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HYDROGEN MARKETS & INFRASTRUCTURE

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Crete

Learning Objectives

- Understand: -
  - Where are the Markets
  - Where hydrogen is used
  - Current progress and ideas

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Where would Hydrogen be used?

@#####...*don't say Fuel Cells*...#####@

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Contents

1. Current Hydrogen Applications and Uses
2. Hydrogen Markets and Costs of Hydrogen
3. Distribution and Infrastructure
4. Hydrogen as a Vehicle Fuel
5. Hydrogen as a energy store
6. The future

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1. Hydrogen Applications

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Hydrogen Applications

- Ammonia synthesis
- Crude oil refining
- Methanol production
- Hydrogenation of fats in food processing
- Metallurgy
- Cooling in gas turbines
- Production of artificial diamonds
- Chemical industry
- Energetic use
- Town gas

Hydrogen Applications

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Ammonia Synthesis

- Process:
  - $N_2 + 3H_2$ ------> $2\ NH_3$ (Haber-Bosch process)
- Usage:
  - Cooling agent (ammonia refrigeration)
- Basis for products:
  - Fertilisers, explosives, fibers/plastics, pharmaceuticals, pulp & paper
- H_2 annual demand
  - 33×10^9 Nm^3 in EU (55% of total)
  - 250×10^9 Nm^3 worldwide
- 50% of total hydrogen consumption (was: 80% in the 1980ies)

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Crude Oil Refining 1/2

- Multi-stage Process:
  - Distillation Tower at atmospheric pressure:
    - division into 4 fractions:
      - - kerosene, light/heavy gas oil, fuel oil (‚Naphtha‘)
  - Cracking by heating, catalytic reforming and fluid catalytic reforming follow for various qualities of fuel
  - Alternatively “Hydrocracking” with hydrogen at ca. 150 bar also delivers various fuel stock under flexible production conditions
- Reforming of naphtha leads to excess hydrogen production from paraffin cracking.

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Crude Oil Refining 2/2

- Hydrogen usage:
  - de-sulphurisation of intermediate products (to prevent poisoning of catalysts and/or improve quality) by forming H_2S
  - Hydrocracking
- Production by
  - naphtha reforming (by-product)
  - fuel gas/methane reforming
- H_2 annual demand
  - 17 x 109 Nm^3 in EU (30% of total)
  - 185 x 109 Nm^3 worldwide
- 37% of total hydrogen consumption

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Methanol Synthesis 1/2

- Two-stage Process:
  - Steam reforming of natural gas (Syngas, H_2 and CO)
  - Catalytic (metal oxide) formation of methanol under pressure and high temperature
- Followed by purification by distillation

- Alternative:
  - Synthesis from CO_2 and H_2
- Energy demand is higher, though, but no fossil fuels necessary if hydrogen is available from other sources

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Methanol Synthesis 2/2

- Products:
  - Methanol
  - MTBE (methyl tertiary butyl ether, gasoline additive)
  - Formaldehyde
  - Others.
- H_2 annual demand
  - 4 x 109 Nm^3 in EU (7% of total)
  - 40x 109 Nm^3 worldwide
- 8% of total hydrogen consumption

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Hythane

- “Synthetic” Town Gas made from natural gas and hydrogen
  - Possible interim energy carrier for transporting hydrogen via the natural gas network
  - Hydrogen content of 5 to 15% supposedly has no (or hardly any) influence on gas appliances
  - Hydrogen content of up to 30 to 50% would require changes to gas appliances, but no replacement of installations

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Further Applications 1/2

- Food processing: hydrogenation of plant fats for hardening (margarine and cooking fat), inert gas in processing
- Metallurgy: use of pure hydrogen/oxygen flames in cutting/welding/brazing, annealing, reduction of metal oxides
- Power industry: generator cooling
- Electronics industry: inert atmospheres for semiconductor producing furnaces

Further Applications 2/2

- Glass industry: high purity flames for cutting and welding, artificial gemstone/diamond production, high purity atmospheres in furnaces
- Space industry: rocket fuel
- Balloon gas
- Chemical industry: styrene, ethylene, peroxide production

Future Applications

- Natural gas substitute:
  - Gas heaters/boilers, cookers, motors
- Electricity storage medium:
  - Electrolytic conversion to electricity and back to electricity by fuel cell
- Fuel cells:
  - Emission free (locally) cogeneration of heat and electricity
- Hydrogen vehicles:
  - Emission free (locally) vehicles with fuel cells or hydrogen ICE (internal combustion engine)

2. Hydrogen Markets

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Market History

- Hydrogen was first used at large scale with the balloons and airships coming into use at the end of the 19th century - leading up to the Zeppelin development

- Many of the now well-known material problems were then first encountered (steel embrittlement, requirements for sealings and washers/gaskets, leakage rates from storage vessels etc.)

- Large scale employment of hydrogen was then spurred by the fertiliser industry in the early 20th century

Market History

- Town gas in the UK till 1950's
- Up to the mid-nineties many town gas networks in Germany (esp. East Germany and Berlin), in 1992 3 x 1012 Nm^3 (being approx. 10% of the pipeline supplied gas in German energy supply)
- Town gas supply still in operation in Stockholm City.

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Size of the Market

- Hydrogen production
  - ca. 500 x 10^9 Nm^3 per year worldwide
  - ca. 60 x 10^9 Nm^3 per year in EU (ca. 180 GWh)
  - Annual rise since year 2000 ca. 5 to 10%
- Comparison:
  - world natural gas market 2.4 x 10^{12} Nm^3 p.a.
  - EU natural gas market 470 x 10^9 Nm^3 p.a. (ca. 5 TWh)

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Market Segments

- EU statistics:

- Captive ca. 55 x 10^9 Nm^3 (93%)
- By-product ca. 3 x 10^9 Nm^3 (5%)
- Merchant ca. 1.2 x 10^9 Nm^3 (2%)

- Direct energetic ca. 0.5 x 10^9 Nm^3

- Surplus (stranded) ca. 0.015 x 10^9 Nm^3

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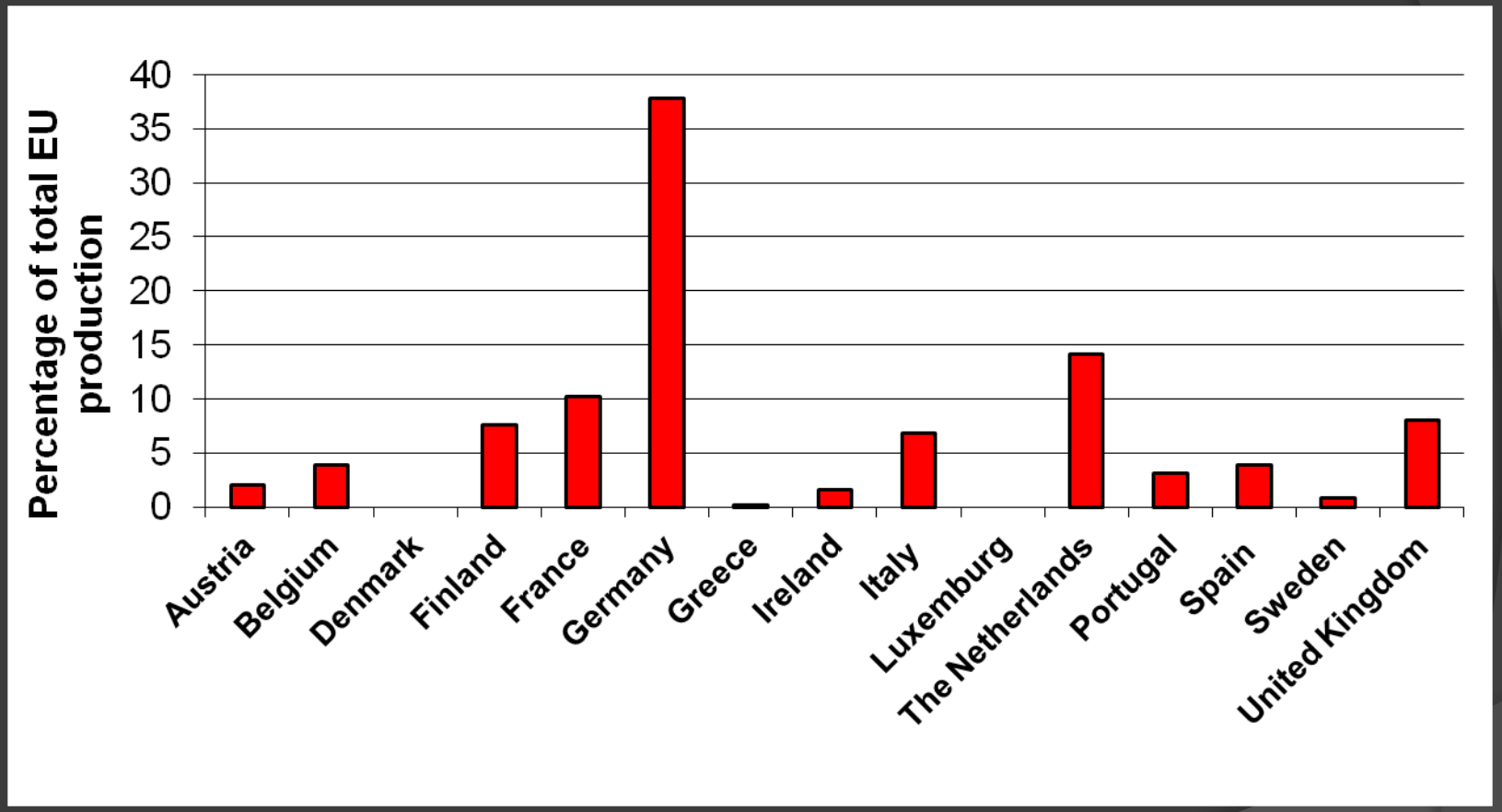
European Production



- EU figures for ca. 1997
- Out of total of 60 x 10^9 Nm^3 p.a

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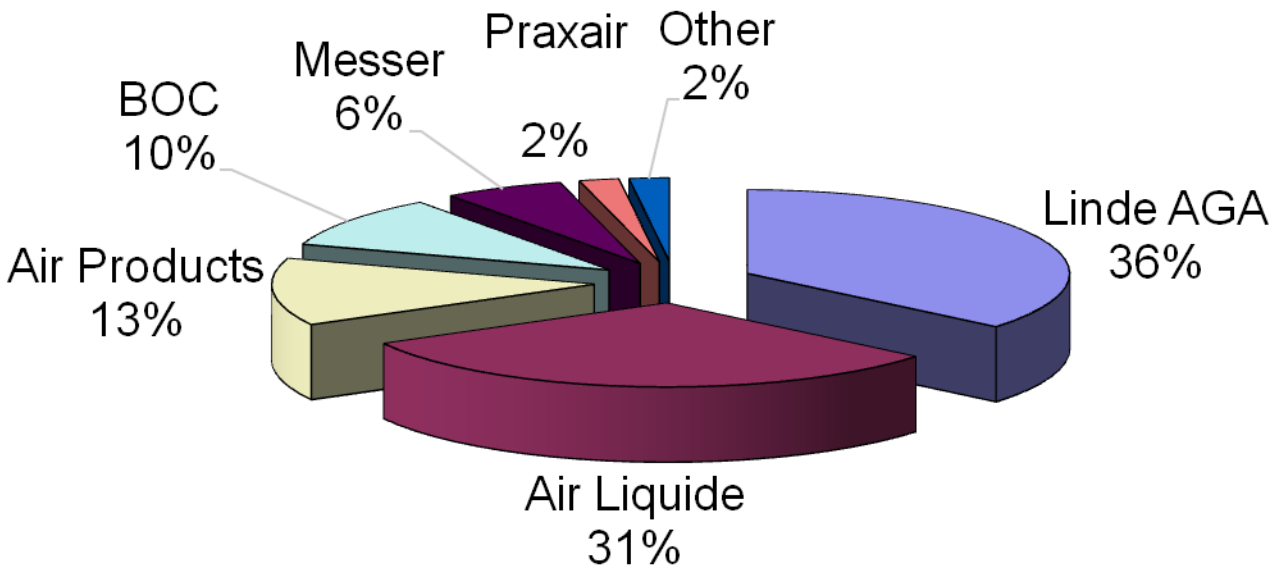
Key Players



Total: 1.2 x 10^9 Nm^3 p.a.

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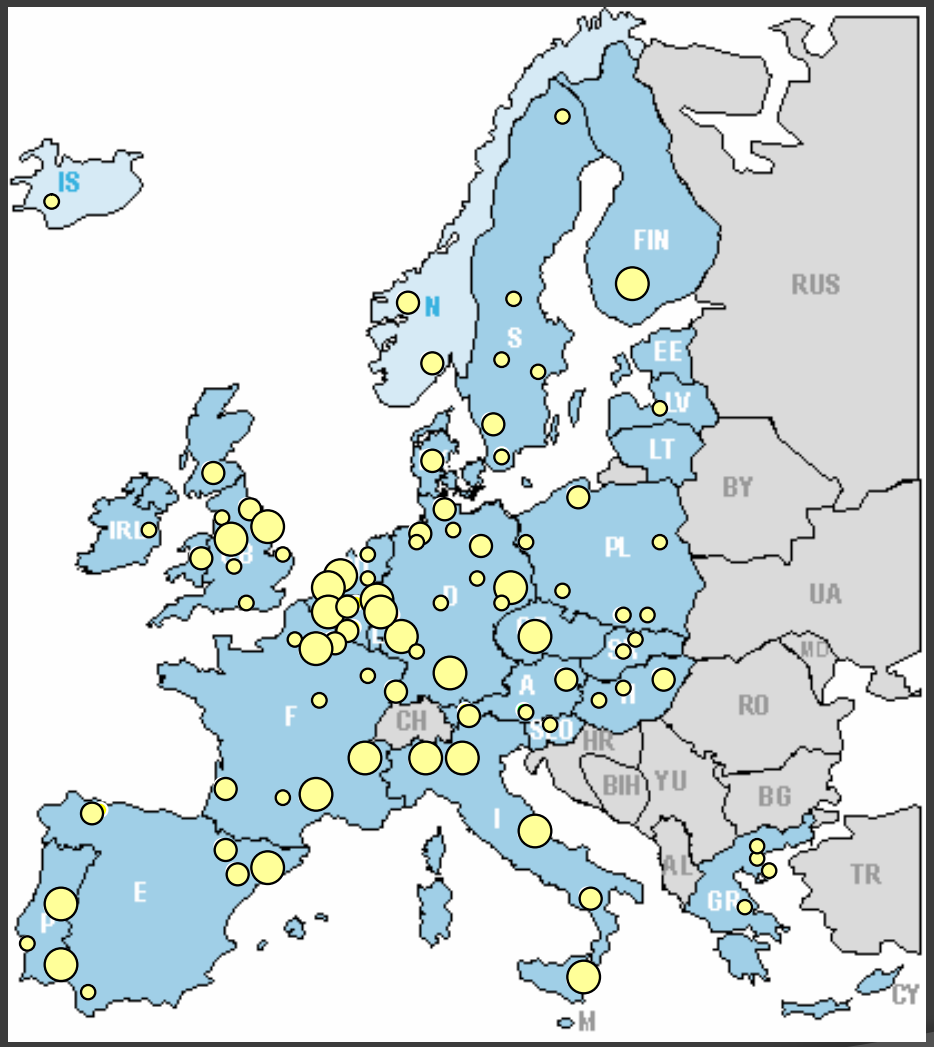
Where in the EU?



- Production Site (1 to 3)
- Production Site (3 to 7)
- Production Site (> 7)

ROADS2HYCOM
www.roads2hy.com

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Hydrogen Costs

Hydrogen Quality	**3.0**	**3.0**	**5.0**	**5.0**
Item	**Costs [EUR]**	**Costs [EUR]**	**Costs [EUR]**	**Costs [EUR]**
10 l bottle / 1.8 Nm^3	48.10		61.50	
50 l bottle / 8.9 Nm^3		67.80		111.90
Energy Surcharge per Bottle	1.00			
Surcharge for Transporting Hazardous Materials	18.00			
Rental Fee per Bottle / daily	0.39			
Rental Fee per Bottle / flat rate for 1.5 years	160.00			
Effective Costs per Nm^3 (excluding bottle rental)	40.00	9.71	46.00	16.74

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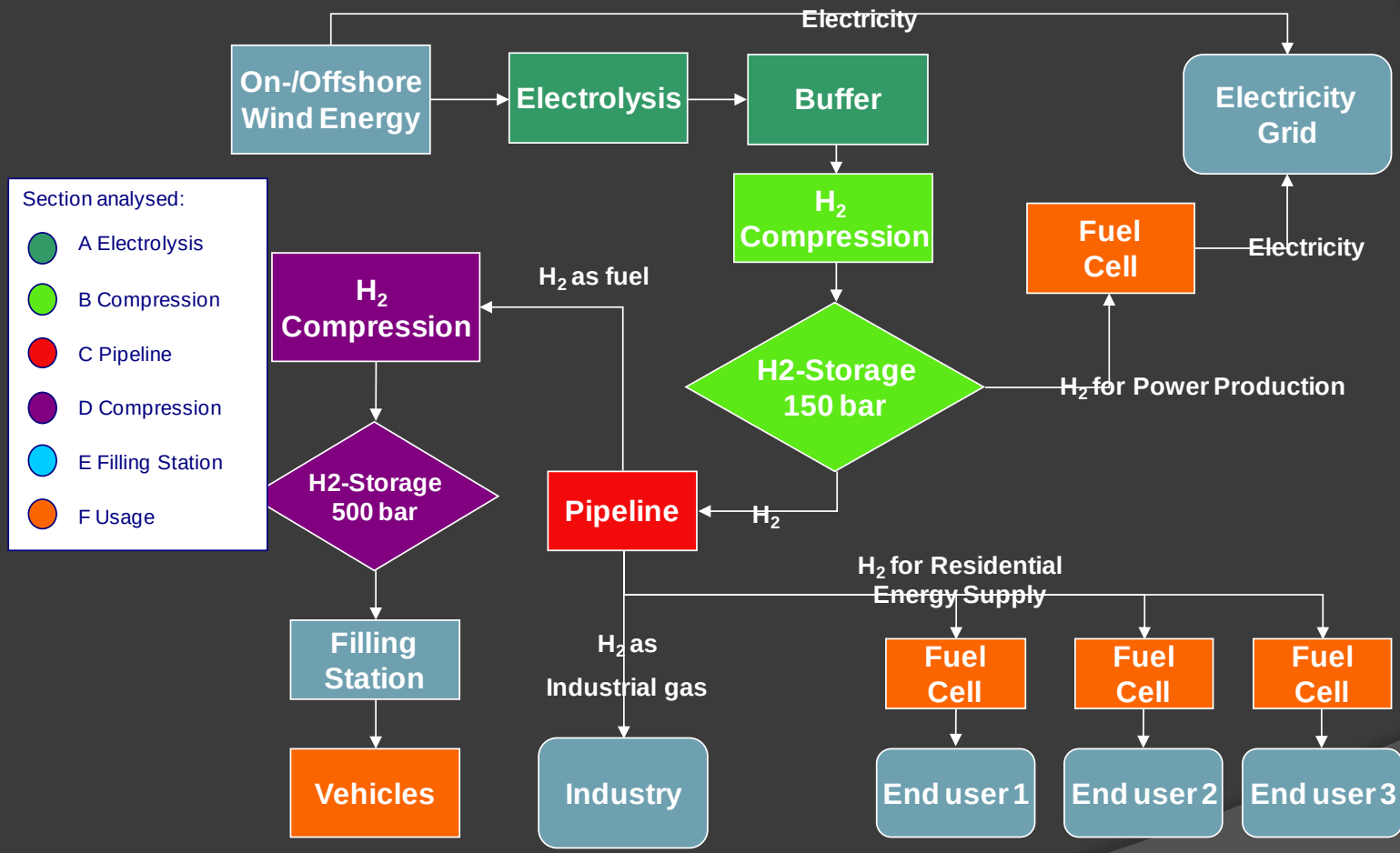
Hydrogen Costs



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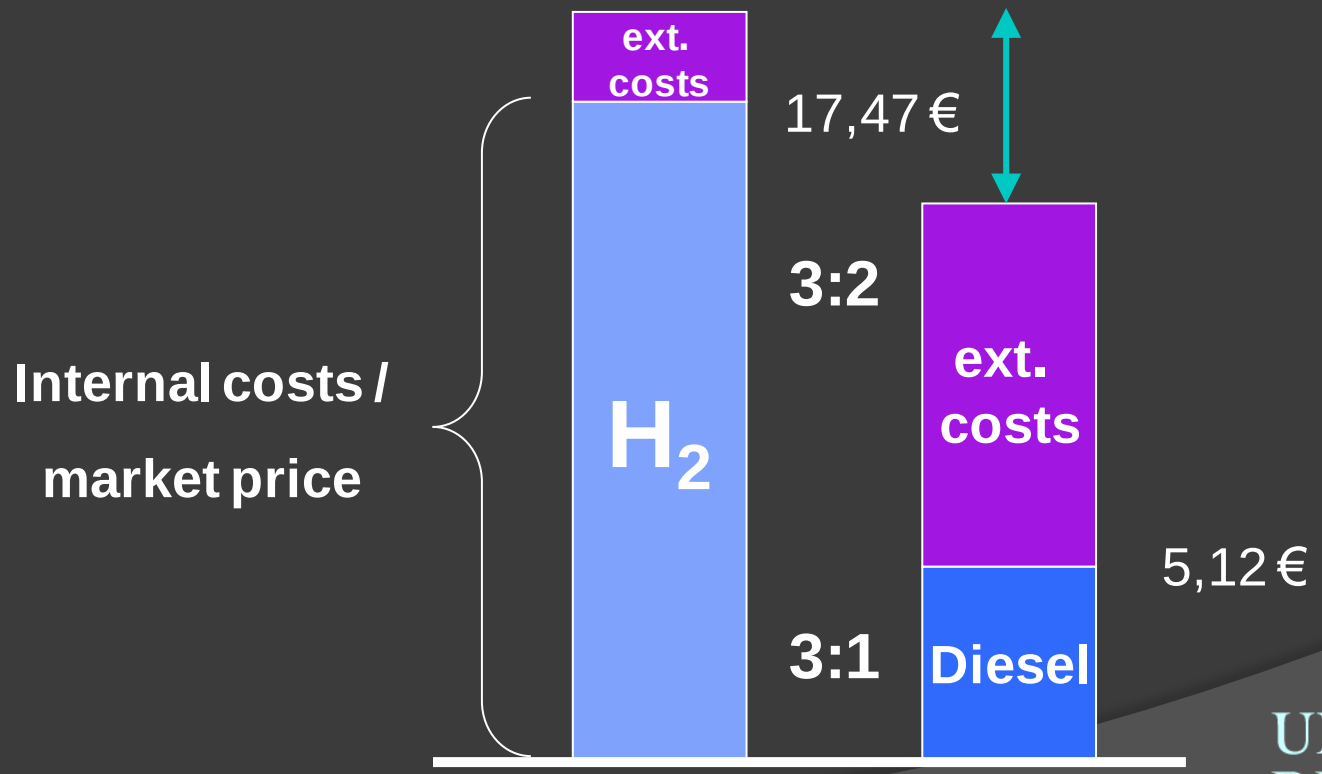
Cost Breakdown

- 3: 1 Ratio Exists on comparison.....



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Why the difference in costs?

- Internal costs:
  - costs of production and delivery of vehicles and fuel
  - taxes and levys
  - market price (as a sum of the above plus company profit)

- External costs
  - costs caused for the society, but not attributed or attributable to single products or services
  - health services due to environmental pollution
  - health and other services due to noise pollution
  - public services in safety, accident prevention etc.
  - general costs of land use, rain run-off management etc.

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Examples for vehicle tariff

3. Hydrogen Distribution

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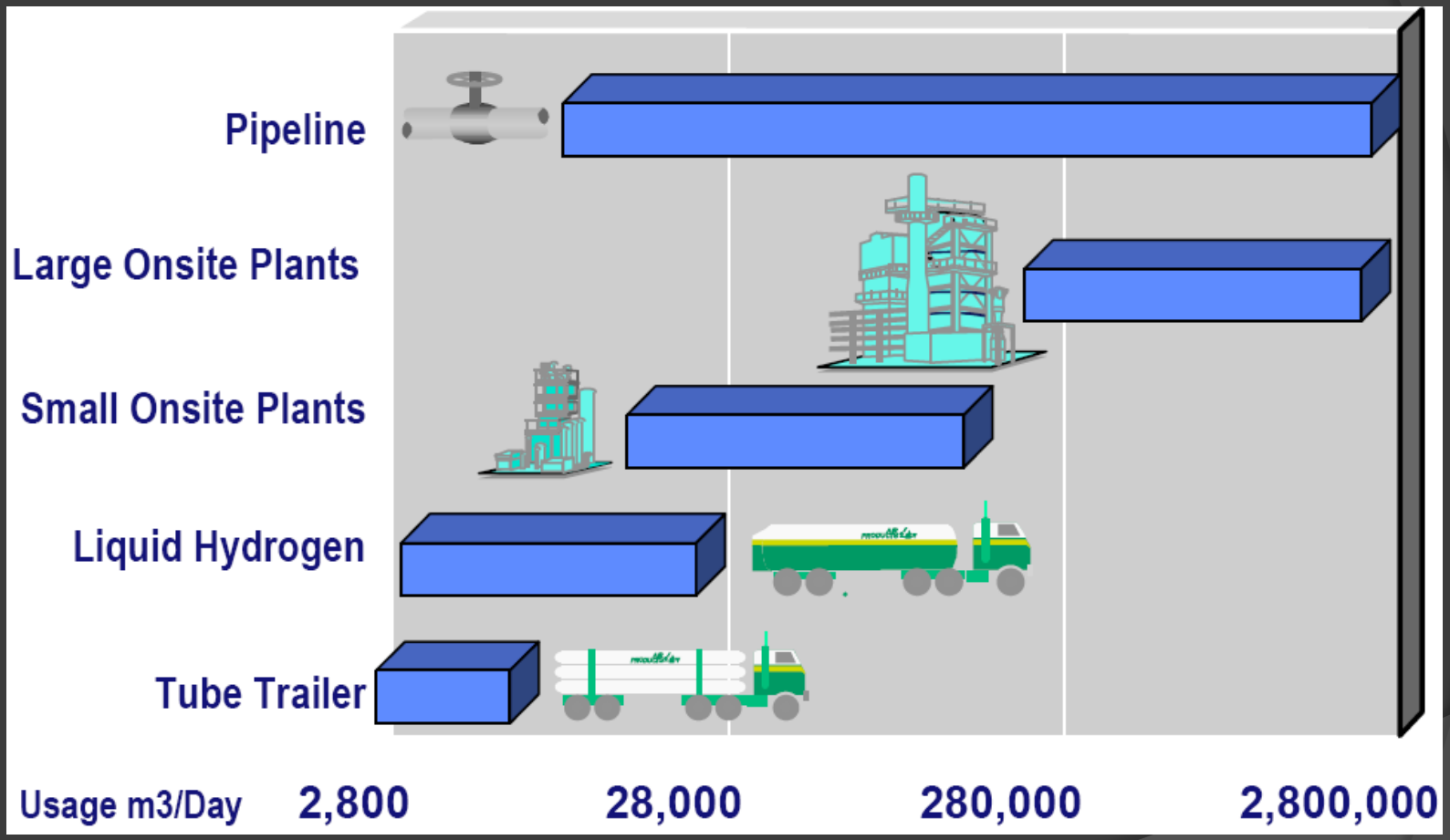
Distribution



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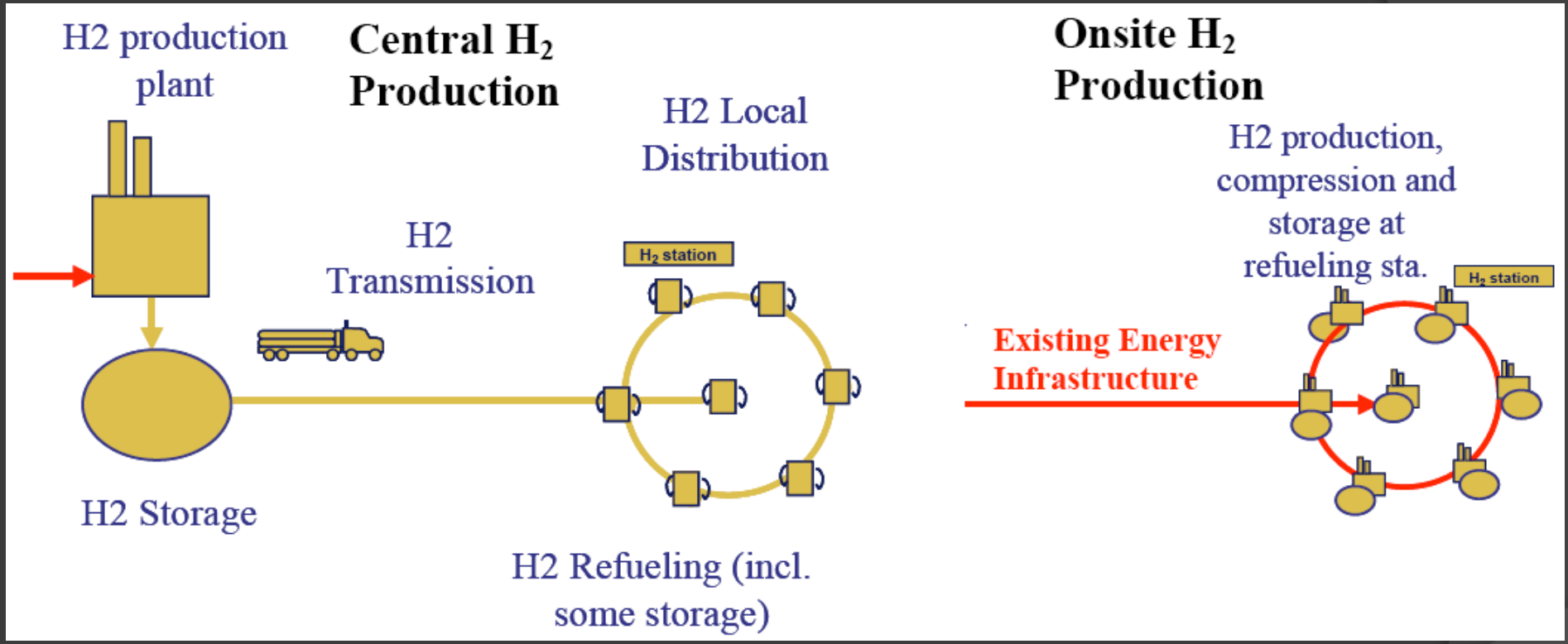
The process



Joan Ogden and Christopher Yang, "Implementing a Hydrogen Energy Infrastructure: Storage Options and System Design" (UCD-ITS-RR-05-28), 2005

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Distribution

- Conventionally distributed
  - Gas Cylinders / Large Vessels
  - Liquefied tanker
  - Liquefied pipeline
- Large scale pipeline?
  - Expensive
- Existing lines
  - Dilute hydrogen to 10%
  - Changeover problems?

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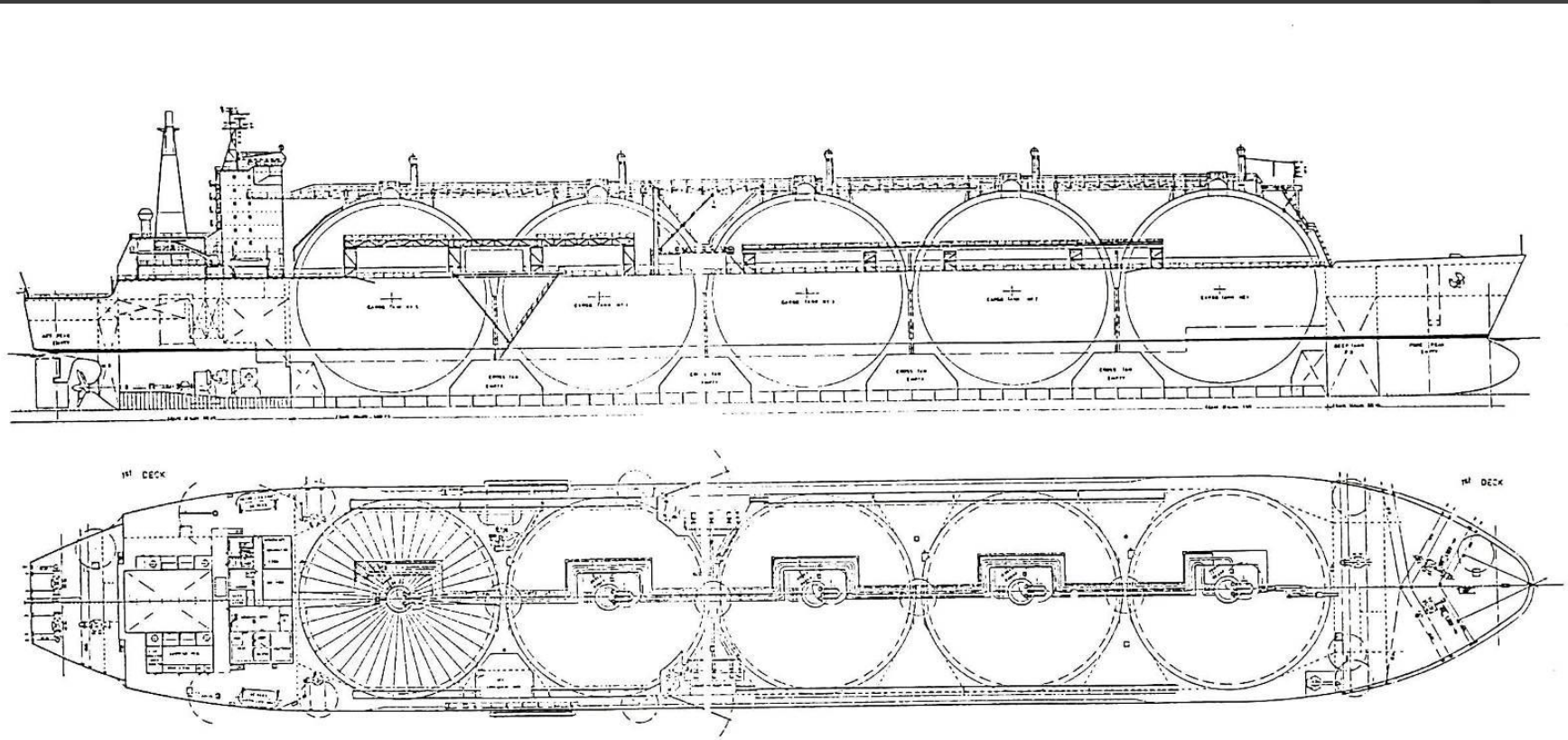
Photographs courtesy of PLANET and HyNet

Marine Transportation:
Gas/Liquid Tanker



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Pipeline

Map courtesy of Air Liquide

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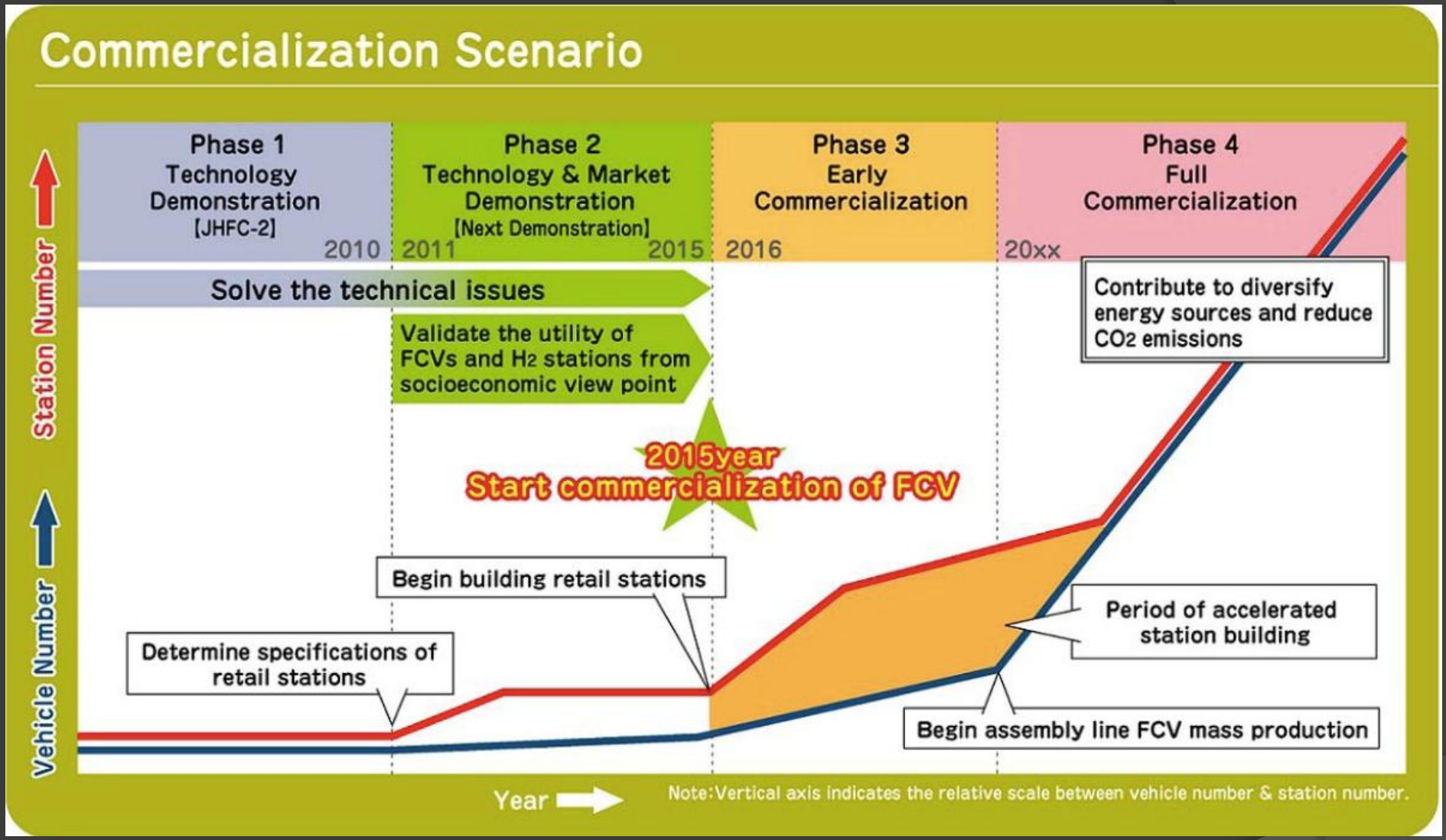

Leading Japanese automakers & energy companies have agreed on a scenario which sees commercialization of FCVs and hydrogen stations beginning in 2015.

FCCJ, http://www.fccj.jp/pdf/20080704sks1e.pdf

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4. Hydrogen in the vehicle Fuel Market: *Refuelling infrastructure*

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…Re fuelling

- Pressure drop between fuelling station and vehicle should be around 150 bar for fuelling process < 10 minutes
- From vehicle tank end-pressure 350 bar it follows that the storage pressure needs to be around 500 bar
- Due to the negative Joule-Thompson effect hydrogen will heat up when filling vehicle tank; subsequent cooling to ambient temperature reduces pressure in tank -> overfilling‘ necessary
- at vehicle tank pressure 700 bar, storage pressure of ca. 1.000 bar would be necessary -> other filling technologies than pressure drop, for instance cooling during filling (isothermal filling)

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Need filling stations

- Number of (conventional) fuelling stations in Germany: 15,000
- Expense to convert a fuelling station to hydrogen:
  - ca. € 1M
- Number of gasoline filling stations in U.S. ca. 170.000
- Gasoline (LNG) distribution solely through road transport

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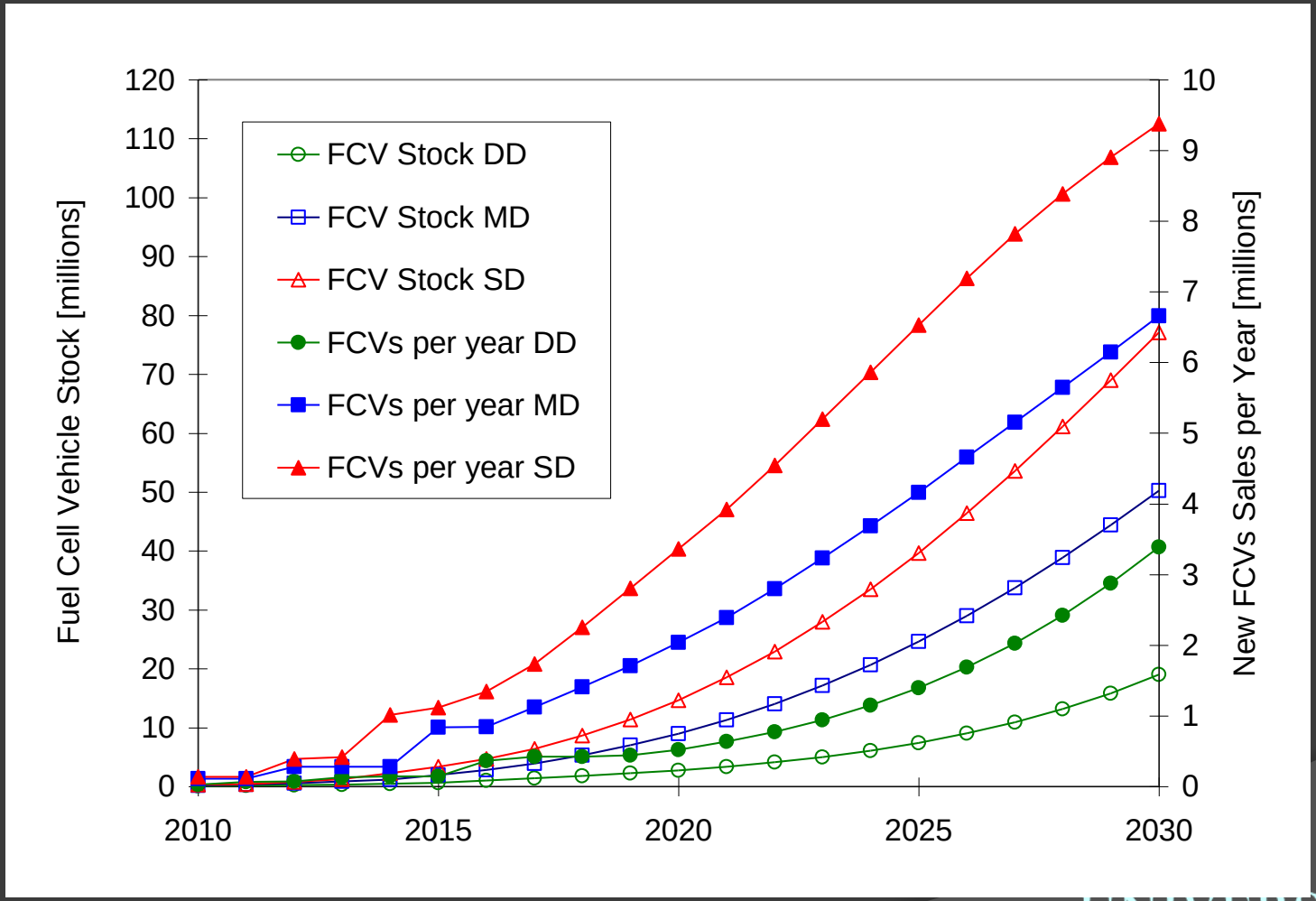
US Scenario - Vehicles



Projection for U.S.:
- DD delayed
- MD moderate
- SD successful development

From: M.Melaina, J.Hydrogen Energy, 2003

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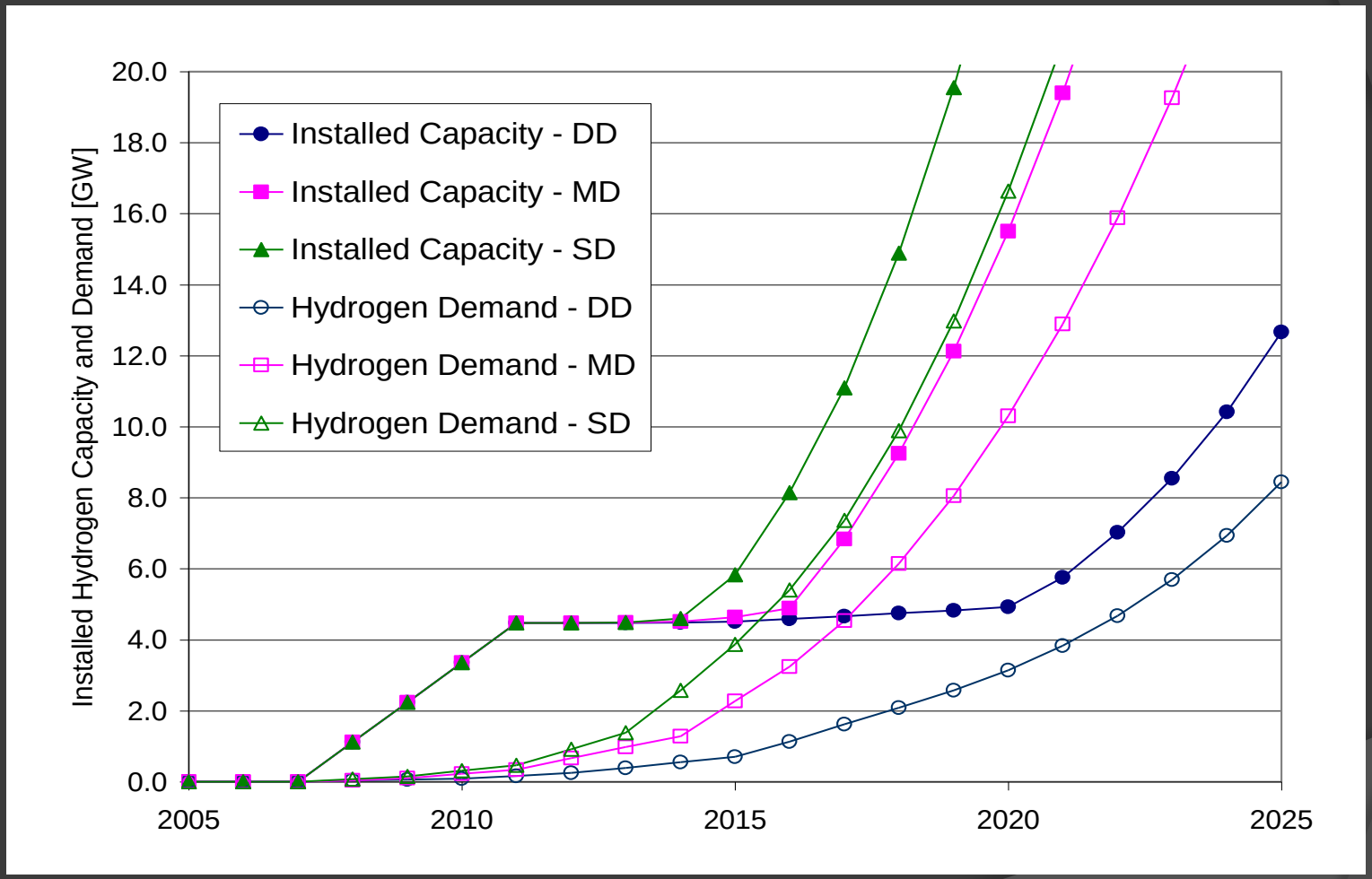
US Scenario - Stations



Projection for U.S.:
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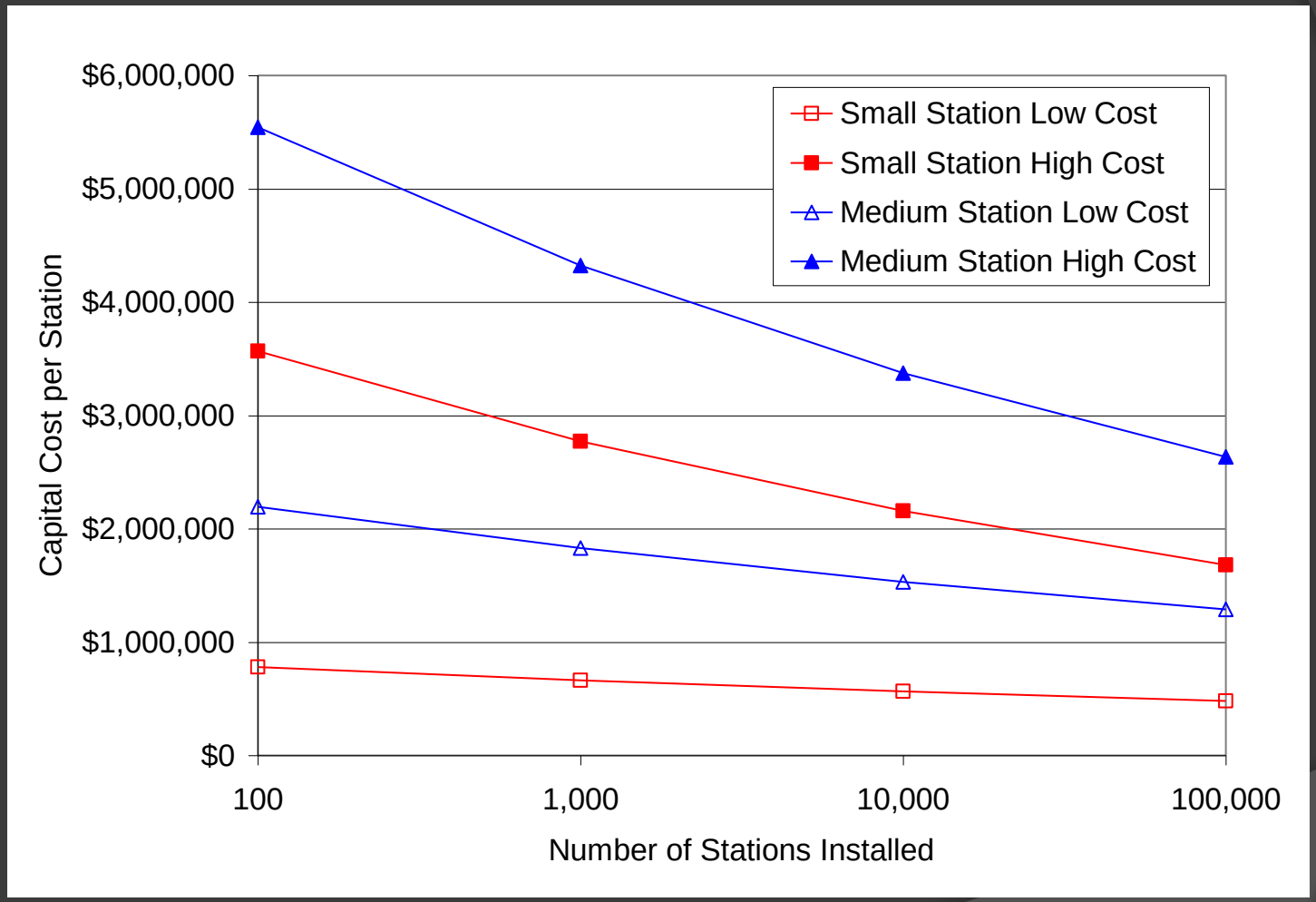
Costs of Fuel Stations



Projection for the U.S.
- small = 500 kg H_2 p.day
- medium = 2.500 kg H_2 p.day

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Filling Stations

- Cute Project

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Components

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Cute Project Stations

Liquid Hydrogen Stations

SMR Station

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5. Hydrogen as a renewable energy store

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Why do we need energy stores?

- Reduction of fluctuations
- Temporal shift of power
- Integration of surplus/stranded production

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Renewable energy sources

Source	Type	Heat	Electricity	Other
Solar	thermal	✸		
	PV		✸	
	tower		✸	
	algae	(✸)	(✸)	H_2
Wind	repellor		✸	
Solar/Wind	thermal flow		✸	
Geothermal			✸	
Hydro	stream		✸	
	dam		✸	
Tidal/ wave			✸	
Biomass	combustion		✸	
	fermentation	(✸)	(✸)	CH_4
	pyrolysis	(✸)	(✸)	syn-gas

A indicative list

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Storage Methods

- Conventional
  - pumped storage
    - limited by topography
  - Batteries
    - capacity tied to device itself
  - flywheels
    - limited capacity
- Novel
  - compressed air
    - limited efficiency
  - super-caps
    - limited efficiency
  - hydrogen
    - arbitrary storage size

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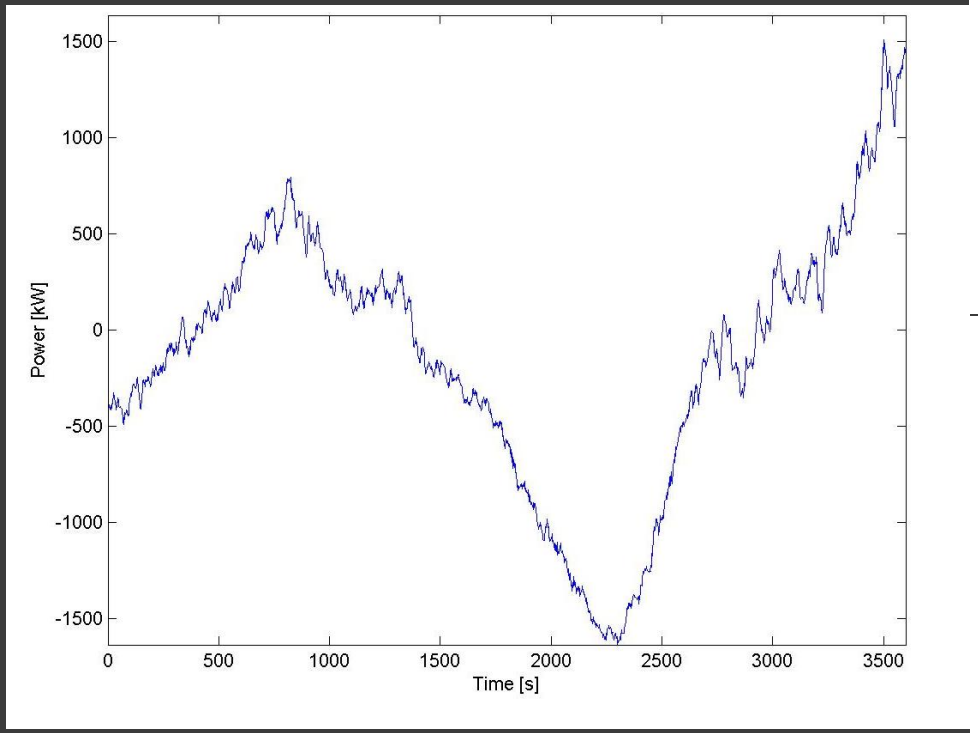
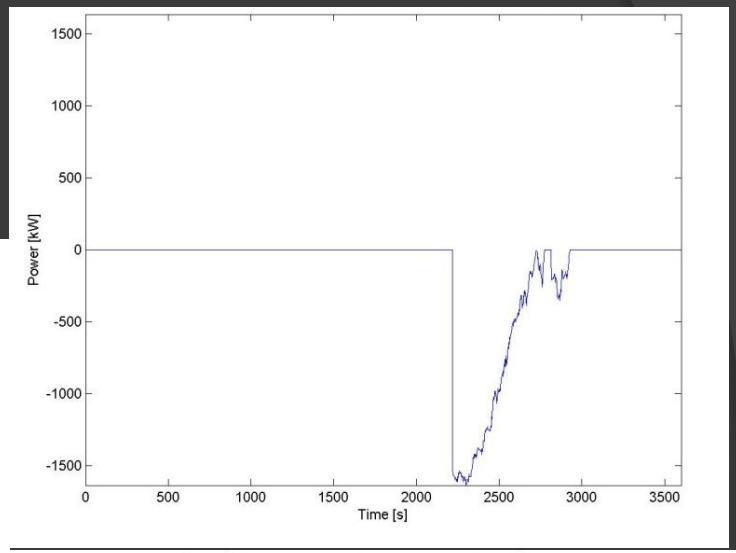
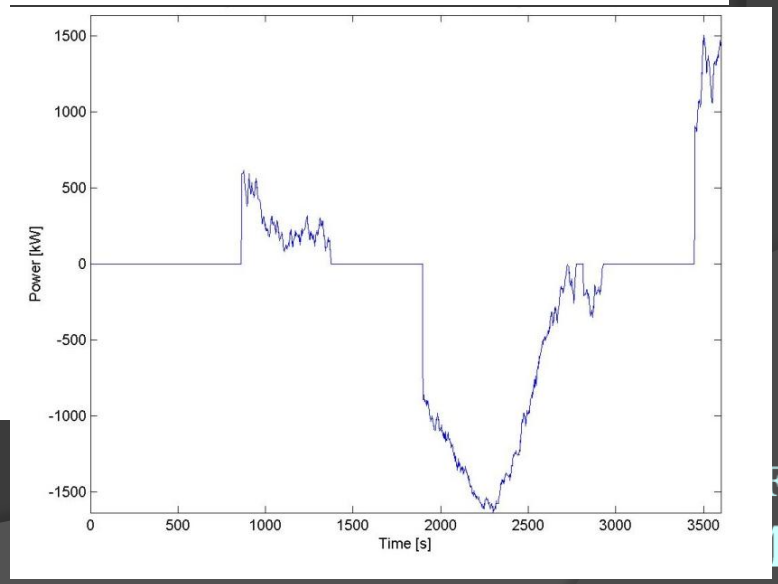
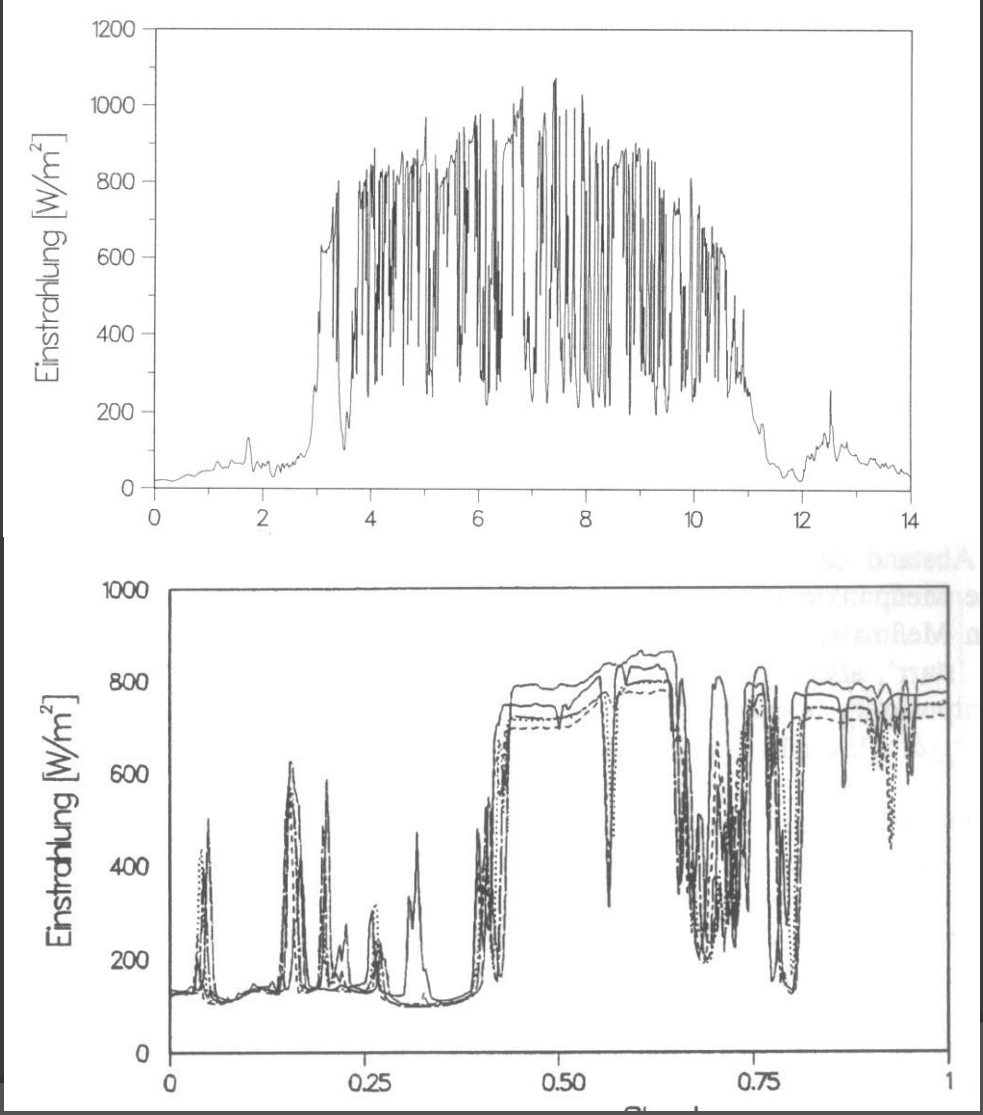
Typical energy use







Typical Energy Production



- Solar production

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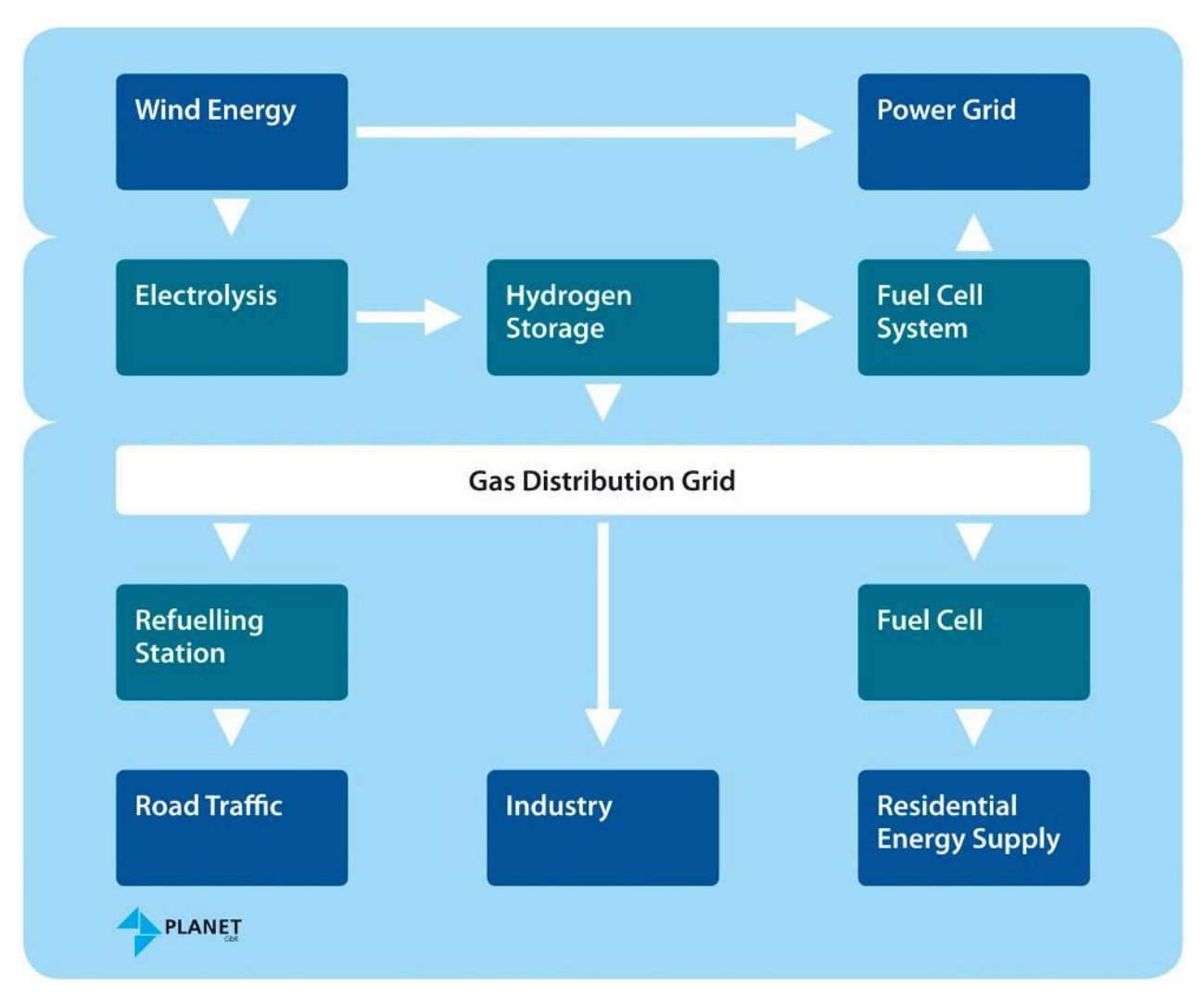
Why is hydrogen important?



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What couplings?

- Sources (realistic):
  - Wind energy (excess and sinking feed in tariffs)
  - Biomass (gasification, reforming of biogas/methane)
  - Hydro
- Far away:
  - Photovoltaics
  - Thermolysis with solar energy

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6. The Future

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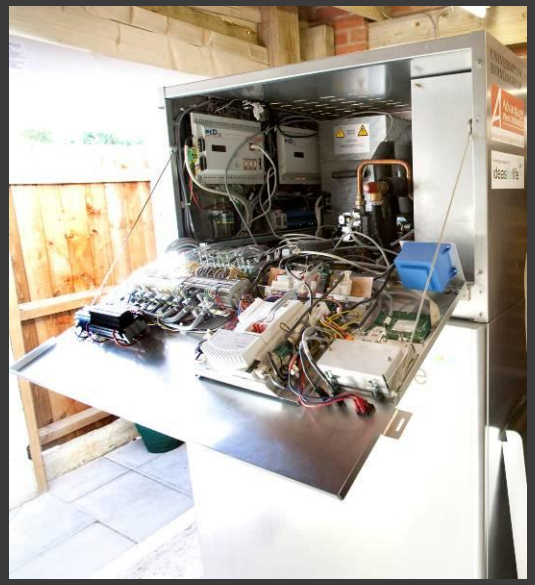
UK Investment



BAXI CHP **H_2 Filling Station** **5 x Hybrid Vehicles**

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House in the West Midlands heated by a Hydrogen Fuel Cell

PEMFC

Fuel:
Natural Gas

The fuel cell has a dual purpose:

(i) Supply of electricity
(ii) Heating

BLACK COUNTRY HOUSING GROUP
Housing and community solutions

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CABLED

- **£25 national project (£7million West Midlands)**

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Hydrogen Refueling Station
UoB

Royal Mail Hydrogen ICE and HFCHV
UoB

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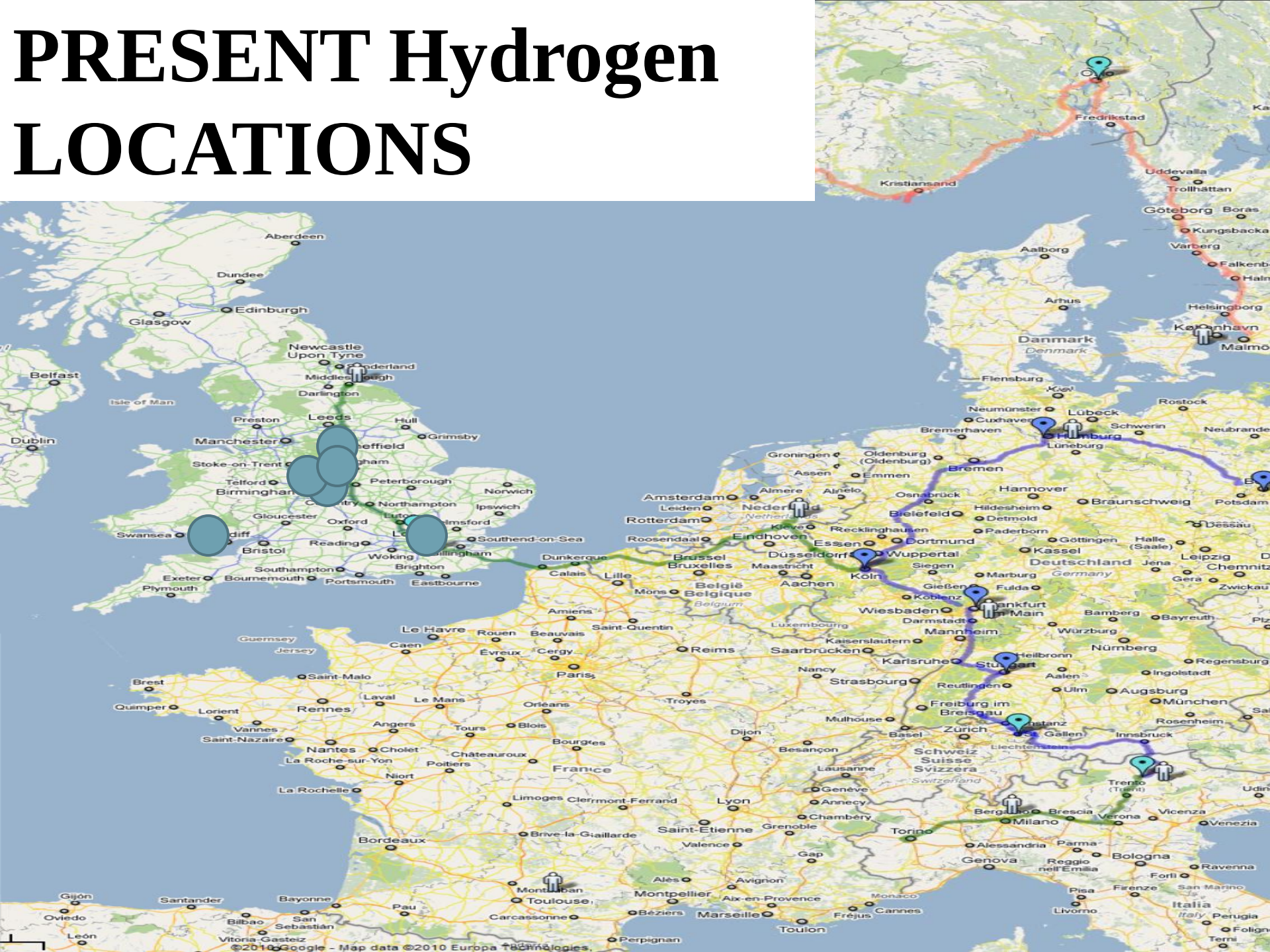
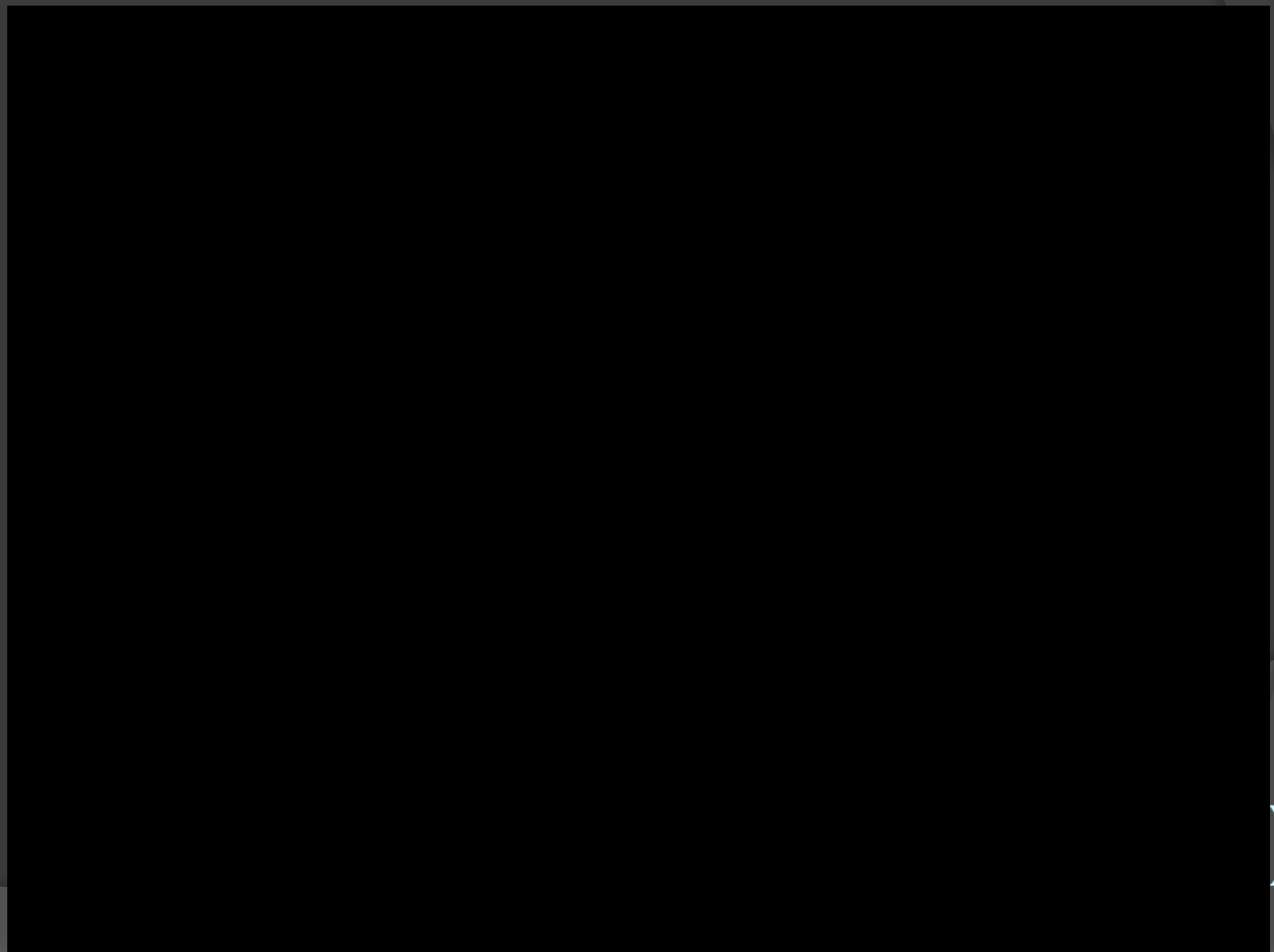
PRESENT Hydrogen LOCATIONS



NEW 2013 LOCATIONS

Next year.....



Summary

- Hydrogen is versatile
- Used in many different and broad applications

- Distribution is difficult at present
  - Projects are on going to improve

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