HYDROG(E)NICS
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Field Experience with Hydrogenics' Prototype Stack and System for MW PEM electrolysis

Jan Vaes, February 17th, 2nd int. workshop on Durability and Degradation Issues in PEM Electrolysis Cells and their Components, Freiburg

Hydrogenics in Brief
International structure

Hydrogenics Corporation

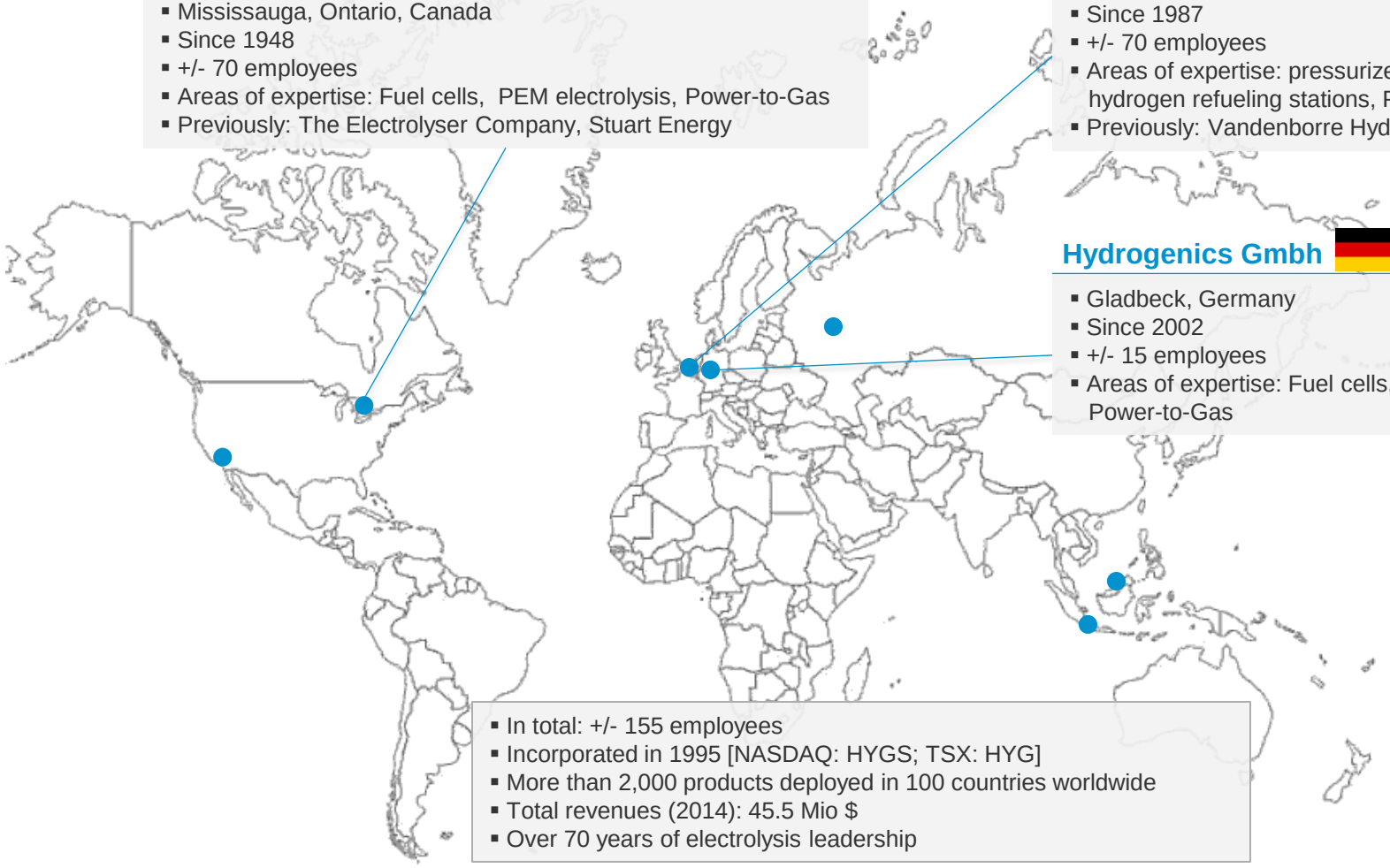
- **Headquarter**
- Mississauga, Ontario, Canada
- Since 1948
- +/- 70 employees
- Areas of expertise: Fuel cells, PEM electrolysis, Power-to-Gas
- Previously: The Electrolyser Company, Stuart Energy

Hydrogenics Europe

- Oevel, Belgium
- Since 1987
- +/- 70 employees
- Areas of expertise: pressurized alkaline electrolysis, hydrogen refueling stations, Power-to-Gas
- Previously: Vandenborre Hydrogen Systems

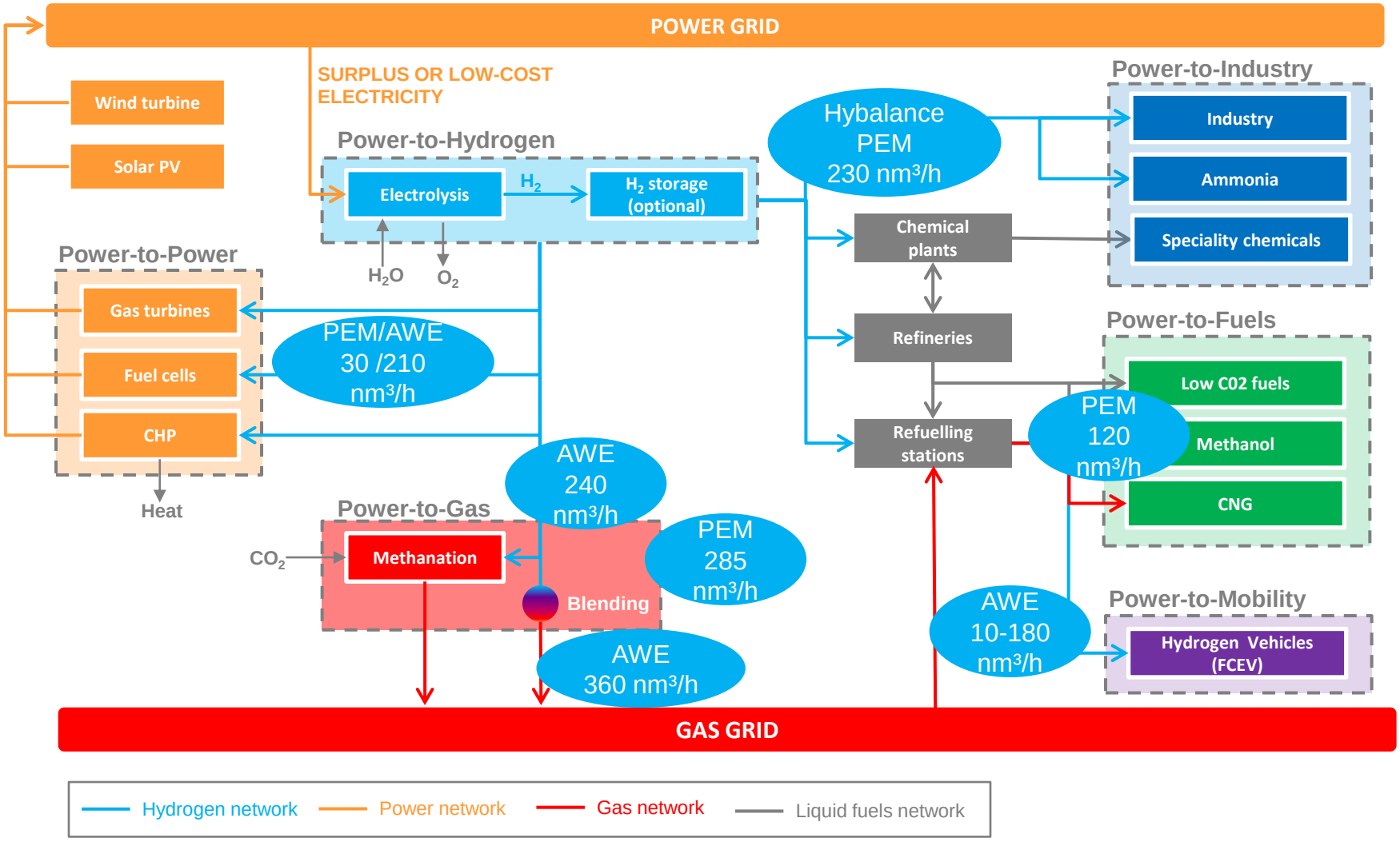
Hydrogenics Gmbh

- Gladbeck, Germany
- Since 2002
- +/- 15 employees
- Areas of expertise: Fuel cells, mobility projects, Power-to-Gas



- In total: +/- 155 employees
- Incorporated in 1995 [NASDAQ: HYGS; TSX: HYG]
- More than 2,000 products deployed in 100 countries worldwide
- Total revenues (2014): 45.5 Mio $
- Over 70 years of electrolysis leadership

Hydrogen generation and **Power-to-X routes**



1500^{E} PEM PLATFORM

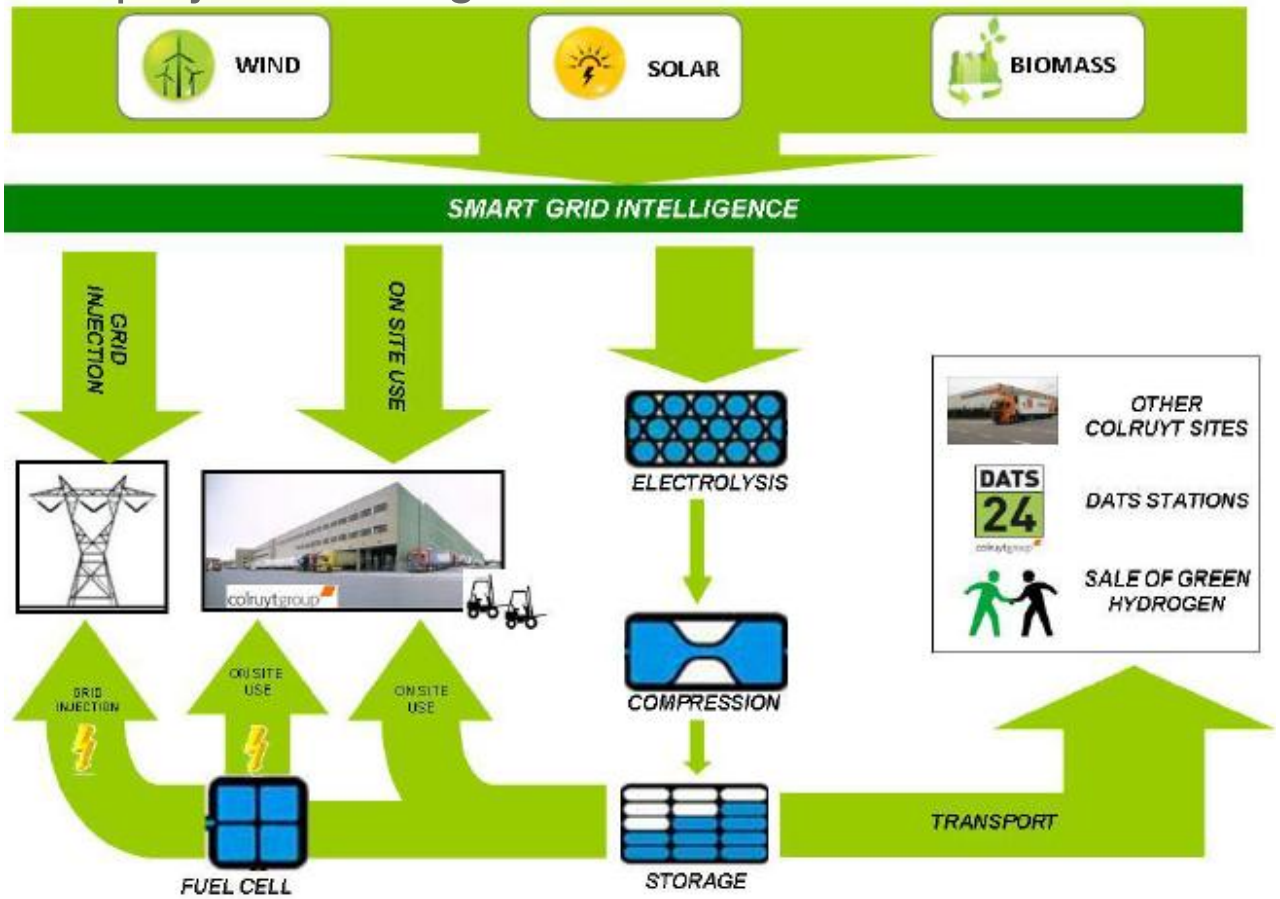
The New Benchmark in Electrolysis

1.5 MW, MODEL 1500E

Electrical Power Input	1.5 MW
Hydrogen Output	285 Nm3/h
Max. Operating Pressure	40 bar (g)
Dimensions	L800xW550x1000mm
Certifications	PED (97/23/EC)

Don Quichote for RE integration

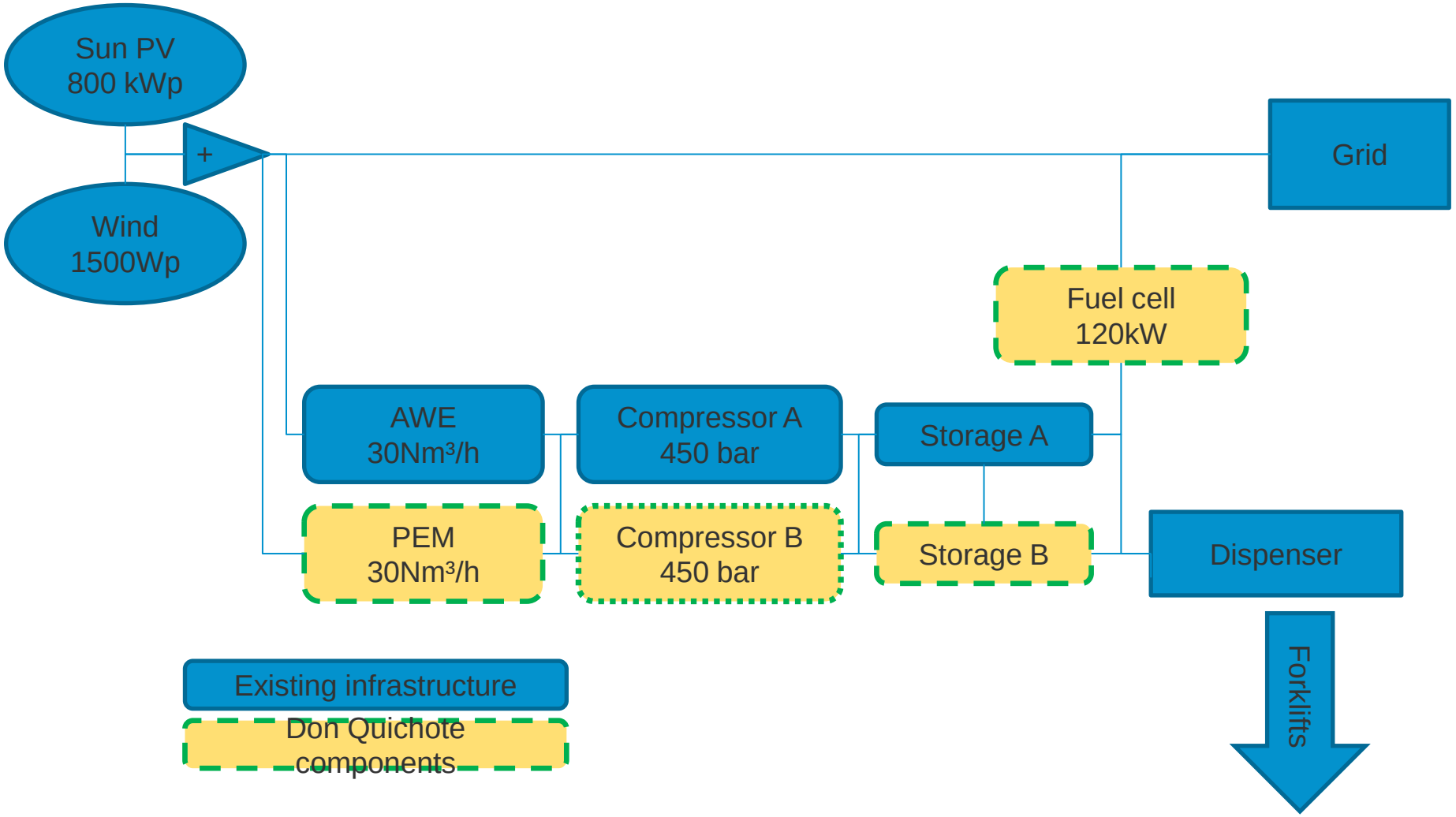
- **DEMONSTRATION OF NEW QUALITATIVE CONCEPT OF HYDROGEN OUT OF WIND TURBINE ELECTRICITY**
- FCH-JU project – FP7 grant n°303411



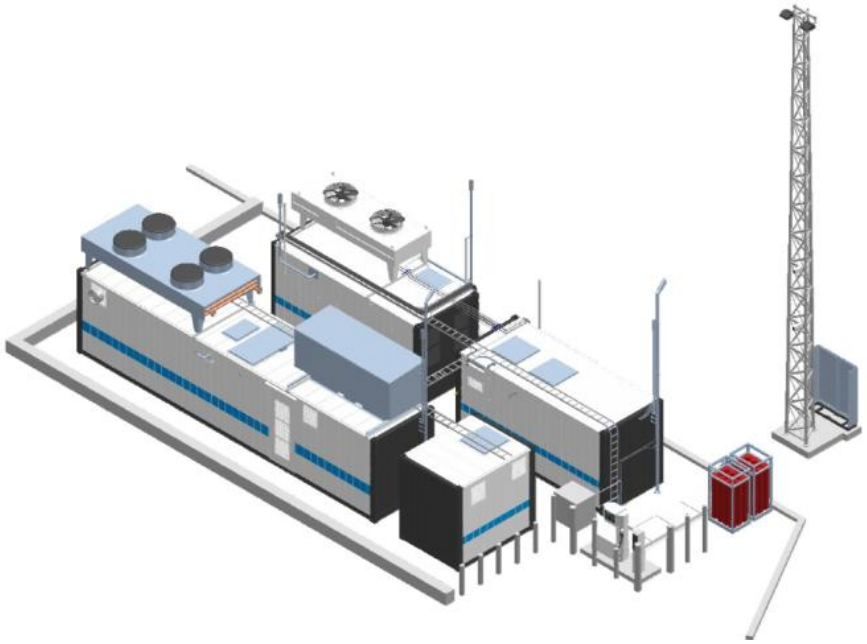
Don Quichote partners

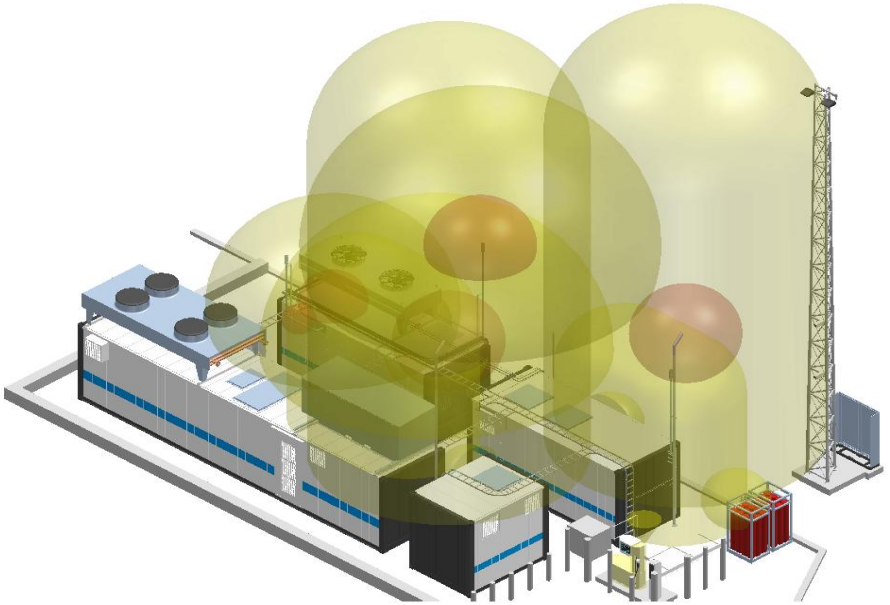
- **Colruyt Group – Eoly**: RE integration and H2 applications
- **Hydrogenics Europe**: Electrolyser and fuel cell
- **Hyet bv**: electrochemical compression development
- **Thinkstep** (PE international): Life Cycle analysis
- **Icelandic New Energy**: total cost of ownership
- **TUV Rheinland**: Regulation, Codes and Standards
- **EHA/FAST**: dissemination
- **Waterstofnet**: dissemination and project management
- **JRC**: testing protocols

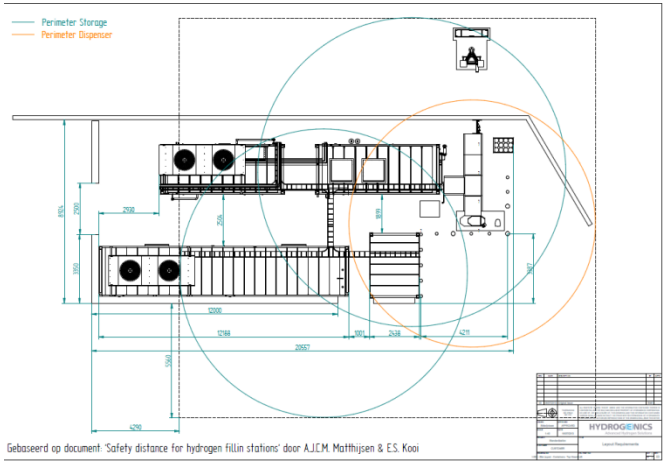
Don Quichote set-up



Hydrogen generation and compression station





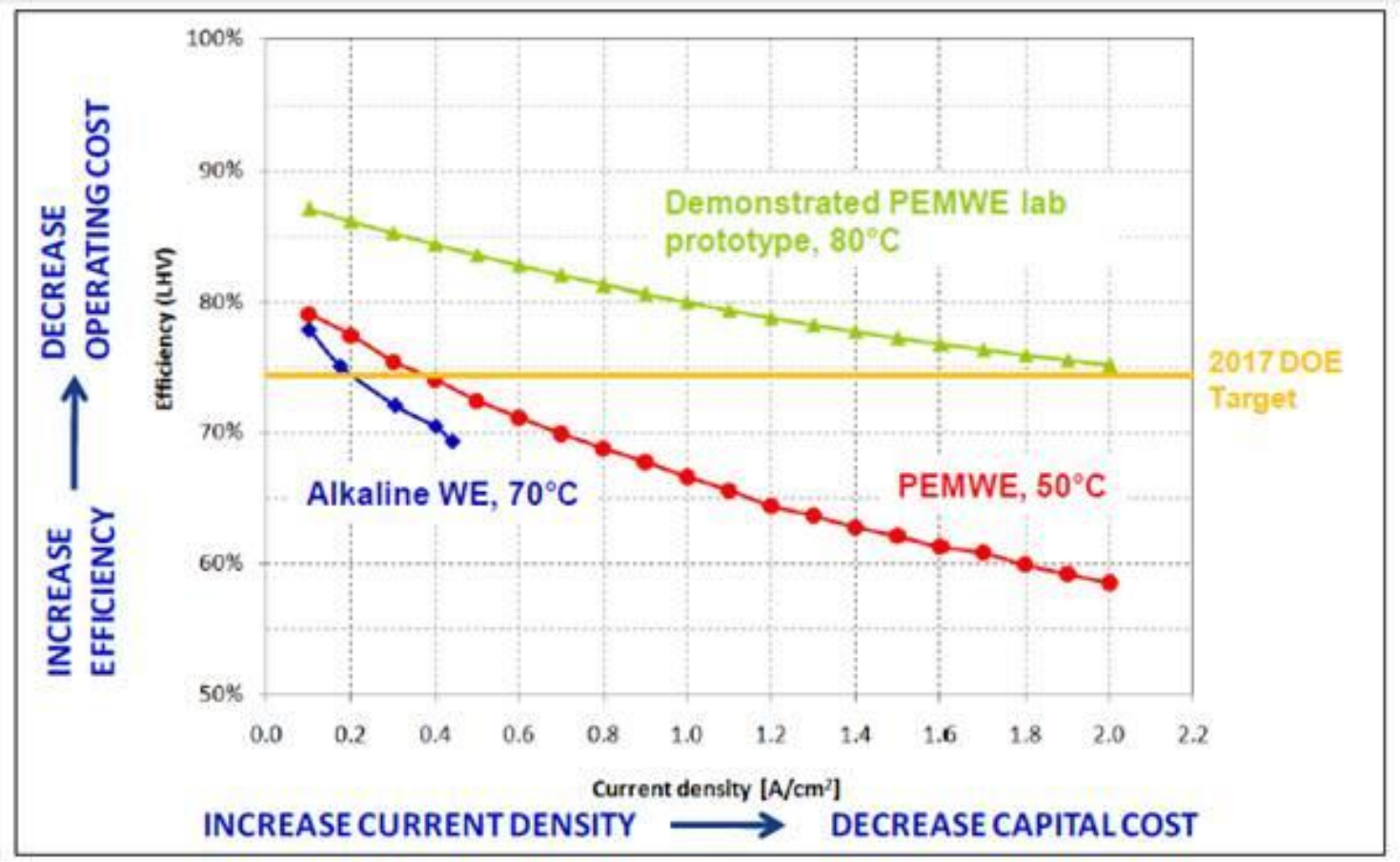


On Site

PEM unit characteristics

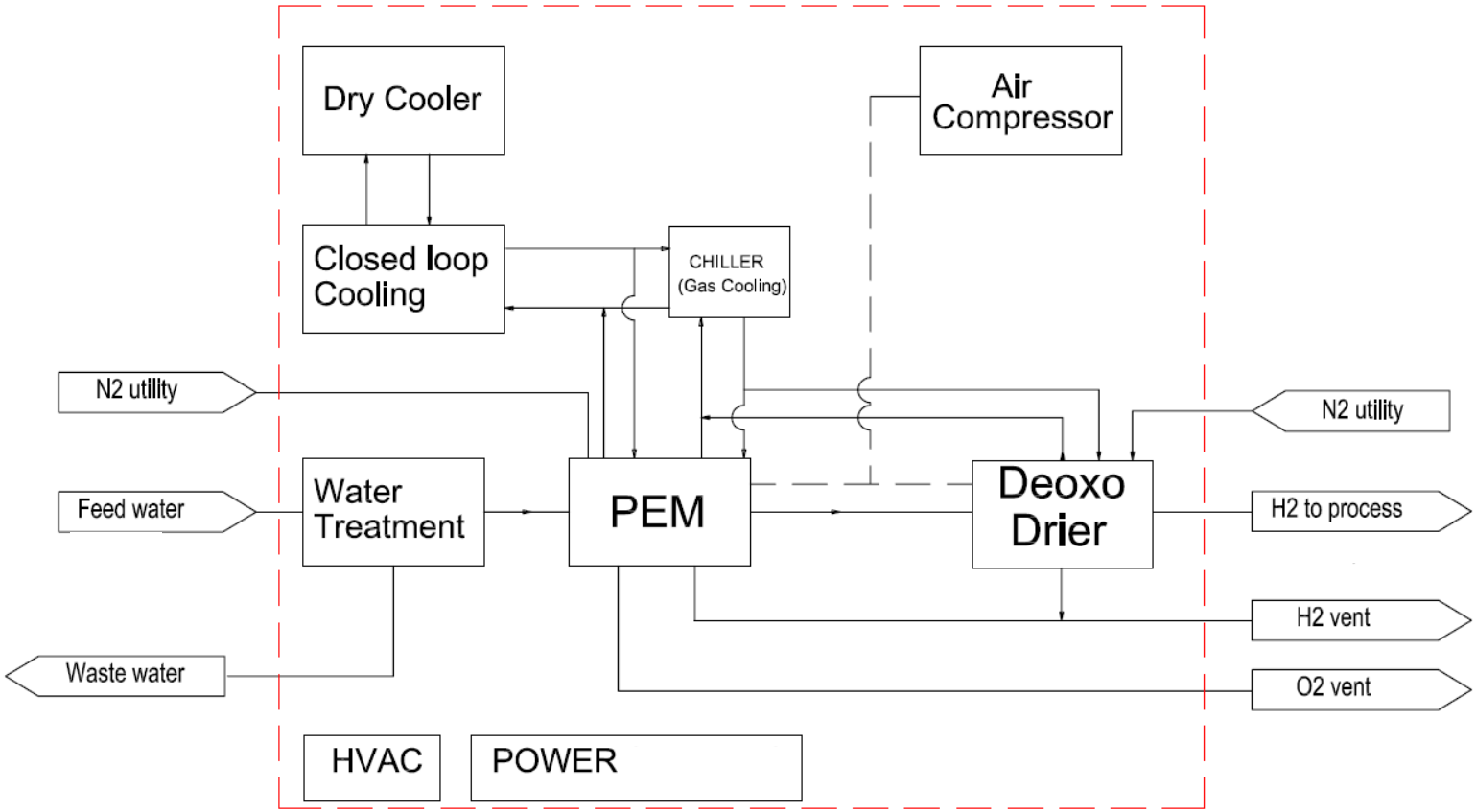
- Safety and reliability
  - No caustic electrolyte
  - Less instrumentation
- Low geometrical footprint
  - 2 A/cm²
  - Higher currents?
    - Efficiency penalty
    - Lifetime impact?
    - Cooling capacity
    - Power capacity
- Atmospheric O_2 degassing
  - Towards differential P

2012 start of the project



Don Quichote field results

Battery limits considered



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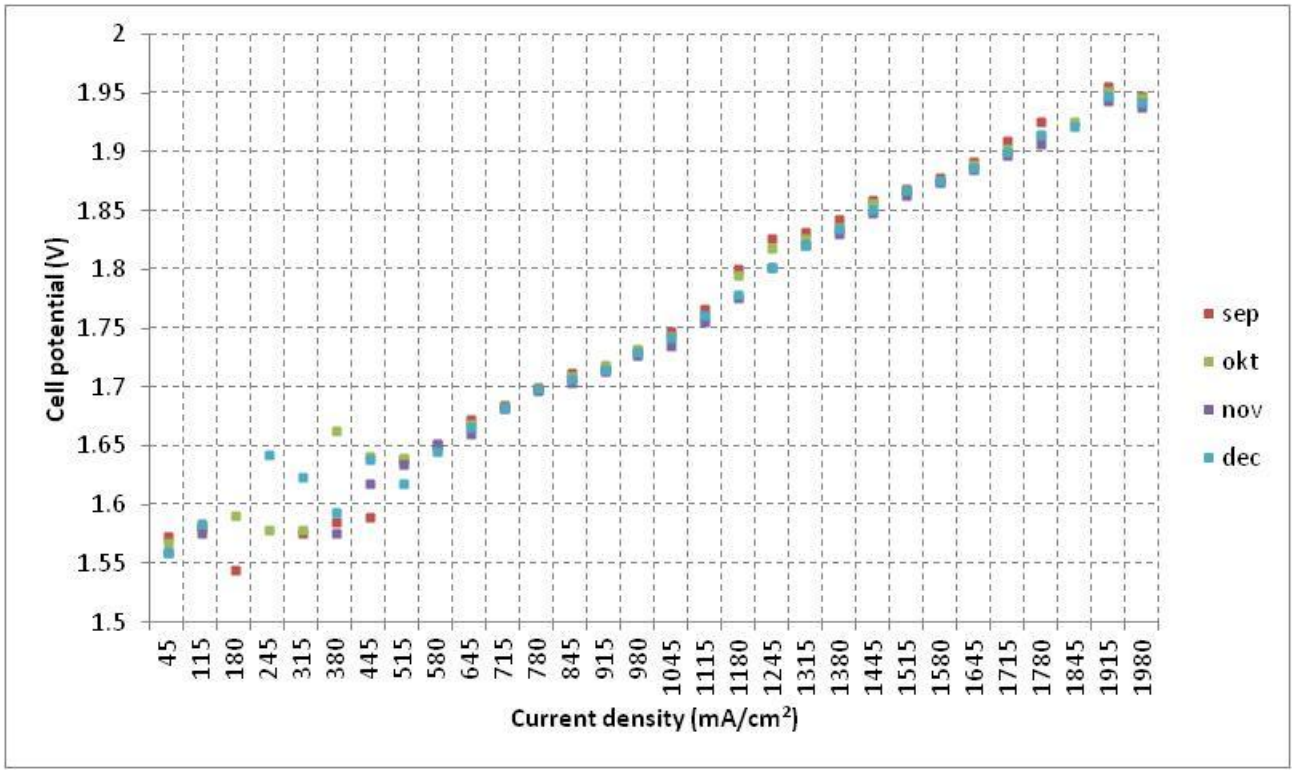
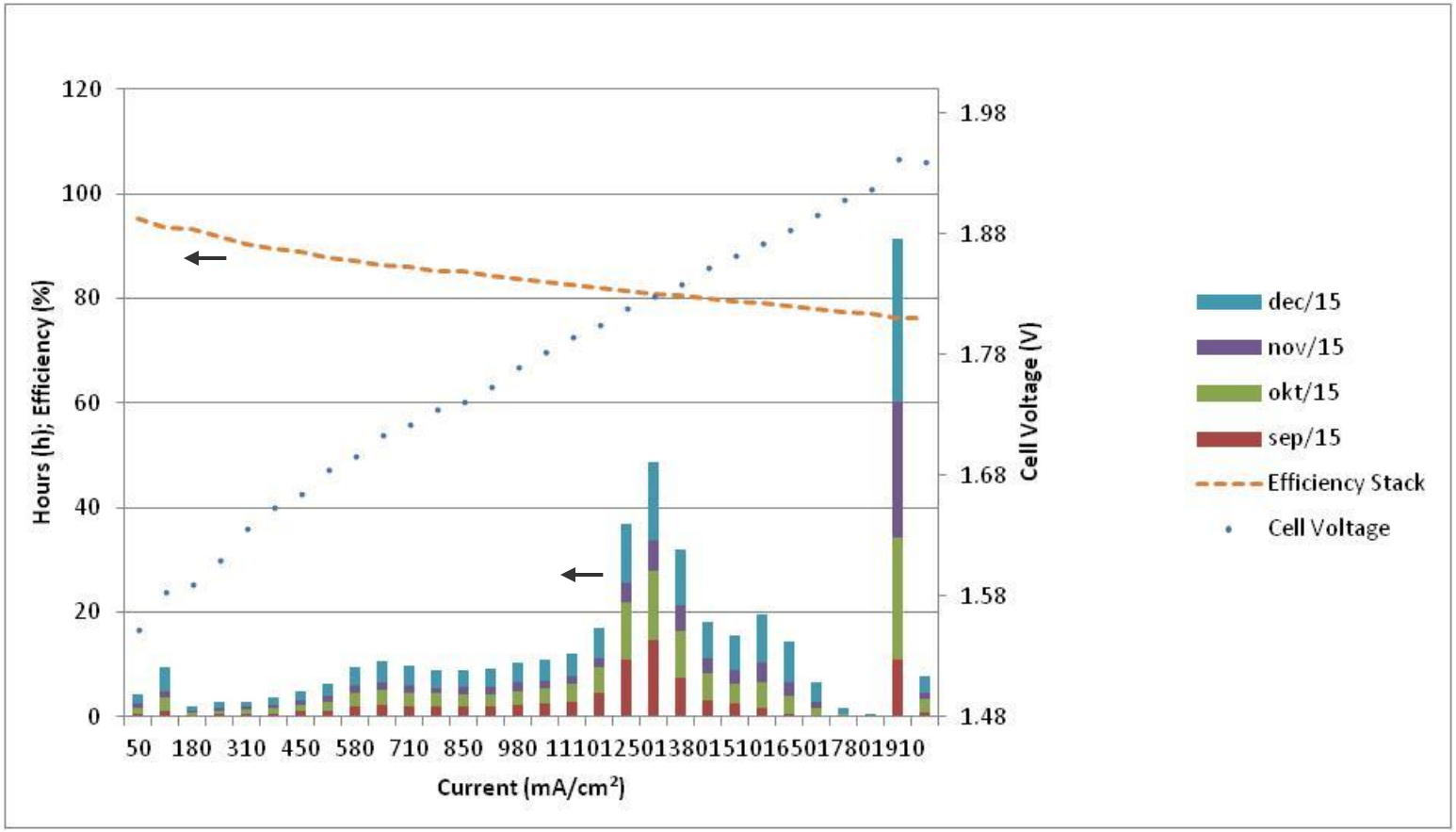
Cell potential average values

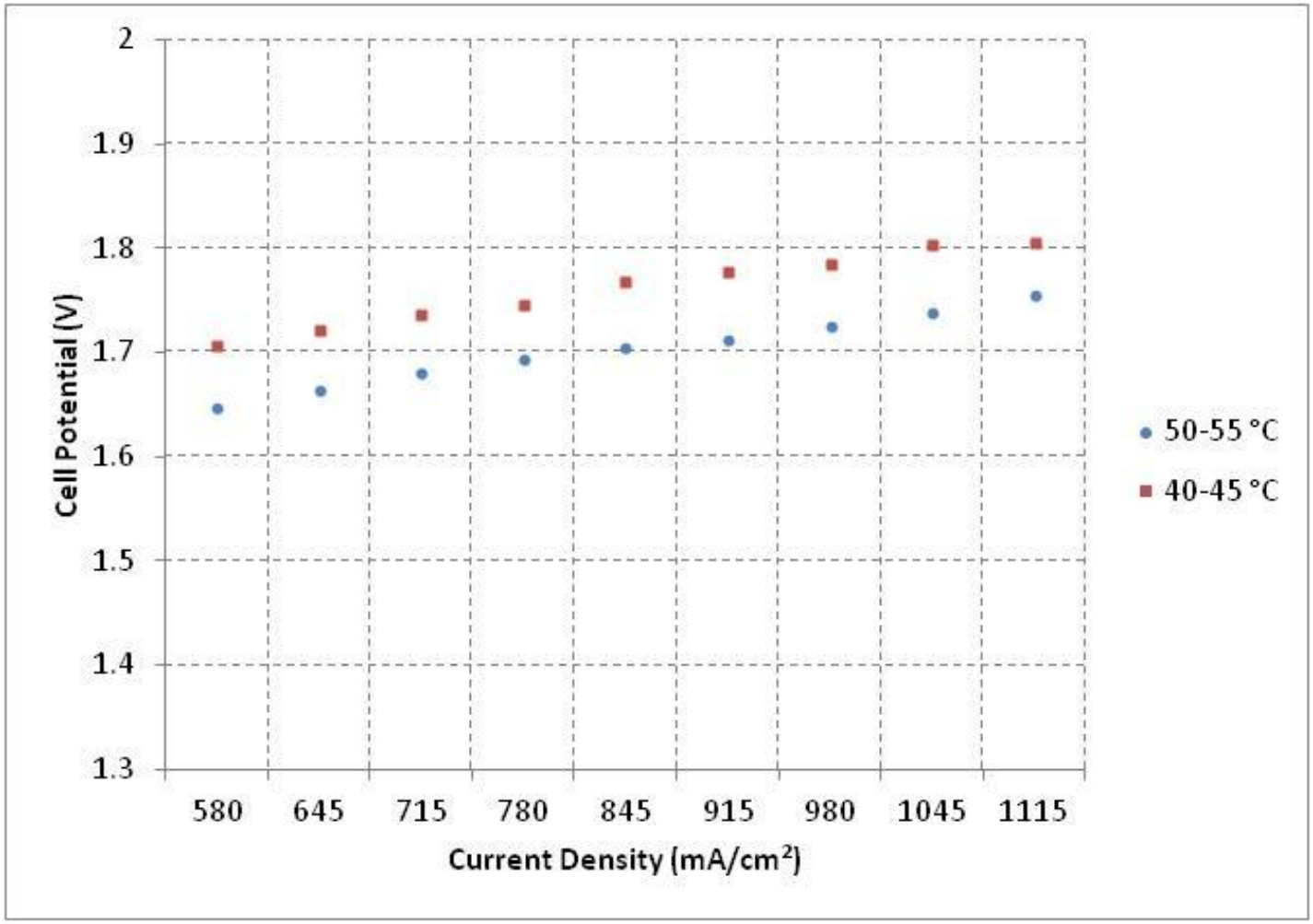
- Averaged values ([50-55]°C,[9-10] barg) / 50 mHz)



Don Quichote 26 cell stack performance



Temperature effect on cell potential

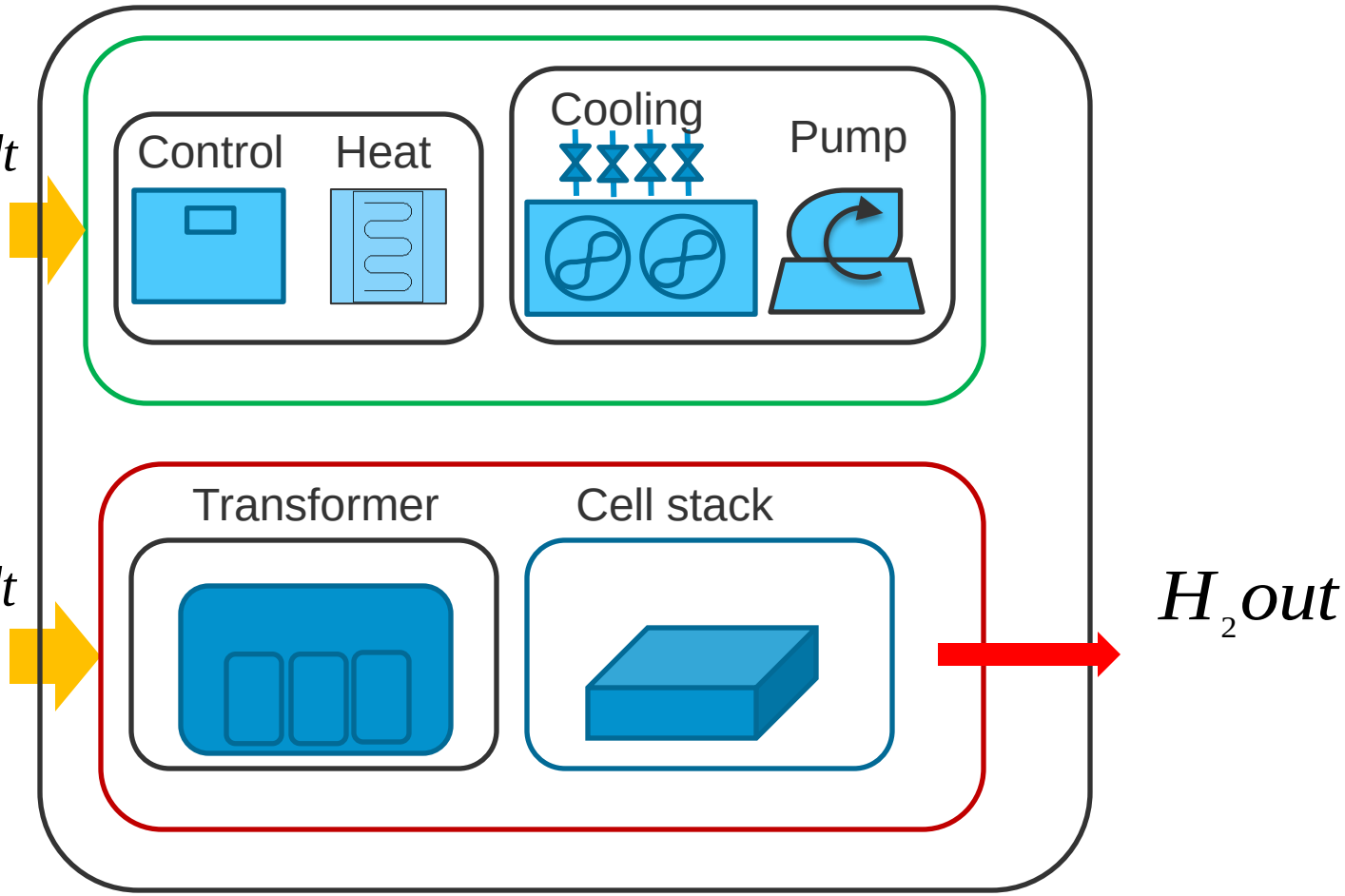


Thermal ramping

Integrated power measurements

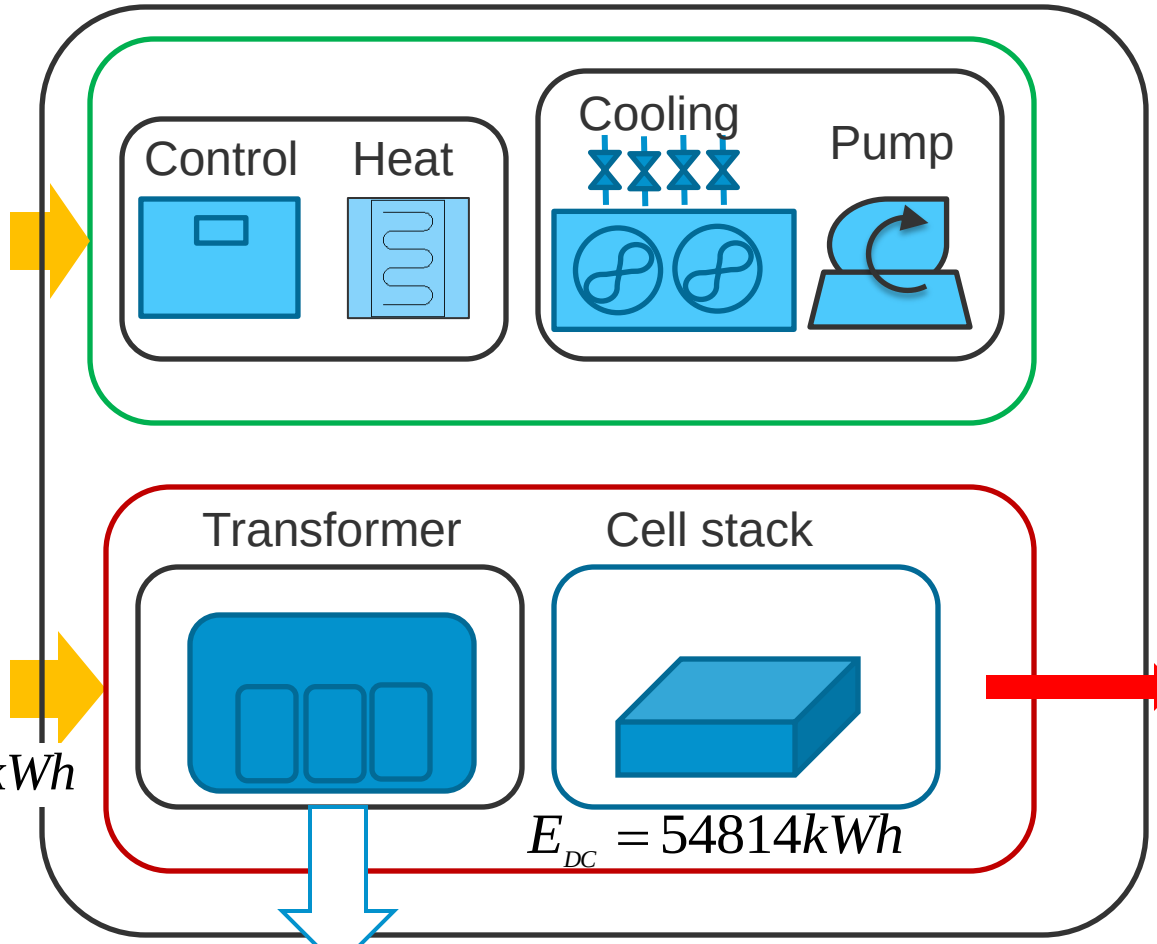
$$E_U = \int P_U(t)dt$$

$$E_{MP} = \int P_{MP}(t)dt$$



$$H_2 out$$

Integrated power measurements



$E_{MP} = 62689kWh$

$E_{DC} = 54814kWh$

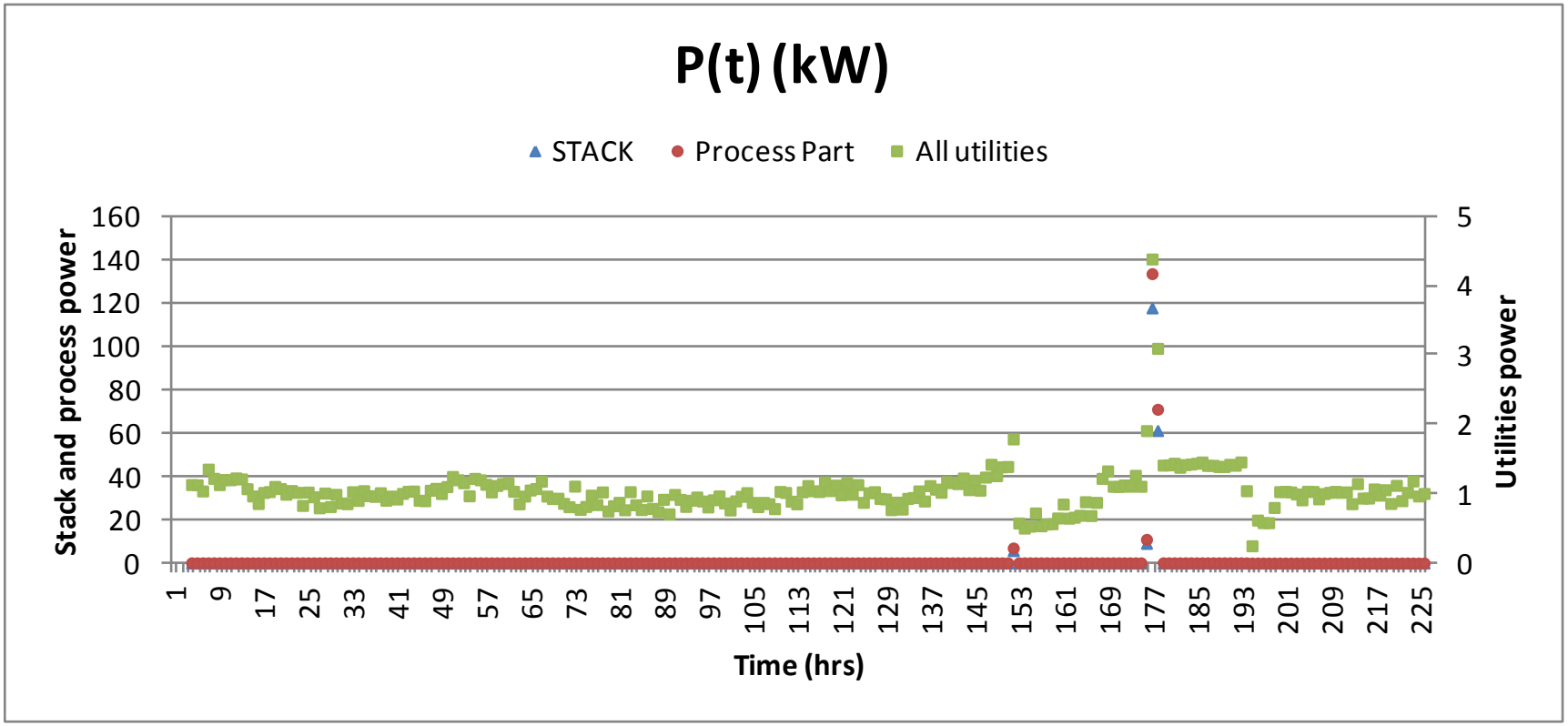
$U_{ACDC} = 7875kWh$

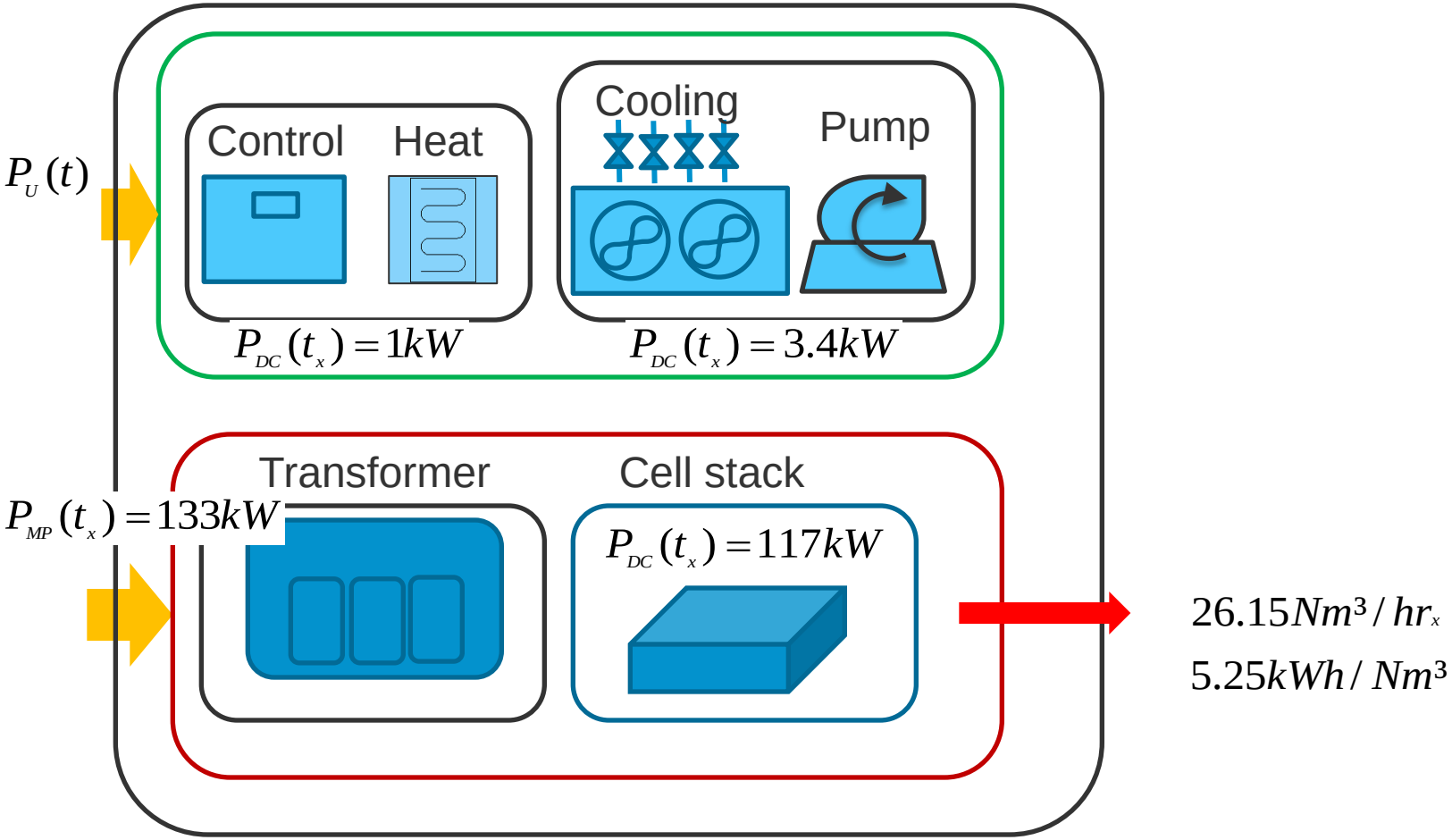
$H_2 out$

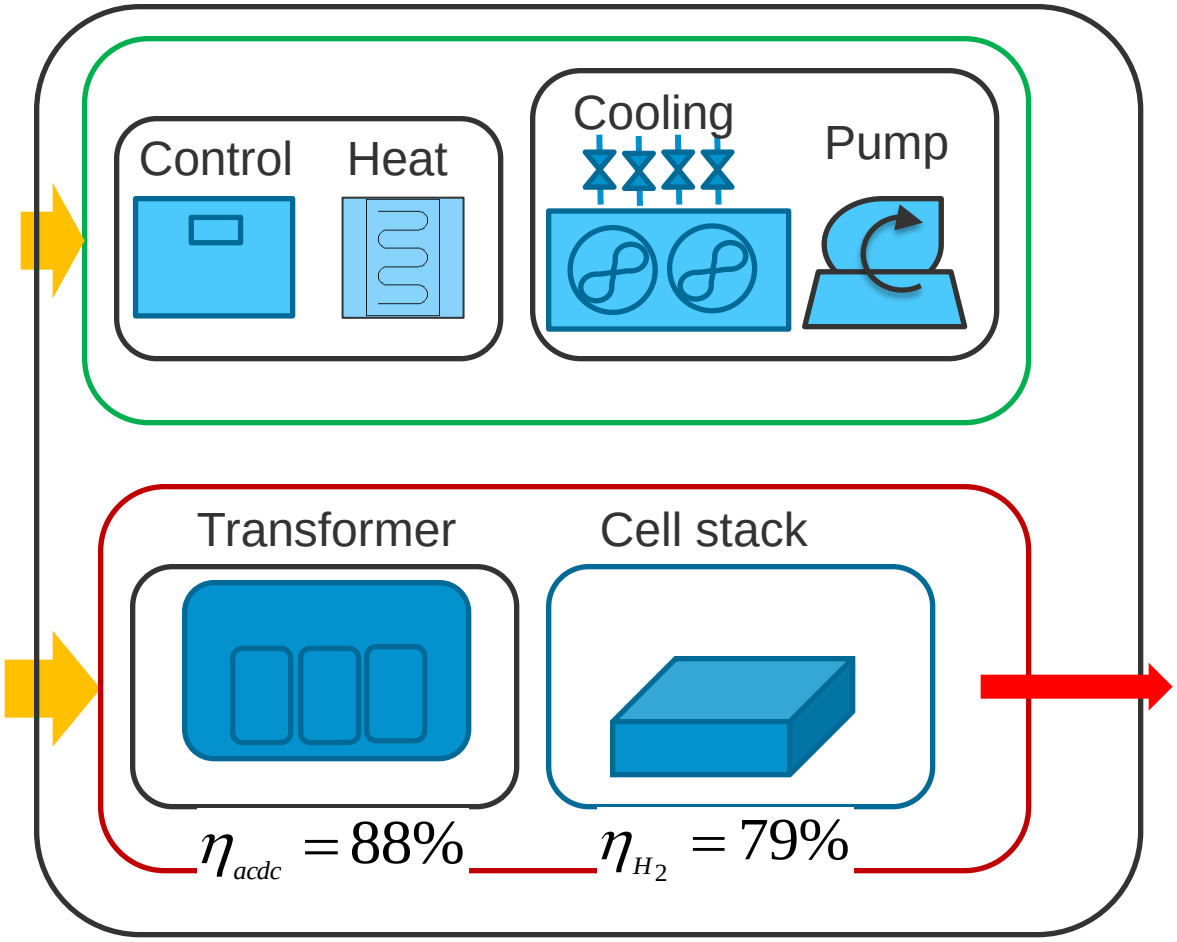
$V_{H2} = 12252Nm^3$

Averaged
4.47 kWh/Nm³ at DC
50.2 kWh/kg

Power monitoring




$P_U(t)$
Control
Heat
Cooling
Pump
$P_{DC}(t_x) = 1kW$
$P_{DC}(t_x) = 3.4kW$
Transformer
Cell stack
$P_{MP}(t_x) = 133kW$
$P_{DC}(t_x) = 117kW$
$26.15 Nm^3/hr_x$
$5.25 kWh/Nm^3$



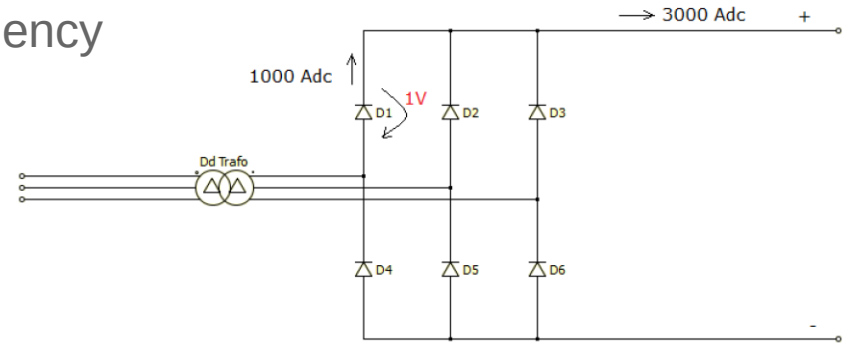
$$\eta_{tot} = 70\%$$

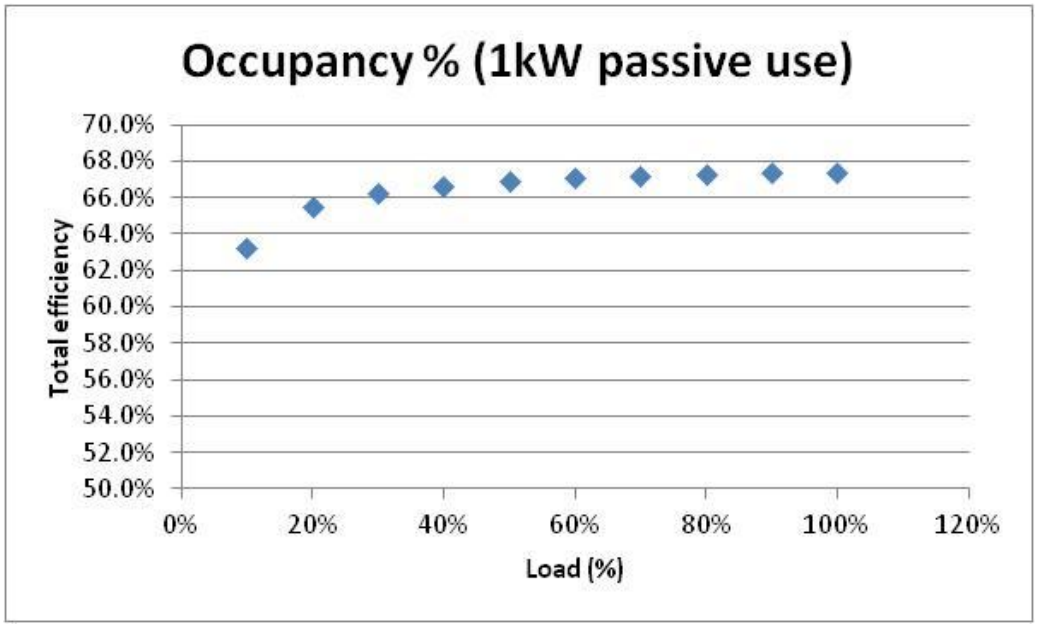
Including 450 barg compression:

$$(5.25 + 0.3) kWh / Nm^3$$

$$60.11 kWh / kg_{H2}$$

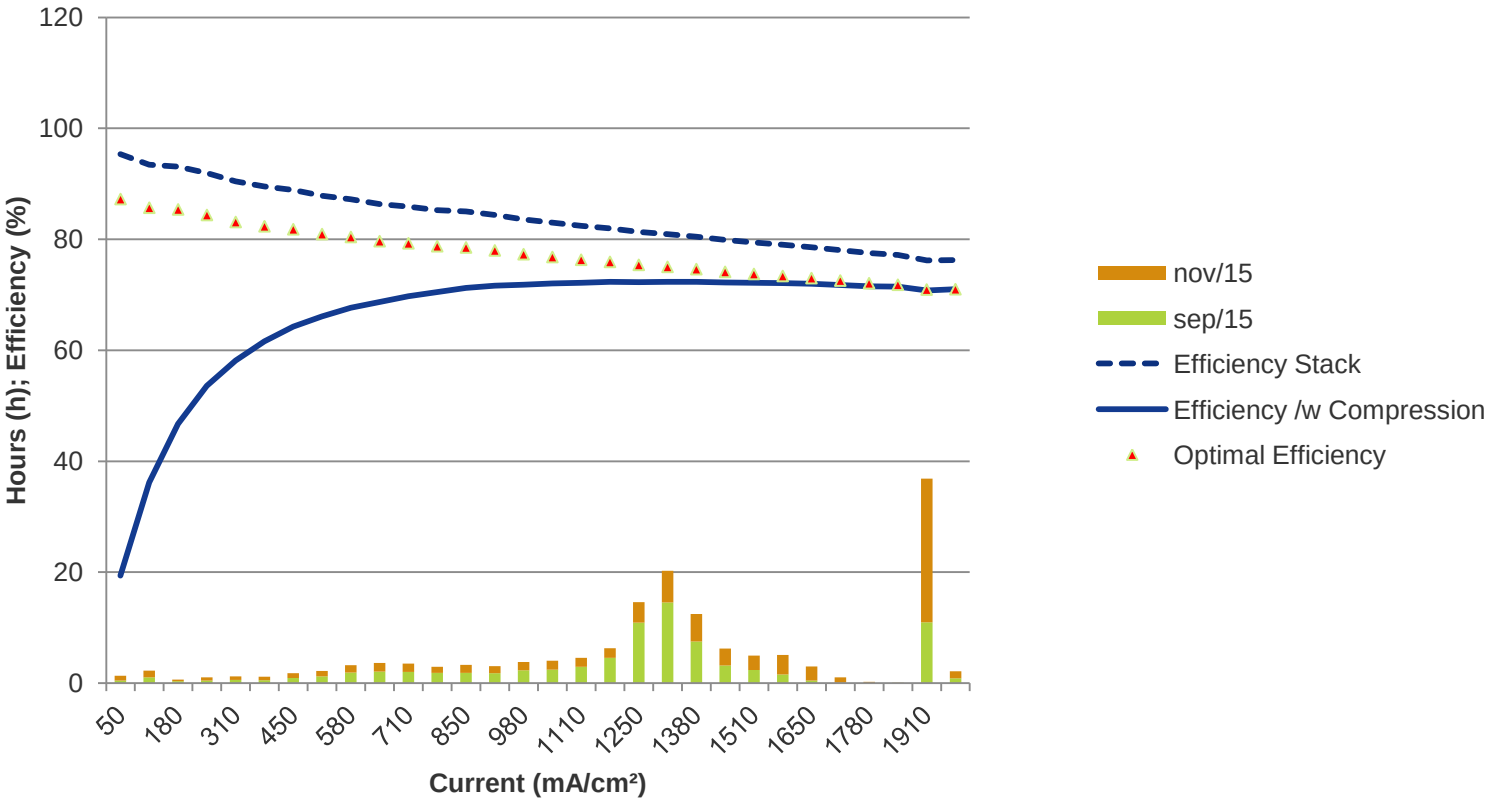
- Poor rectification transformer efficiency
  - Diode losses
  - Carry full current of 1000 A/phase
    - 6kW
    - Pdc= 26*2V*3000 Adc= 156 kW
  - Utility power is not significant
    - Depending on ambient temperature



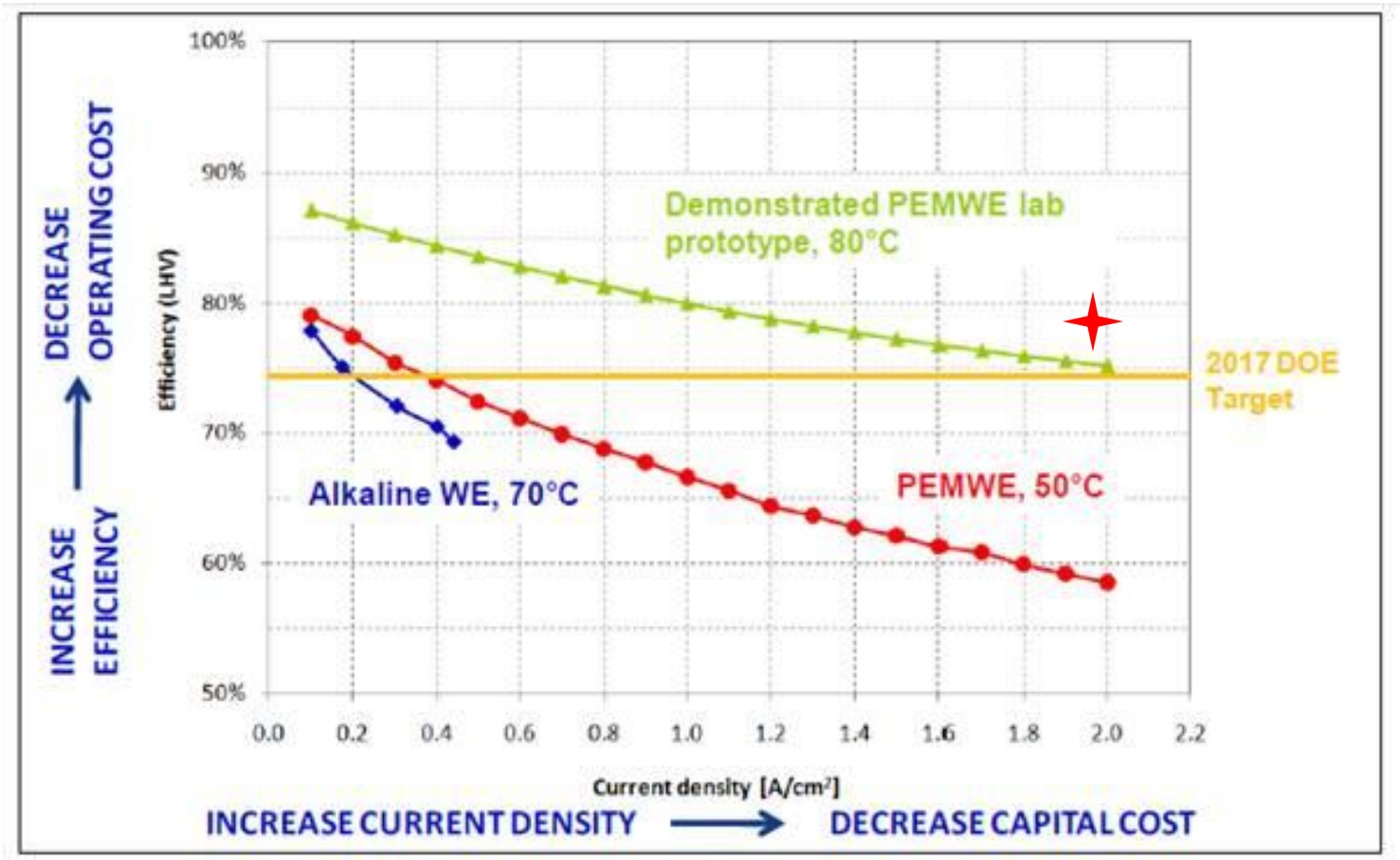


Effect of compression

- Compressor has larger flow capacity than needed
- Lower current density benefit on stack level, gets lost in spill back



2016 status


100%
90%
80%
70%
60%
50%
Efficiency (LHV)
DECREASE OPERATING COST
INCREASE EFFICIENCY
Demonstrated PEMWE lab prototype, 80°C
2017 DOE Target
Alkaline WE, 70°C
PEMWE, 50°C
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
Current density [A/cm²]
INCREASE CURRENT DENSITY
DECREASE CAPITAL COST

PEM or AWE for Power to **xyz** ?

- Dynamic operation:
  - PEM : 5-100% - **nano porosity** in membrane
  - AWE: 20 -100 % range
    - Micrometer scale porosity
- Cold start:
  - N2- Purging / getting hydrogen out a given purity
    - **Smaller volume** for PEM
  - Limited current because of rise to operational temperature
    - PEM: smaller ΔT required / smaller volume
- Overload regime, response times
  - Power electronics and cooling are determining
  - Size matters => limited ΔT for AWE
- Capex
  - Similar € numbers **> 5MW**
  - **Site footprint** smaller for PEM
- Opex
  - Similar electricitiy consumption (η~capex)
  - Maintenance:
    - known for AWE (2-10%)
    - to be derisked for PEM (stack)

Ongoing MW PEM projects

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Sponsors:

Gefördert durch:

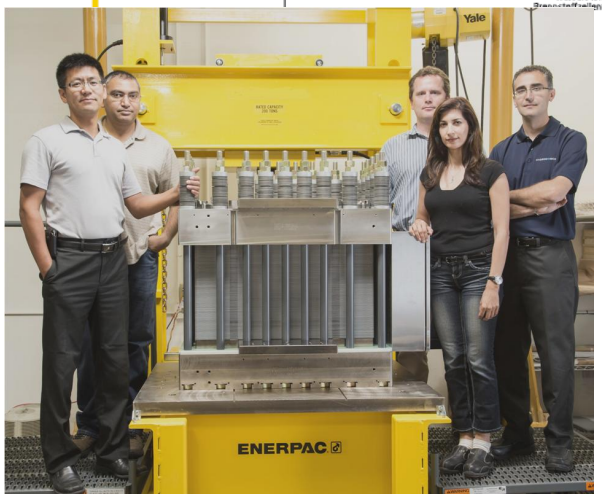
Bundesministerium für Verkehr und digitale Infrastruktur

Coordinators:

Koordiniert durch:

NOW Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

nip Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie



WindGas Hamburg Reitbrook, Germany (2015)

1,5 MW Power to Gas

OBJECTIVES

- Development of 1,5 MW PEM Electrolysis Stack and System
- Optimize operational concept (fluctuating power from wind vs. changing gas feed).
- Gain experience in technology and cost.
- Feed H_2 into the natural gas pipeline

SOLUTION

- 1x 1,5 MW PEM Electrolyser with all peripherals in 40Ft. housings for max 285 Nm^3/h H_2.
- Power: 1,5 MW

•This 1,5 MW building block will be the foundation for multi MW P2G plants

More info: www.windgas-hamburg.com

Partners:

e·on

SolviCore Fuel Cell Technologies

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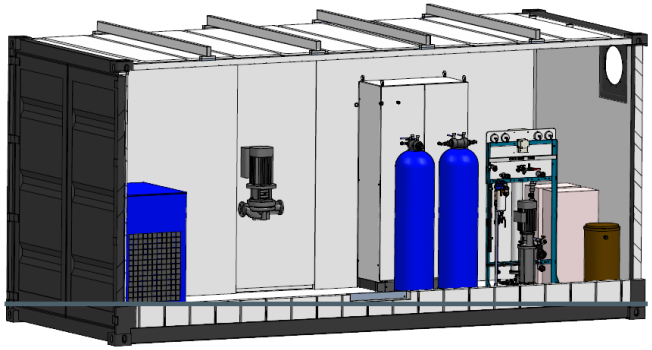
DLR

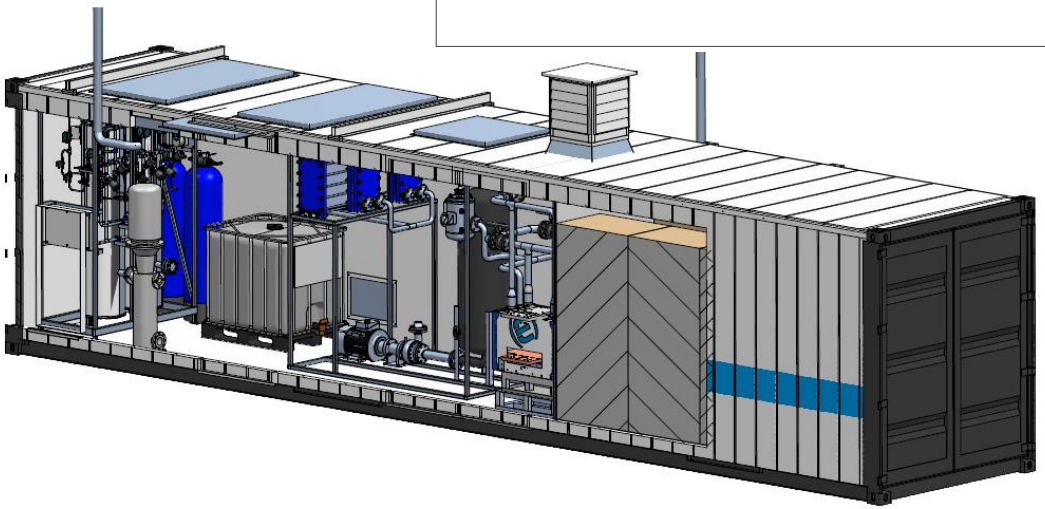
Fraunhofer ISE

Hybalance dual stack 230 Nm³/hr – HOBRO Denmark

HyLYZER 230/30: OVERVIEW 20FT CONTAINER



HyLYZER 230/30: OVERVIEW 40FT CONTAINER



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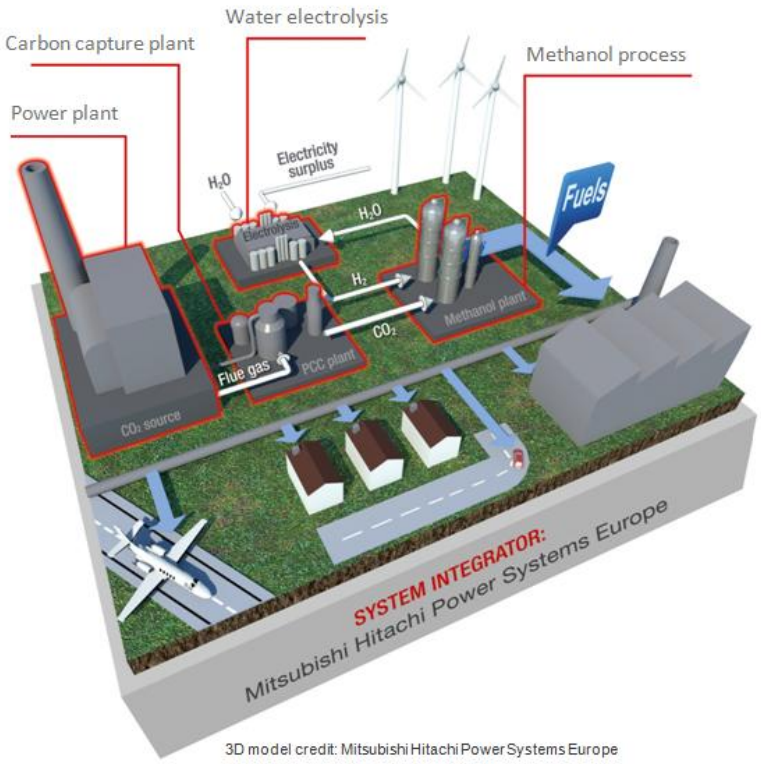

3D model credit: Mitsubishi Hitachi Power Systems Europe

Carbon capture unit
Photo credit: University of Duisburg-Essen

Lünen, Germany

MefCO2 project (Methanol Fuel from CO2)

OBJECTIVES

- Increase efficiency and reduce emissions of STEAG's coal fired power plant
- Leverage existing carbon capture pilot plant (= CO_2 source) owned by UDE

SOLUTION

- 600 kW 1500E PEM electrolyser for 120 Nm^3/h of Hydrogen
- EU Horizon 2020 research and innovation programme funding (SPIRE)
- Flexible methanol synthesis.
- Power: 600kW

More info: http://www.spire2030.eu/mefco2/

i-deals
National Institute of Chemistry Slovenia
Mitsubishi Hitachi Power Systems Europe
Cardiff Catalysis Institute
Carbon Recycling International
DIME - University of Genoa
Hydrogenics Europe
University of Duisburg Essen

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Thank you for your attention !

We're Ready.

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