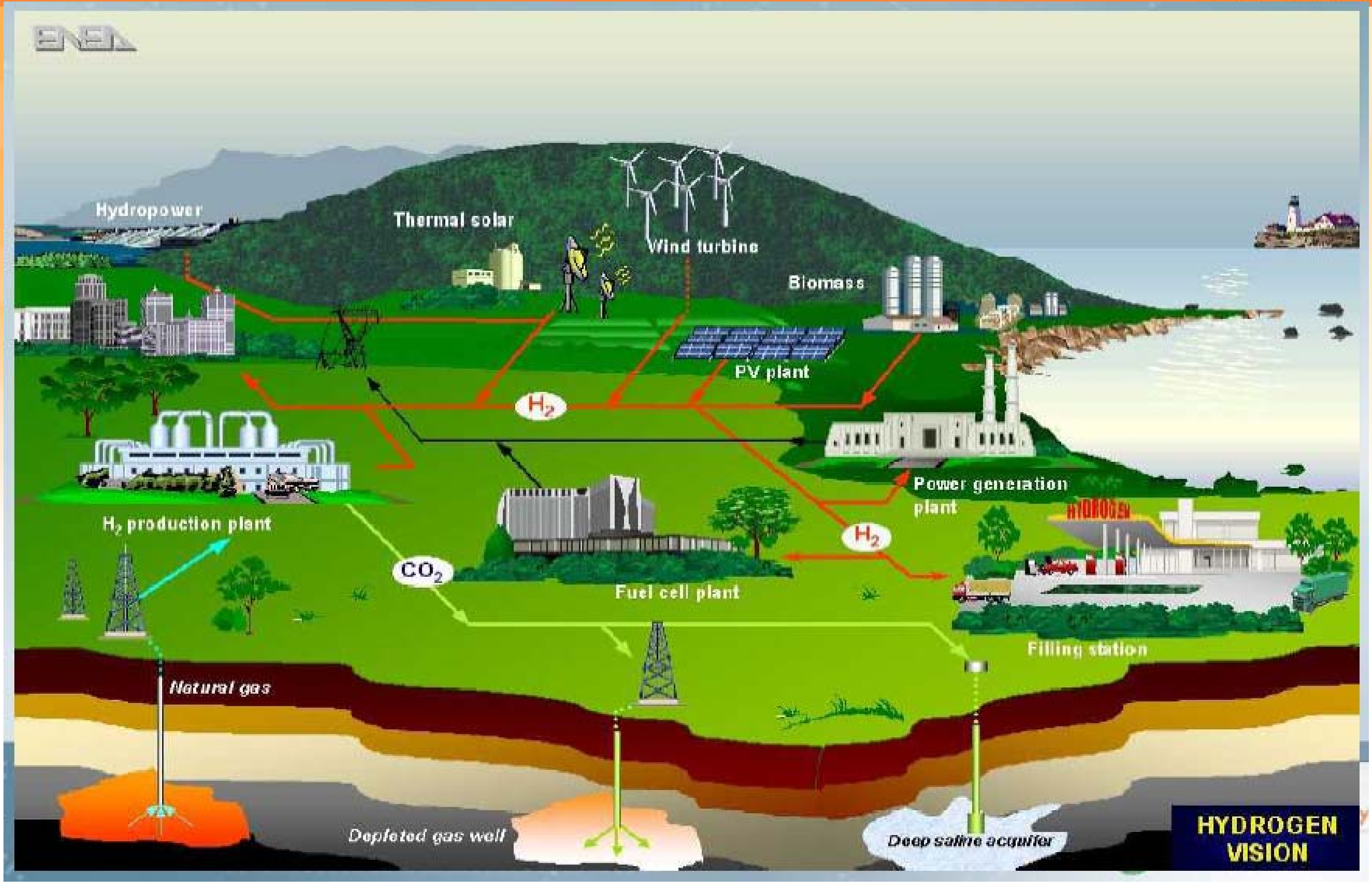
- Near-zero emission of pollutants
- Can be twice as efficient as conventional vehicles
- Operate silently

Disadvantages

- Expensive
- Unreliable (lack robustness)
- Hydrogen should come from renewable resource (supply currently constrained)
- Hydrogen on-board storage a problem.

Hydrogen as an energy carrier




Hydropower
Thermal solar
Wind turbine
Biomass
PV plant
H_2
Power generation plant
H_2 production plant
CO_2
Fuel cell plant
H_2
Filling station
Natural gas
Depleted gas well
Deep saline acquifer
HYDROGEN VISION

Promising Technology Areas to Reduce GHG Emissions & Improve Energy Security

- Efficient energy end-use technologies
- Renewable energy
- Fossil fuel power generation with carbon capture and storage (CCS)
- Advanced nuclear power
- Hydrogen as a clean energy carrier for transport, energy storage, and distributed power generation
- Fusion

Stationary Power: Constraints on Fuel Cells & Hydrogen

High initial cost (lack of economies of scale)

Short operating life

Immature technology

Deregulated power industry (wants low risk)

Competing technologies (some “renewable”)

Stationary Applications of Fuel Cells

- Commercial Applications

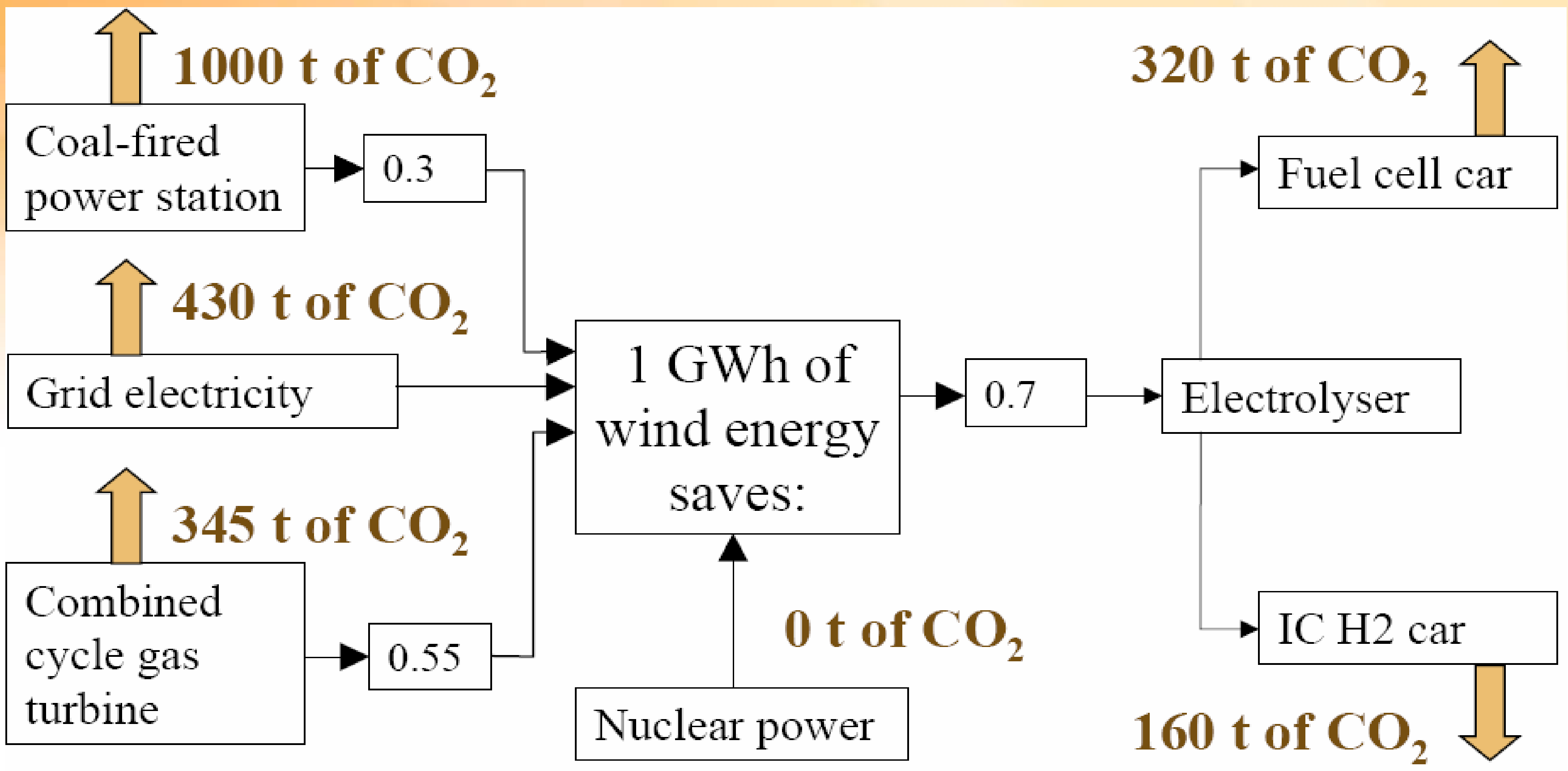
  Combined (low) heat and power applications (e.g. schools, hospitals, apartment blocks)
- Industrial Applications

  High temperature fuel cells for co-generation.
- Distributed Generation

  Niche markets
- Residential Applications

CO_2 savings from 1 GWh of wind energy

(Source: Tyndall Centre)



Current Challenges

How does a hydrogen strategy fit in with other opportunities to reduce environmental externalities of energy use in both the stationary power and transport sectors?

Time horizons needed to develop supporting technologies:

- Fuel cells
- CO_2 sequestration
- Renewable energy capacity

Costs and benefits of alternative approaches for both sectors.

Externalities

Definition

Benefits or costs generated as an unintended by-product of an economic activity that do not accrue to the parties involved in the activity, and where no compensation is paid.

Environmental Externalities of Energy Use

- Health damages from emission of pollutants
- Damages resulting from emission of greenhouse gases

Calculation of Environmental Externalities

- Life cycle analysis: “cradle to grave” accounting of all energy and material flows (& hence pollutants).
- Quantify impacts/damage in terms of physical units
- Translate physical impacts/damage into monetary units: “externality adders” (¢/kWh or ¢/vkm).

Damage from Air Pollutant Emissions

Damage costs vary greatly due to:

- Vintage of combustion technologies
- Emission-reducing devices employed
- Population density in receptor area
- Fuel quality (particularly coal)

Other damage costs:

- Mining and fuel transport externalities (particularly accidents)

Financial v. Economic (Societal) Analysis

- Financial Analysis

  Private net benefit of an investment
- Economic (or Societal) Analysis

  Net benefit to society of an investment

Societal Analysis = Financial Analysis

remove Market distortions (taxes & subsidies)

add in Net environmental impacts (generally negative), on a total lifecycle cost basis.

Transport Sector Accounts for 25% of CO_2 Emissions: Options

- Possibilities for near-zero CO_2 emissions for transport:
  - hydrogen
  - electricity
  - biofuels
- Each technology has its own set of limitations and challenges
- Hydrogen is increasingly seen as the next generation of motor vehicle technology

Fuel Cells and Hydrogen for Cars

Current Problems:

- Huge “fuel” infrastructure investment required
- On-board storage of hydrogen (compactness missing)
- Expense of fuel cells (no economies of scale)
- Energy security benefits not “internalised”
- Environmental impacts of gasoline ignored

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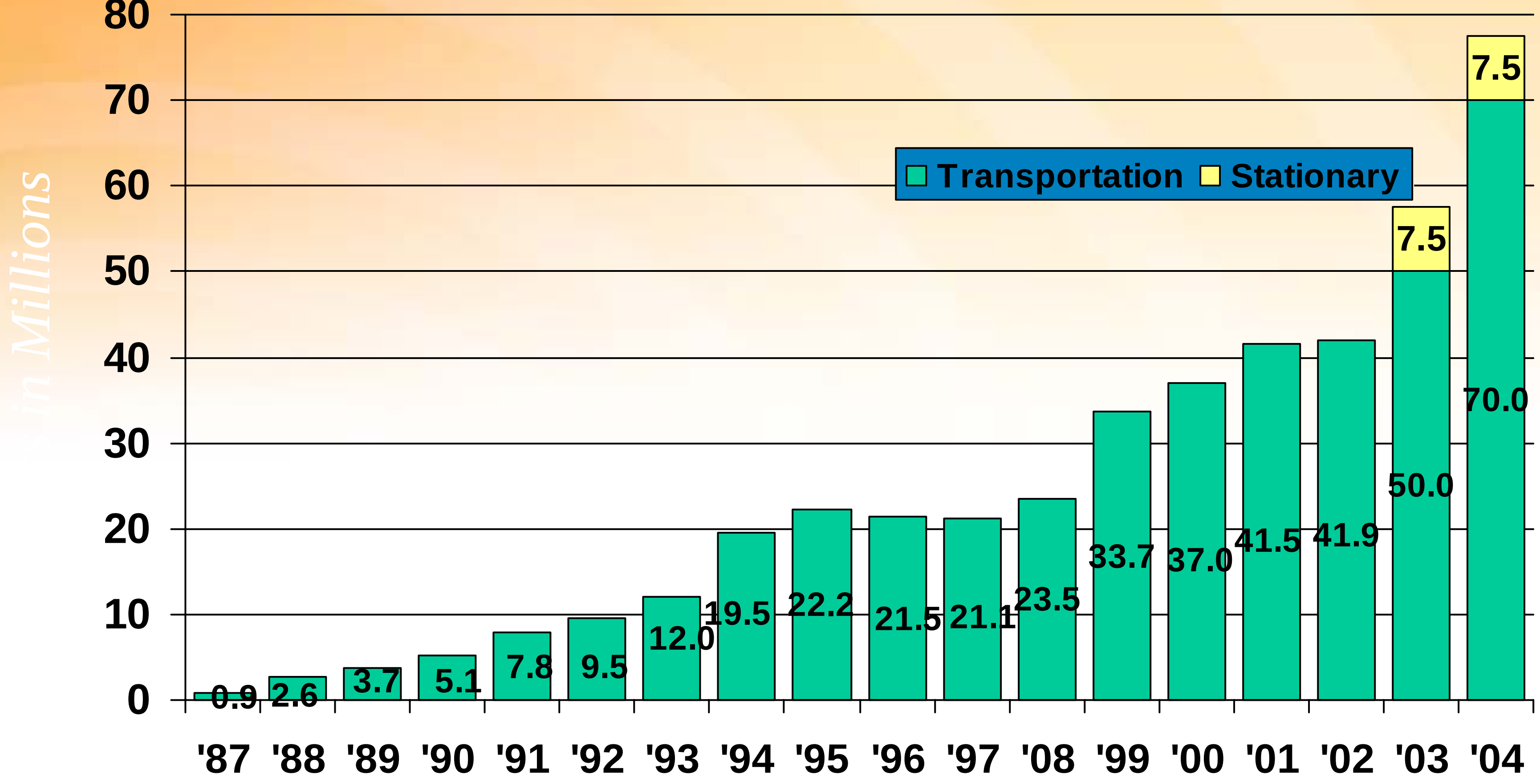
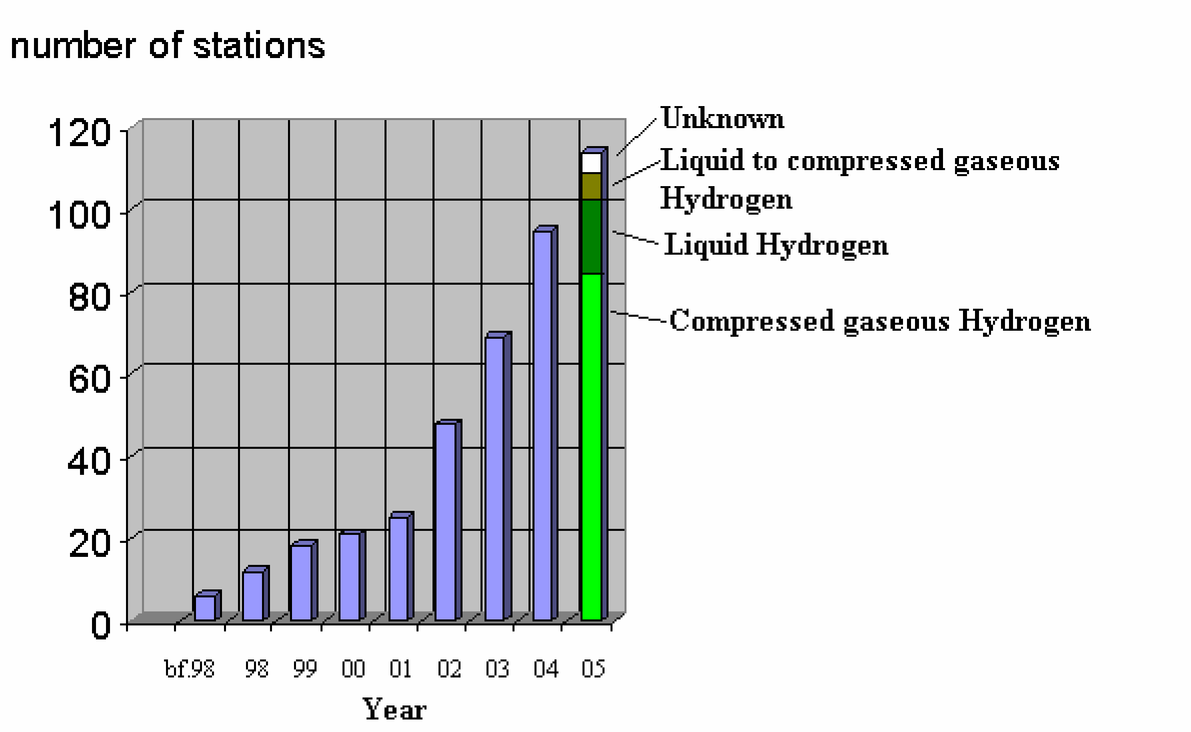
DOE Fuel Cells for Transportation: Funding History



Source: Breakthrough Technologies Institute

Hydrogen Filling Stations in the World



Hydrogen Supply Cost Projections

	Future fuel/elec. resource price	Fuel cost ($/GJ)	Other prod. costs ($/GJ)	Transport cost ($/GJ)	Refuelling ($/GJ)	Future supply cost ($/GJ)
Gasoline/diesel	$25-29/bbl	4-5	2	<1	2	8-10
Natural gas	$3-4/GJ	3-4	n.a.	<1	4	7-9
H2 (gas) CO2 seq.	$3-5/GJ	3.8-6.3	1.2-2.7	2	5-7	12-18
H2 (coal) CO2 seq.	$1-2/GJ	1.3-2.7	4.7-6.3	2	5-7	13-18
H2 (biomass)	$2-5/GJ	2.9-7.1	5-6	2-5	5-7	14-25
H2 (wind-onshore)	3-4c/kWh	9.8-13.1	5	2-5	5-7	22-30
H2 (wind-offshore)	4-5.5c/kWh	13.1-18.0	5	2-5	5-7	27-37
H2 (solar thermal)	6-8c/kWh	19.6-26.1	5	2-5	5-7	32-42
H2 (PV)	12-20c/kWh	39.2-65.4	5	2-5	5-7	52-82
H2 (nuclear)	2.5-3.5c/kWh	8.2-11.4	5	2	5-7	20-27
H2 (HTGR cogen.)	n.a.	n.a.	8-23	2	5-7	15-32
Source: IEA (2003)						

Energy Security of Supply

- Marked asymmetry: value of unit of energy delivered and the value of the same unit not delivered.
- Supply interruptions can swiftly lead to widespread economic dislocation due to difficulty/expense of energy storage.
- Resilience of energy systems to extreme events a major problem for industrialised societies.
- Damage to GDP reflects cost of energy insecurity.

Emerging Priorities
Research and Development

- Reduce cost of producing and storing CO_2-neutral hydrogen
- Reduce cost and improve durability of fuel cells
- Development new technologies to store hydrogen

Emerging Priorities
Policy and Communication

- Identify impact and cost pathways to the H_2 economy
- Quantify infrastructure requirements
- Develop international codes and standards
- Identify early commercialisation niches
- Improve information to policy makers
- Coordinate international initiatives
- Build public education and awareness
- Proceed with cautious optimism and realism

Summary

- Economic viability of hydrogen vehicles dependent upon valuation of damages arising from other technologies, and removal of market distortions.
- Considerable uncertainty surrounds level of damage costs.
- What value security of supply?
- Transition via natural gas economy or technology "leap"?
- Alternative technological developments?
- Net cost of transition to a hydrogen economy?
- Integration with urban planning.
- Social welfare impacts of the transition.

Societal lifecycle costs: automobiles with alternative fuel/engine options

Technology	Retail Cost Drive Train + Fuel Storage	Cost of Alum. Frame	Present Value			
			Lifetime Fuel Costs	Total Private Lifecycle Costs	Lifetime Externalities	Total Societal Costs
Current gasoline	2837	0	2828	5665	6723	12388
Gasoline HEV	2837+1342	936	1316	6432	3015	9446
H_2 (NG) HEV	2837+2780	936	2823	9376	1081	10457
H_2 (NG) FCV	2837+2459	936	2169	8402	736	9138
H_2 (wind) FCV	2837+2459	936	3394	9626	182	9808

Commercialisation of HFC cars

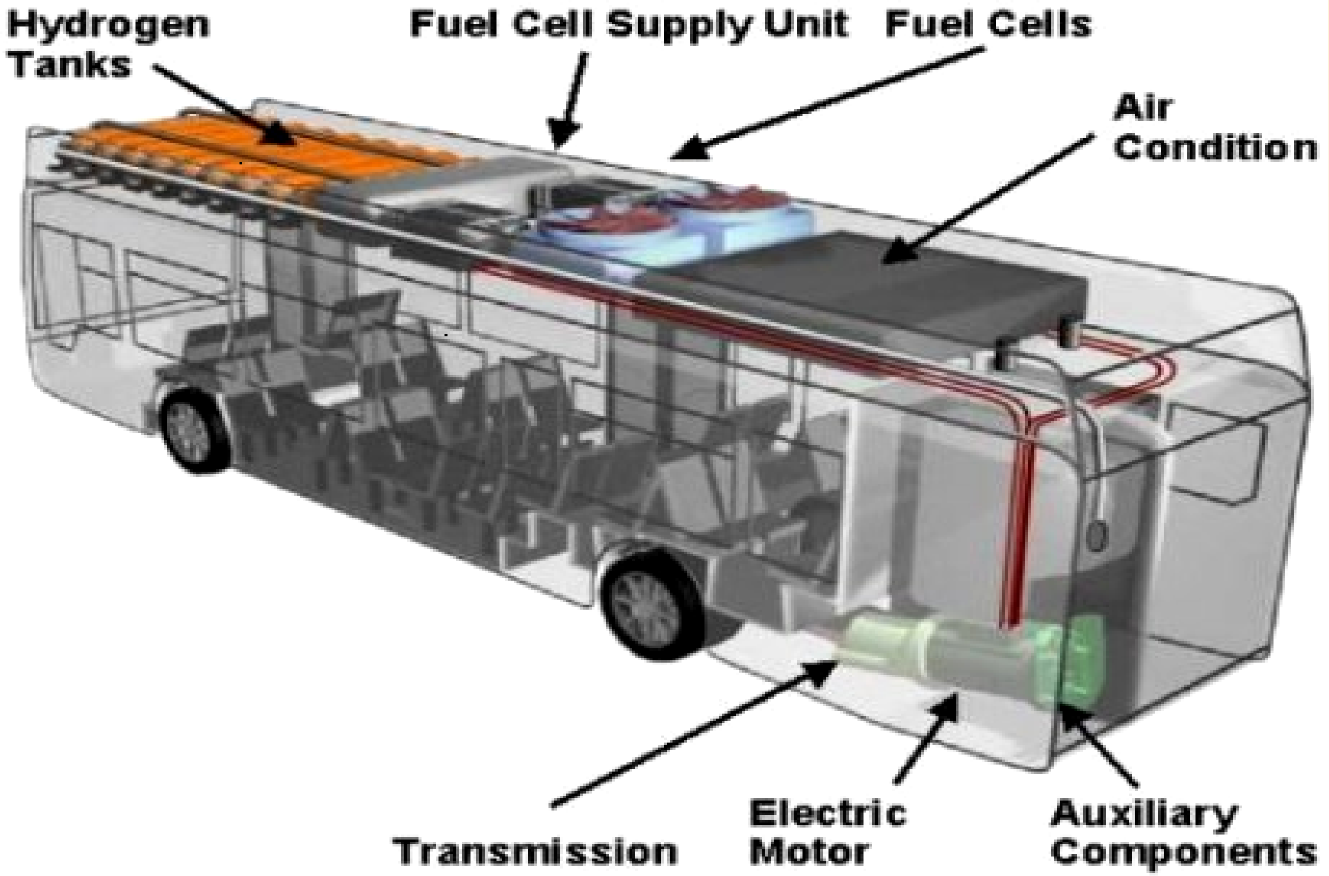
- Hybrid cars current benchmark technology.
- Most car manufacturers expect commercially viable fuel cell vehicles to available 2010-2012.
- Requires fuel cells to be < $100/kW and of greater reliability than today.
- Production and distribution of hydrogen major problem: cost of both.
- Light, hybrid/FC vehicles to minimise fuel use and storage.

Hydrogen and buses

Advantages of buses for hydrogen trials

- Regularly return to a depot
- Minimum need for compactness of technology
- Long operating periods
- Low emission regulations in urban areas
- Urban authorities may subsidise operations

Public utility vehicles may have similar benefits


Hydrogen
Tanks
Fuel Cell Supply Unit
Fuel Cells
Air
Condition
Transmission
Electric
Motor
Auxiliary
Components

Key R&D requirements

Increase efforts in key R&D areas:

- **Reduce cost of CO2-free hydrogen**
- **Reduce cost, improve life-time of fuel cells**
- **Improve hydrogen storage in FC vehicles**
- **Develop carbon sequestration to extract H2 from fossil fuels**