"RES & H_2 Technologies and Applications"

by

Prof. Chris N. Christodoulou

5-Year Diploma, **Chemical Engineering**, Aristotle University of Thessaloniki, Greece

M.Sc., **Chemical Engineering**, Kansas State University, Manhattan, KS, USA

Ph.D., **Metallurgical Engineering & Materials Science**, Carnegie-Mellon University, Pittsburgh, PA, USA

Scientific Contributors

Acknowledgements

FREDERICK UNIVERSITY

Hystore Tech Ltd, Hystore Technologies Ltd, Hydrogen Filling Stations Ltd

NCSR “Demokritos”

Deutsches Zentrum für Luft-und Raumfahrt , DLR

Acknowledgements to:
INTEGRATED/0916/0031: Integration of innovative green technologies on existing public transportation buses for 5% to 30% fuel savings
INTEGRATED/0609/0074: Storage & Renewables Electrifying Cyprus
EUROSTARS/1018/0010: E113229 HyFly-VTOL: Development of small vertical take-off and landing UAV with dedicated Hydrogen fuel cell

OVERVIEW

1. **The transition from the "Oil Economy" to the "Hydrogen Economy"**
2. **Do we have companies in Cyprus working on Hydrogen Technologies? (examples?)**
3. **Why RES & Hydrogen**
   - Why Renewable Energy Sources (RES)
   - Why to use Hydrogen (H2)?
4. **RES & H_2 Technology Applications**
   - PV Parks, Wind Parks
   - H_2/Fuel Cell Electricity generation
   - Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)
   - RES Storage in the form of Hydrogen
   - PV Electrolysis, Compressed Hydrogen Gas (CHG) for Hydrogen Filling Stations
   - HHO generators for Vehicles and Marine applications
   - Hydrogen production from recycle metals (Aluminium, etc)
5. **Conclusions**

1. The transition from the "Oil Economy" to the "Hydrogen Economy"

European Targets for 2030

- At least 40% cuts in greenhouse gas emissions (from 1990 levels)
- At least 32% share for Renewable Energy Sources (RES)
- An electricity interconnection of at least 15%

Achieve Climate neutrality by 2050

At the same time we have to act within the UN Agenda for 2030 which includes among others "Circular Economy"

The Envisioned System in Cyprus for the Penetration and Contribution of RES in Decarbonization and "Green" Transportation, towards "Hydrogen Economy"

HyStore H_2 Tech LIMITED

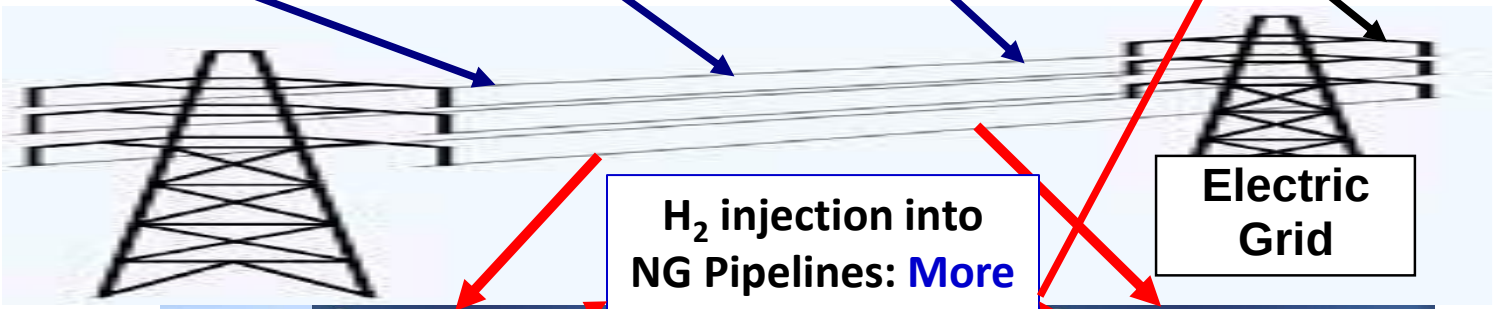
Renewable Energy Sources (RES)

Solar Thermal

PV Parks

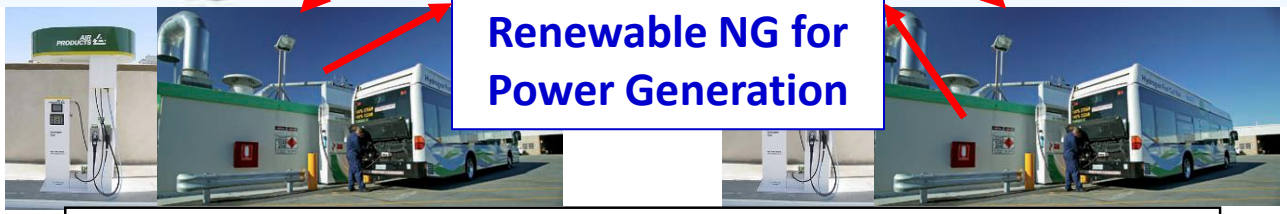
Wind Parks

Power Station



Electric Grid

H_2 injection into NG Pipelines: More Renewable NG for Power Generation



"Green" Hydrogen Production form RES and Hydrogen Filling Stations for H_2/FC, H_2ICE Buses

2. Do we have companies in Cyprus working on Hydrogen Technologies?

(Hystore Tech Ltd, Hystore Technologies Ltd, Hydrogen Filling Stations Ltd)

Established from 2003, Ergates Industrial Area, Nicosia
1080 m² Factory: 240 m² offices and 840m²
Research/Development and Production

Hystore Tech Ltd Activities

Activities:

Renewable Energy Sources (RES)

- Design/Construction/Operation of PV Parks
- Constructed 4X150kW PV Parks operating in Orouda area since 2010

Hydrogen Technologies

- Hydrogen Production by PEM and Alkaline Electrolysis
- PV Electrolysis to produce "Green H_2"
- "Green Electricity" production with H_2/Fuel Cells
- Metal Hydrides (AB_2, AB_5-type) materials and MHC
- Hydrogen Storage (Metal Hydride Tanks (MHT), Compressed Hydrogen Gas (CHG))
- Hydrogen Systems to power Drones and increase their flying time
- HHO Generators for Buses, Boats, Vessels to save fuel consumption by 5-30% and reduce the exhaust gas emissions by >20%
- H_2 Production by semi-catalytic decomposition of H_2O by using recycle metals (Aluminium, etc), without electricity
- H_2 Production by Chemical Hydrides

3. Why RES & Hydrogen

Why Renewable Energy Sources (RES)

- We are running out of fossil fuels
- For a cleaner environment
- For sustainability

Why to use Hydrogen (H_2)?

- It can be produced by RES anywhere (Water Electrolysis)
- It can be stored as Liquid, Compressed Gas, Metal Hydrides, Chemically (LiH, $NaBH_4$, $LiAlH_4$, NH_3, CH_3OH, $(CH_3)_2O$, CH_4)
- It can be used as a fuel in transportation and other applications
- It is the cleanest and **only** carbon-less fuel producing only harmless water

The Color of Hydrogen

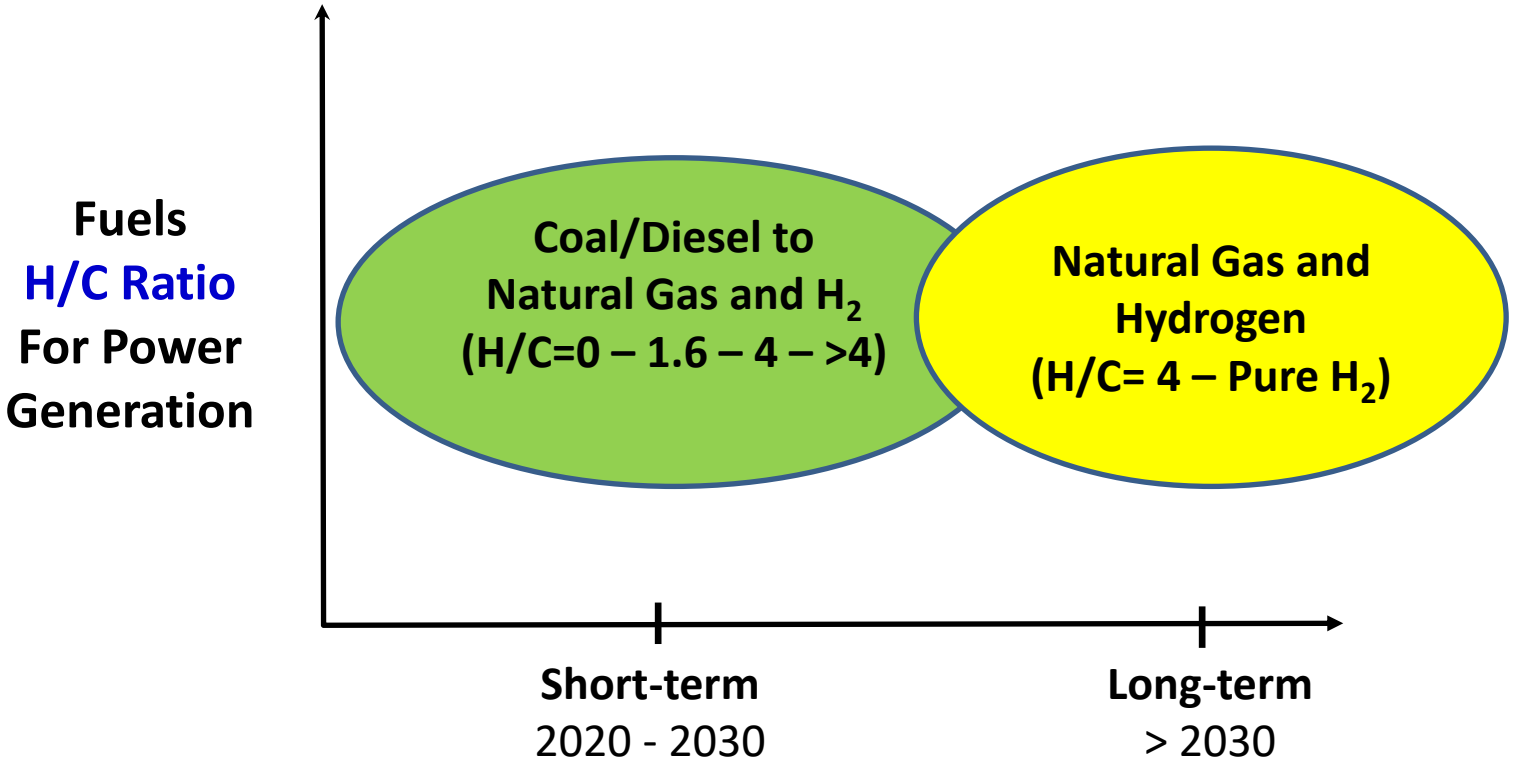
- **Green H_2: Water Electrolysis via RES (Cleanest Option)**
- **Yellow H_2 : Water Electrolysis via RES and Fossil Fuels**
- **Pink H_2 : Water Electrolysis via Nuclear Energy (Clean or What?)**
- **Blue H_2 : NG reforming with** Carbon Capture Usage and Storage (CCUS)
- **Grey H_2? NG reforming without** Carbon Capture Usage and Storage (CCUS)
- **Turquoise H_2 : Methane** Pyrolysis (H_2, Carbon)
- **Brown/Black H_2 : Gasification** of Coal (H_2, CO, CO_2)

4. RES & H_2 Technology Applications

- Short Run: Transition from the "Oil Economy" to the "Hydrogen Economy" (2020 – 2030 - ?)

- Long Run: Sustainable "Hydrogen Economy" (>2030 - ?)

Fuel transition from the "**Oil Economy**" to the "Hydrogen Economy"



4. RES & H_2 Technology Applications

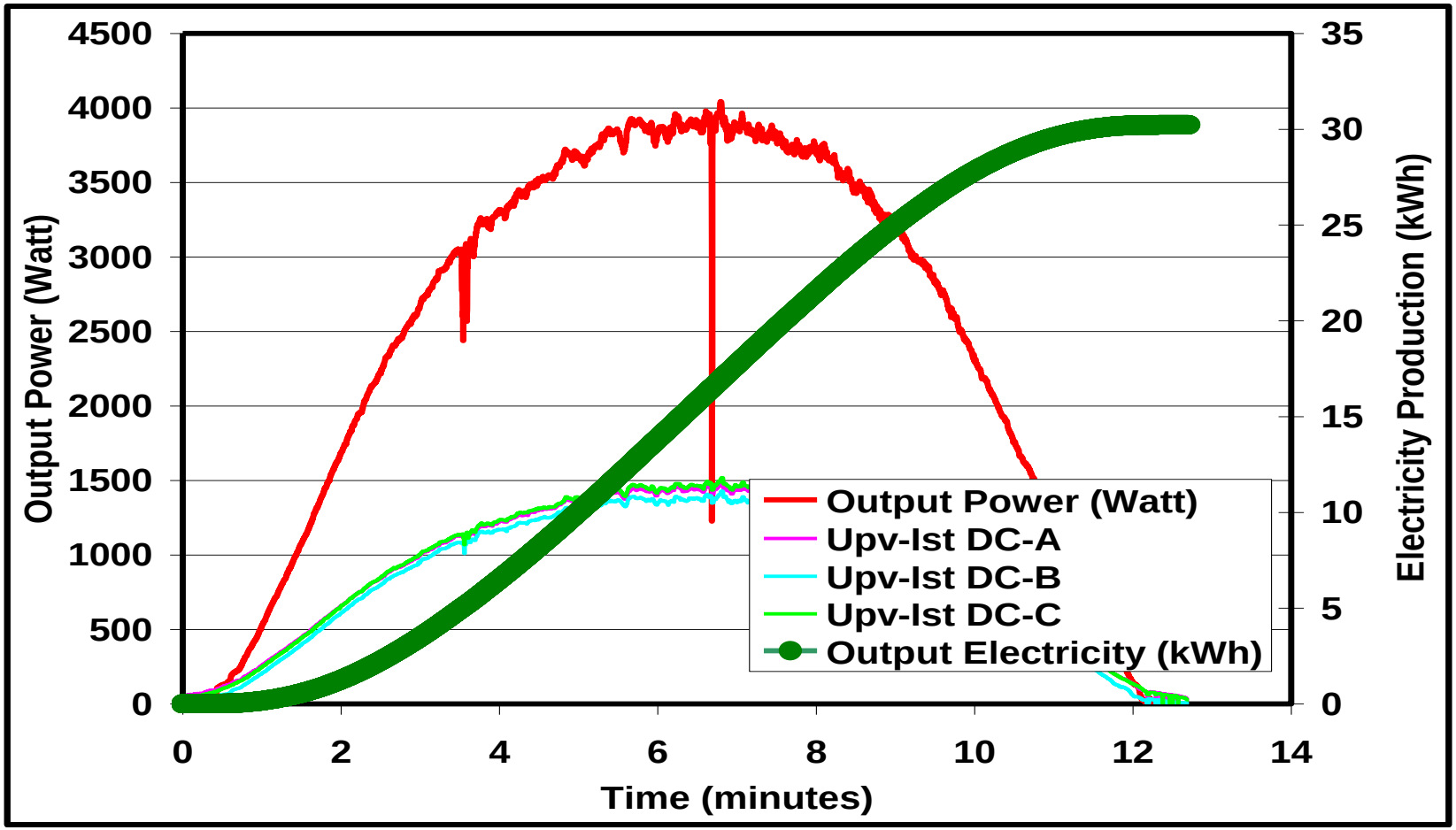
- Sustainable "Hydrogen Economy" (>2030 - ?)

4. RES & H_2 Technology Applications

- PV Parks
- Wind Parks
- Solar Thermal?

Grid-connected Photovoltaic System (5.25 kW) in 2005

Grid-connected Photovoltaic (5.25 kW) substation with possible electricity storage in the form of H_2

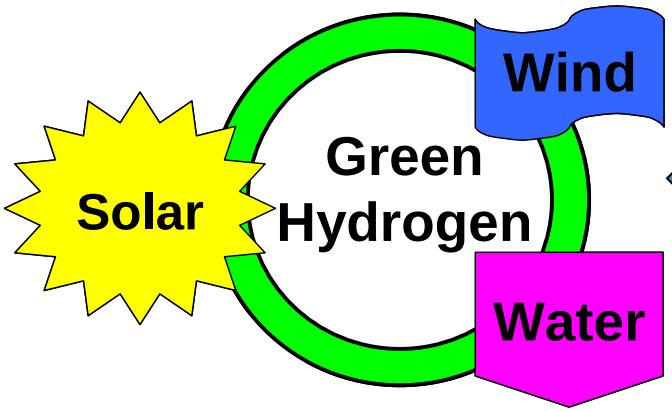


Design/Construction/Operation of 4X150kW PV Parks

4. RES & H_2 Technology Applications

H_2/Fuel Cell Electricity generation

Abundant: Solar – Wind – Water

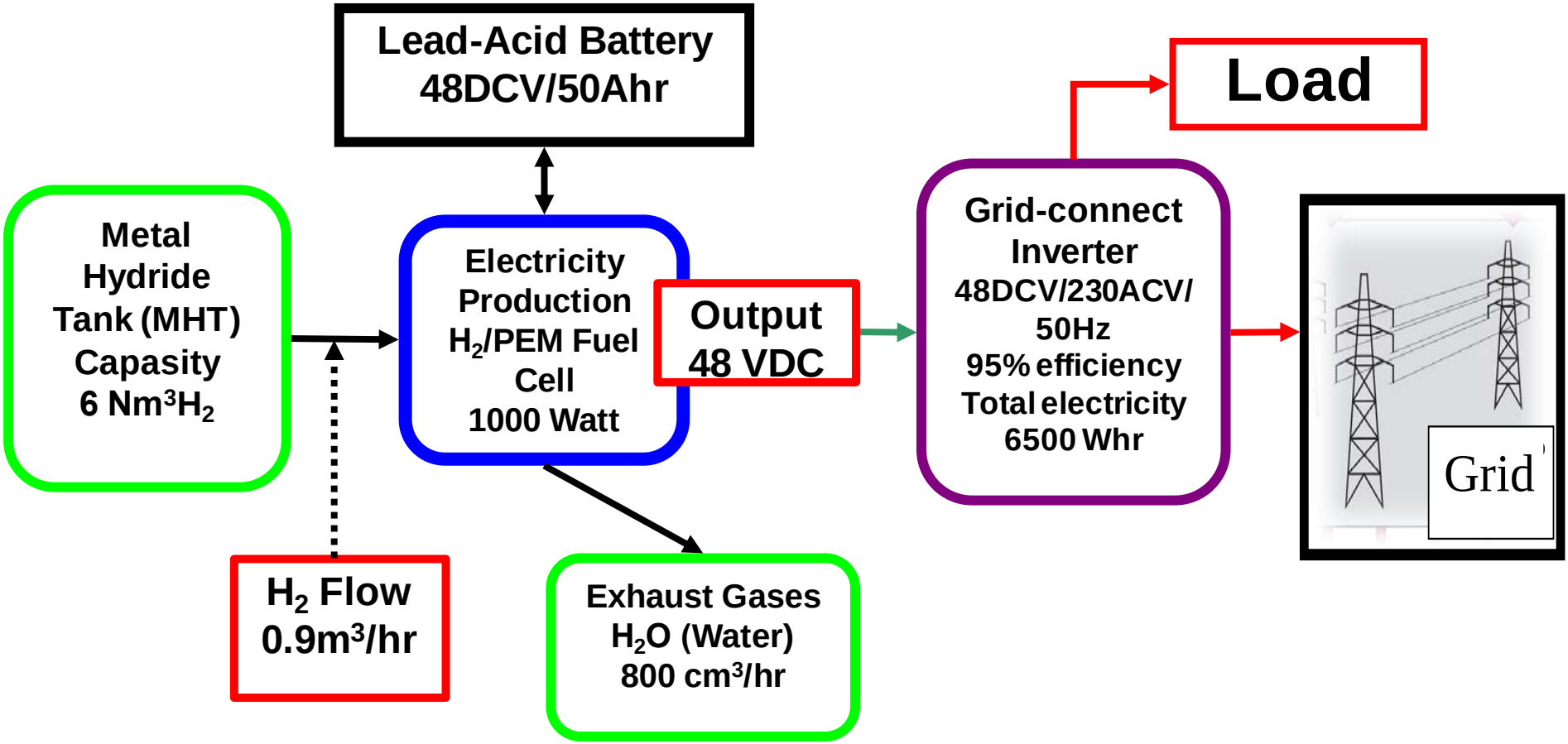


H_2/Fuel Cell
H_2/ICE
Gas-Turbines

"Green" Electricity

Thermal Energy
H_2O

Distributed Electricity Generation (DER) with the use of H_2/Fuel Cells, with zero CO_2 emissions (TEXNO/0603/03)



Distributed electricity generation with the use of H_2/Fuel Cells, with zero CO_2 emissions (TEXNO/0603/03)

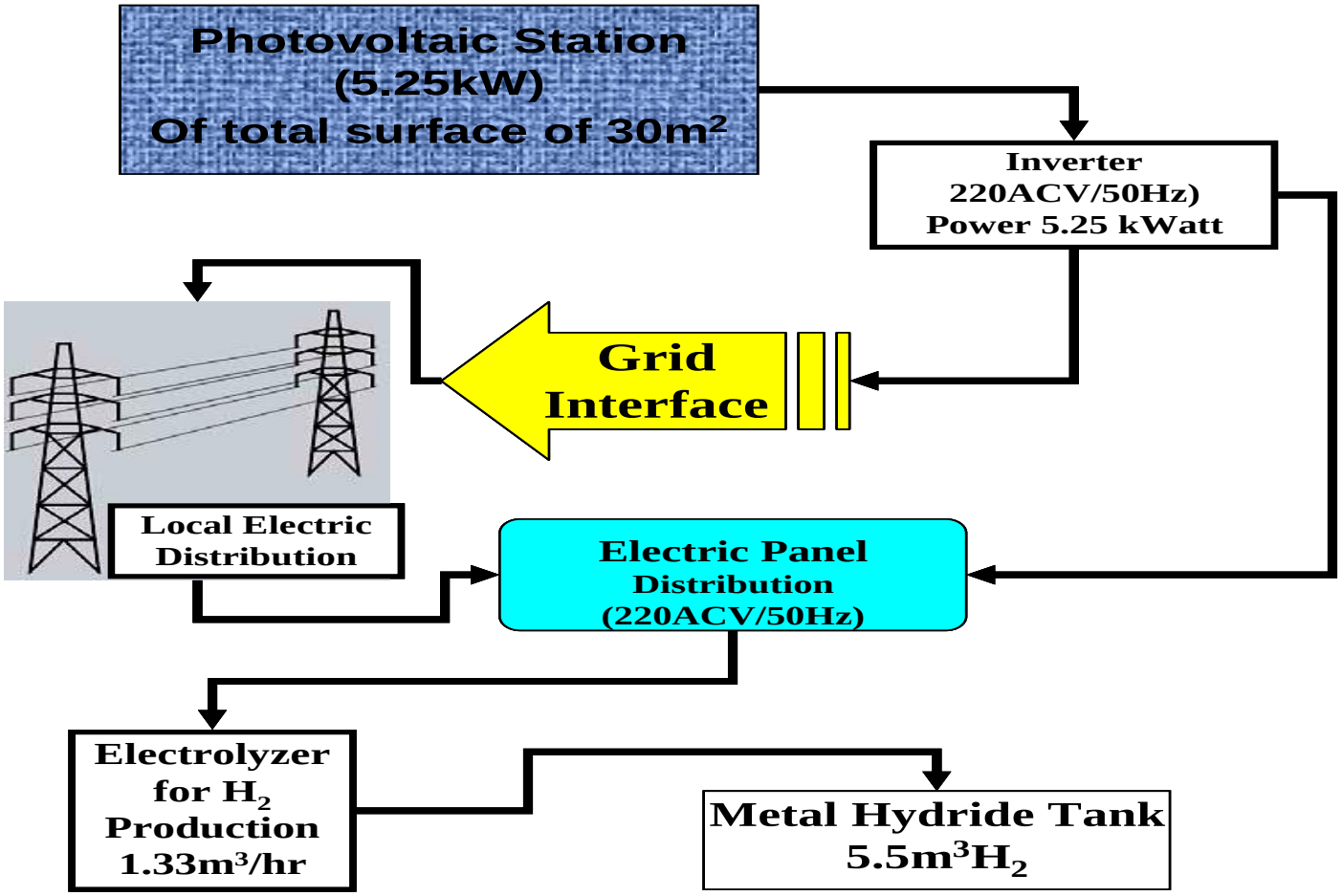
1 kW H_2/Fuel Cell

4. RES & H_2 Technology Applications

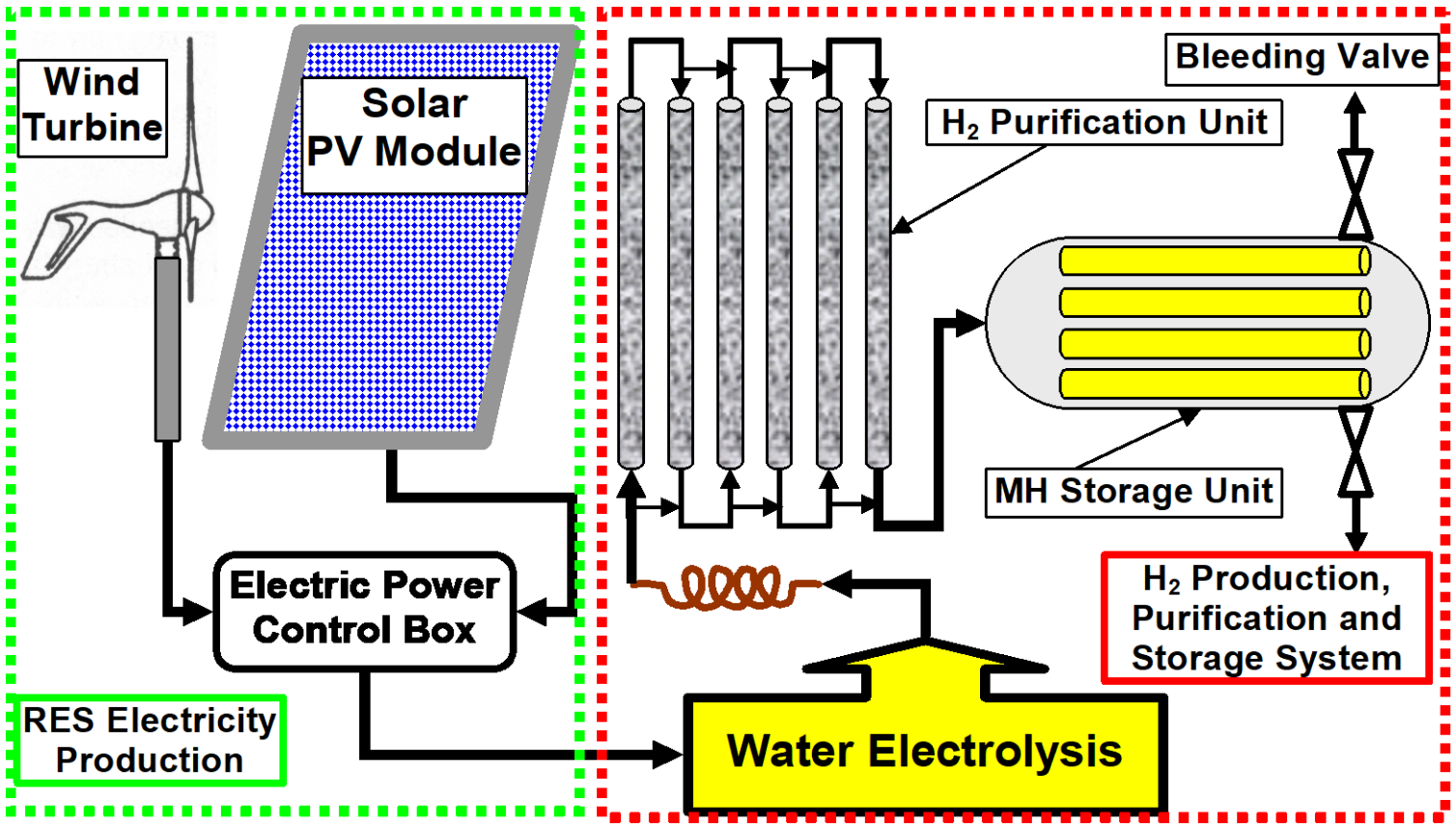
RES Storage in the form of Hydrogen

PV Electrolysis

Grid-connected Photovoltaic substation with possible electricity storage in the form of H_2 (ΝΕΠΡΟ/0204/09)



Stand-alone Pilot unit for the production, purification and storage of hydrogen by using Renewable Energy Sources such as, Solar and Wind energy (ΝΕΠΡΟ/0603/02)



Stand-alone Pilot unit for the production, purification and storage of hydrogen by using Renewable Energy Sources such as, Solar and Wind energy (ΝΕΠΡΟ/0603/02)

Photovoltaic (PV) Wind-Turbine Station

Electricity Management and DC/AC Inversion

Hydrogen Production Unit (Electrolyser)

Hydrogen Purification Unit

Hydrogen Storage in Metal Hydride Tank Further Purification

Cluster Pilot Project for the Integration of Renewable Energies into European Energy Sectors Using Hydrogen (RES2H2)

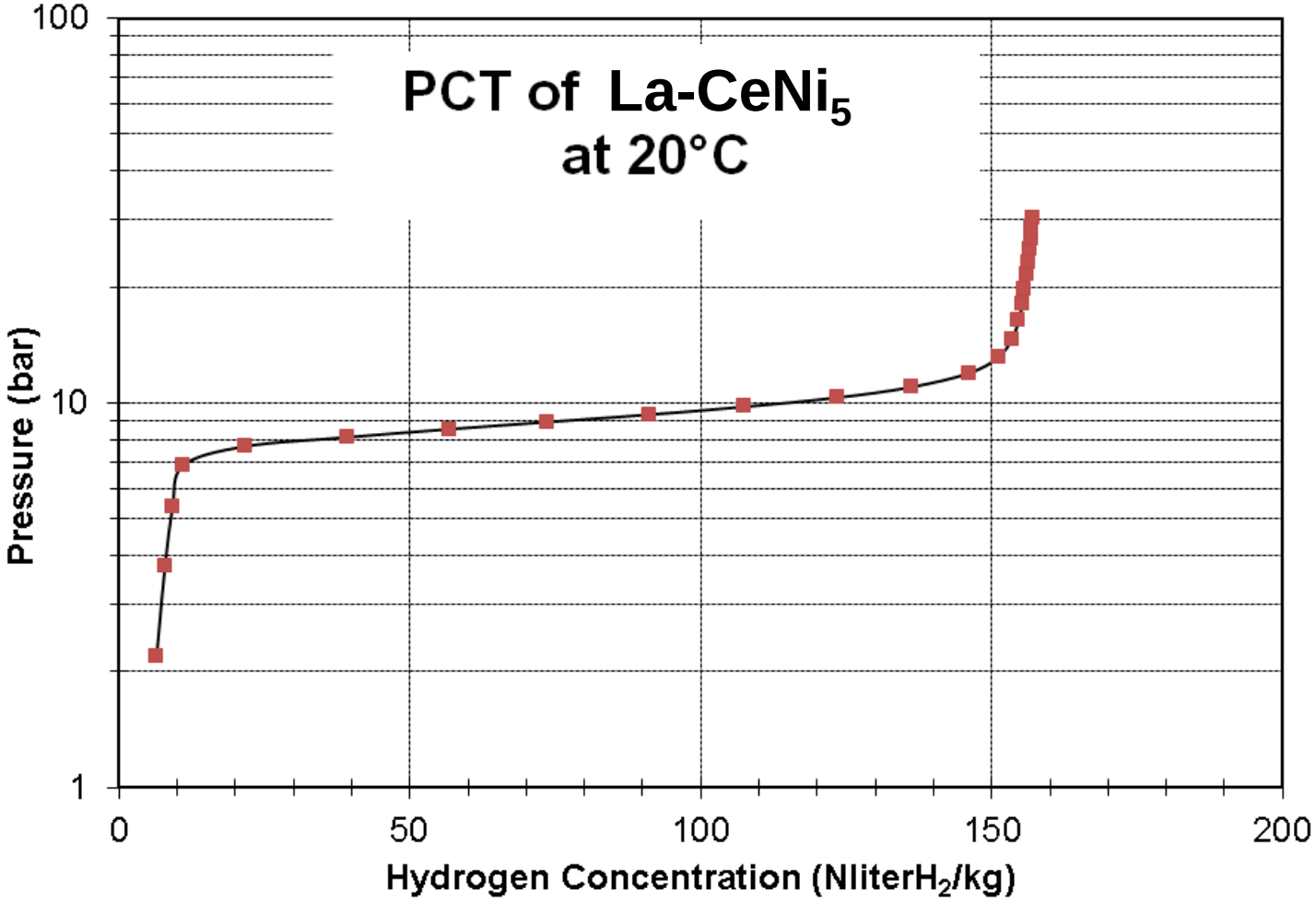
H_2 production from Wind-turbines by water-electrolysis and MH storage

Cluster Pilot Project for the Integration of Renewable Energies into European Energy Sectors Using Hydrogen (RES2H2)

H_2 production from Windturbines by water-electrolysis and MH storage

Hydrogen Storage in Metal Hydride Tanks (MHT) using AB_5H_6-type AB_2H_3-type of Materials

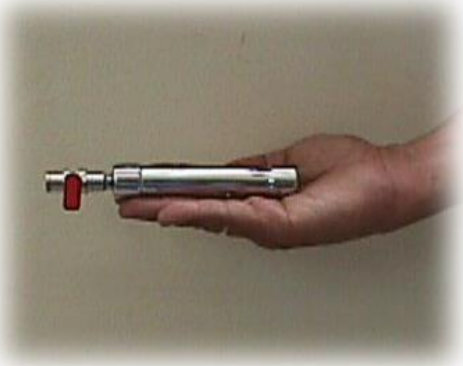
Metal Hydride Materials: The principle



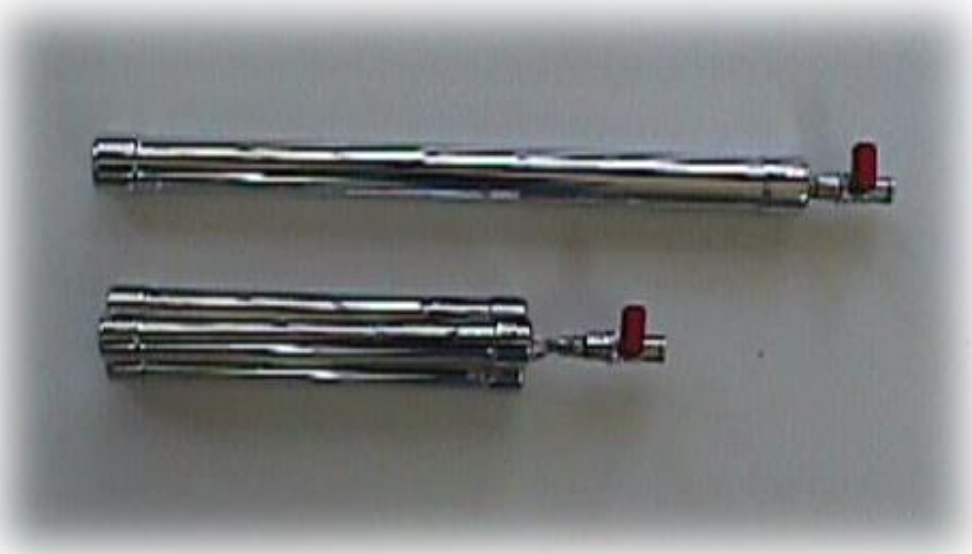
Metal Hydride Tanks (MHT) Designs/Products

Air-cooled MHT

20 NlitersH_2



Air-cooled MHT



100 NlitersH_2

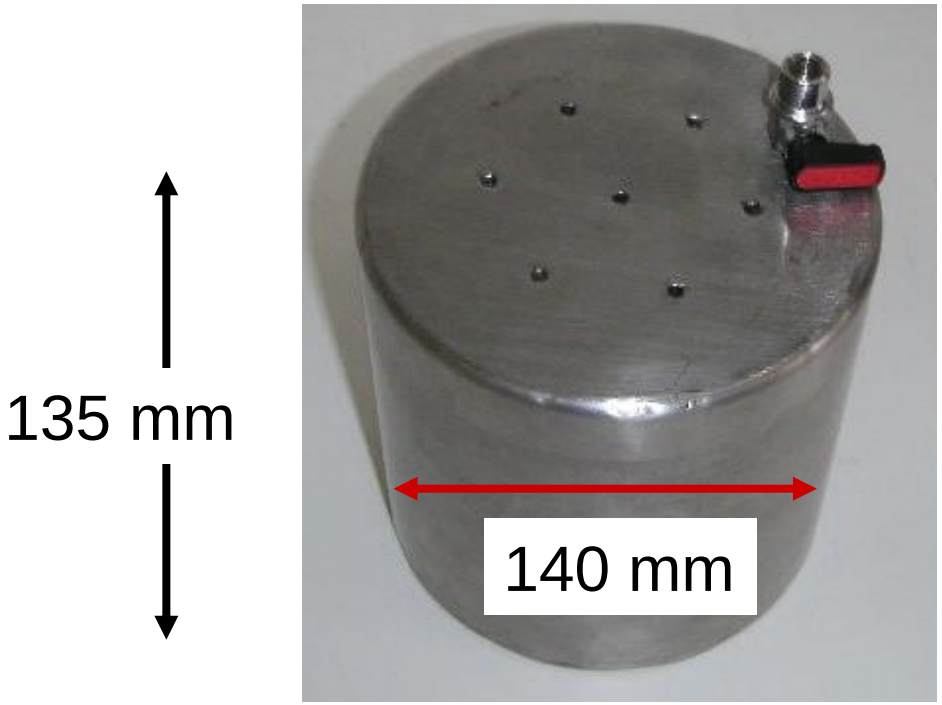
Air-cooled MHT

15 cm

100, 50 NlitersH_2

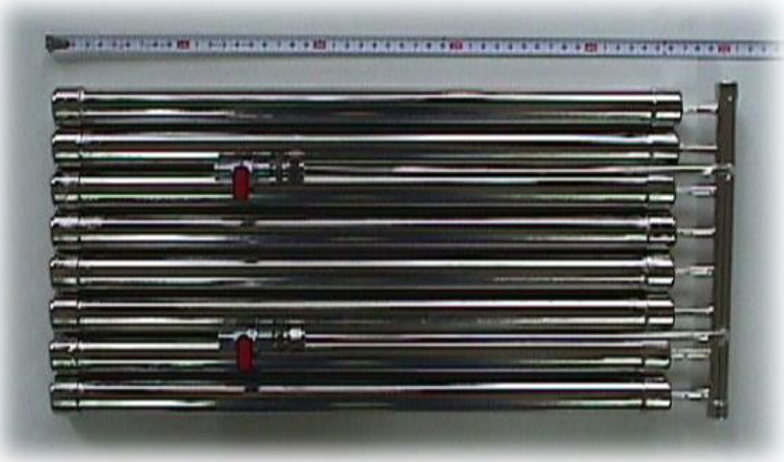
150 NlitersH_2

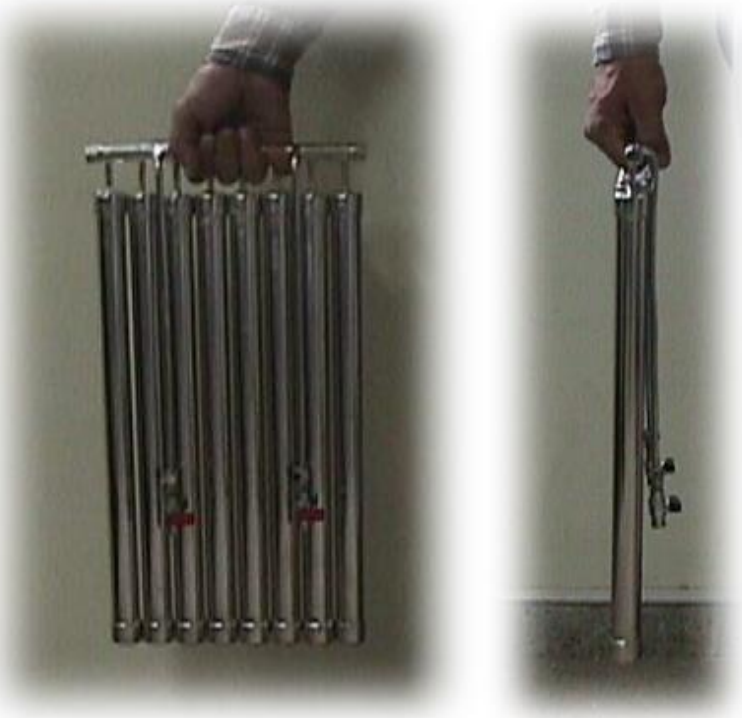
Air-cooled MHT



1110 NlitersH_2

Air-cooled MHT



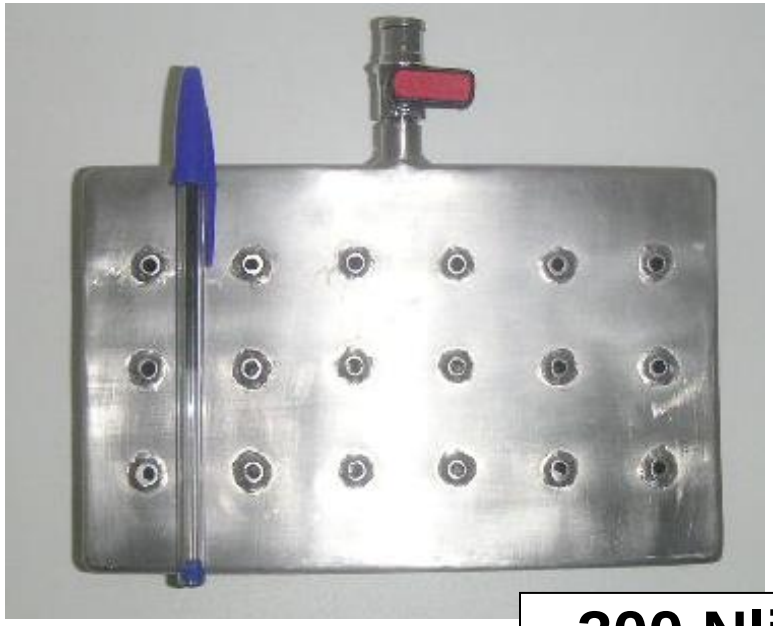


1000 NlitersH_2

Air-cooled MHT

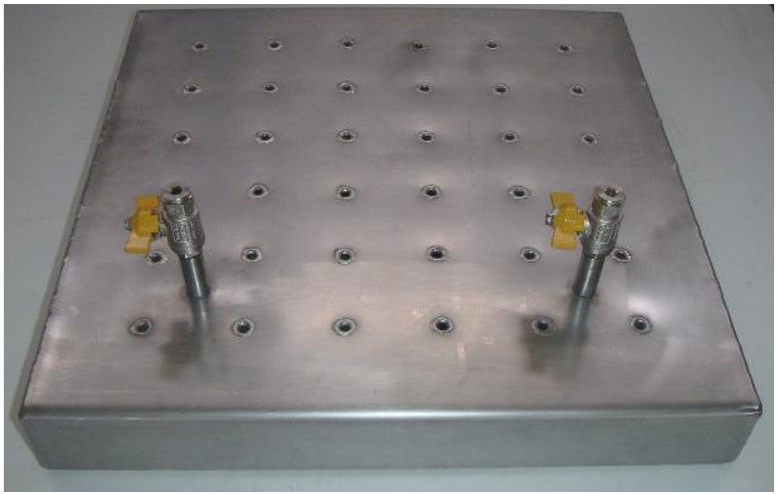
50-75-100 NlitersH_2

Air-cooled MHT



300 NlitersH_2

Air-cooled MHT



6000 NlitersH_2, 120NlitersH_2/kgMHT (1.2wt%H_2)

450 NlitersH_2/literMHT

Air-cooled MHT, Aluminum Canisters

500-1500 NlitersH_2

80000 NlitersH_2

Water-cooled MHT

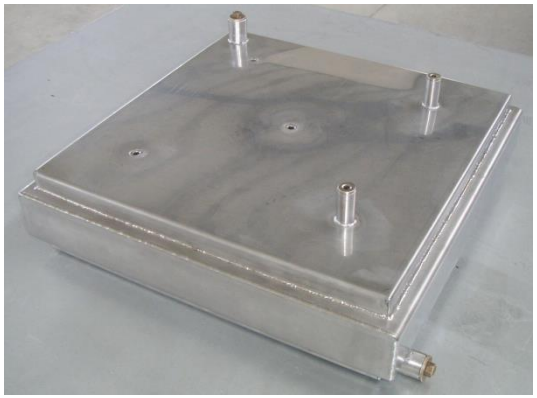
Water-cooled MHT

35000 NlitersH_2

Water-cooled MHT

2500 NlitersH_2

Water-cooled MHT



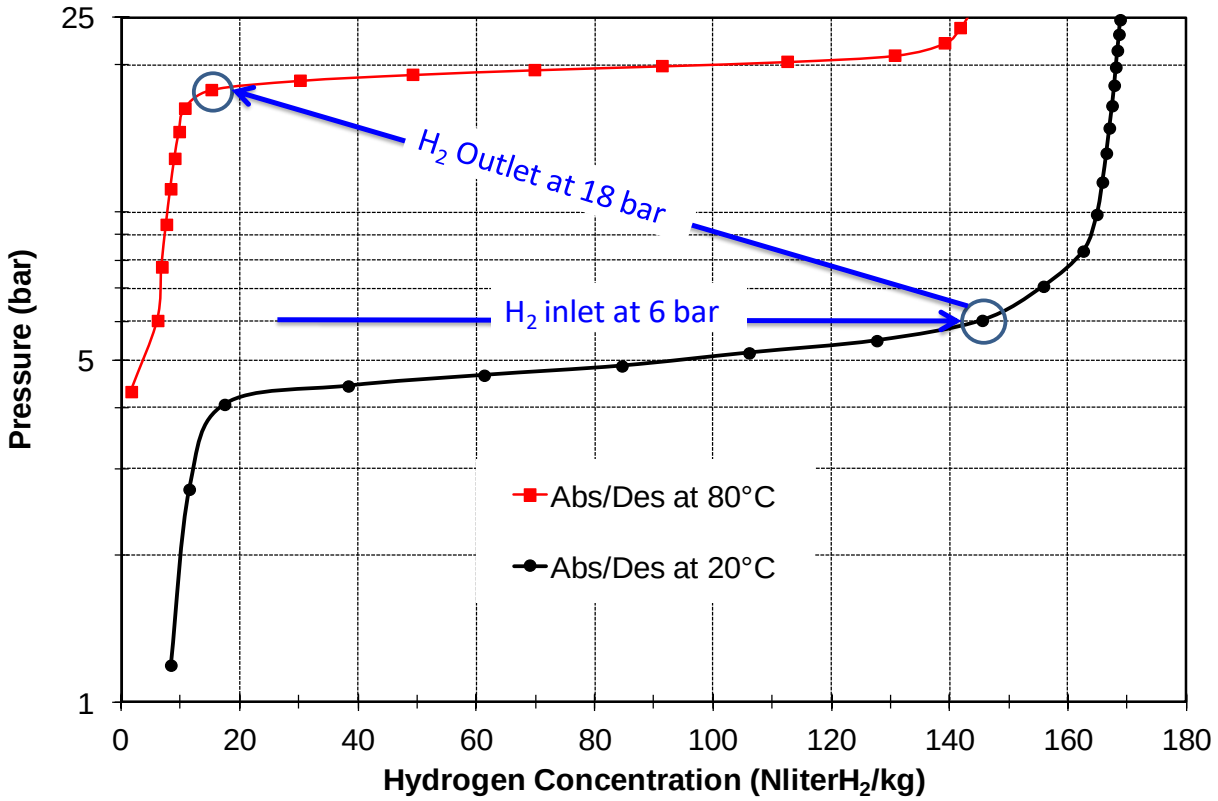
6000 NlitersH_2, 110NlitersH_2/kgMHT (1.1wt%H_2)

4. RES & H_2 Technology Applications

Hydrogen Storage in the form of Compressed Hydrogen Gas (CHG) for **Hydrogen Filling Stations**

Hydrogen Storage as Compressed Gas (CHG) at P>200bar): Metal Hydride Compressors (MHC)

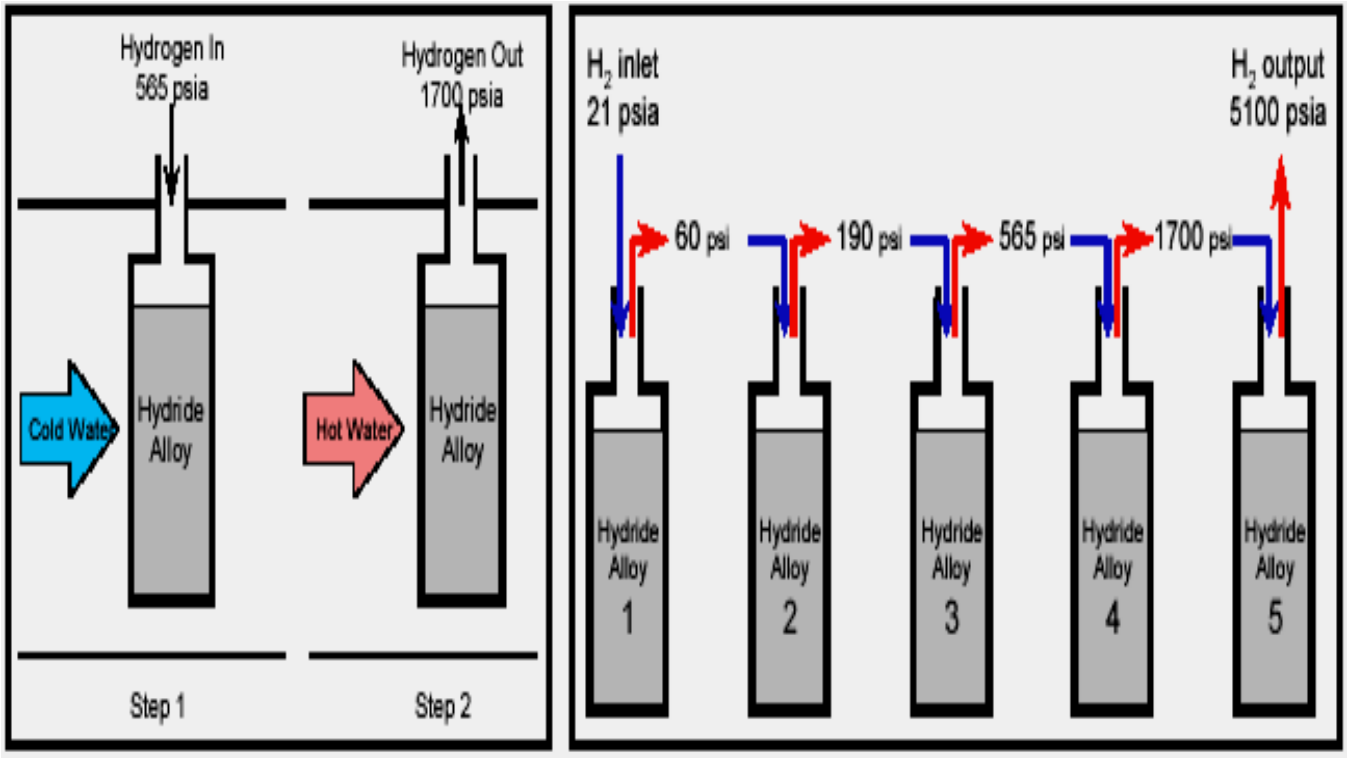
The principle



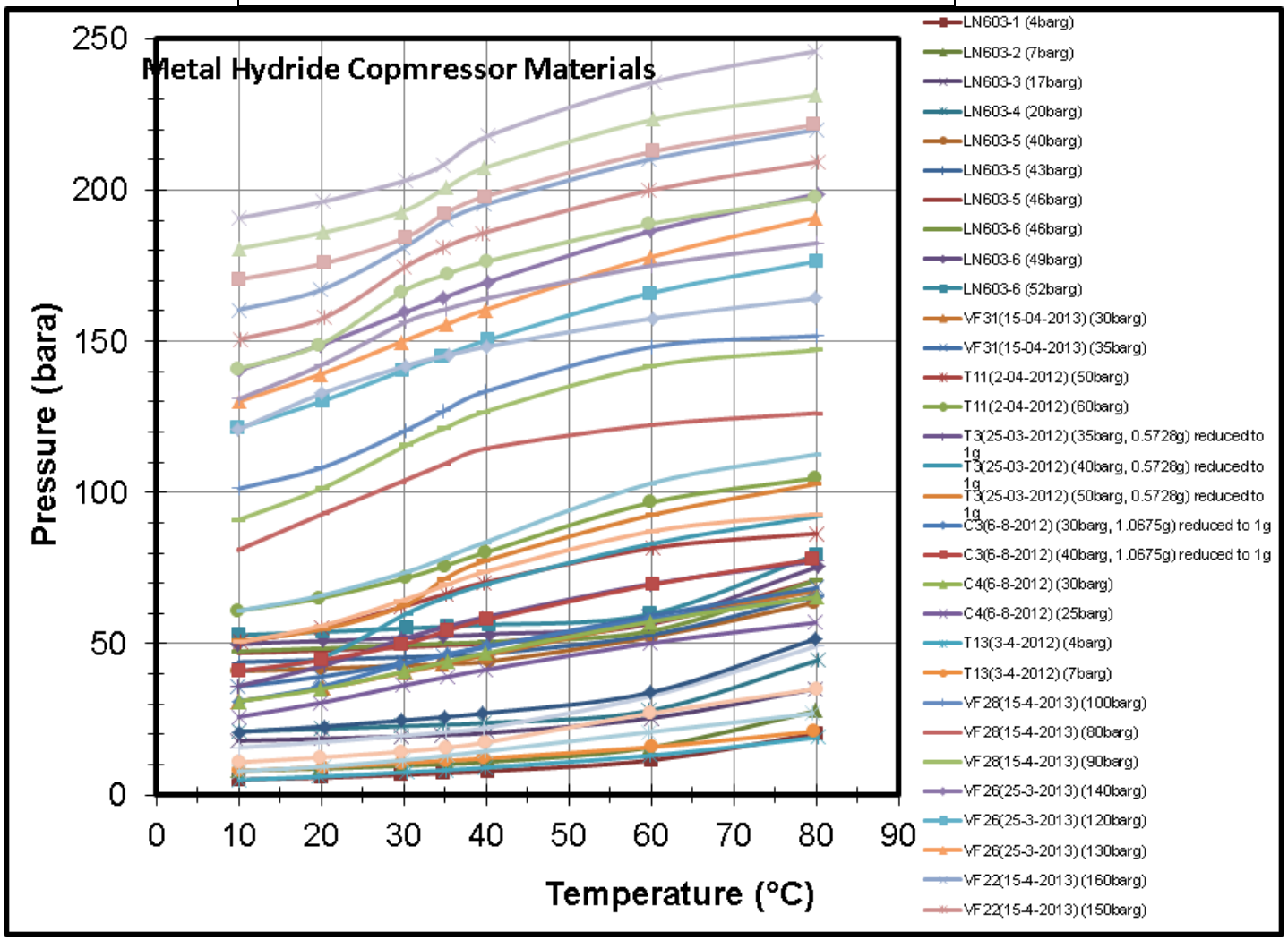
3. Metal Hydride Applications

Metal Hydride Compressors (MHC)

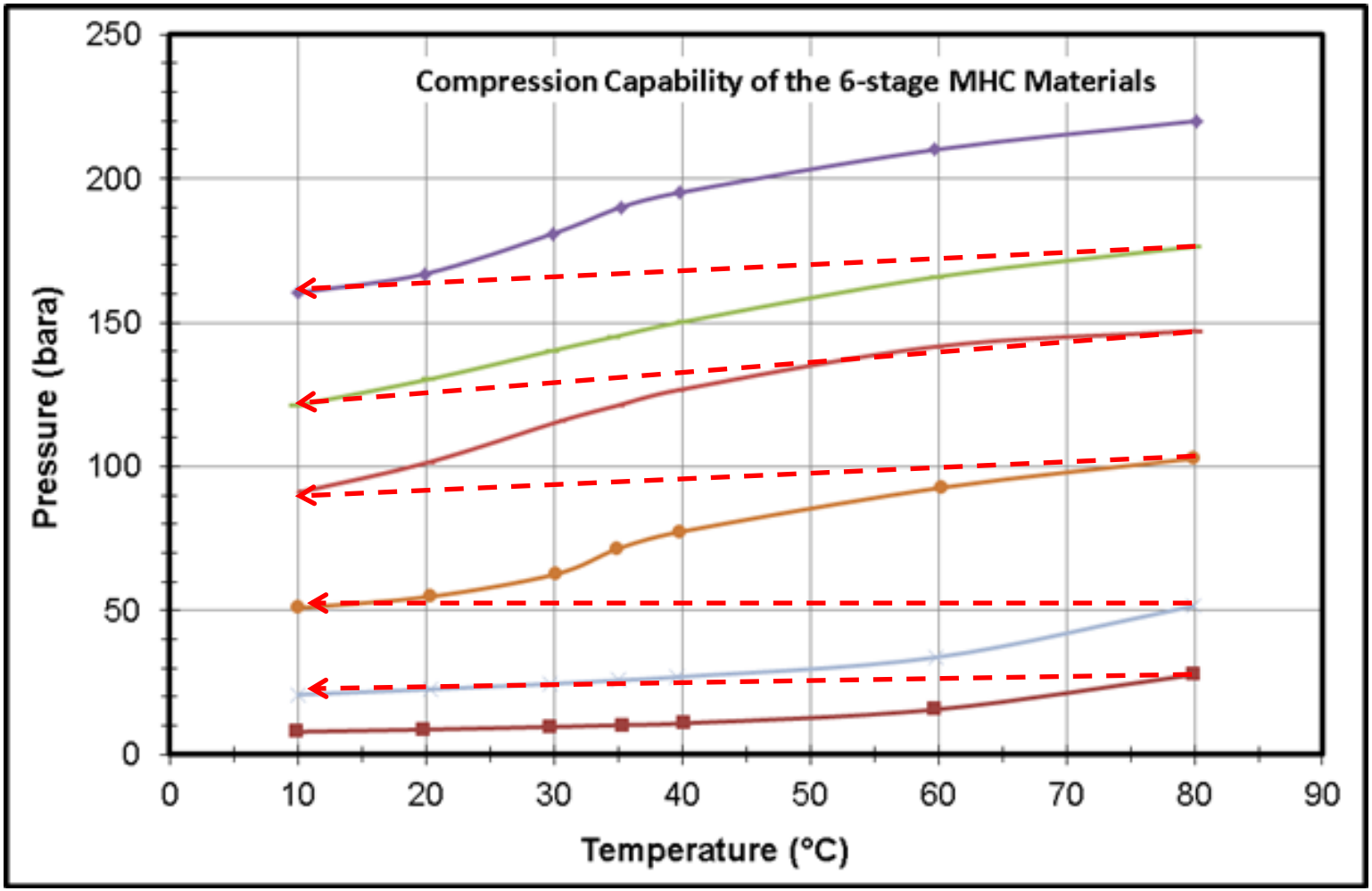
The principle



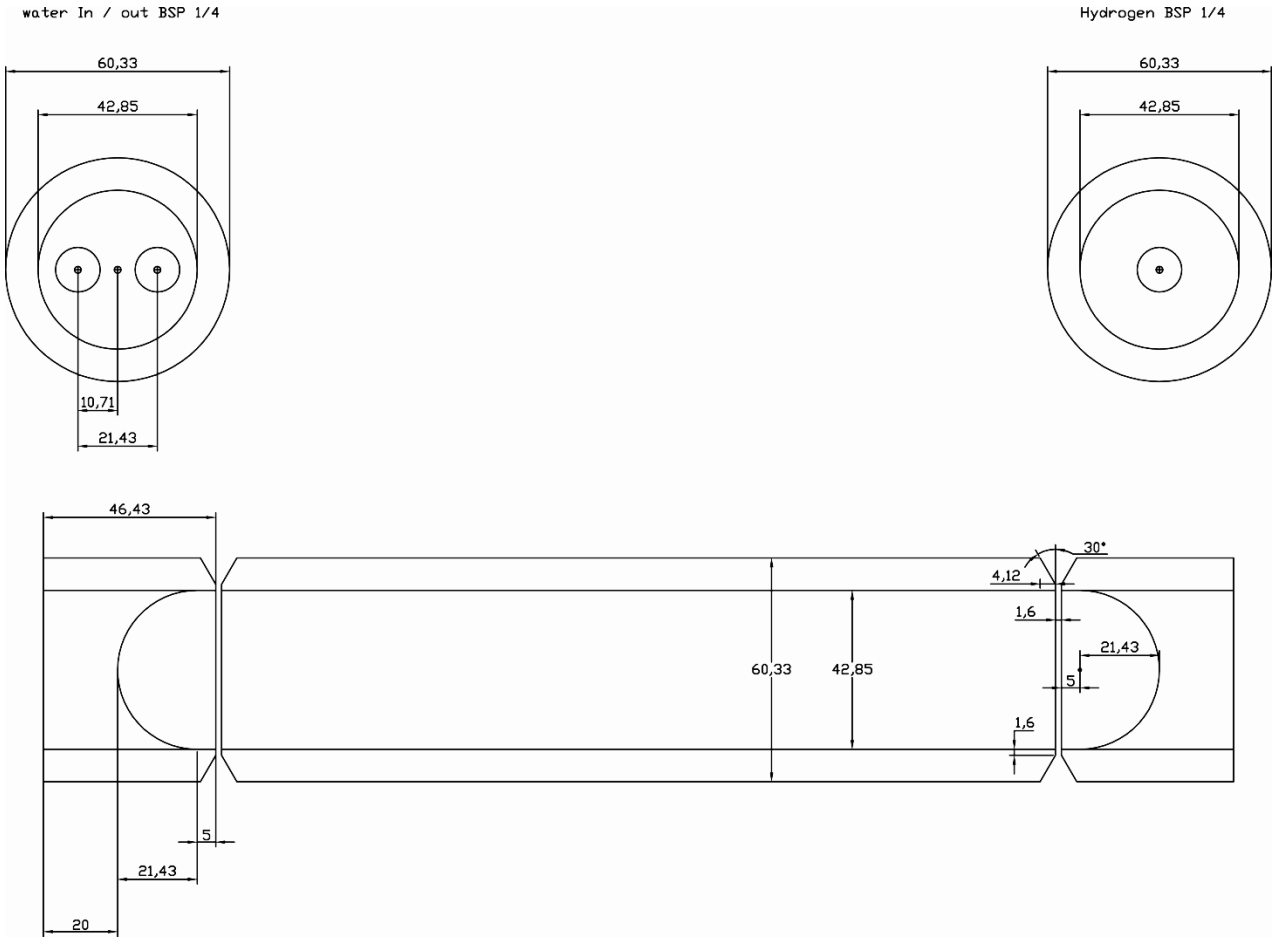
MH materials tested



6-Stage MH materials used



Design and construction of Tubular 300bar MHT



Design and construction of Tubular 300bar MHT









Design and construction of Tubular 300bar MHT



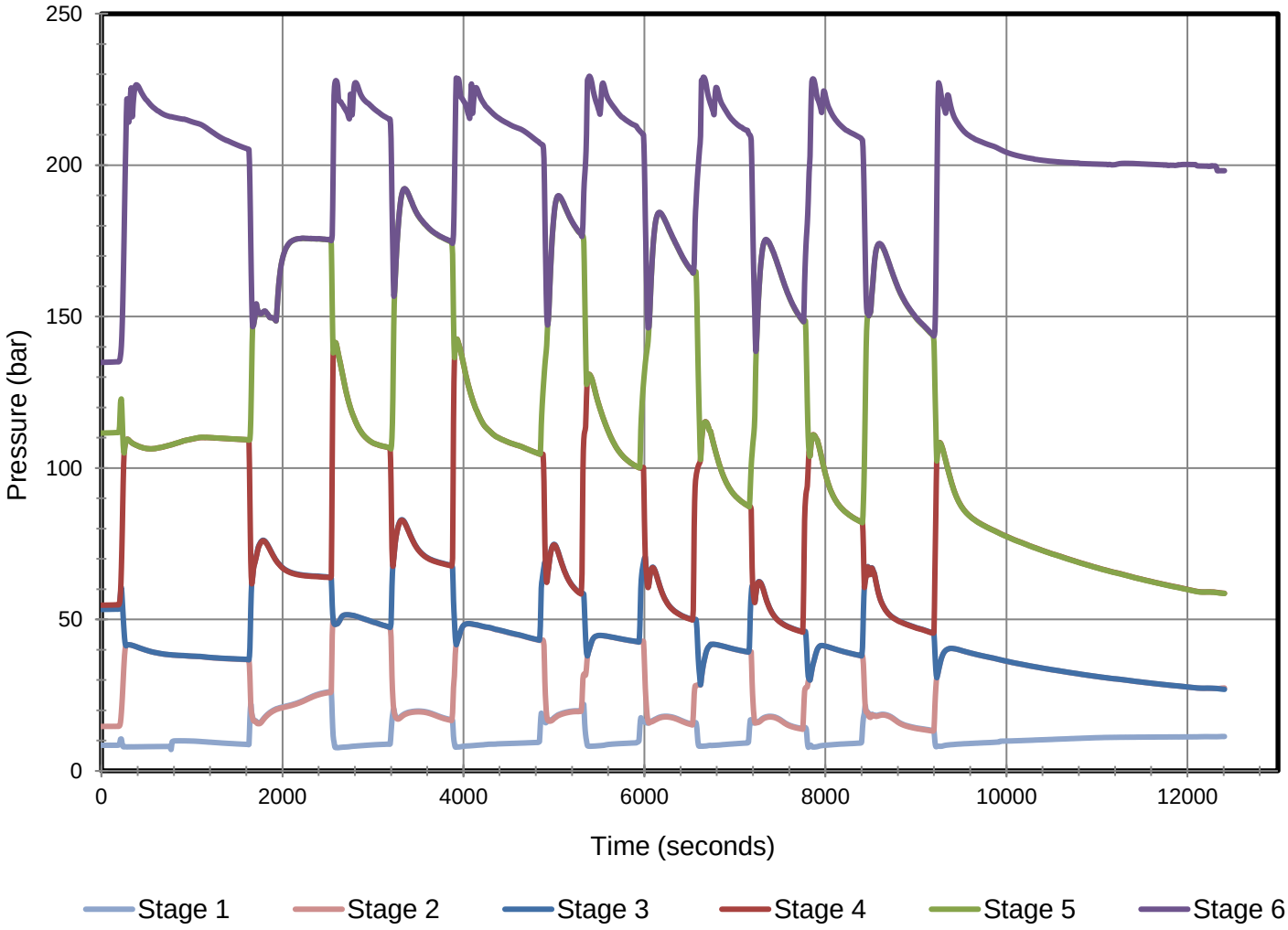



Design and construction of Tubular 300bar MHT

Cold/Hot Water Management for the MHC

6-Stage MHC Operation, (10-80°C) 2.5m³H_2/h, >220bar

6-Stage MHC Operation, (10-80°C) 2.5m³H_2/h, >220bar



Metal Hydride Compressor (MHC) by CYRUS PC at ΕΚΕΦΕ «Δημόκριτος»

Compressed Hydrogen Gas Storage in Steel Cylinders up to 300bar on in Carbon-fiber composites >700bar

4. RES & H_2 Technology Applications

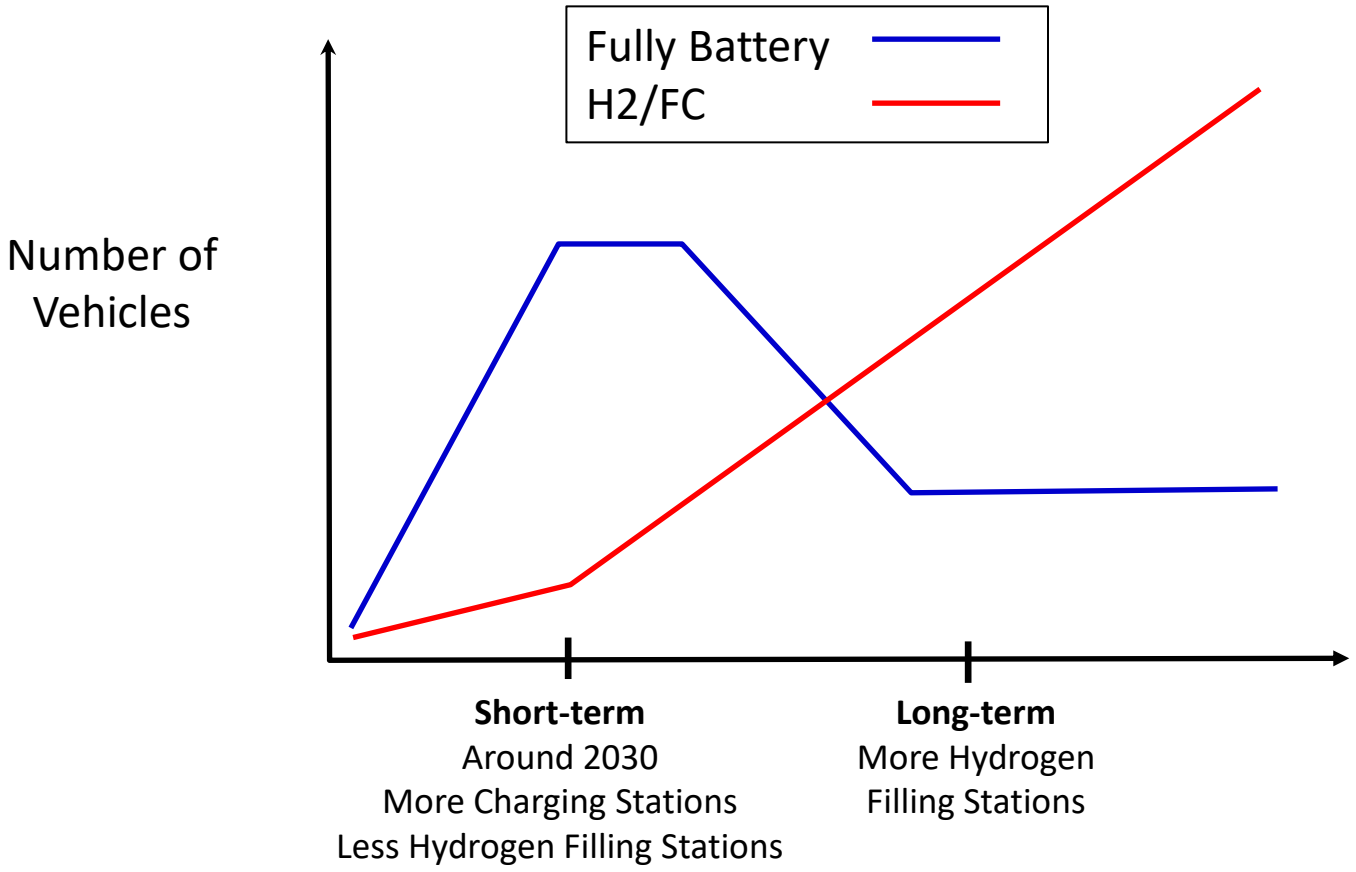
Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)

The race between Fully Battery Electric Vehicles and Hydrogen Fuel Cell Electric Vehicles

Who is going to win?

Infrastructure and Refuelling time will be the determining factor

The race between Fully Battery Electric Vehicle and Hydrogen Fuel Cell Electric Vehicles



Fully-Battery Electric Vehicles (TESLA)

It takes X? hours to fully charge: Who is going to sit and wait X? hours in a Charging Station for charging? Unless he/she is going to wait anyway (Home, Workplace, Cafeteria, Shopping Mall, etc)

Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)

It takes only 3-5 minutes to fill-up the Hydrogen Reservoir and Go. Just like for a conventional car

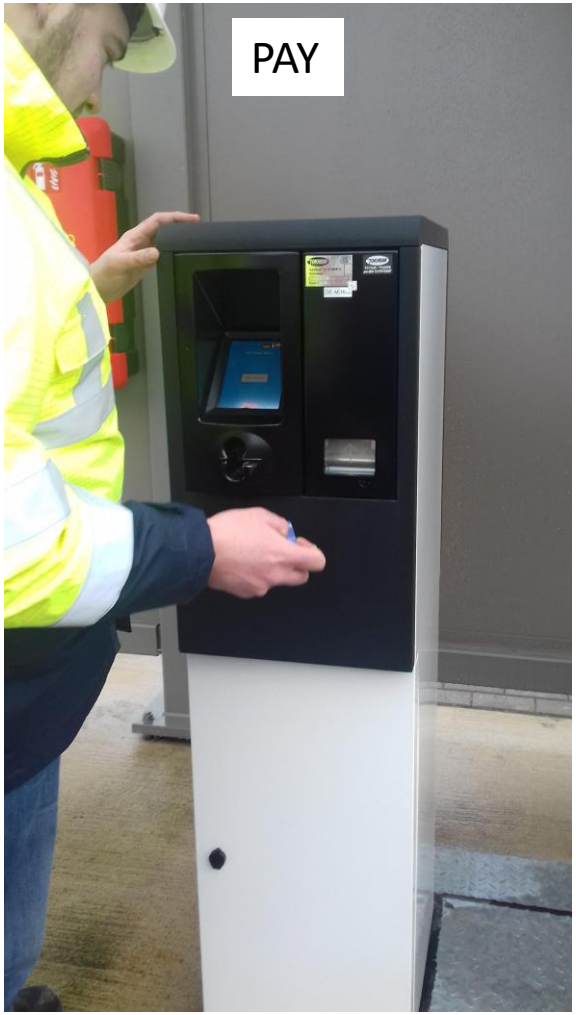
Through 2011, Honda is expected to build 200 FCX Clarity's. Production began last June.

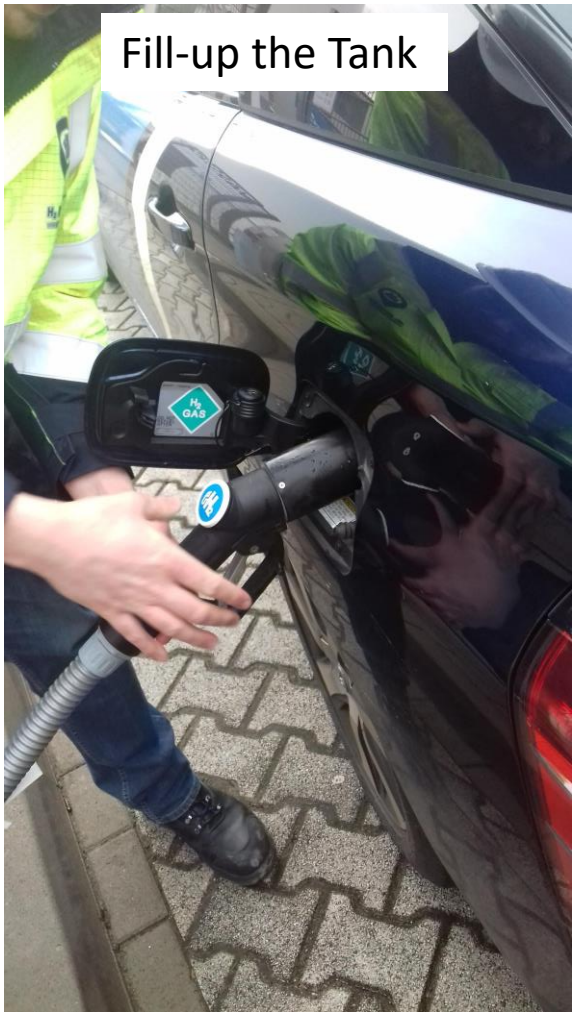
Most of the Automobile Companies have developed Hydrogen Fuel Cell Electric Cars

Most of the Automobile Companies have developed a Hydrogen Fuel Cell Electric Cars or Buses

Hydrogen Filling Stations (Linde in Germany)

Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)





Hydrogen Fuel Cell Electric Vehicles (The Toyota Mirai)

Rough Cost-Comparison between Conventional (Diesel) and Hydrogen Fuel Cell Electric Buses

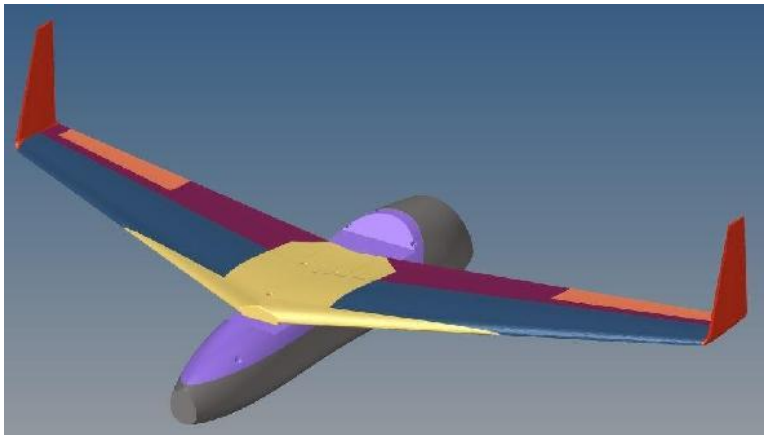
For a 100 km distance						
	Fuel Consumption		**Fuel Price (€)**		**Total Fuel Cost (€)**	**Fuel Cost per km (€/km)**
Conventional Diesel Bus	50.0	liters Diesel	1.22	€/liter Diesel	61	**0.61**
H_2/FC Electric Bus	12.5	kgH_2	3.64	€/kgH_2	46	**0.46**
	Electricity Cost		0.06	€/kWh		
	H_2 Production		5	kWh/Nm^3H_2		

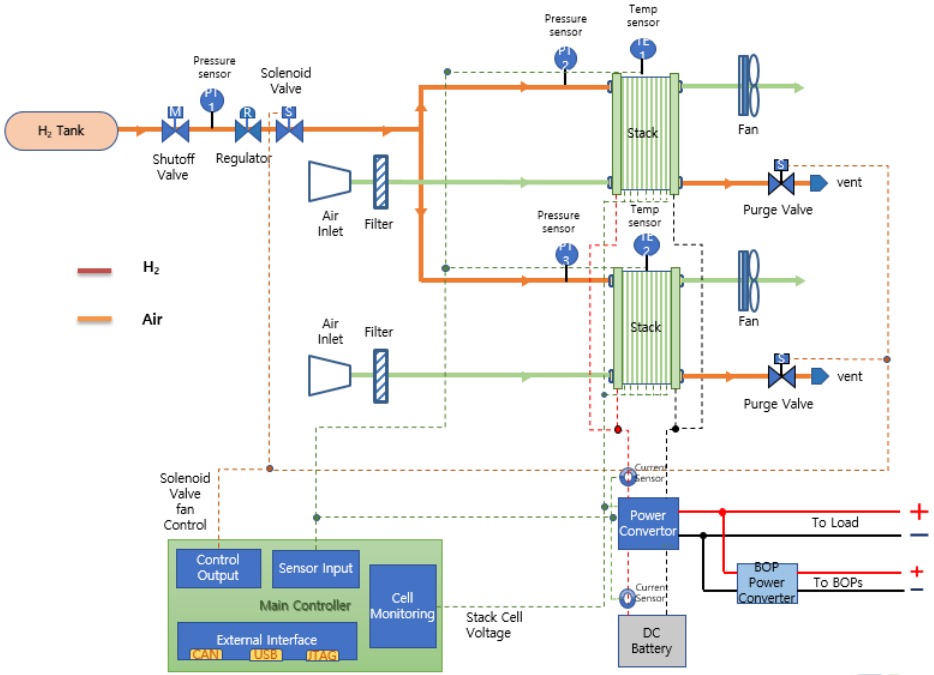
4. RES & H_2 Technology Applications

Drones

4. RES & H_2 Technology Applications

Drones: EUROSTARS/1018/0010: E113229 HyFly-VTOL: Development of small vertical take-off and landing UAV with dedicated Hydrogen fuel cell





4. RES & H_2 Technology Applications

- Transition from the "Oil Economy" to the "Hydrogen Economy" (2020 – 2030 – ?)

4. RES & H_2 Technology Applications

Transition from the "Oil Economy" to the "Hydrogen Economy" (2020 – 2030 - ?)

- Until we reach a nearly full Hydrogen-driven Economy, still, we have to cope with the existing Hydrocarbon-based Machines (Cars, Buses, Trucks, Marine Vessels, Heat-Boilers, Gas-Turbines, etc). We just cannot replace them from Day One.
- Therefore, what can we do?
- We have to increase their **efficiency** to save fuel and at the same time **emit less exhaust gases** (CO_2, CO, C particles, NO_x)

4. RES & H_2 Technology Applications

- HHO generators for Vehicles Gas-Turbines and Marine Applications
- Hydrogen production from recycle metals (Aluminium, etc)

RES & H_2 Technology Applications

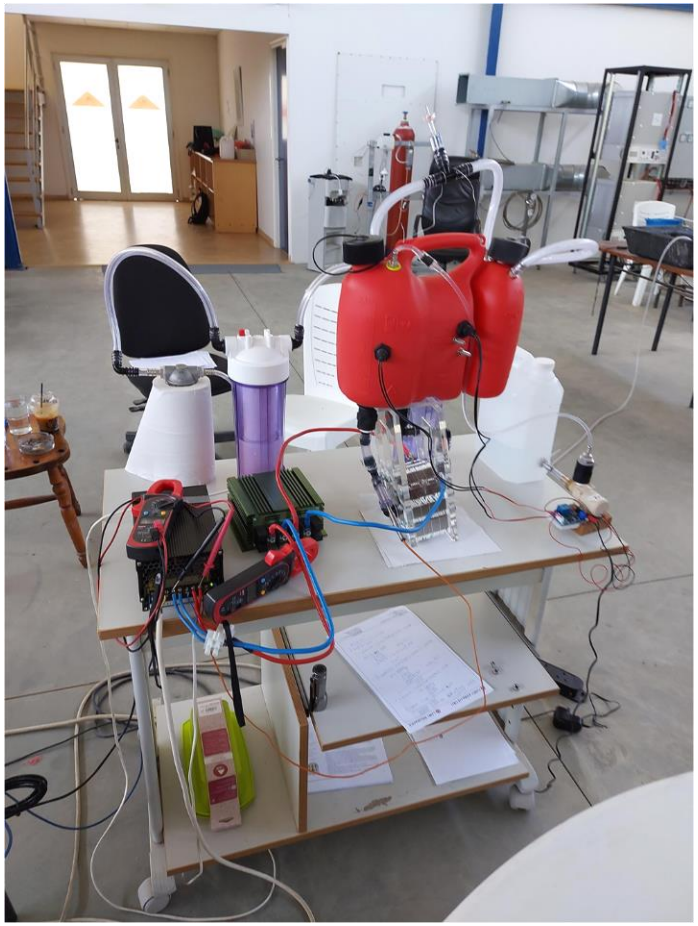
- HHO generators for:
  Vehicles (Buses, Trucks, etc)
  Gas-Turbines
  Marine applications

HHO generators for Vehicles, Gas-Turbines and Marine Applications

INTEGRATED/0916/0031: Integration of innovative green technologies on existing public transportation buses for 5% to 30% fuel savings and exhaust gas reductions

- Hystore Tech Limited
- RTD Talos Ltd
- Signal Geneix Ltd
- Frederick Research Centre
- Ministry of Energy, Commerce, and Industry
- Cyprus Energy Regulatory Authority
- Inomob Ltd

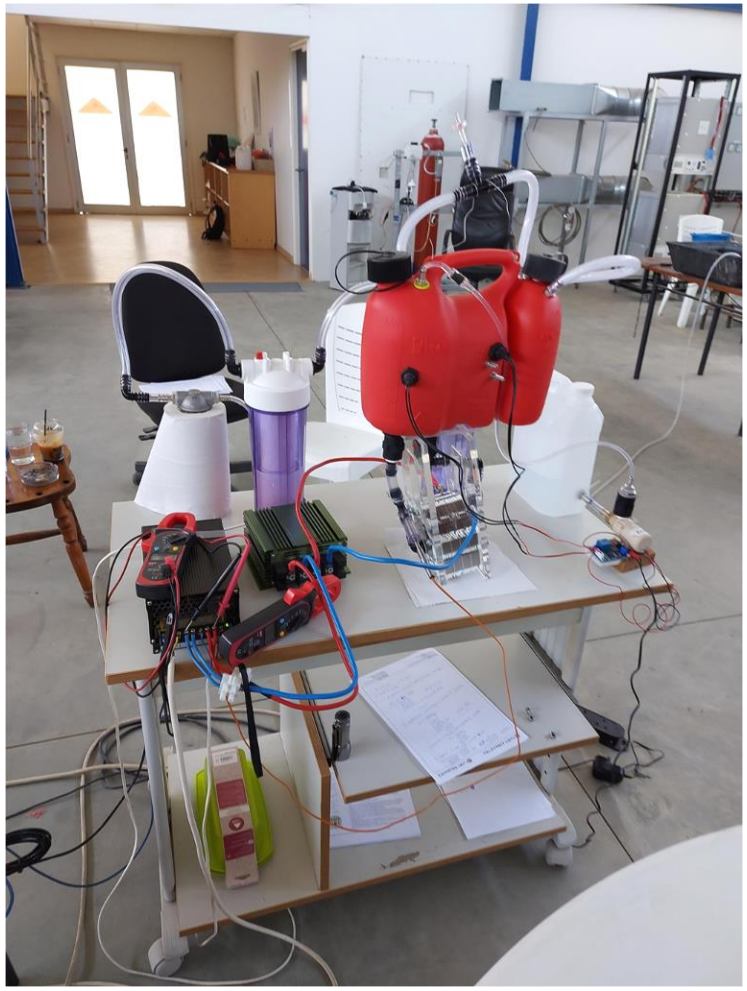
HHO generators for Vehicles, Gas-Turbines and Marine Applications: Additive Technology

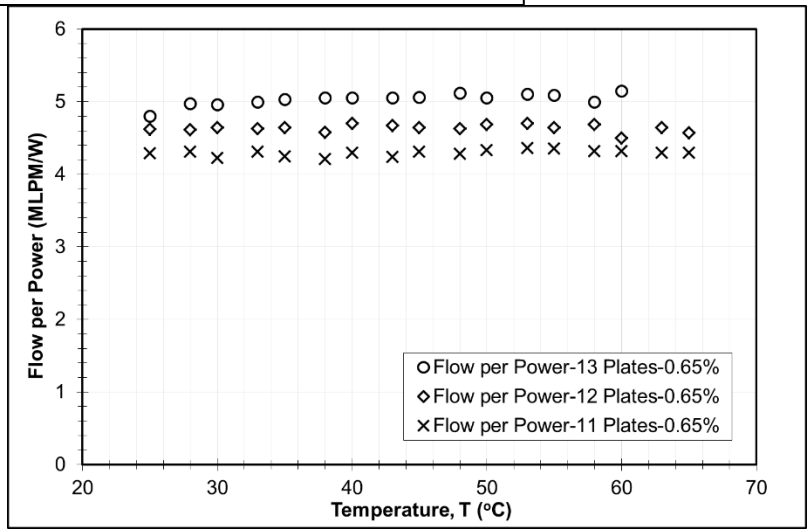


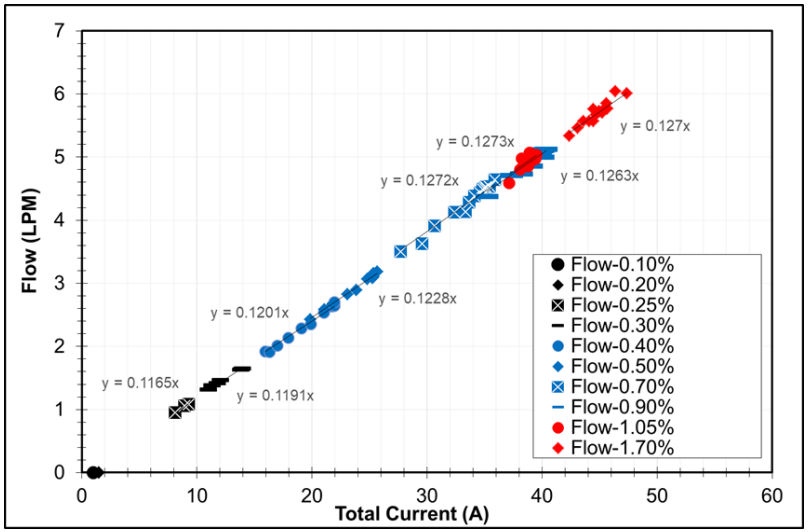
HHO Generator

It is a DC (12/24Volts) Water Electrolysis System producing a stoichiometric mixture of nascent 2H+O (Υδρογόνο και Οξυγόνο «εν τω γεννάσθαι») which is fed into the air-intake of an ICE causing the complete combustion of fuel (diesel or Gasoline) **saving** 5-30% of fuel with diminished CO, NOx, UH emissions

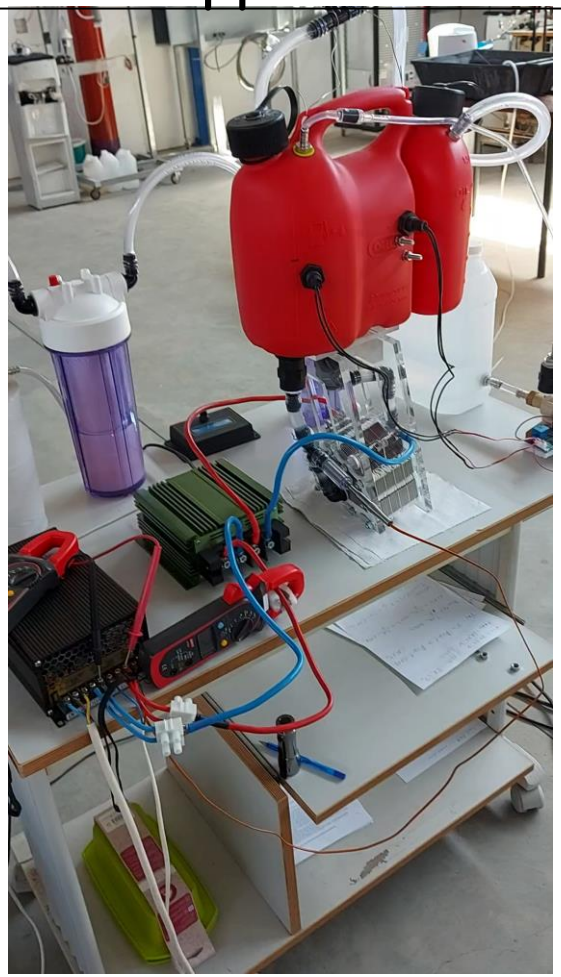
HHO generators for Vehicles, Gas-Turbines and Marine Applications- Characterization







HHO generators for Vehicles, Gas-Turbines and Marine Applications



4StacksX13-Plate Design for 24DCV

Hydrogen Production by semi-catalytic decomposition of H_2O by using recycle metals or Chemical Hydrides, without any electricity

$M + H_2O \rightarrow MO + H_2$ 1200litersH_2/kg

$MH + H_2O \rightarrow MO + H_2$ 1700-2800 litersH_2/kg

Any quality of Water can be used !!!:

- Potable Water
- Sea Water
- Gray Water
- Muds
- Even urine

Hydrogen Production by semi-catalytic decomposition of H_2O by using recycle metals or Chemical Hydrides, without any electricity

$M + H_2O \rightarrow MO + H_2$ 1200litersH_2/kg

$MH + H_2O \rightarrow MO + H_2$ 1700-2800 litersH_2/kg

Domestic/Neighborhood Applications

- H_2/FC Decentralized Electricity Production
- Thermal Energy (Central Heating) Production (More Renewable NG and LPG)

$M + H_2O \rightarrow MO + H_2$ 1200litersH_2/kg

$MH + H_2O \rightarrow MO + H_2$ 1700-2800 litersH_2/kg

Niche Applications (H_2/FC)

For On-Board, on-demand H_2 Production where high gravimetric energy density (kWh/kg) is needed

- Drones (increased flying time, >>Wh/kg)
- Military (Unmanned Electric Vehicles, Mobile Combat Silent Power Supplies, etc)
- For Laboratory uses in schools

CONCLUSIONS

1. RES & H_2 Technologies is the name of the game for moving from the "Oil Economy" to the "Hydrogen Economy" and de-carbonization
2. For higher efficiencies and fuel savings
3. For fossil fuel independence
4. For less CO_2 emissions, slowing-down global warming, combating extreme climatic changes, less pollution, a clean Environment and sustainability

I Thank You Very Much

And Always Think H_2