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HYDROGEN ECONOMY

Status and Outlook

August 2010

What drives

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- Fortune usually smiles on the diligent, who have gotten prepared well in advance for opportunities coming our way *Anonymous*
- The future is something that most of the times already happens before most of us anticipate it *Anonymous*
- Not ambition nor sense of duty only, can develop true values, but rather the love and loyalty to the people and the things involved will *Albert Einstein*

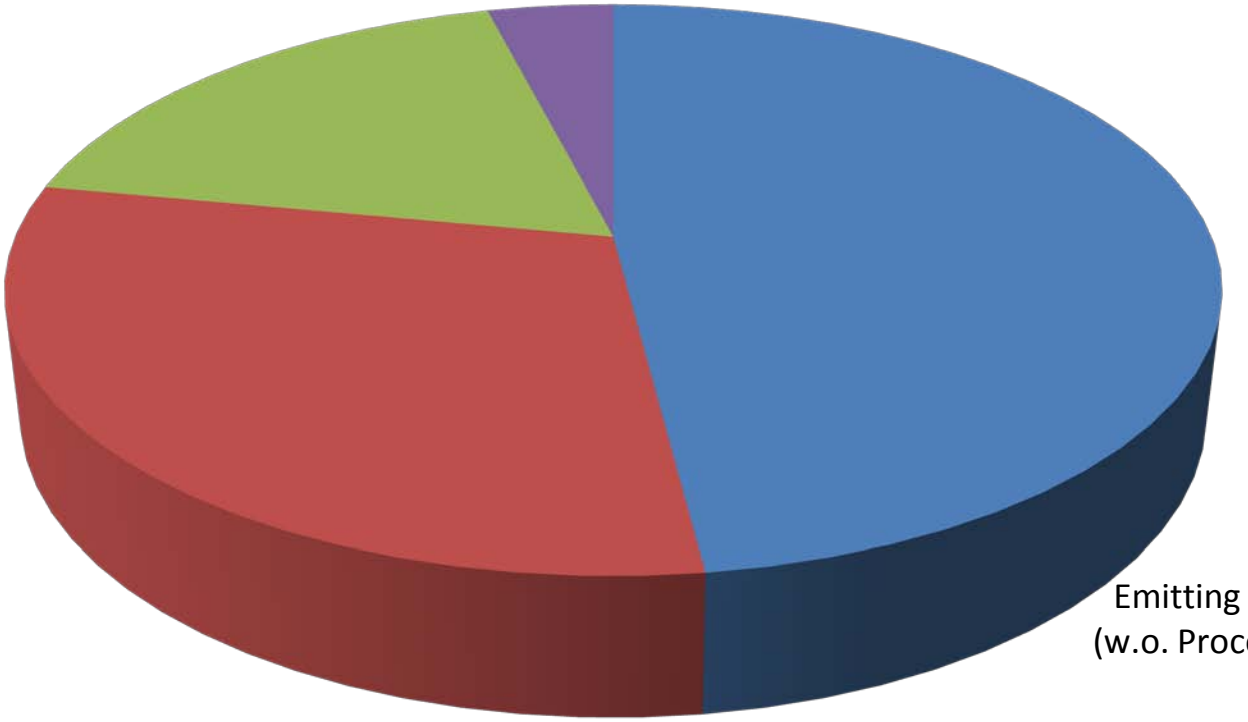
guo - Business Development holds certain IP rights supporting best practices to Climate Change mitigation efforts and would like to attract your awareness to our planet's future

LET's JOIN EFFORTS TO DO SOMETHING FOR IT !

The Hydrogen Industry

Current Status

Production Capacity of Hydrogen
~ 50 million tons / year(worldwide)

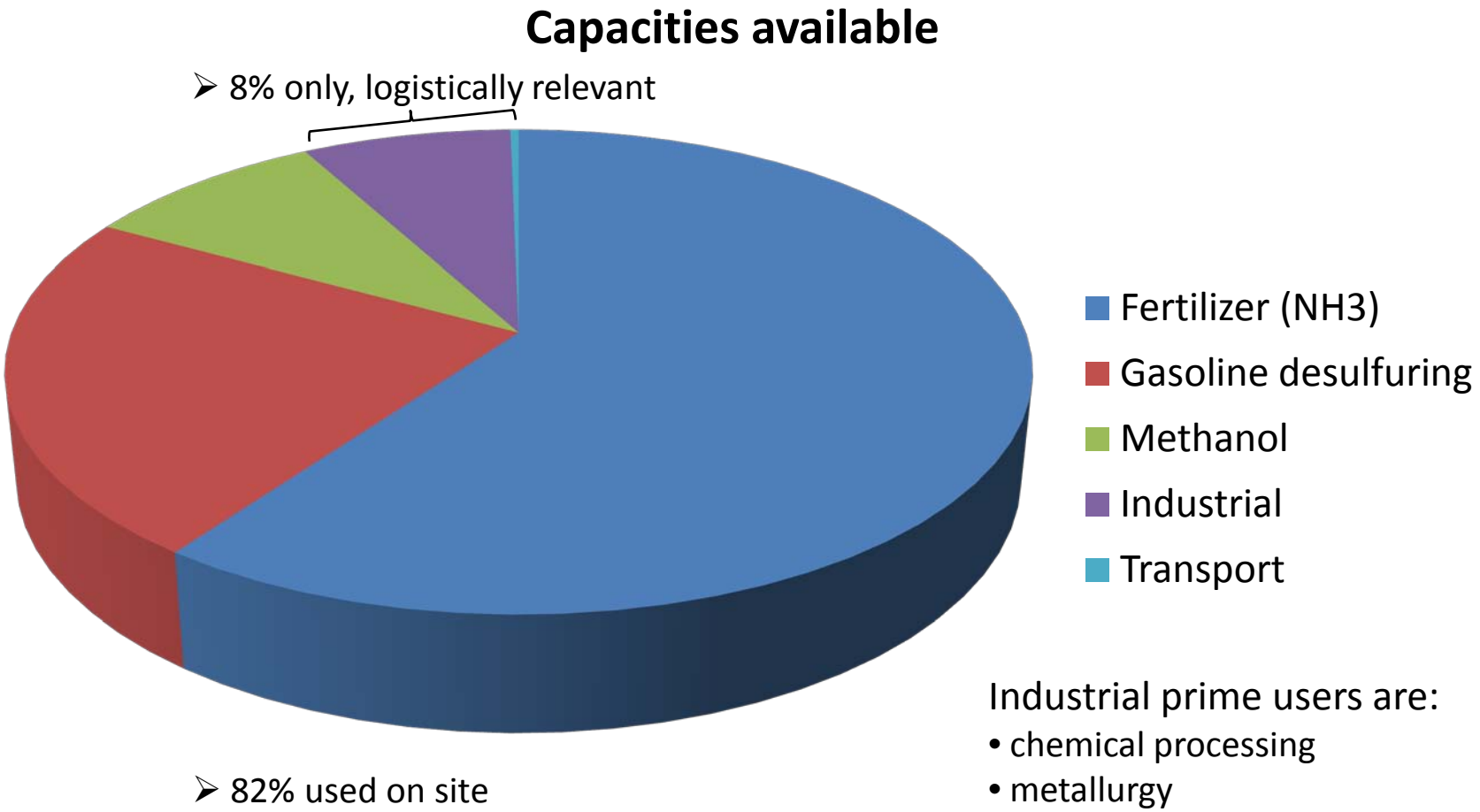


at € 1,67 – 7,75/kg

Emitting ~ 350 million tons CO2/yr
(w.o. Process Energy CO2 equivalent)

Today‘s use of Hydrogen

By Sectors



Industrial prime users are:

- chemical processing
- metallurgy
- Semiconductor

H_2 Production to boost Incineration Temp.

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Commonly discussed Technologies

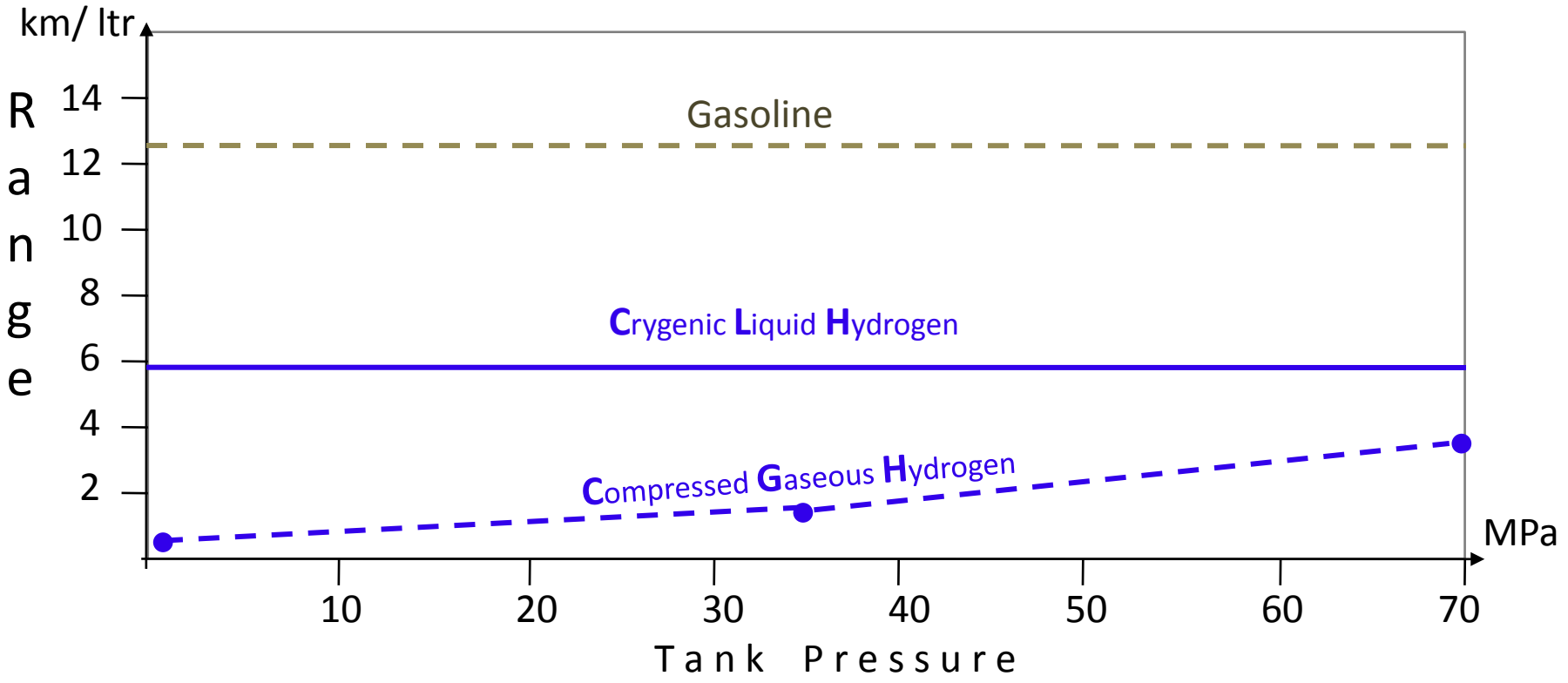
- **Natural Gas Reforming**
  - large CO_2 emissions, mostly centralized in petro-chemical plants could be captured together with Incineration exhaust in **Algae CCS Process**
- **Renewable Electrolysis**
  + wind, solar power,
  - very low yield
  - process safety and overall efficiencies of electrolysis under volatile electric supply ?
- **Renewable Liquid Reforming**
  ? Early state of the art if limited to Organic Solid Waste and agricultural debries
- **Nuclear High Temperature Electrolysis**
  + uses excess heat of NPPs, - centralized, rare, long development time of plant
- **High Temperature Thermo-chemical Water Splitting**
  + solar concentrators to be centralized in locations suiting solar reception
- **Photo-biological and Photo-electrochemical**
  - so far low H_2 yield yet achieved

➢ **Main issue of Hydrogen however is its very inefficient distribution logistics**
=> Need for decentralization of smaller installations

The Logistics of Hydrogen

Volumetric H2 Energy Density Compared to Gasoline-Equivalent

- 1 kg H2 equates 2,9 kg gasoline (density ρ = 0,75 g/ltr.) => 1 kg H2 equals 3,9 ltr. gasoline
- a FC – Car runs ≈ equal distance per 1 kg H_2 as a gasoline car does on 7,5 ltr. Gasoline
- BMW's sedans (5 – 7) on Hydrogen Combustion demonstrated 100km/kg H_2 gas milage



Unsatisfactory Issues for H_2 on Board

Concerning State of the Art Tank Technologies

- Due to Hydrogen being the smallest atom is, if not bound to a compound, that the gas migrates (venting) depending on Temperature and Pressure through any tank wall
- In liquid state the Temperature has to be kept low continuously, generating energy demand during storage and transportation.
- The total Energy Efficiency in using Hydrogen therefore is jeopardized by the energy needed for Compression or cryogenic cooling
- Venting and volumetric constrictions have been limiting the economic transportation range for the supply infrastructure of Hydrogen.
  - **Need for distributed production sites of smaller scale by Technologies free of additional Green House Gas Emissions**

Why Hydrogen should become the Future Fuel

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CO_2 Emissions Aspects

- There are currently 600 million motor vehicles (worldwide)
- Well-to-Wheel (production, distribution, dispensing and use as fuel) the current refining of oil into gasoline is
  - causing significantly more emissions, as in the use of H_2 (for combustion or Fuel Cell vehicles) , and
  - impossible to capture and sequestrate CO_2 from car tailpipes
- Carbon Capture for Sequestration [**CCS**]is a rather new Technology, however most feasible
  - in locations only that extract oil or Natural Gas, or elsewhere
  - by even further New Technologies, like the ALGAE Process,

  but **will cause additional cost across the supply chain**
- For Hydrogen the introduction of CCS would almost double current cost per kg, bringing the cost for gasification of coal near the cost of electrolysis by Renewable Energy

Recent Break Throughs in H_2 Technology

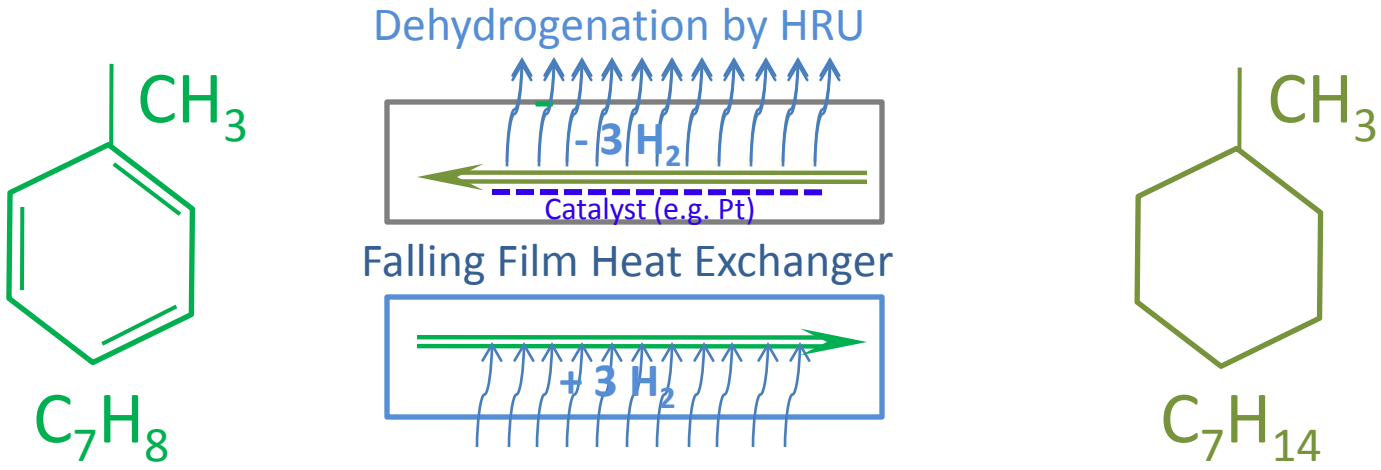
for Low GHG Emission H_2 Production and Storage in Liquids

- The principle of storing Hydrogen in a Liquid Organic Hydrogen Carrier (or Compound) [**LOHC**] has not been broadly recognized in public yet. (www.asemblon.com)
- Methane splitting by capturing the Carbon Content in solid form, such as demonstrated
  - Energy Conversion Devices Inc.'s (MI, US) Ovonic Renewable Hydrogen Base facilitated Reforming one-step low temperature process from Renewable Fuel, or (www.energyconversiondevices.com)
  - C-Polymers' (AUT) Closed Loop Continous CVD process, that can be run on any Hydro Carbon Gases including the Methane from landfills, sewage and/or ADOS plants (www.c-polymers.com)
- Direct Hydrogenization from low pH pre-ADOS (various scientific publications)
- Various RE and Photonic Electrolysis (Scientific Reports)

Liquid Organic Hydrogen Compounds [LOHC]

A schematic example for LOHC

Organic chemical hydride Dehydrogenation system



Toluol 0,87kg/l — Hydrogenation — Methylcyclohexan 0,77Kg/l

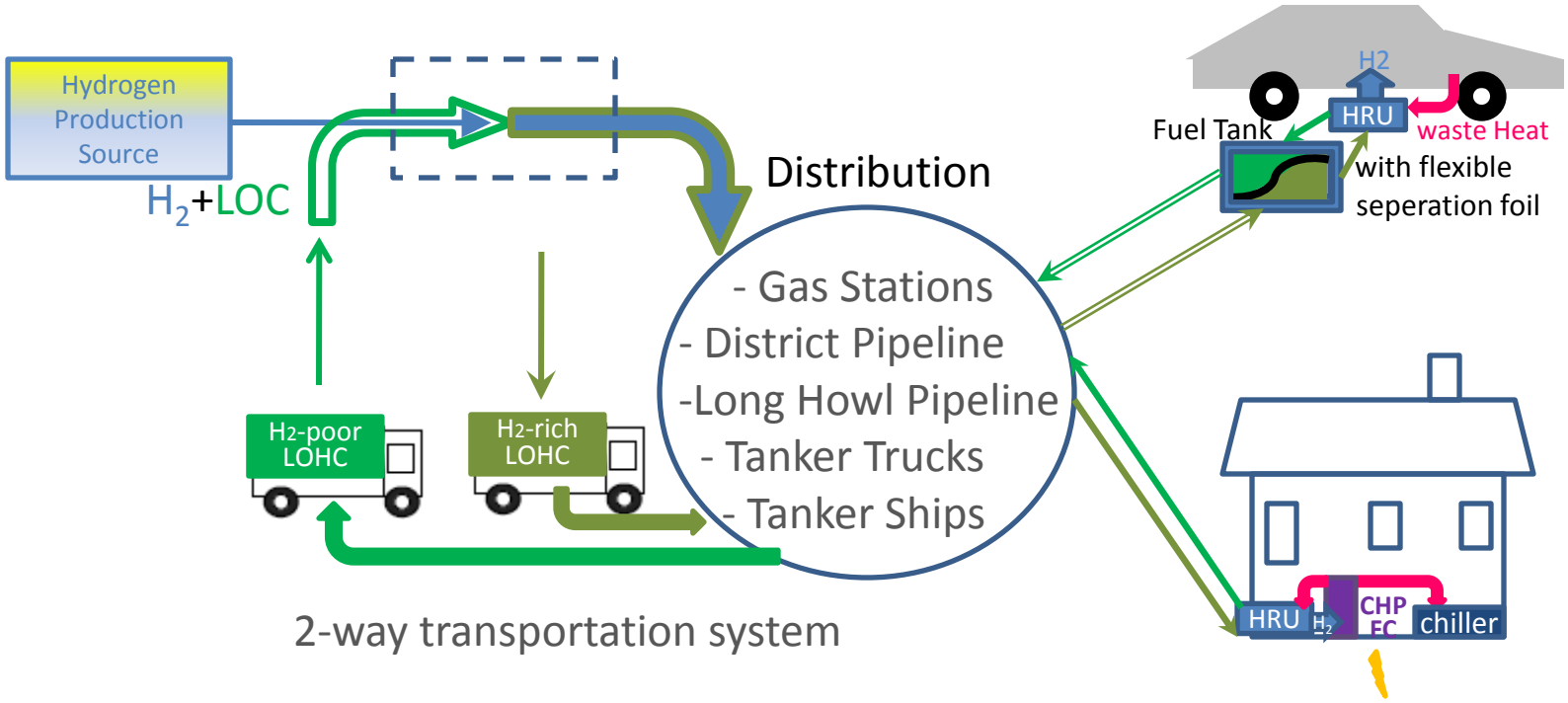
Advantages:

1) High gravimetric hydrogen density MCH has 6.1 wt% and 47.0 kg-H_2/m^3
2) Utilization of existing transport and distribution system (Tanker Trucks, Pipelines, etc.)
3) De- and Hydrogenation works like Absorption helped by a Catalyst

=> LOHC Logistics need **High Efficiency Heat Exchanger Technology**

US Department of Energy [DOE] Project

DE–FG36-05GO15015



An Integrated Production, Storage and Delivery of Hydrogen –
Using Reversible Liquid Carriers

Japan‘s Concepts based on LOHC

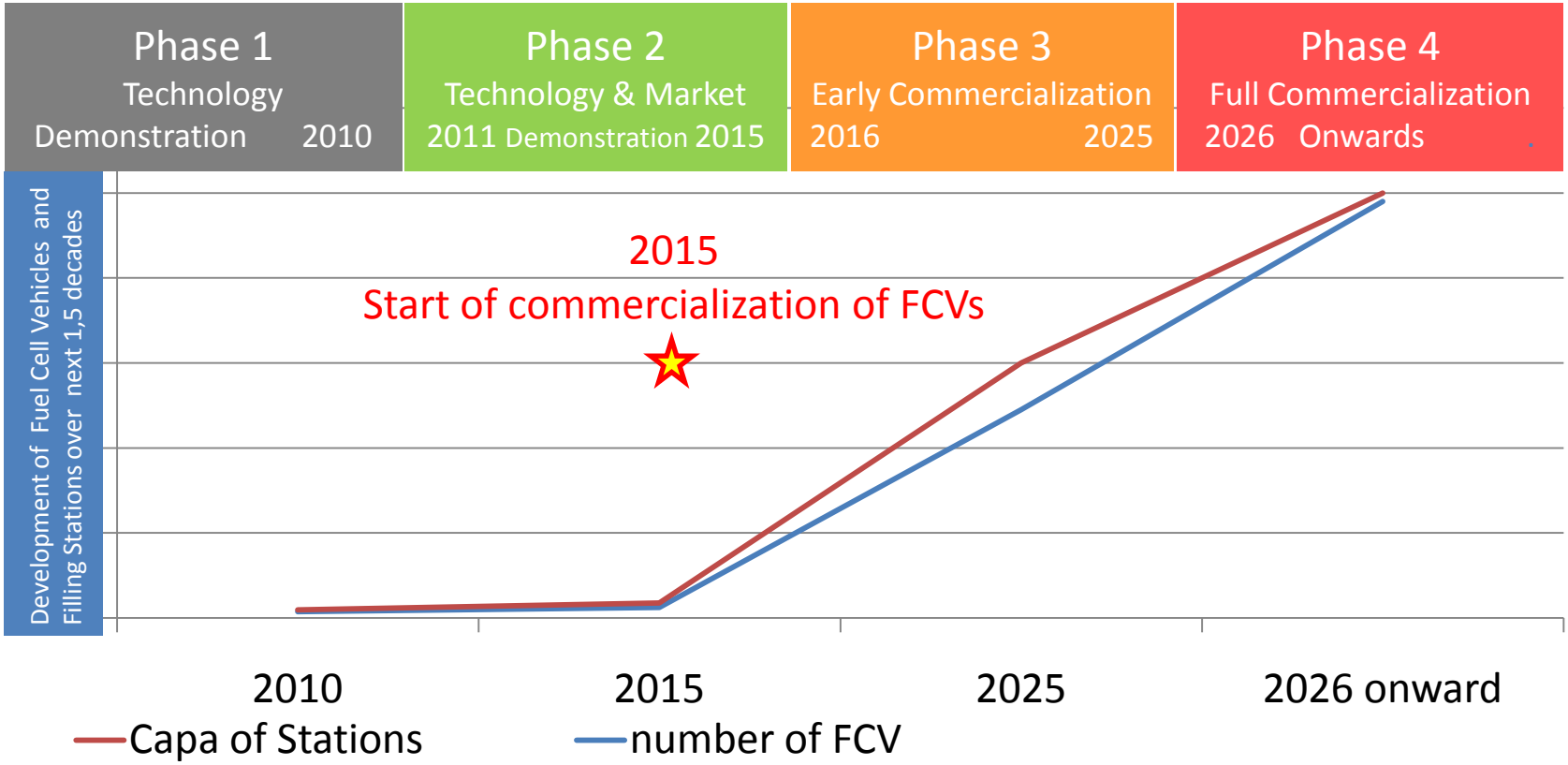
Import of higher value fuel to save CCS needs domestically

Outside Japan	Trans Ocean	Domestic
H_2 Production	2-way Transportation	Distribution ex Harbor
o Renewable Energy • Solar PV / Wind Electrolysis • Biomass Hydrogenation o Fossil Fuel • SMR with CCS (where the geology exists from the • NG or Oil Fields	LOHC shipping	LOHC Long Howl Pipeline District Pipelines Tanker Truck Terminals Import Terminal (Harbor) Gas Stations Industry Users Home Appliance Use

- Japan has to import all NG and raw oil today already, but with CO_2 emission reduction regime, can’t afford to refine without CCS
- Carbon Sequestration however is difficult if not possible into original NG or oil well
- All raw Energy Importers will have a vital interest to import LOHC Hydrogen in stead of raw oil. This will be new business opportunities:
  - ✓for NG/Oil producing countries to sell higher value products in the form of clean fuel
  - ✓ for tropical countries agricultural bio-wastes can generate new revenue streams

Japan‘s Commitment to Hydrogen Economy

The HySUT (14 companies under METI) Road Map



published by Tokyo Gas at WHEC 2010

Since BMW has demonstrated with spark and compression internal combustion engines that Hydrogen use is not limited to FCV only, the take off will be perhaps even faster

4th European Energy Technology Plan

[SET-Plan] to be launched at Brussels Conference 10/11

a) European Industrial Bioenergy initiative (EIBI),

b) European Sustainable Nuclear Industrial Initiative (ESNII)

c) Kick-off the international dimension of the SET-Plan

d) FCH JU (Fuel Cell & Hydrogen Joint Undertaking) **is an integral part of the SET-Plan,** next to the seven European Industrial Initatives and the EERA (European Energy Research Alliance)

e) Plenary session with strategic partners for international cooperation **(US, Japan,..)**

Hydrogen: Diversification of resource base as energy carrier; Improvement of energy efficiency with fuel cells, -> Research + development, demonstration projects

Electricity: Diversification of resource base as energy carrier; Improvement of energy efficiency with electric motors; -> Demonstration, early markets, research & development

Marguerite -the 2020 European Fund for Energy, Climate Change and Infrastructure

- joint initiative of Europe's leading public financial institutions, including EIB
- supports green field investments in a number of target sectors, including transport
- Planned, integrated approach to infrastructure build up –exploit synergies for production, distribution and storage

Other instruments and Programs: STEER, MARCO POLO, DG MOVE, Clean Transport, Urban Transport and ITS

Germany‘s Roadmap to Hydrogen Economy

beyond current Clean Energy Partnership Program

	2010	2015	2020	2030	2050
H_2 demand-costs	< 1 000 cars • CEP II • Demo activities approx. 10 refuelling stations	< 100,000 cars • Early markets 142 – 218 refuelling stations	350 – 580,000 cars 56 – 96,000 trucks 1 296 – 2 666 Refuel. stat. 4 – 5.5 €/kg	4.1 – 6.4 m cars 382 – 598,000 trucks 3 497 – 8 816 Refuel. stat. 3.5 – 4.5 €/kg	22 – 38 m cars 1.56 – 2.71 m trucks 7 275 – 12 388 refuelling stations
H_2 sources	Natural gas Coal with CCS Renewable (wind) Biomass By-product H_2/REG power imports				
H_2 infra-structure	Liquid hydrogen tank trucks Pipeline transport Natural gas/electrolysis		Onsite H_2 production		Electrolysis

published by DWV

Supported by the German Hydrogen Innovation Program (NIP), funded by NOW (National Organisation for Fuel-Cell and Hydrogen)

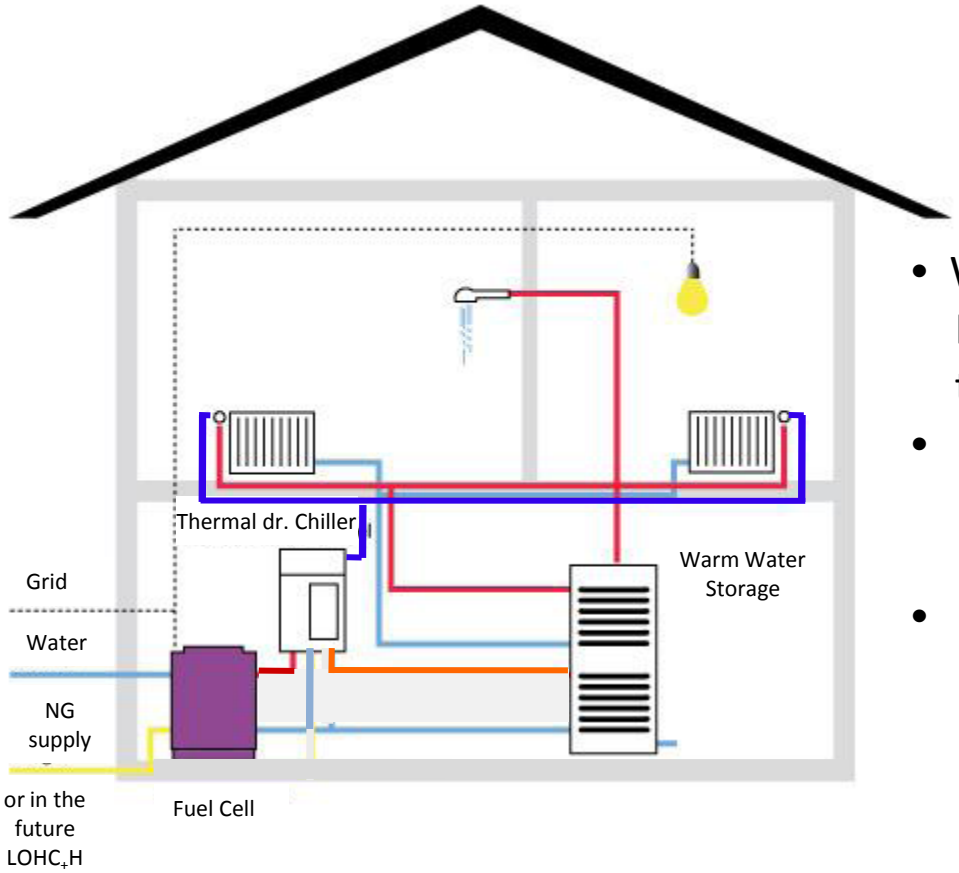
Targets for Hydrogen Economy

and Infrastructure Development

- Existing H_2 fueling station capacities have to scale up from currently 200kg/day to 500kg/day for small stations and 1.500kg/day in large stations (NHA Evolution Report)
- H_2 storage has to meet 5kg on board fully fueled (BMW)
- Cost of H_2 (before taxes) including production, CCS (if not low GHG Technology), **C**ompression, **S**torage & **D**ispensing [**CSD**] will have to meet € 2,40/kg (CCS = € 1,4/kg & CSD = € 1,5/kg; production € 1,67/kg today) (Hydrogen Association US)
- EU27 to reduce CO2 Emissions from now 26Gt to 15Gt (1990 -25%) by 2050 (www.civitas.eu)
- Independence of Energy Supply from other Nations through
  - extending the use of Biomass up to 15% Energy Contribution by 2050 (National Renewable Energy Laboratory [NREL])
  - 6,5% Energy Efficiency improvements by 2020 and 29% by 2050 also by extending use of CHP FC Technology (warm water, heating/cooling) (SET Plan EU Admin.)

CHP Household Appliance

For Heating/Cooling and Warm Water



- Whenever Heat is needed Electricity is delivered to the Grid.
- The FC is efficient across partial load operation and delivers Heat for the rest
- Depending on climat zone one might add CSP and/or air-Heat Pumps/chiller

Environmental added Value Aspects of LOW Green House Gas Emission Hydrogen

- CL-CCVD can be combined with direct Hydrogenation of biomass where ever organic substrate flow < 24/7/52

- Hydrogen can be logistically handled by **L**iquid **O**rganic **H**ydrogen **C**arrier Technology and so enable remote locations economic counter value for Biomass Treatment
  - Hydrogen Storage and Release Units need

    High Efficiency

    Falling Film Heat Exchangers,

    able to handle significant Enthalpies and to use waste Heat

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