NEEST

NEW ENERGY & ENVIRONMENTAL SOLUTIONS AND TECHNOLOGIES

TETHYS WEBINAR – GREEN HYDROGEN PRODUCTION

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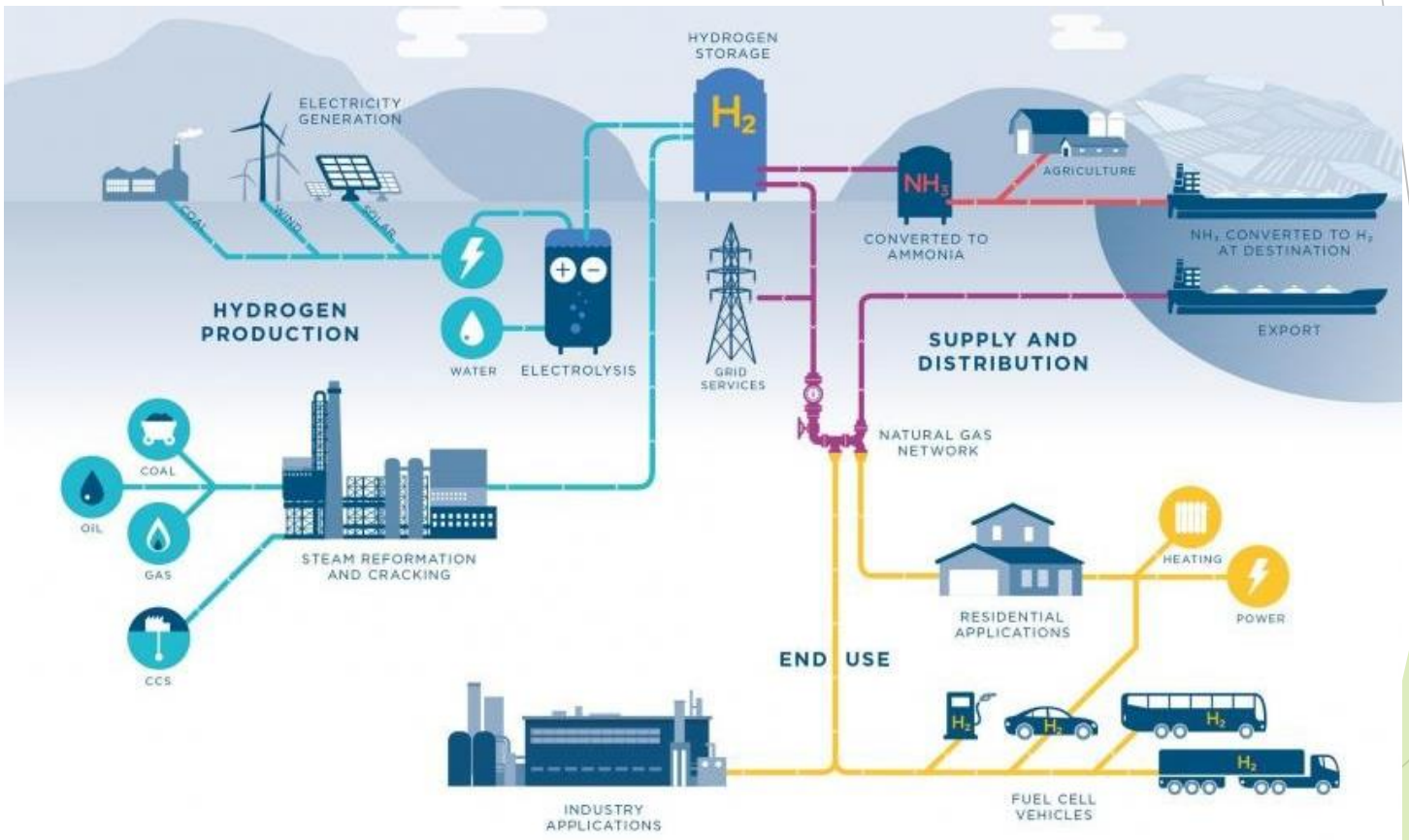
H2 APPLICATIONS & USE IN VARIOUS SECTORS

Transport (Light & Heavy Duty Vehicles, Ships, Trains…)

Industry (Hard to Abate Sectors)

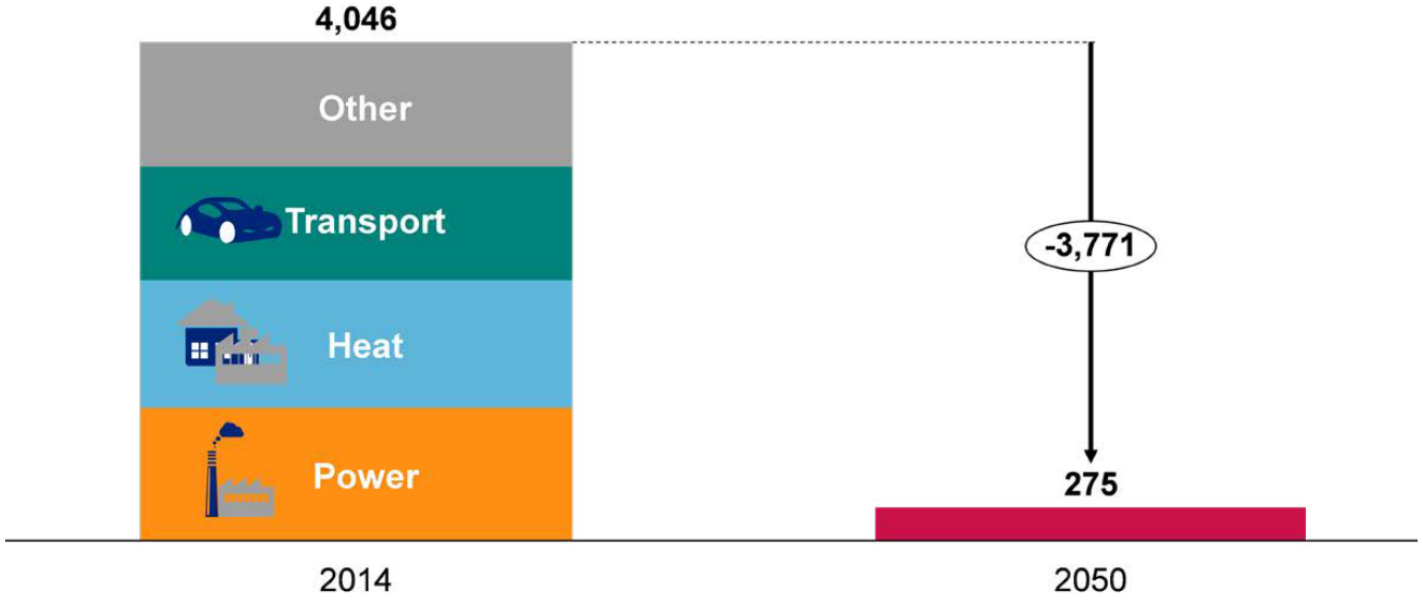
Fuel Cells – Use in ICEs

From H2 Production towards an H2 Ecosystem



Intensification of effort is needed

FIGURE 1 – THE SCALE OF EUROPE'S DECARBONISATION PROBLEM ($MtCO_2e$)



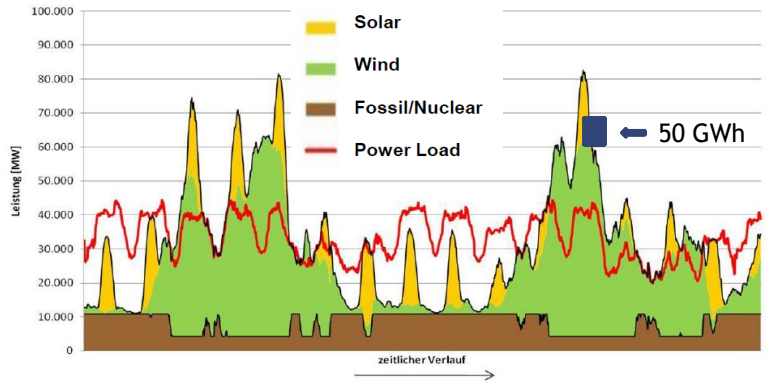
Source: 2016 National Inventory Submissions (Common Reporting Format) for EU, Norway and Switzerland.

Source: Poyry point of view, fully decarbonising europe's energy system by 2050, May 2018

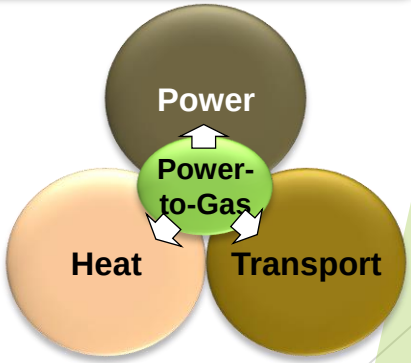
Power-to-Gas
From electric energy to gaseous fuels

Integration of renewables

Storage

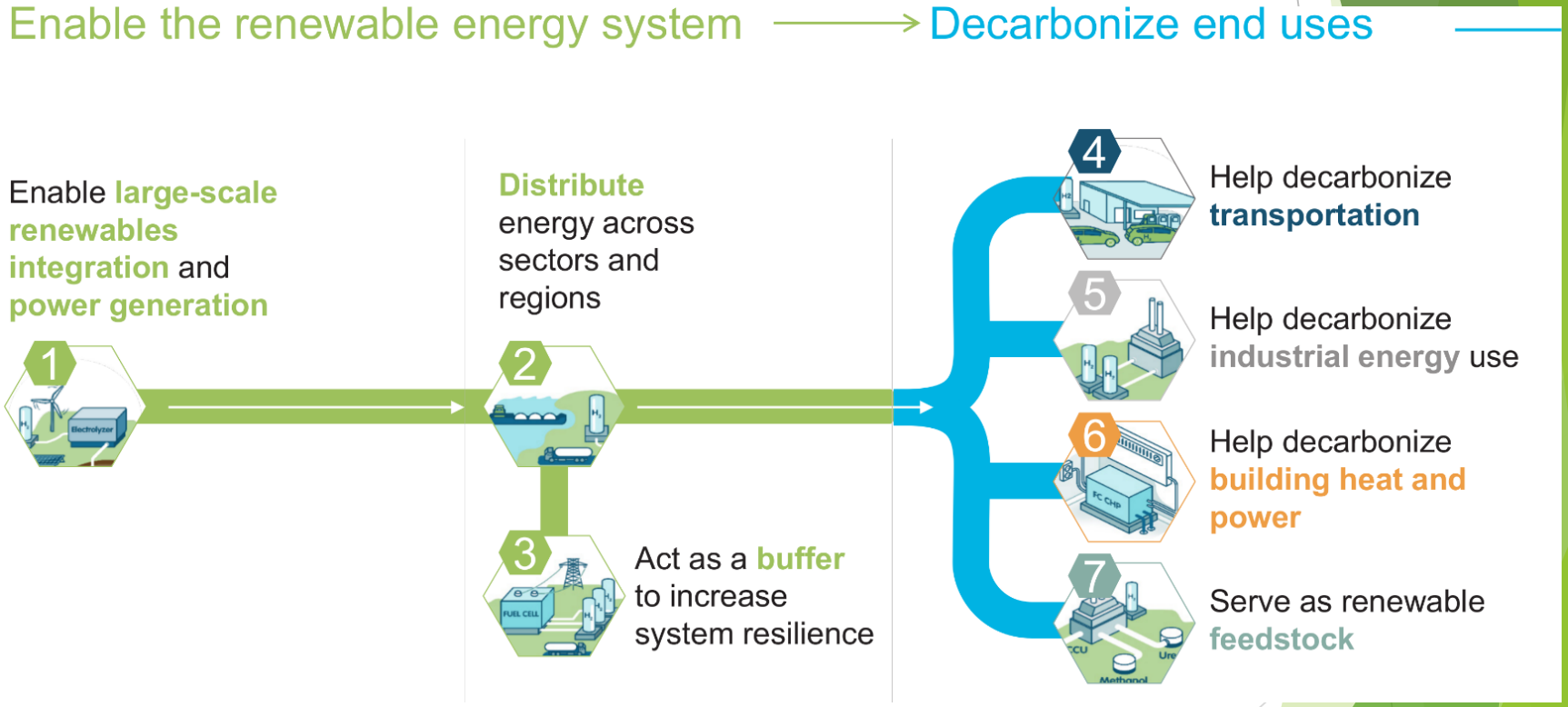


Power-to-X: Sector Coupling

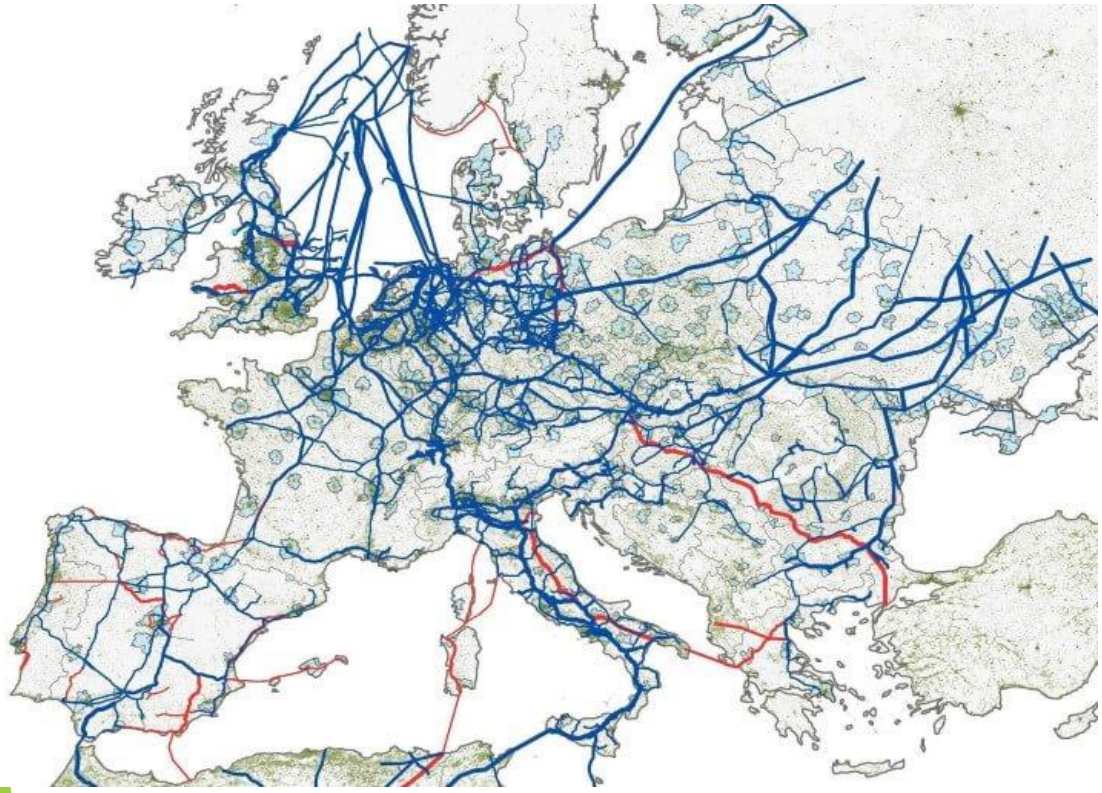


Source: BTU Cottbus, innogy

Hydrogen is key for the unification of the energy sector

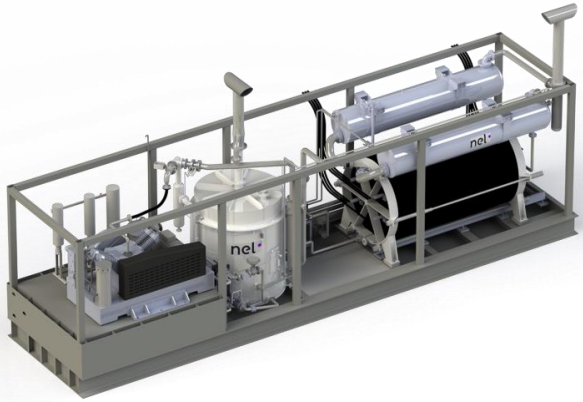


Gas network / pipelines:
A basis for carbon independence processes in energy



Opening the market via a series of appropriate initiatives

A “coalition” needed for 40 GW Electrolysers!



Europe is among the world leaders in this technology!

EU Regulatory Framework: Fit for 55

European climate law sets the reduction targets for net greenhouse gase emissions

- Ultimate goal: climate-neutrality by 2050
- Intermediate goal: reduce net GHG emissions by at least 55% by 2030, compared to 1990 levels

Fit for 55

- Proposals to revise and update EU legislation
- Framework for achieving the climate targets

–New cars and vans on the market as of 2035 should have zero-emissions. Creation of a new, separate emissions trading system for road transport and building sectors

–Hydrogen filling stations on main roads at least every 200 km (end of 2030) – denser network expected in urban areas

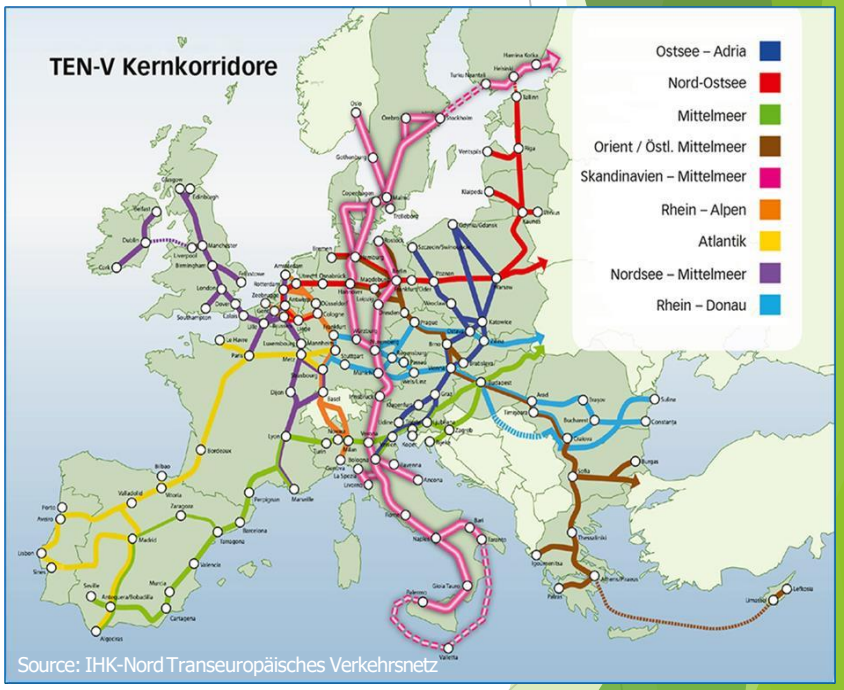
EU Regulatory Framework: AFID – Alternative Fuels Infrastructure Directive

- Adopted in 2014, on the development of alternative fuels' infrastructure in Europe for transport networks
- Implementation of AFID at the federal level (poor results)

AFIR[1] (Regulation) proposed in July 2021

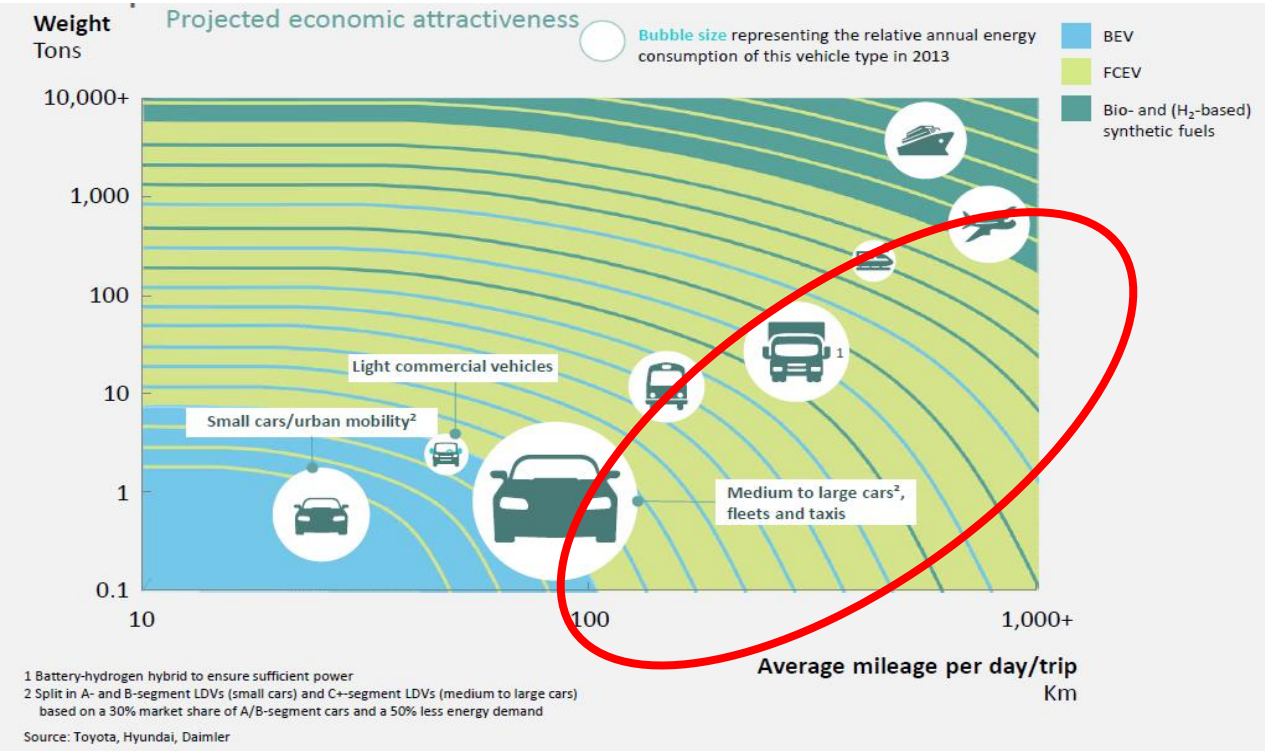
TEN-T-comprehensive network & TEN-T-core network until 2030:

- Hydrogen dispensers (700 bar): max. 150 km distance in both driving directions
- Hydrogen dispensers for liquid hydrogen: max. 450 km distance in both driving directions



[1] On 19 October, the European Parliament adopted in plenary session its position on the Alternative Fuels Infrastructure regulation (AFIR) proposal

Hydrogen for transportation / car industry



Source: H2 Council

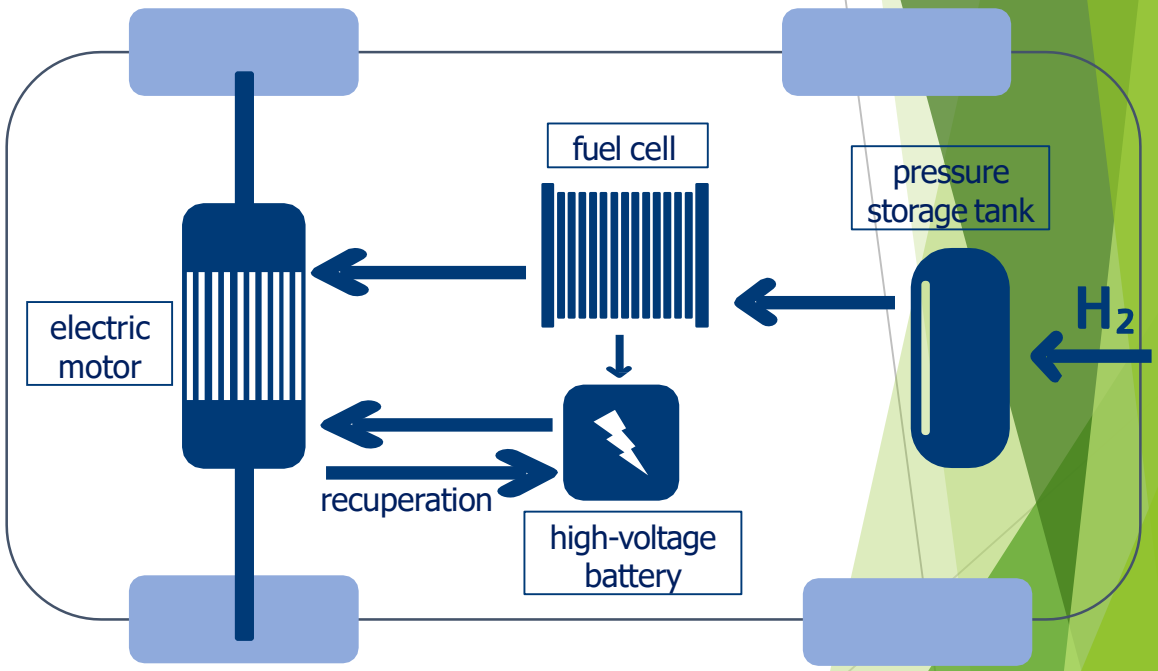
The FC-Vehicle market: Overview

Type	Passenger car	Bus	LD-Truck	HD-Truck	Garbage truck	Forklift
Range [km]	400 – 650	Ca. 400	Ca. 400	Ca. 400 (– 1200)	Ca. 500	Ca. 6 h
Pressure [bar]	700	350	700	350/700 (liquid)	350 / 700	350
Fuel capacity [kg]	4 – 6	35 – 40	4 - 5	> 35	10-20	1,5 - 2
Fueling time [min]	3 – 5	Ca. 10	3 – 5	Ca. 10	Ca. 10	< 3
Fuel consumption [kg/100km]	Ca. 1	6 – 10	1 – 1,5	7 – 10	7 - 10	0,3 kg/h
						

source: www.faun.com, 2020; www.still.de, 2020; Hyundai, 2020; Toyota, 2020; www.auto-motor-und-sport.de

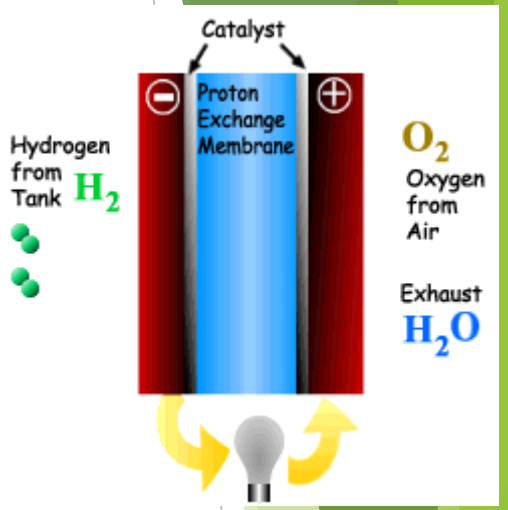
Fuel Cell Vehicle Technologies

- Full electric drive, no hydrogen combustion
- Additional low-capacity high voltage battery for recuperation
- CGH_2 (350 bar / 700 bar) is standard, future utilization of LH_2 is open
- Hydrogen pressure tanks type 3 (standard in mobility) and type 4 (lighter/newer) are the most used
- Tanking times from approx. 5 to 15 minutes

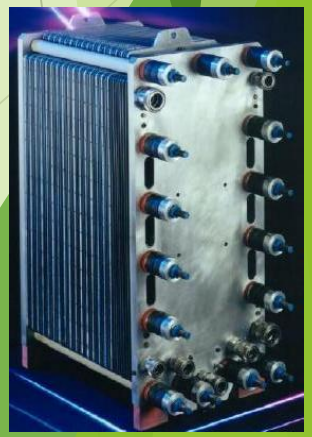


Fuel Cells

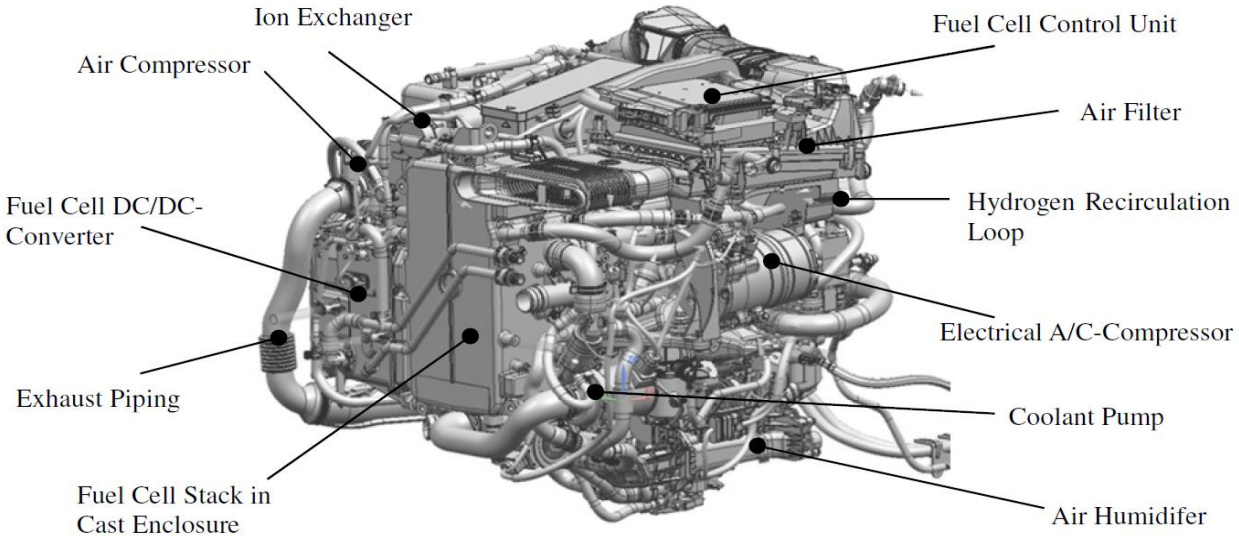
- Electrochemical Equipment operating similar to Batteries
- Consume Hydrogen and Oxygen to produce:
  - Electrical Energy
  - Heat
  - Water
- They are not RES, but a conversion equipment for power which has been stored in the form of a fuel (Hydrogen, Methane, Natural Gas, Methanol)
- Capital Cost between € 2,000 – € 5,000 / kW
- When the fuel is "green" hydrogen, the only emission is water
- When hydrocarbons are used FCs emit CO_2 but in significantly lower quantities compared to ICEs (ca. 1kg CO_2 per m^3 H_2)



The electrolyte: special polymer or similar material, allowing ions to pass trough it, but is not permeable from electrons

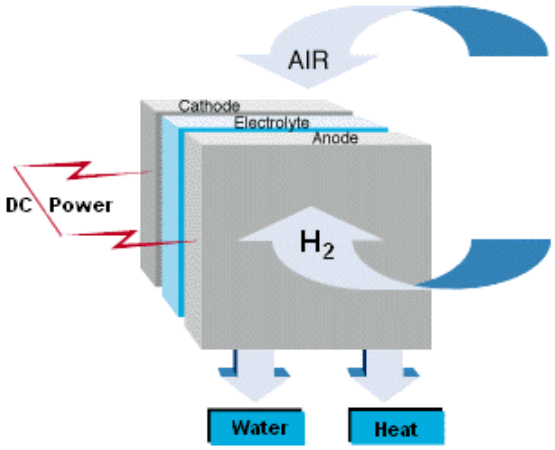


Fuel cells may keep the value chain in Europe!



Source: Daimler

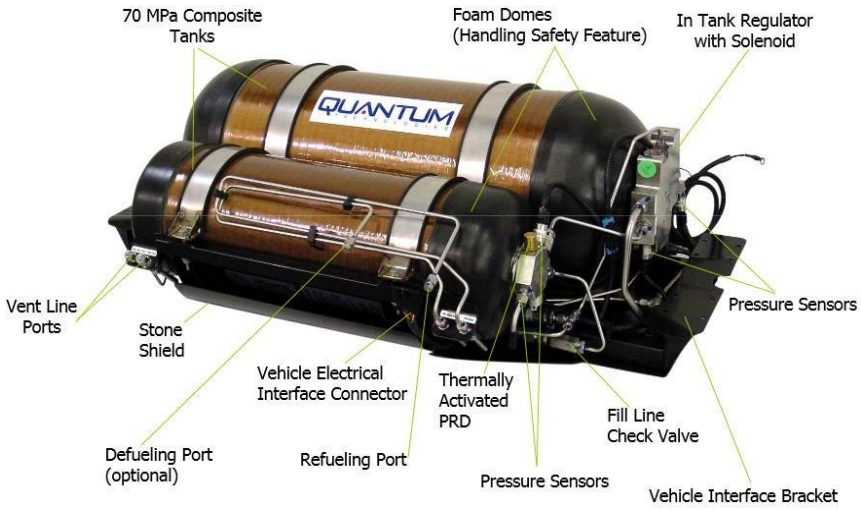
Fuel cells in vehicles



- **Reversed process of electrolysis. Here hydrogen reacts with oxygen to produce electricity and water**
- **Electricity is then used to power an electric motor**
- **FCEVs* are essentially electric vehicles**
- **FCEVs and BEVs** are not always competing technologies**
- **FCEVs can be considered complementary to BEVs**

Fuel Cell Vehicles: Types of hydrogen tanks

Compressed hydrogen gas container assembly



Source: Quantum

Type 3 tank

WHAT IS A FUEL CELL VEHICLE (FCEV)?

An EV drive train that's refuelled rather than recharged

- Refuel in 3 mins
- Range >300 miles

Image by Toyota

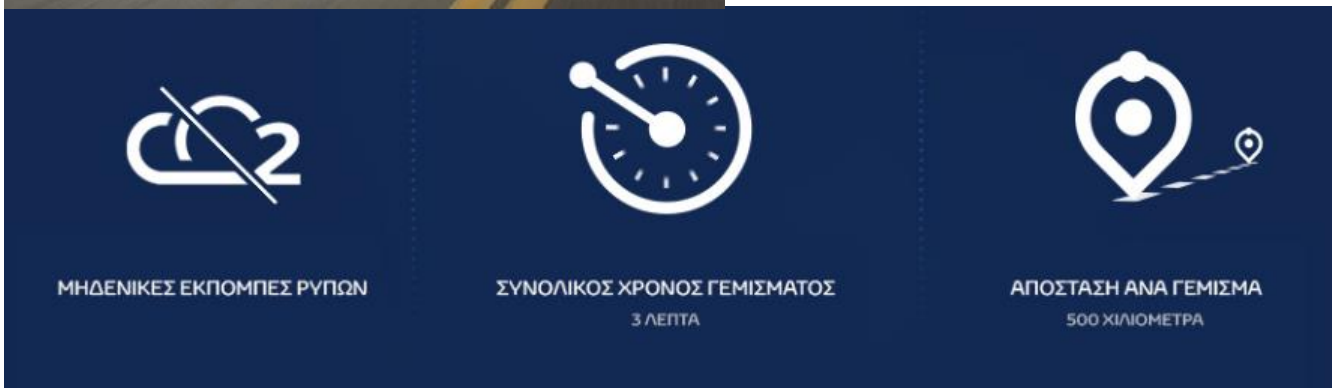
FUEL CELL VEHICLES

ENERGY STORAGE | CLEAN FUEL

ITM POWER
Energy Storage | Clean Fuel

TOYOTA MIRAI

First mass produced FCEV



EARLY MARKETS- SPECIAL TRANSPORTATION APPLICATIONS

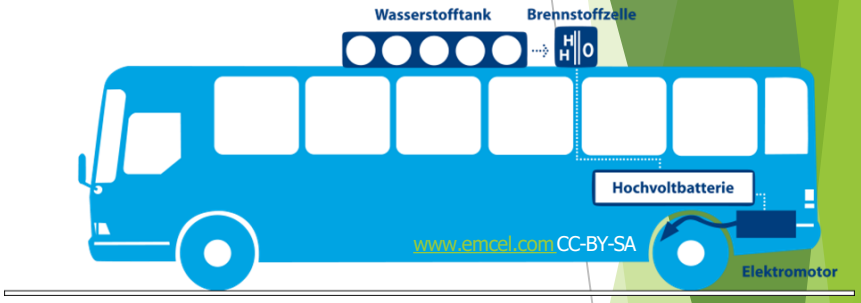
Fuel cell powered forklift

- **An early market for hydrogen vehicles is the forklift market**
- **Already entered the market by being used in warehouses, ports and industrial zones**
- **Value proposition of productivity gains**
- **In order for hydrogen to get traction in different segments there are several alternative routes**

The case of Fuel Cell Buses

Advantages

- Approx. 400 km range and short refueling times
- Route planning as for diesel buses
- Flexible to use
- No local emissions, low global emissions



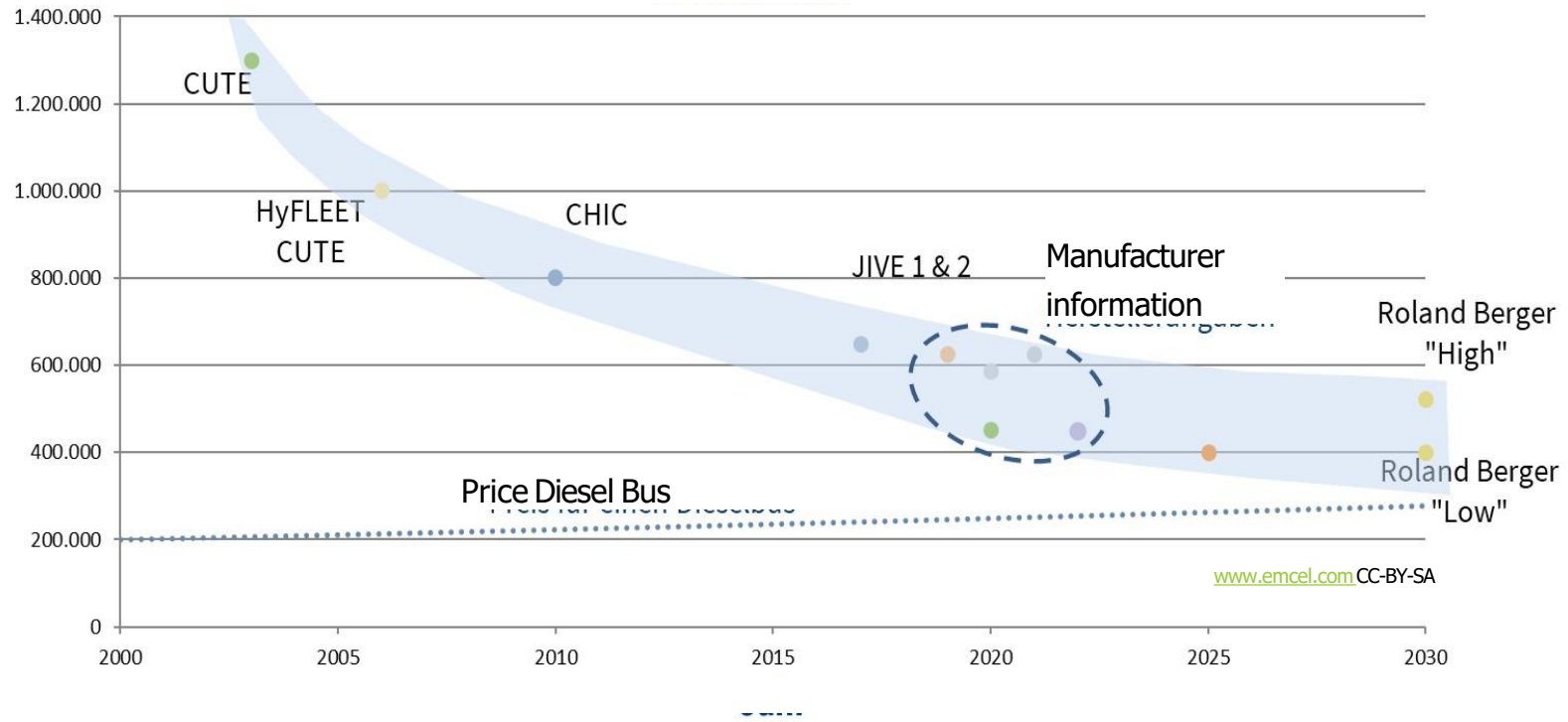
Disadvantages

- Acquisition costs (as of today)
- Establishment of own hydrogen infrastructure (start-up costs)

Consequence / possible solution

- Shared use of hydrogen refueling stations, also public
- Hydrogen filling station in operator mode

The FC-Bus market: 20 years of proven technology



Buses: A flexible competitive clean solution

Europe is world leader

Achieved

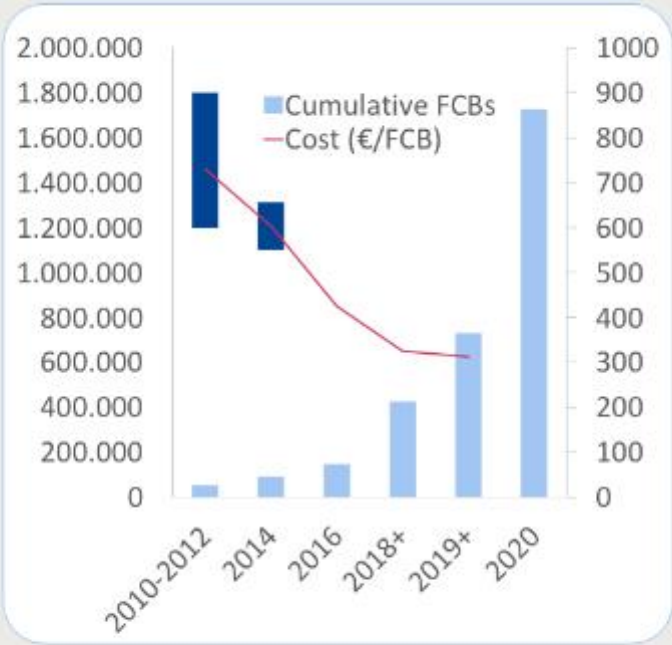
- >5,000,000 km driven since projects started
- > 300,000 h of operation
- >159 tn of H_2 consumed only in 2016

Pre-commercialisation phase

- 25,000 h lifetime reached
- Availability proven but with teething problems
- 650,000 €/bus offered
- Average 9.86 kg/100km (very dependent on city)

Challenges

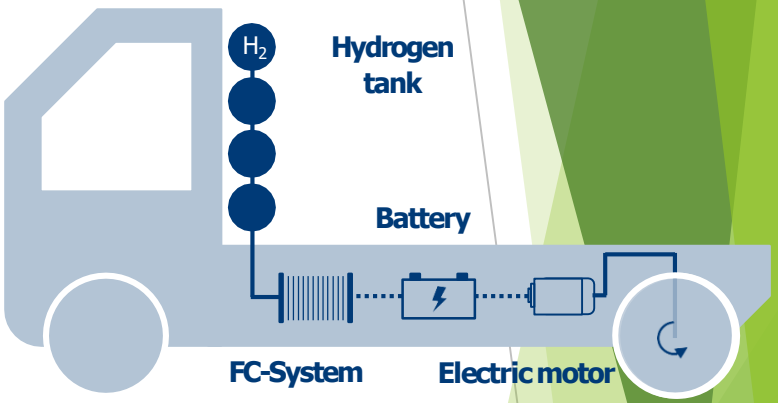
- Mature supply chain to ensure availability
- Continue reducing the price of the bus
- European fuel cell supplier



The case of Fuel Cell Trucks

Advantages

- Approx. 600 km range and short refuelling times
- Flexible use
- No local emissions, low global emissions



Disadvantages

- Acquisition costs (as of today)
- Establishment of hydrogen infrastructure necessary (start-up costs)

Consequence / possible solution

- Shared use of hydrogen refueling stations, also public
- Hydrogen filling station in operator mode

Fuel Cell Vehicles: H_2 ICE

Advantages

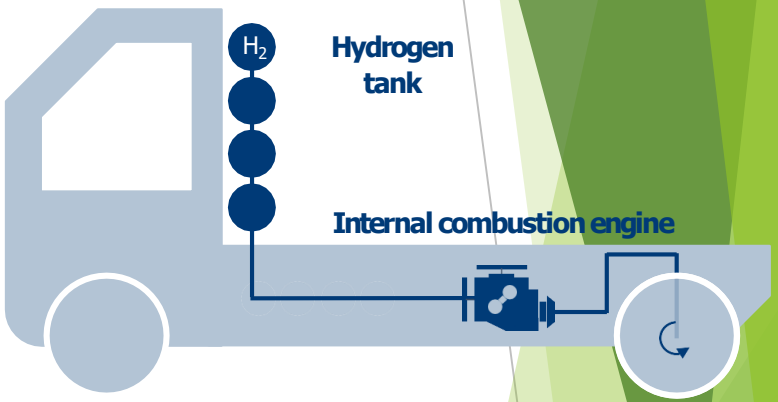
- Approx. 450 km range and short refuelling times
- Known engine technology
- Vehicle investment costs could be lower than FC truck (short term)

Disadvantages

- Higher operating costs than fuel cell
- Noise (possibly louder than trucks with electric drive)
- Possible NO_x emissions (however lower than diesel engines)

Consequence / possible solution

- Adaptation in workshop necessary
- Vehicles still in development / testing phase



Hydrogen Trains

World premiere: Alstom's hydrogen trains enter passenger service in Lower Saxony

"This is a revolution for @Alstom and for the #FutureOfMobility.

The world's first #hydrogen #fuelcell train is entering passenger service and is ready for serial production" emphasises Henri Poupart-Lafarge, Chairman & CEO of Alstom

16 September 2018

Switzerland: 1000 hydrogen trucks ordered for the 5 coming years

Hydrogen vehicles available in the market

Renault HyKangoo: 300 km range, plug-in-battery with 5 kW range extender, ca. 200 pcs

Hyundai NEXO, 800 km range
Hyundai ix 35: 600 km range, 300 pcs in Europe

Toyota Mirai: 650 km range, market introduction in Japan in 2015, > 4,000 pcs by now

Mercedes GLC: starting 2019, fuel cell with plug-in-battery, 500 km range (50 km by battery)

Hydrogen buses / trains

FC bus hotspot at RVK Cologne

- Today: 16 FC buses in Germany in operation, 80 in Europe
- Additional 140 FC via EU project JIVE and 150 via JIVE 2 by 2020/21
- “JIVE hotspot” NRW: Cologne (45) and Wuppertal (20)

Source: RVK

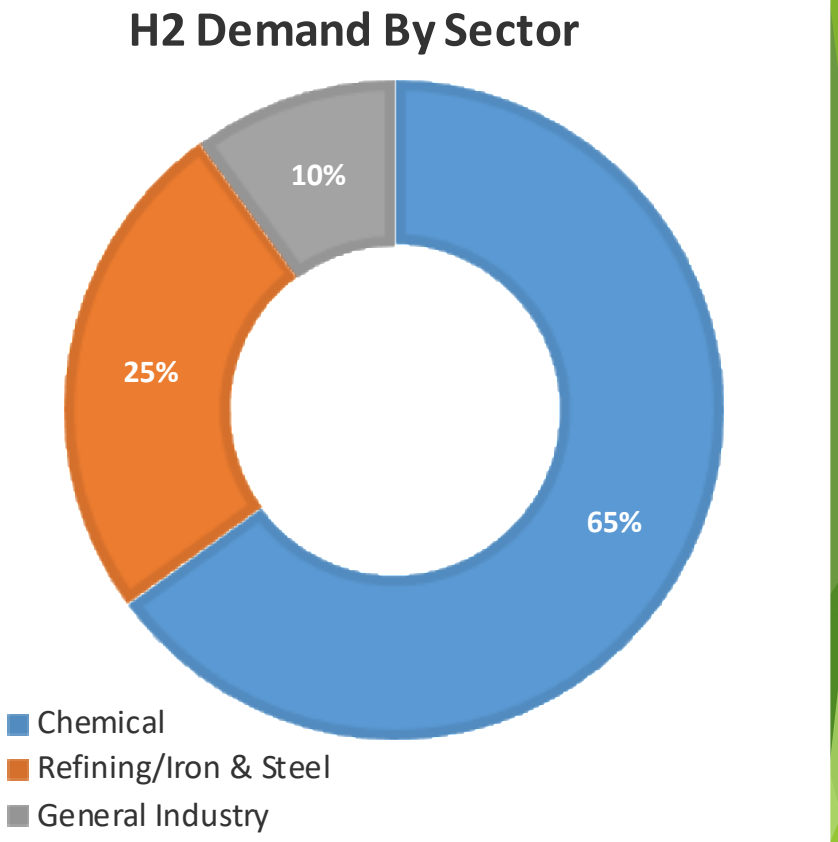
Prototype of Alstom FC train

- About 100 FC trains in Germany by 2021 on non-electrified railway tracks
- CO_2 mitigation: 40 % (H2 from natural gas compared with diesel)
- Suppliers from NRW
- Application of FC trains in NRW under preparation

Source: Alstom

HYDROGEN DEMAND BY INDUSTRY

INDUSTRY SECTOR	KEY APPLICATIONS
CHEMICAL	• Ammonia • Polymers • Resins
REFINING	• Hydrocracking • Hydrotreating
IRON & STEEL	• Annealing • Blanketing gas • Forming gas
GENERAL INDUSTRY	• Semiconductor • Propellant fuel • Glass production • Hydrogenation of fats • Cooling of generators



Green Steel - role of EU

The EU evolved starting with coal and steel

European Coal and Steel Community	Treaty of Rome	Treaty of Maastricht	„Green Steel“ redefines Europe‘s global role
1951	1957	1992	2020?