Fuel Cells & Hydrogen Technologies
Potential Large Implementation Projects in Greece

Fuel Cells & Hydrogen technologies role in the Energy Union

Energy Security

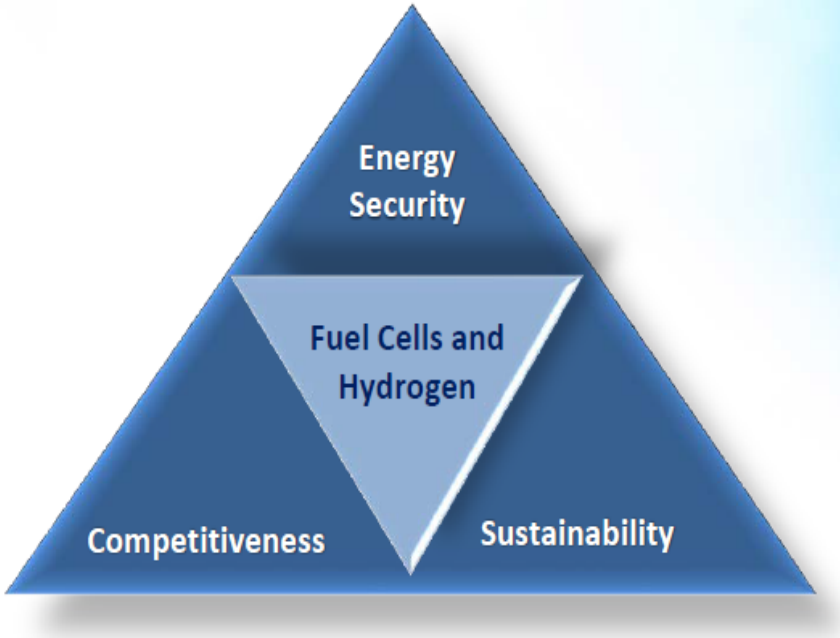
- Increase independence from unstable outside regions

Competitiveness

- research excellence leading to industry innovation and growth

Sustainability

- H_2 is a clean energy carrier
- Transport and Energy applications, generate electricity and heat with very high efficiency
- Possibility for storage of renewable energy sources
- Reduction of CO_2 emissions



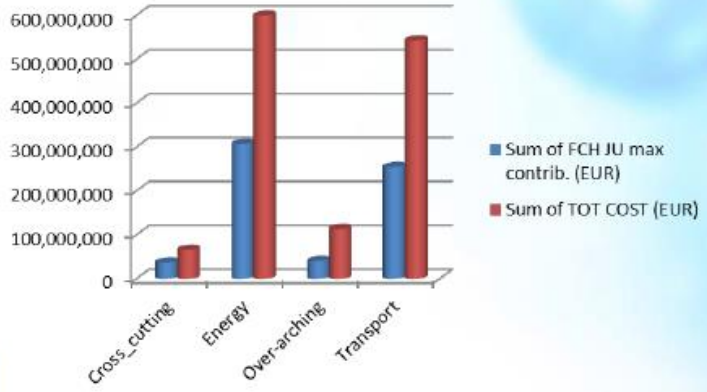
Are Fuel Cell & Hydrogen Technologies a REALITY for EUROPE today ?

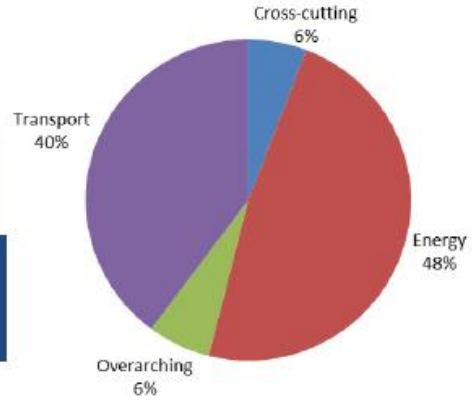
Which could be Potential Large Implementation Projects in Greece ?

FCH2 JU portfolio of projects

185 projects supported for about 638 mill €

50/50 distribution between Energy and Transport pillars





Similar leverage of private funding: 682 mill €

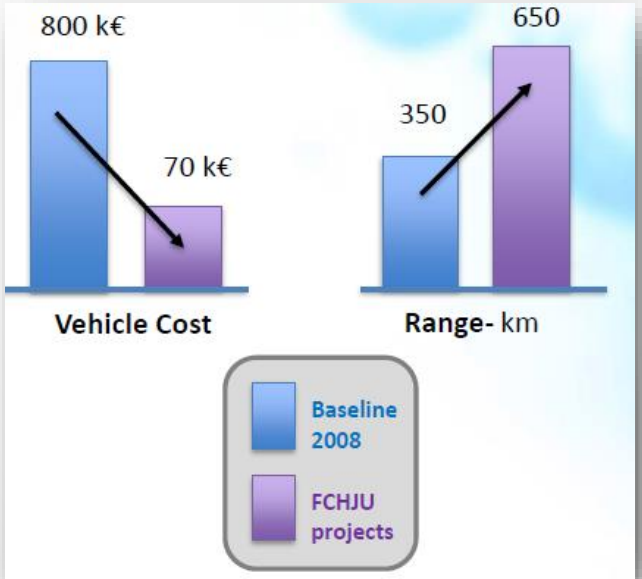
Continuous/constant annual support (through annual calls for proposals)

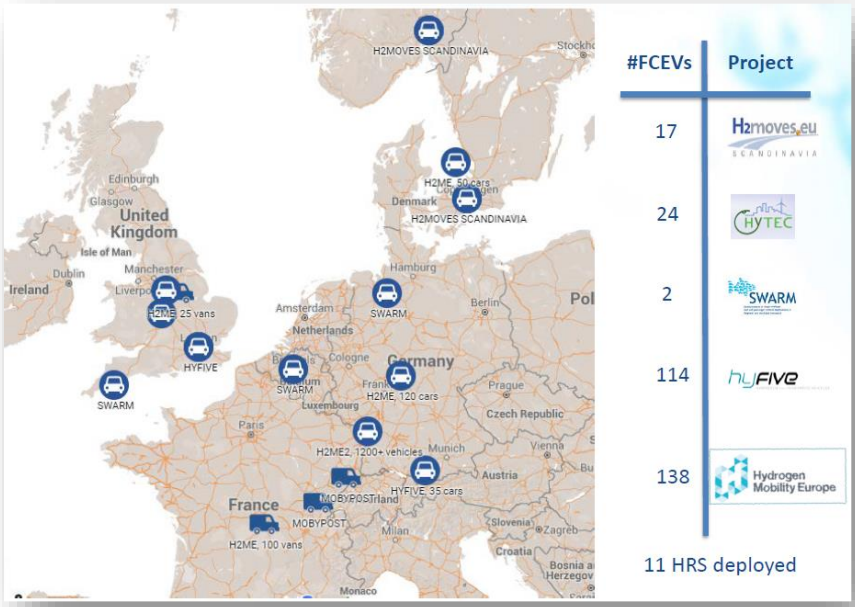
Transport portfolio

Total FCH JU support:
- **286.6M€ for 45 projects**

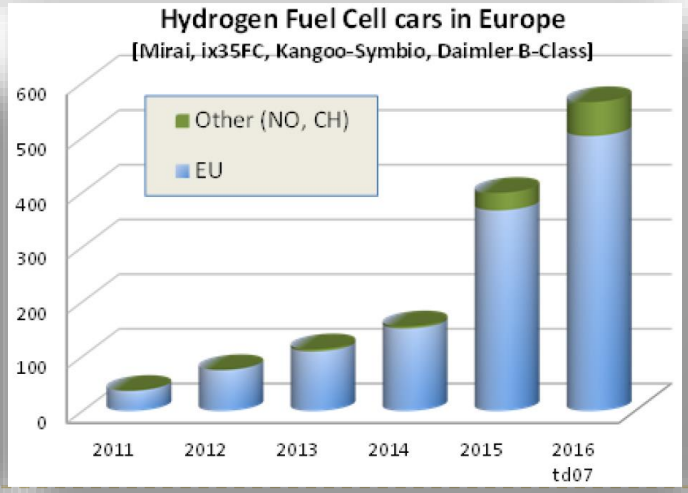
of which 215.3M€ for demos (incl. 21.8M€ APUs)

Achievements





Short-Term



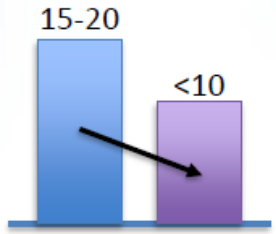
Buses: Achievements and Challenges

61M€ for 67 buses from 4 projects in 12 locations

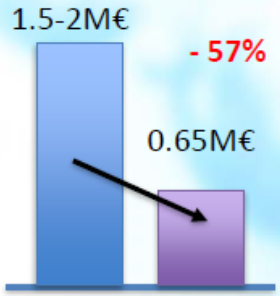
Contributions of FCH JU demo projects

Achievements

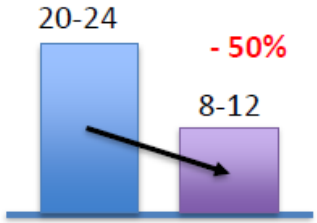
- As flexible as diesel buses
  - Full operations: 12-20hr daily shifts
  - Short refuelling time
- Cost reduction
- Efficient electric drivetrain



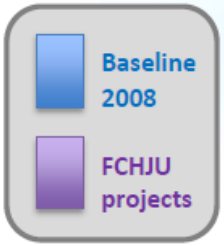
Refuelling Time - *min*



Vehicle Cost



Fuel Consumption *kg/100 km*



Challenges

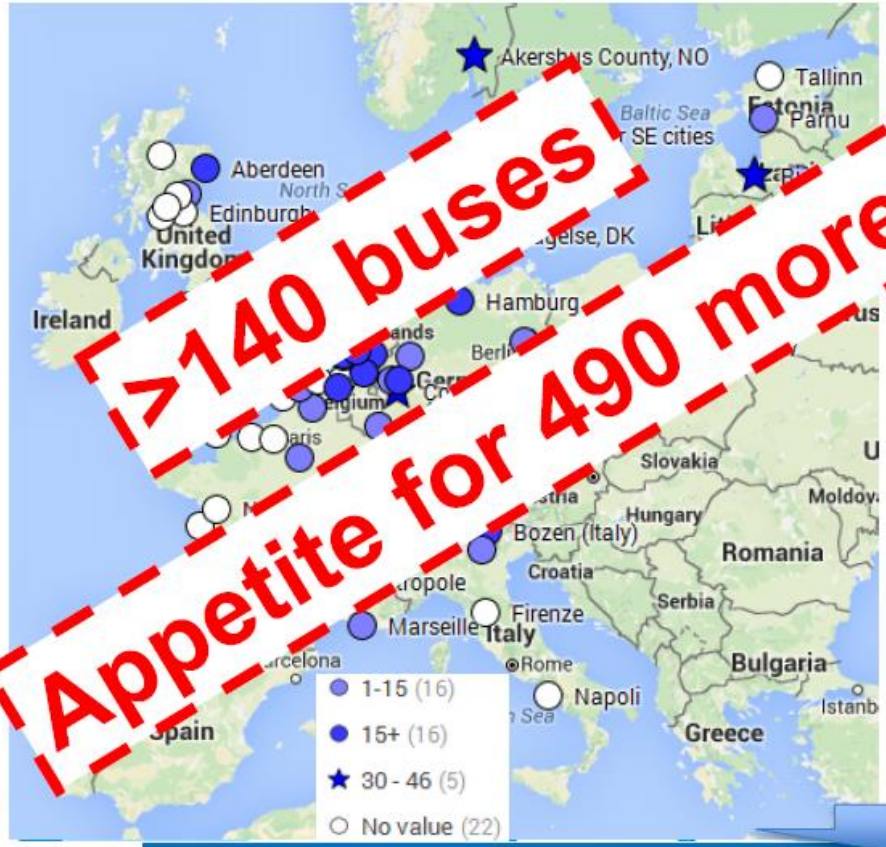
- Availability
- Spare parts
- Time to repair
- Trained staff
- Cost of FCBs, Infrastructure/H2

Volumes bring lower costs and mature supply chain

Buses: from demo to a 1.5 B€ market appetite

A broad stakeholder coalition of 82 organisations established within studies
- Operators and local governments have grown now to 64 locations

Participating locations



≥140 buses

Appetite for 490 more

Commercialization Study – Industry members

Bus manufacturers

VANHOOL, MAN, SOLARIS, ŠKODA, EvoBus, APTS, VDL

Infrastructure/ H_2 providers

H2 Logic, Shell, Ballast Nedam, Linde, AIR LIQUIDE, ITM POWER, AIR PRODUCTS, SIEMENS, HYDROGENICS, McPhy

Technology providers

HYDROGENICS, BALLARD, SIEMENS, PM, Intelligent Energy

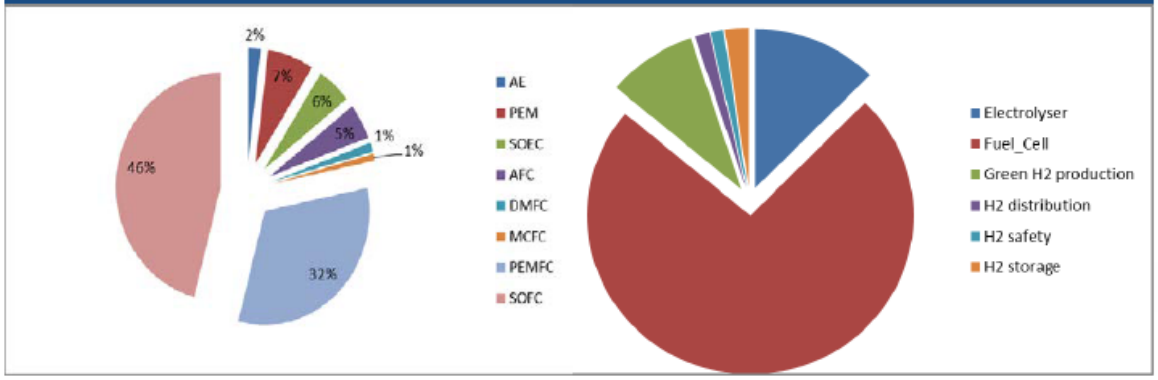
Other organisations

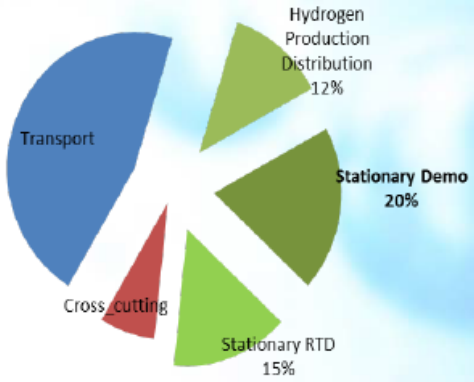
Government of the Netherlands, VRR, NOW, by SOLUTIONS, VDV Die Verkehrsunternehmen, Energie Region NRW, iit

Secured commitments for roll-out and large scale demos

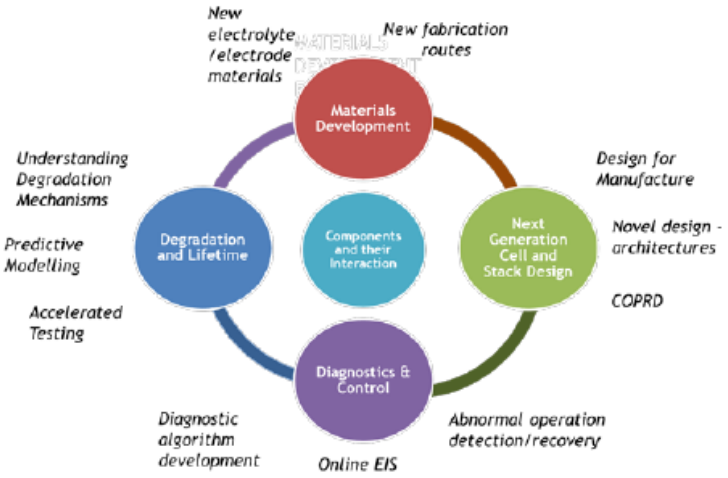
ENERGY portfolio

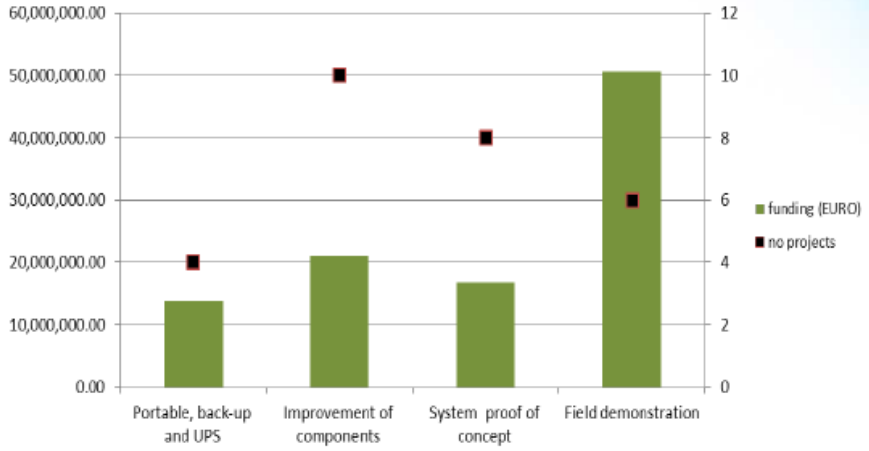
106 projects under Energy pillar, for more than 326 mill €





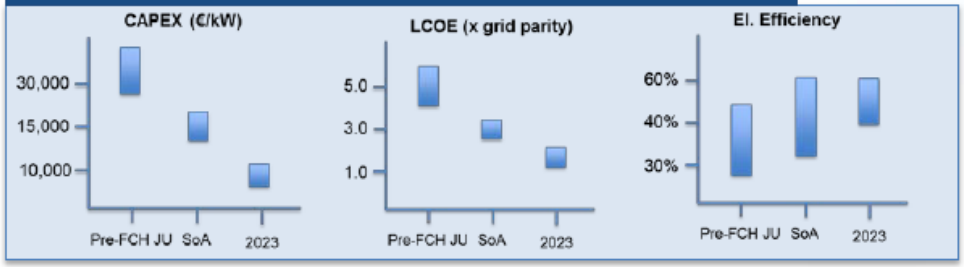
Technology neutral approach, however most support to Solide Oxide and PEM for both fuel cells and electrolyser applications





Accomplishments
(examples of projects achievements)

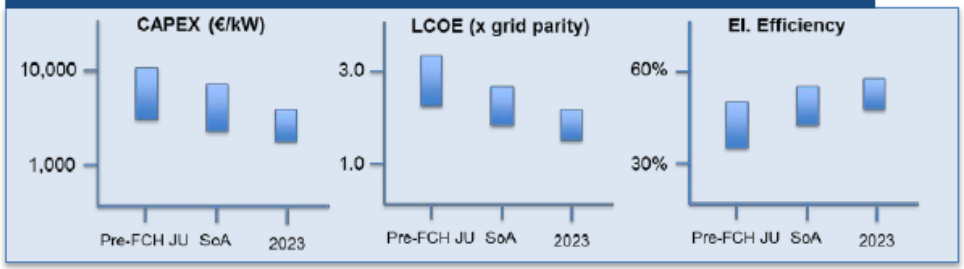
Residential Market Segment (< 5 kW)



ene.field project: more than 500 units installed in 10 countries of Europe, reliabilities confirmed, very good customer satisfaction (70% positive feedback),

SOFT-PACT project: 65 fuel cell systems, electrical efficiency higher than 42 % over lifetime (total efficency higher than 78%), 25% cost reduction

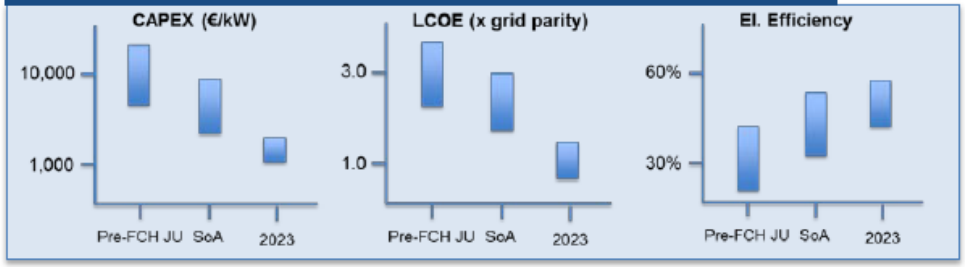
Commercial Market Segment (5-400 kW)



SOFCOM project: proof-of-concept poly-generation SOFC systems fed by biogenous primary fuels (biogas and bio-syngas, locally produced), modular concept, cost driver identified → next step: upscaling to hundreds kW size (DEMOSOFC project)

POWER-UP project: first module of 40kW (out of 240 kW) in the field, 61% electrical efficiency

Industrial Market Segment (0.3-XX MW)



ClearGenDemo project: 1 MW PEM to be installed near Bordeaux, FR on by-product H2 from clori-alkali plant

DEMCOPEM-2MW project: 2 MW PEM (European technology) to be demonstrated in China

Potential Implementation Projects in Greece

Hydrogen – Road Transport

- 400 kg/day HRS – 15 Buses
- 150 - 200 kg/day HRS – 8 Buses
  10 kgH_2/100 km

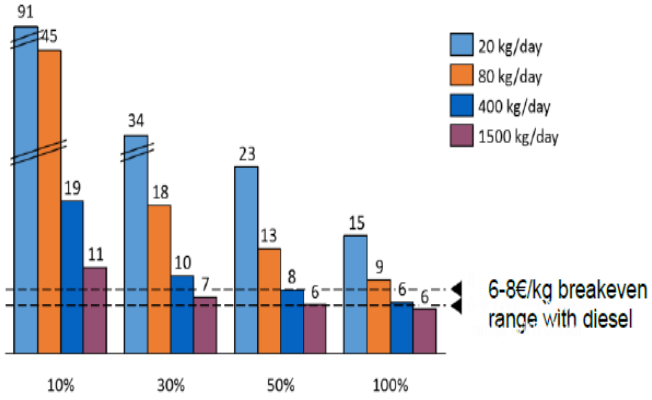
Images of fuel cell buses recently deployed by European manufacturers – Van Hool, EvoBus (Daimler) and Solaris

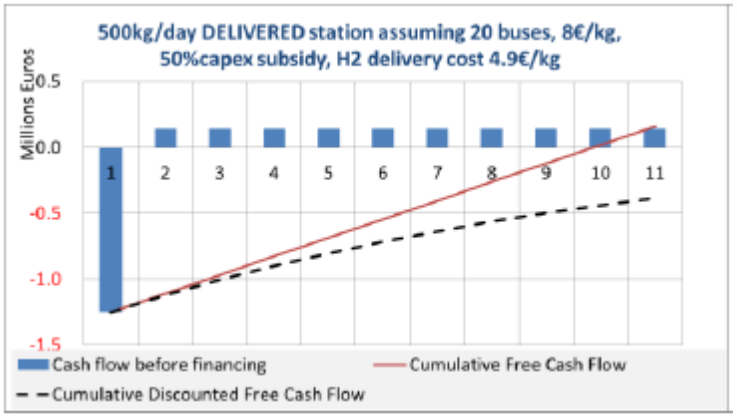
or a mix with cars (5 kgH_2/100km)

- Taxi Unions
- Car Rental Companies
- Hotel Shuttle Buses
- Hop on – Hop off Buses
- Car fleets in Air-(Ports)
- Forklifts in Air-(Ports)
- Buses for disabled people
- State, Regional, Local authorities cars, scooters

Hydrogen – Road Transport

Large stations are needed to create plausible investment case





Calculation of the breakeven price for hydrogen at stations of different sizes and load factors (fraction of capacity used per

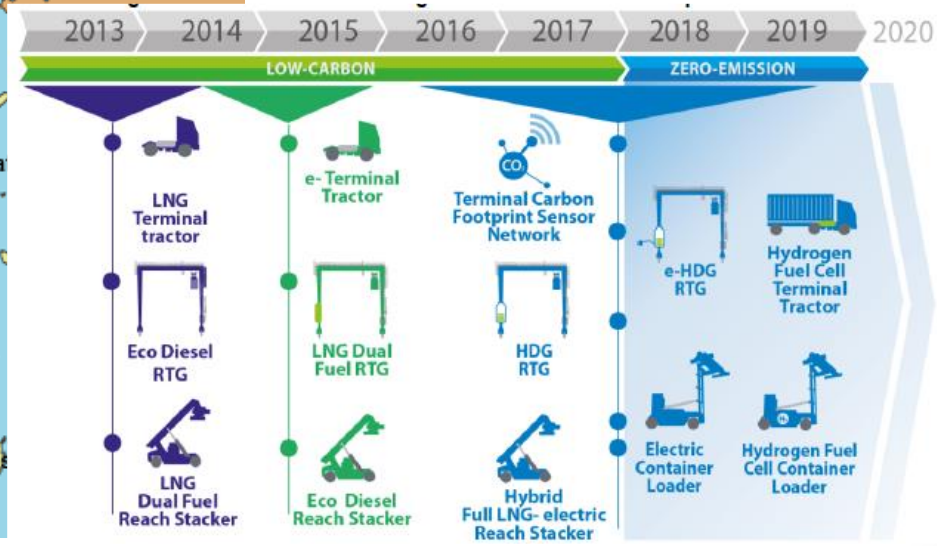
Task	Capacity of station	Source of hydrogen
1.1 Installation in Bruneck	400 kg/day	On-site electrolysis using green electricity
1.2 Installation in Cologne	500 kg/day	By-product from nearby chemical plant
1.3 Installation in Hürth	300 kg/day	By-product from nearby chemical plant
1.4 Installation in Wuppertal	320 kg/day	On-site electrolysis using green electricity
1.5 Installation in South Rotterdam	480 kg/day	On-site electrolysis using green electricity
1.6 Installation in Birmingham	680 kg/day	On-site electrolysis using green electricity
1.7 Installation in London	400 kg/day	Delivered liquid
1.8 Installation in Groningen	200 kg/day	By-product from nearby chemical plant

Location	Total Cost €	CEF funding €	Other funding
Bruneck	6.86 Mio	3.43 Mio	1 Mio from regional/local budgets 1.6 Mio from applicant's own resources
Cologne	3.07 Mio	1.53 Mio	1.53 Mio from applicants own resources
Hürth	0.85 Mio	0.43 Mio	0.43 Mio from applicants own resources
Wuppertal	5.04 Mio	2.52 Mio	2.52 Mio from applicants own resources
South Rotterdam	5.00 Mio	2.5 Mio	2.0 Mio from applicants own resources 0.5 Mio from revenue generated
Birmingham	4.83 Mio	2.42 Mio	1.34 Mio national funding 1.07 Mio other funding
London	4.5 Mio	2.25 Mio	1 Mio National funding 1.25 Mio applicants own resources
Groningen	2.0 Mio	1.0 Mio	0.25 Mio applicants own resources 0.75 Mio regional/local funding

Hydrogen – Ports Operation

In the port sector, more than 250 container terminals are currently operating in EU countries.

Ports contain energy intensive operations resulting in ca. 1.3 mtn of CO_{2eq} on 2014



Hydrogen – Ports Operation

Figure 5. HDG (Hybrid-Diesel) and e-HDG (Electric Pluggable Equipped with Super-Caps) Prototypes

Source: Paceco Spain

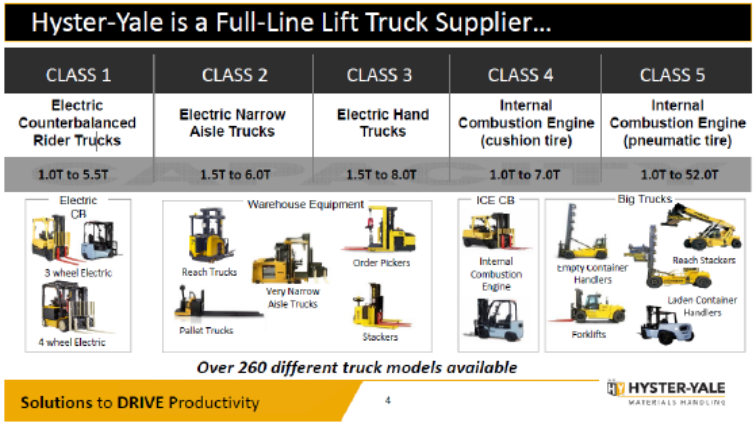
Dual-Fuel LNG-Diesel Reach Stacker to be retrofitted to Full LNG-Electric Prototype

Figure 8. Hydrogen Fuel Cell Yard Terminal Tractor Prototype

Figure 7. Hyster-Yale Container Top Loader

Source: Hyster - Yale

Figure 6. Lift Truck Classification according to Lifting Capacity



Source: Hyster-Yale

Hydrogen – Ports Operation

Base Line Scenario (2016) vs. Eco-Efficient Conservative and Optimistic Scenarios

	Energy Consumption		CO2e Emissions (tonnes)		
	Energy Consumer	Base Scenario 2016	Base Scenario 2016	2020 Scenario	2025 Scenario
Electrical Consumption (kWh/year)	STS Cranes	8.556.723	2.567	2.439	924
	Reefer Containers	9.567.227	2.870	2.727	1.033
	Yard Lightning	3.150.345	945	898	340
	Offices	1.005.346	302	287	109
	Sub-Total (kWh)	**22.279.641**	**6.684**	**6.351**	**2.406**
Fuel Consumption (litres/year)	RTG Cranes	2.970.000	9.177	4.648	2.753
	Yard Tractors	1.750.000	5.408	4.110	1.947
	Cont. Handlers	560.000	1.730	1.150	156
	Other Vehicles	70.000	216	164	156
	Sub-Total (litres)	**5.350.000**	**16.531**	**10.072**	**5.012**
	Total CO2e (tonnes)		**23.215**	**16.423**	**7.418**

Source: Fundación Valenciaport

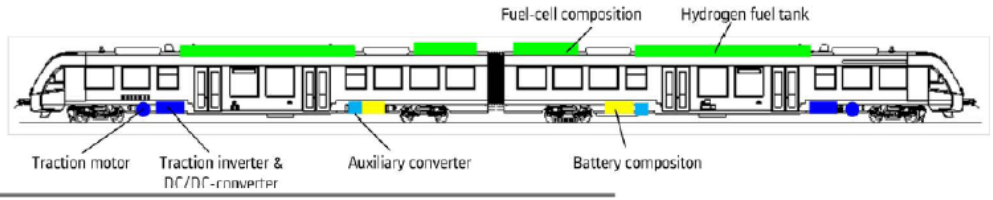
The current study shows CO_{2e} reduction of 29.2% in the conservative scenario and 51.6% considering the optimistic scenario in comparison with the 2016 baseline. These results confirm the potential benefits derived from the BEST Ports prototypes implementation. Given that more than 1.3 million CO_{2e} tonnes are generated at European port terminals (see Section 2.1), by extending these hypotheses at European level, a potential reduction between 400,000 and 650,000 CO_{2e} tonnes could take place in European ports yearly. This potential reduction surpasses even in the conservative scenario Europe's 20/20/20 Objectives.

Hydrogen – Rail Transport

Hydrogen-powered Coradia iLint at the September 2016 InnoTrans Rail Exhibition in Berlin

Alstom's passenger rail car variety

Electric drive system of Coradia iLint



	DMU (Benchmark)	FCMU
Laufleistung	150.000 km/a	150.000 km/a
Einsatzdauer	30 Jahre	30 Jahre
Spezifischer Verbrauch	1,36 l Diesel/km (13,33 kWh /km)	0,26 kg H_2/km (8,67 kWh/km)

FCH CHP Possible Applications in Greece

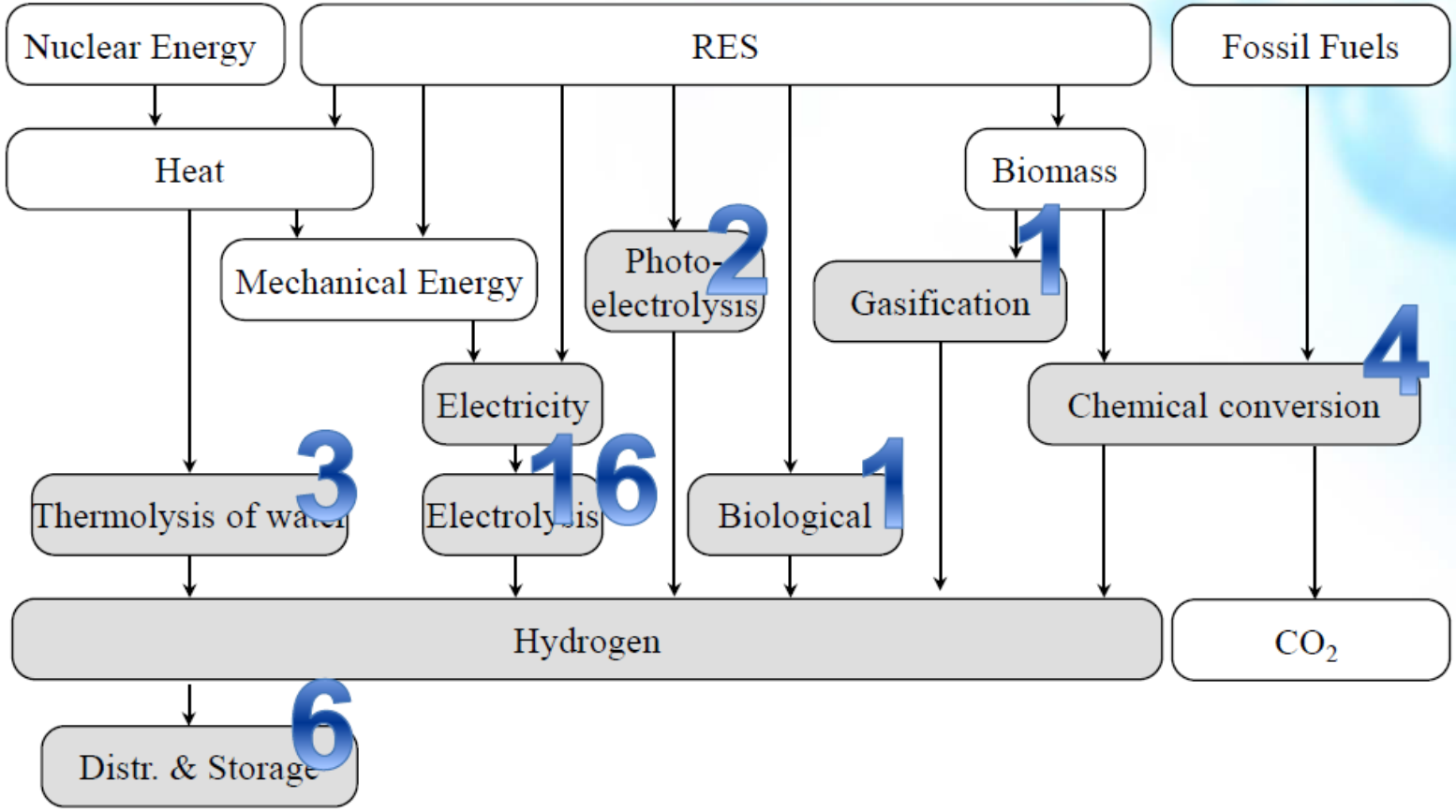
- CHP in stand alone applications (islands) and isolated operations (e.g. power supply in telecommunication antennas)
- FCH CHP integration with Biogas or Bio-methane production … or in general biomass potential
- Small-medium FCH CHP for residential/commercial applications
- Hydrogen production and use for efficient energy storage
  - RES penetration in off-grid applications (e.g., islands)
  - Use of excess power in current PPC power plants

Requirements for the deployment of FCH projects ….

- **Political commitment and strategy** (Road Map) for FCH deployments
- **Funding** (European grants, EIB loans, Governmental/Regional funding, PPPs …)
- **Maturity** (Permits, Selection of location, National laws in place, AFI)
- **Training** of engineers/technicians
- **Standards/Specifications** (already developed in several countries)
- **Social awareness/acceptance** (studies, monitoring, training of public)
- **Coordination of efforts** to deliver the first studies/roadmaps/education material and to "pull" public-private interest for investments and "push" the roll out of FCH products.
  - ***Hellenic Hydrogen Association*** with University/Research and Industry (HELPE, Air Liquide, ELBIO, etc) Pillars. Expected to be established on early 2018.

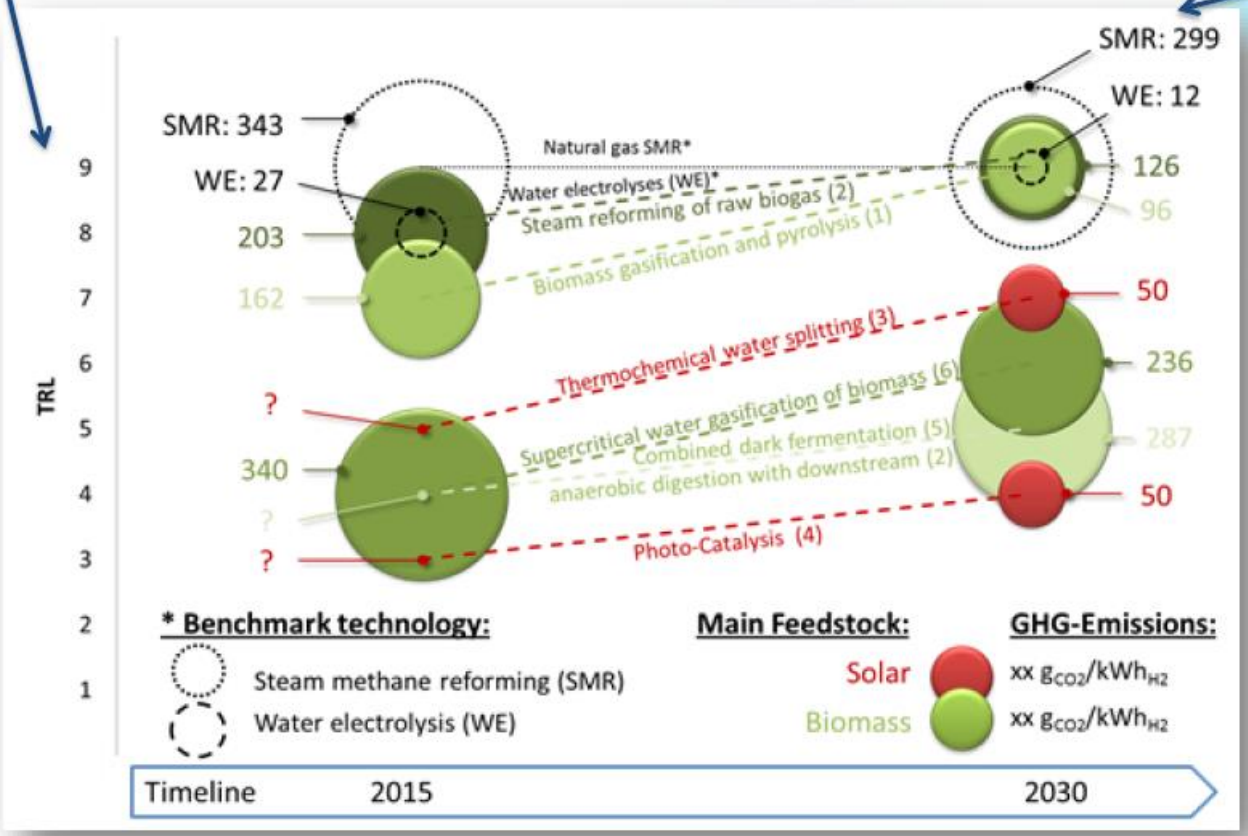
H_2 Production – Present Technical Coverage

95% of FCH JU support on H_2 production goes to renewable pathways



H_2 Production – Strategy

Green Hydrogen Study identified 6 most promising pathways besides RES+WE



Pathways

(2) Raw biogas reforming
(1) Biomass gasification
(3) Thermo-chemical water splitting
(6) Supercritical H2O gasification
(5+2) Fermentation
(4) PEC

Criteria

- TRL
- Feedstock
- GHG-emissions

P2H & H2X - from 150kW to 6MW

Industry acknowledges the potential of Hydrogen to the greening of industrial products through increased penetration of renewables

DonQuichote

Hybalance

GrInHy
Green Industrial Hydrogen

Transport, Steel industry, Refineries, Chemical industry