

# Enphos srl. PEM electrolyzer integrator (Verona)



ENPHOS



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## Collaborators



**E2C**, Vicenza. Power electronics.



**Methydor**, Chivasso/Genova.  
Metal hydride ( $AB_5$ ), T - swing  $H_2$   
Storage ( $T = 40^\circ C$ , 30 bar).



**Blue energy Revolution**, Genova.  
PEM electrolyzer integrator.  
MOSE compact 14 kW PEM ( $5N H_2$ ).

# Electrolysis technologies comparison

Water splitting reaction:  $2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$

Minimum theoretical consumption: 39.4 kWh/kg

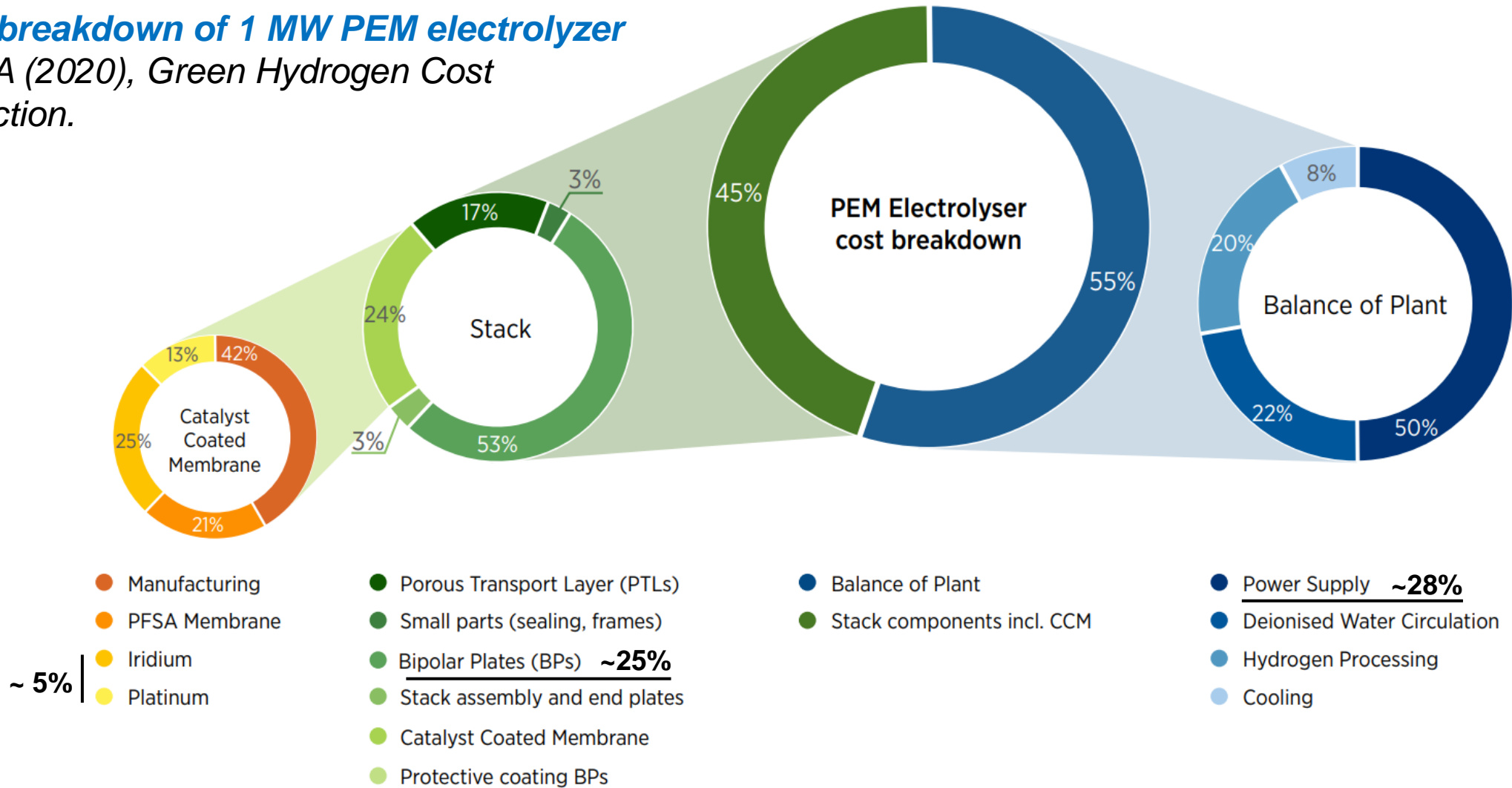
Parameter	AEL	PEM	AEM	SOEC
Temperature (°C)	60 - 90	50 - 80	40 - 60	650 - 850
Pressure (bar)	< 30	< 70	10 - 30	atm
Current density (A/cm <sup>2</sup> )	0.2 - 0.4	1 - 2	0.5 - 1	1 - 2
Catalyst	Ni	Ir, Pt	Ni	Ni/YSZ
Membrane	ZrO <sub>2</sub> filled diaphragm	PFSA, Nafion	Anion ex. .	Yttria-stab. ZrO <sub>2</sub>
Charge carrier	OH <sup>-</sup>	H <sup>+</sup>	OH <sup>-</sup>	O <sup>2-</sup>
Consumption (kWh/Kg)	48 - 55	50 - 60	50 - 60	37 - 45 + heat
CAPEX per MW	0.5 - 1.0	1.0 - 2.0	0.7 - 1.2	2.0 - 4.0
OPEX (% CAPEX per year)	2 - 3 %	3 - 5 %	3 - 5 %	4 - 6 %

PEM lifetime target: 40 - 60 k hours

Efficiency: 65 - 75 %

# Balance of plant and CAPEX distribution

*Cost breakdown of 1 MW PEM electrolyzer  
IRENA (2020), Green Hydrogen Cost  
Reduction.*



# Electrolyser plant architecture

*Electrolysis plants behave like **chemical process plants***

## Main **subsystems**:

- Power electronics and rectifiers
- Electrolyser stacks
- Water purification system
- H<sub>2</sub> purification
- H<sub>2</sub> compression
- Storage integration

## Water purification requirements:

Practical plant demand: 12 - 18 kg/kg H<sub>2</sub>  
(stoichiometric water demand: 9 kg H<sub>2</sub>O / kg H<sub>2</sub>)

Required water conductivity: <1 μS/cm

## Purification chain:

- pre-filtration
- reverse osmosis (RO recovery: 65–75 %)
- deionization
- Polishing

# Gas separation and drying

Hydrogen leaving stack contains:

- water vapor --> dew point sensor (slow)
- oxygen traces: De-oxo (H<sub>2</sub> and O<sub>2</sub> combustion)

Separation methods

- phase separation
- Membranes (diffusion)
- PSA (pressure swing)
- TSA (temperature swing)

<b>Grade</b>	<b>Purity</b>	<b>Typical impurities</b>	<b>Typical applications</b>	<b>Tech.</b>
<b>2N</b>	99.0 %	10,000 ppm	Basic industrial use	AEL
<b>3N</b>	99.9 %	1,000 ppm	General industrial hydrogen	AEL
<b>4N</b>	99.99 %	100 ppm	Chemical processes	PEM
<b>5N</b>	99.999 %	10 ppm	PEM fuel cells, electronics	PEM
<b>6N</b>	99.9999 %	1 ppm	Semiconductor manufacturing	PEM

# Stack configuration and control

Aspect	Series connection	Parallel connection
Electrical behaviour	Same current through all stacks	Same voltage across stacks
System parameter	$V_{\text{tot}} = \sum V_{\text{stack}}$	$I_{\text{tot}} = \sum I_{\text{stack}}$
Effect	High voltage	Higher currents, higher resistive losses ( $P_{\text{loss}} = I^2R$ )
Cables/busbar	Smaller size	Larger size (higher costs)
Power electronics	High-voltage rectifiers required	High-current rectifiers required
Mismatch tolerance /failure impact	Weakest stack limits the string	Stacks operate independently
Maintenance flexibility	Harder to isolate individual stacks	Easy to isolate the stacks
Current balancing	Automatic (same current)	<b>Balancing control requested</b>
Key takeaway	Improves <b>electrical efficiency</b>	Operational <b>flexibility</b> and <b>reliability</b>

# Electrolyser manufactures and startups – installed plants

## **Alkaline**

thyssenkrupp nucera (Germany)

Nel Hydrogen (Norway) – 20 MW installed at Puertollano green hydrogen plant (Spain)

HydrogenPro (Norway) – 220 MW installed at ACES Delta hydrogen project (Utah, USA)

John Cockerill (Belgium)

McPhy (France)

Green Hydrogen Systems (Denmark)

LONGi Hydrogen (China) – 20 MW installed at Uzbekistan hydrogen project (Uzbekistan)

## **PEM**

ITM Power (UK) – 34 MW installed at REFHYNE / Yara Porsgrunn (Germany)

Siemens Energy (Germany) – 9 MW installed at Wunsiedel hydrogen plant (Germany)

Elogen (France)

Plug Power (USA) – 1 MW demonstrator at Sealhyfe offshore hydrogen pilot (France)

Cummins (USA) – 20 MW installed at Bécancour plant (Canada)

Hystar (Norway)

## **AEM**

Enapter (Germany / Italy), Hysata (Australia)

## **SOEC**

Sunfire (Germany), Topsoe (Denmark), Elcogen (Estonia), Ceres Power (UK)

# Producer stack specs (example)



## PEM - Stacks ( 40 bar )



	PURIFIER	CUSTOMIZER	SUPPLIER	STORAGER
<b>Possible Application Fields</b>	Gas generators, Laboratory applications	Customized electrolysis stack for a wide range of applications	"Smart Solution" energy container, home energy supply	Power-To-Gas, H2 filling station supply, Power-to-X
<b>Max. H<sub>2</sub>-Productionrate</b>	≈ 2.5 kg/d ≈ 1.2 Nm <sup>3</sup> /h	≈ 6.0 kg/d ≈ 2.8 Nm <sup>3</sup> /h	≈ 16.3 kg/d ≈ 7.6 Nm <sup>3</sup> /h	≈ 43.5 kg/d ≈ 20.3 Nm <sup>3</sup> /h
<b>Elektrode Diameter</b>	Ø 60 mm	Ø 93 mm	Ø 153 mm	Ø 250 mm
<b>Active Area</b>	28.3 cm <sup>2</sup>	67.9 cm <sup>2</sup>	183.9 cm <sup>2</sup>	490.9 cm <sup>2</sup>
<b>Max. Number of Cells</b>	45			
<b>Max. H<sub>2</sub>-Output Pressure</b>	40 bar			
<b>Max. H<sub>2</sub>O-Input Pressure</b>	1.5 bar	1.5 bar	1.5 bar	2.5 bar
<b>Electrical Connected Load BOL<sup>1</sup> @ 45 Cells</b>	≈ 6.2 kW	≈ 15.0 kW	≈ 40.5 kW	≈ 102.0 kW
<b>Electrical Connected Load EOL<sup>2</sup> @ 45 Cells</b>	≈ 7.3 kW	≈ 17.5 kW	≈ 47.3 kW	≈ 120.6 kW
<b>Height x Width x Length (approx.) @ 45 Cells</b>	120 x 122 x 470 mm	206 x 210 x 520 mm	291 x 297 x 550 mm	480 x 490 x 690 mm
<b>Weight (approx.) Unwatered @ 45 Cells</b>	12 kg	46 kg	97 kg	385 kg
<b>Weight (approx.) Watered @ 45 Cells</b>	13 kg	48 kg	101 kg	393 kg

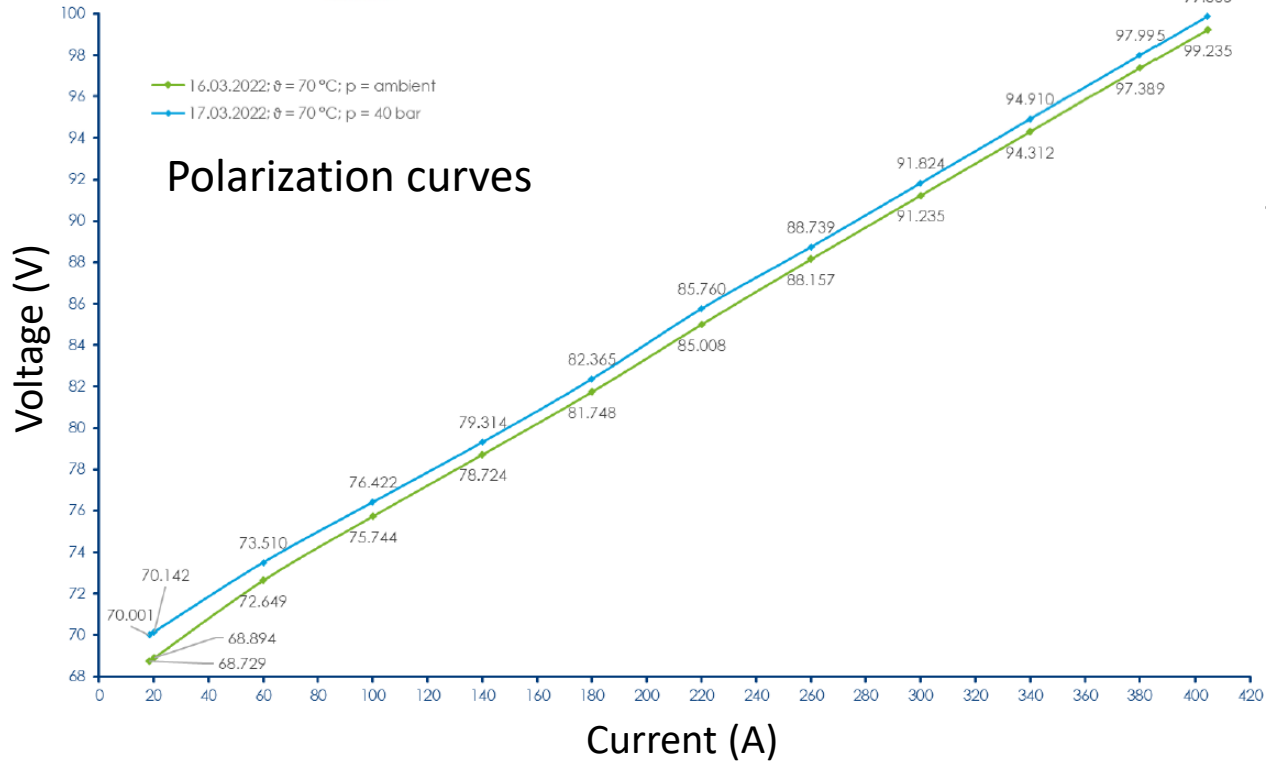
<sup>1</sup> Beginning of Life (Time after first commissioning and function validation)

<sup>2</sup> End of Life, caused by a process-related cell degradation of approx. 10 µV/h under optimal conditions

# Producer stack specs

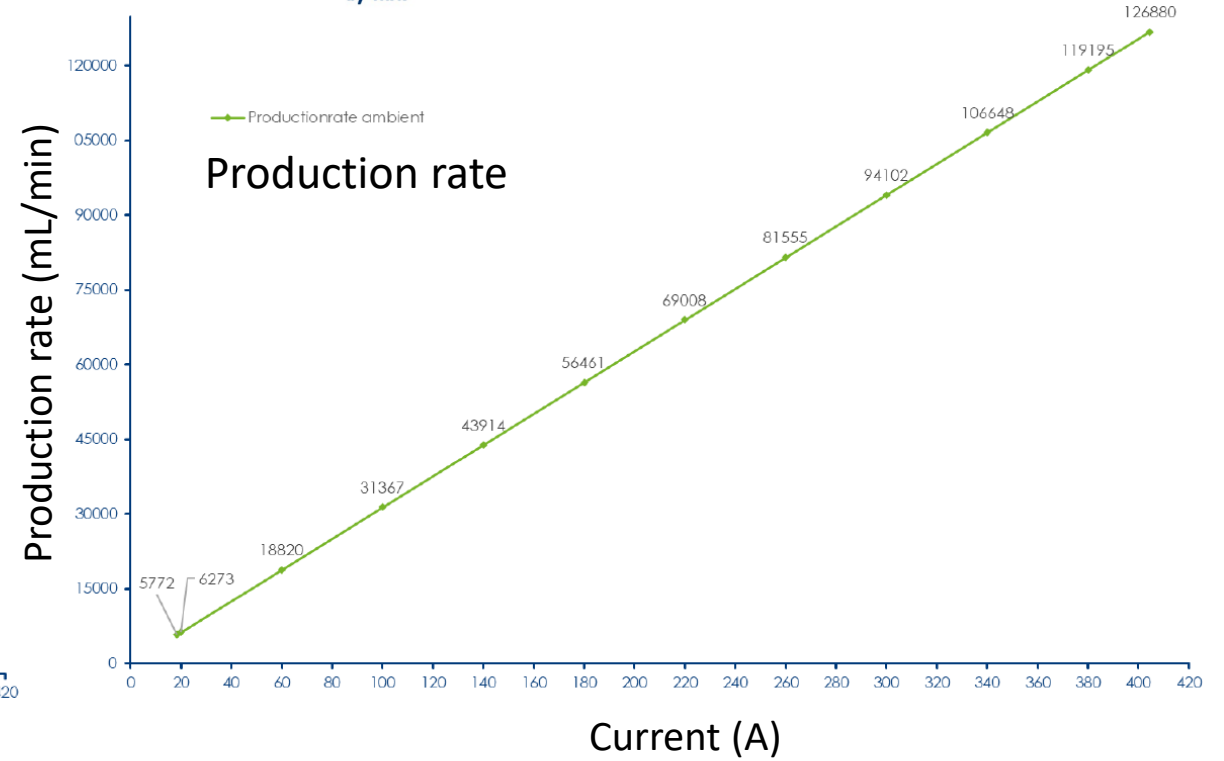
PEM ELECTROLYZER  
by HIAT

EN-0222-001

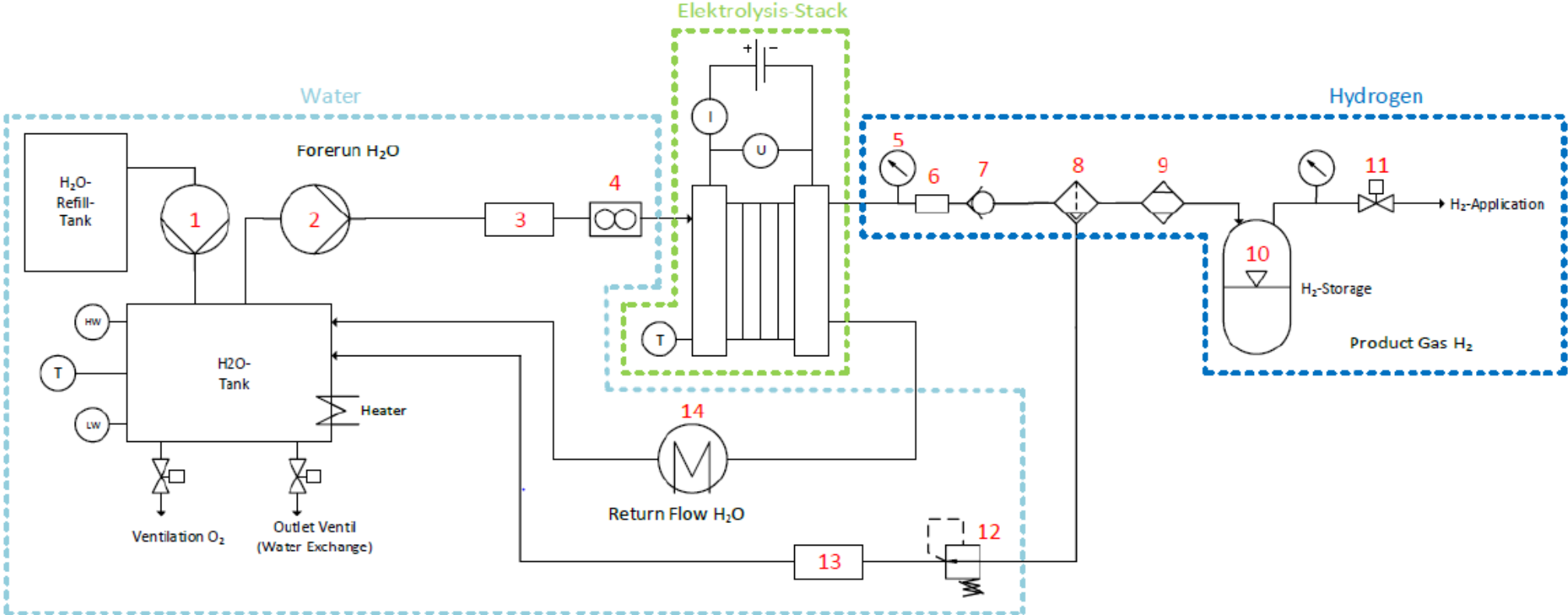


PEM ELECTROLYZER  
by HIAT

EN-0222-001



# Stack integration

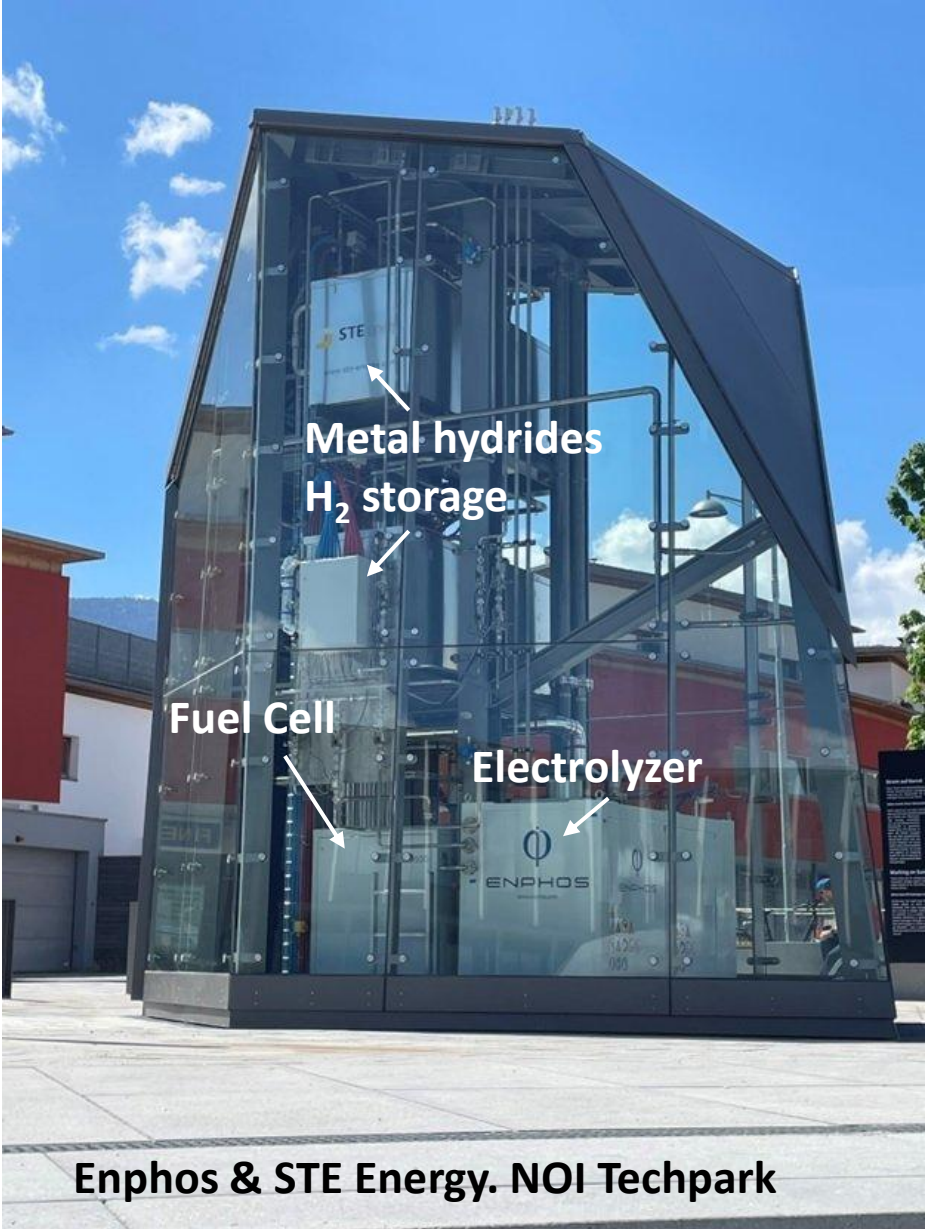


- (U) Voltage
- (I) Current
- (LW) Fill Level (MIN)
- (HW) Fill Level (MAX)
- (T) Temperature

- 1 – Refill Device/Pump (optional)
- 2 – Forerun Pump
- 3 – Ion Exchanger H<sub>2</sub>O
- 4 – Flowmeter/Flowswitch H<sub>2</sub>O
- 5 – Operating Pressure Elektrolyzer H<sub>2</sub>
- 6 – Dielectric Connection
- 7 – Check Valve
- 8 – Demister H<sub>2</sub>
- 9 – Gas Cleaning/Gas drying
- 10 – Pressure Reservoir/Storage H<sub>2</sub>

- 11 – Control Valve H<sub>2</sub>
- 12 – Pressure Reducer H<sub>2</sub>
- 13 – Ion Exchanger H<sub>2</sub>O
- 14 – Heat Exchanger

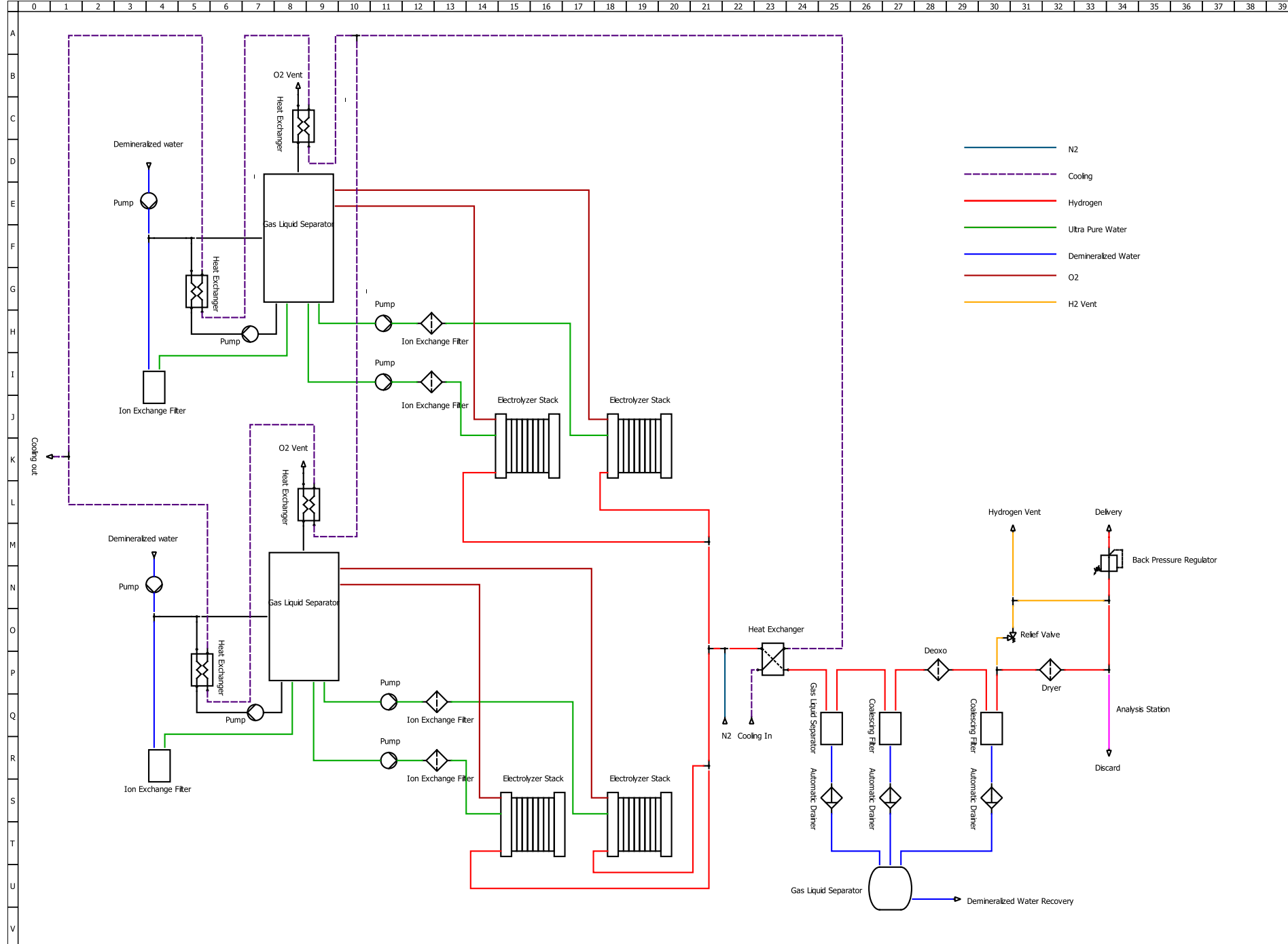
# Hyris: H<sub>2</sub> system, Brunico



Photovoltaics: 185 kWp  
PEM electrolyzer: 146 kW, 8 - 32 Nm<sup>3</sup>/h  
H<sub>2</sub> Storage: 40 kg H<sub>2</sub> (metal hydrides)  
Fuels cell: 85 kW  
Batteries: 20 kWh



# Hyris, BoP PFD



# Controls

**Feed Tank 1**  
**Maintain**

CT-X102: 0.201 uS  
TT-X103: 13.3 °C  
LT-X104: 23.6 L

PMP-U302    PMP-G201

**ELS 1 Feed**  
**Start Block**

CT-U509: 0.217 uS  
TT-X512: 13.3 °C  
DT-X512: -2.70 °C

**ELS 2 Feed**  
**Start Block**

CT-U809: 0.147 uS  
TT-X812: 13.2 °C  
DT-X812: -1.94 °C

**Electrolyzers 1 - 2**

ET-1178: 0.2 V    ET-1180: 0.6 V    DET-1182: 0.4 V    IT-1178: 0 A    JT-1181: 0 kW

Power Limit: 10639 W    Current Limit: 20 A

Controls: Stop, Minus, 5%, Plus, Plus

**Electrolyzers 3 - 4**

ET-1279: 0.3 V    ET-1280: 0.9 V    DET-1282: 0.6 V    IT-1278: 0 A    JT-1281: 0 kW

Power Limit: 11210 W    Current Limit: 20 A

Controls: Stop, Minus, 5%, Plus, Plus

**Feed Tank 2**  
**Maintain**

CT-X202: 0.339 uS  
TT-X203: 13.2 °C  
LT-X204: 48.5 L

PMP-G301    PMP-U402

**ELS 3 Feed**  
**Start Block**

CT-U709: 0.260 uS  
TT-X712: 13.0 °C  
DT-X712: -2.17 °C

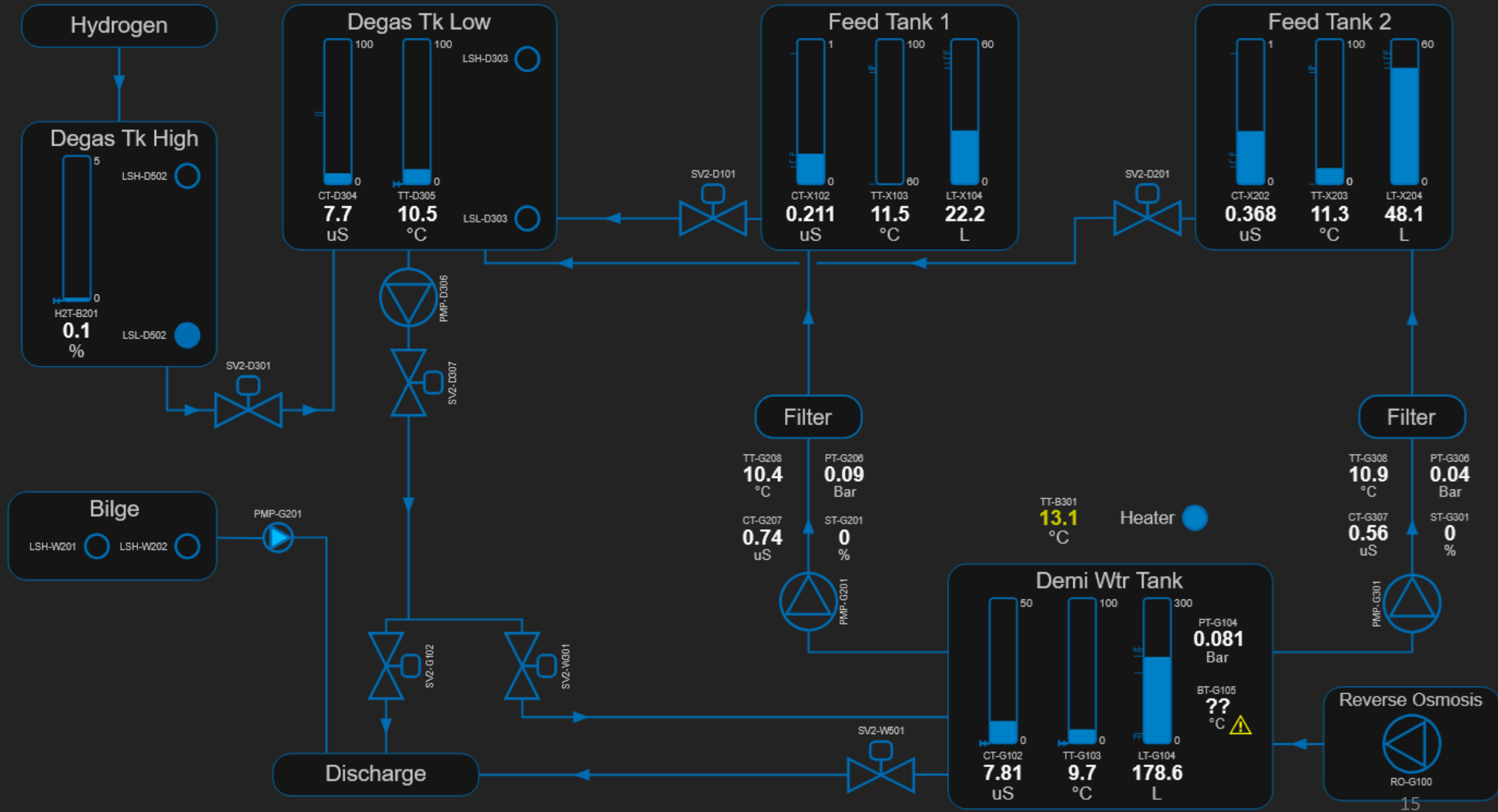
**ELS 4 Feed**  
**Start Block**

CT-U809: 0.243 uS  
TT-X812: 13.7 °C  
DT-X812: -1.66 °C

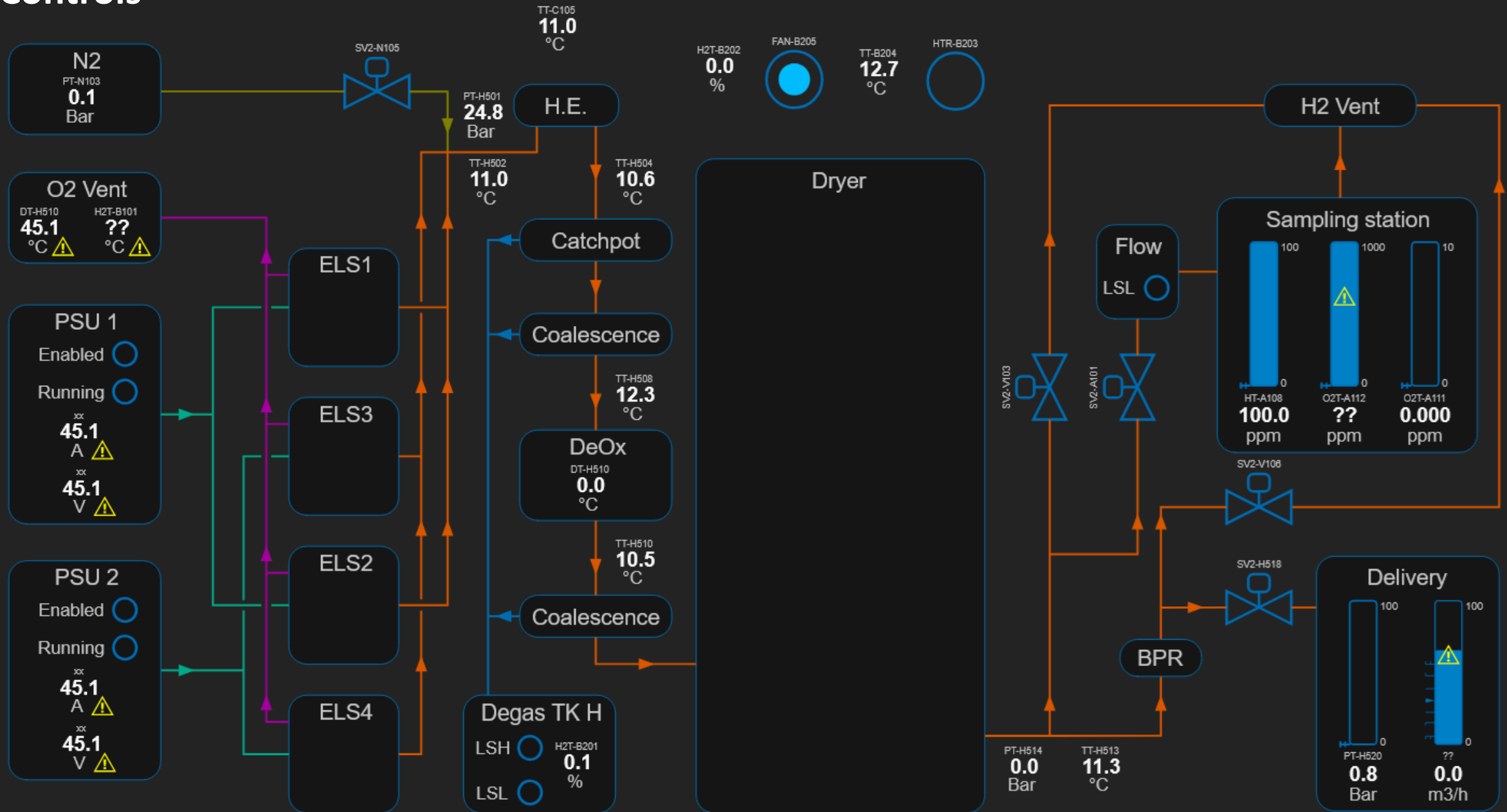
Auto Mode   
  Storage   
  STE   
  Auto Mode



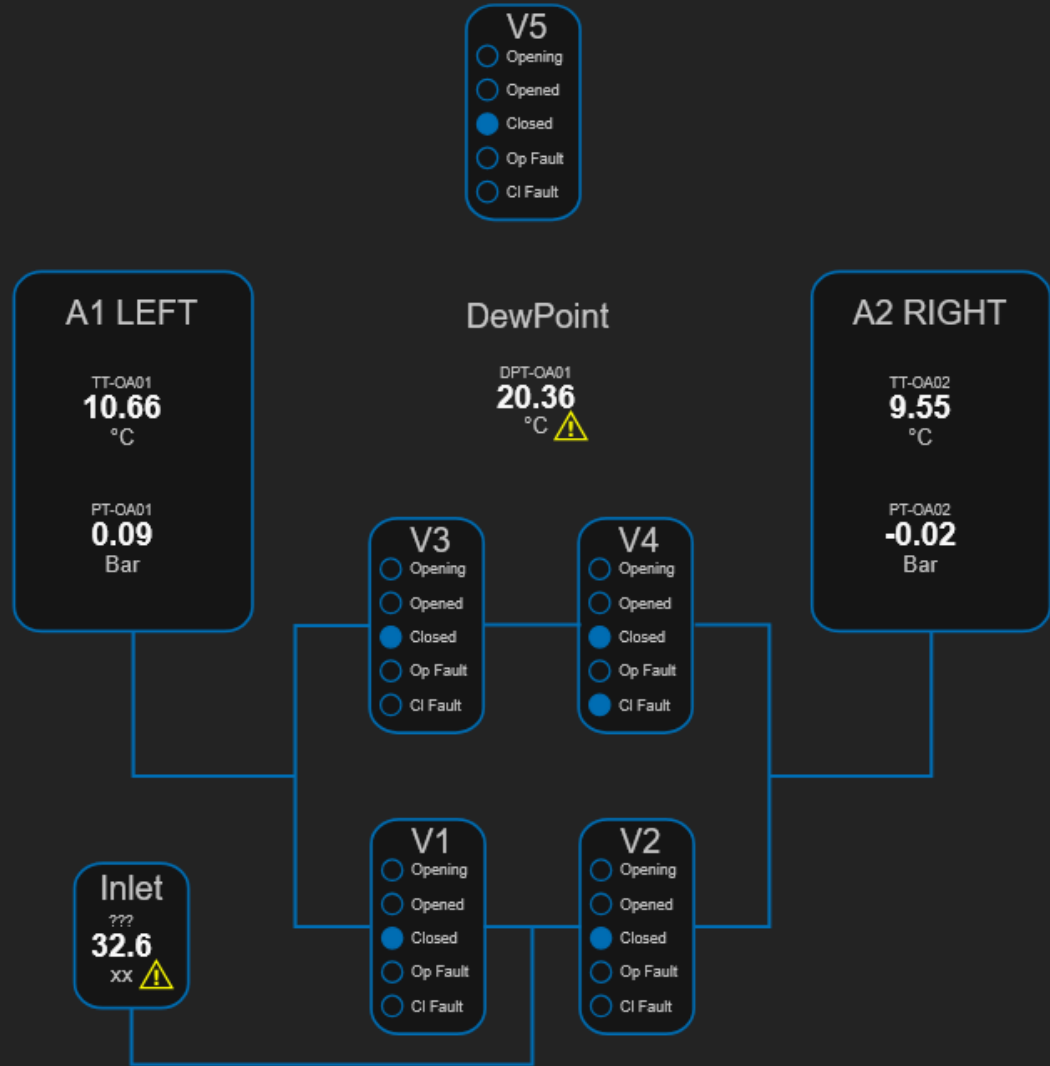
# Controls



# Controls



# Controls



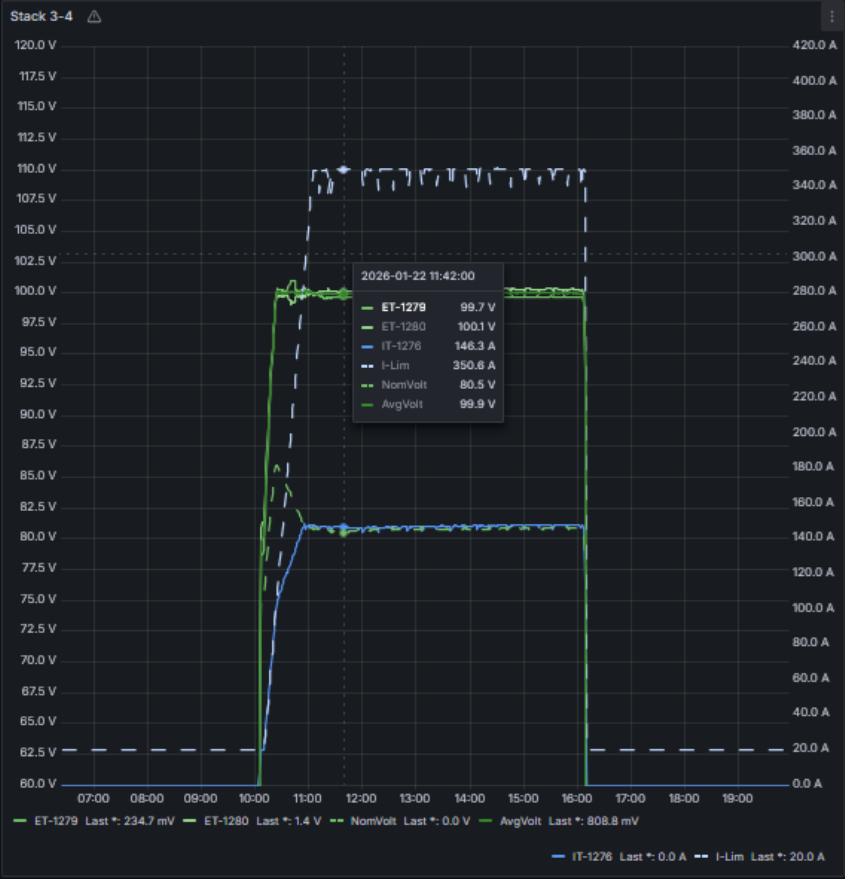
- Heater CB Fault
- Relay CB Fault
- estop

- rel\_press\_right\_too\_long
- heat\_right\_too\_long
- cool\_right\_too\_long
- build\_press\_right\_too\_long
- ads\_right\_vessel

- rel\_press\_left\_too\_long
- heat\_left\_too\_long
- cool\_left\_too\_long
- build\_press\_left\_too\_long
- ads\_left\_vessel

- START
- STOP
- JUMP
- RESET
- RESET 10
- RESET 60

# Controls



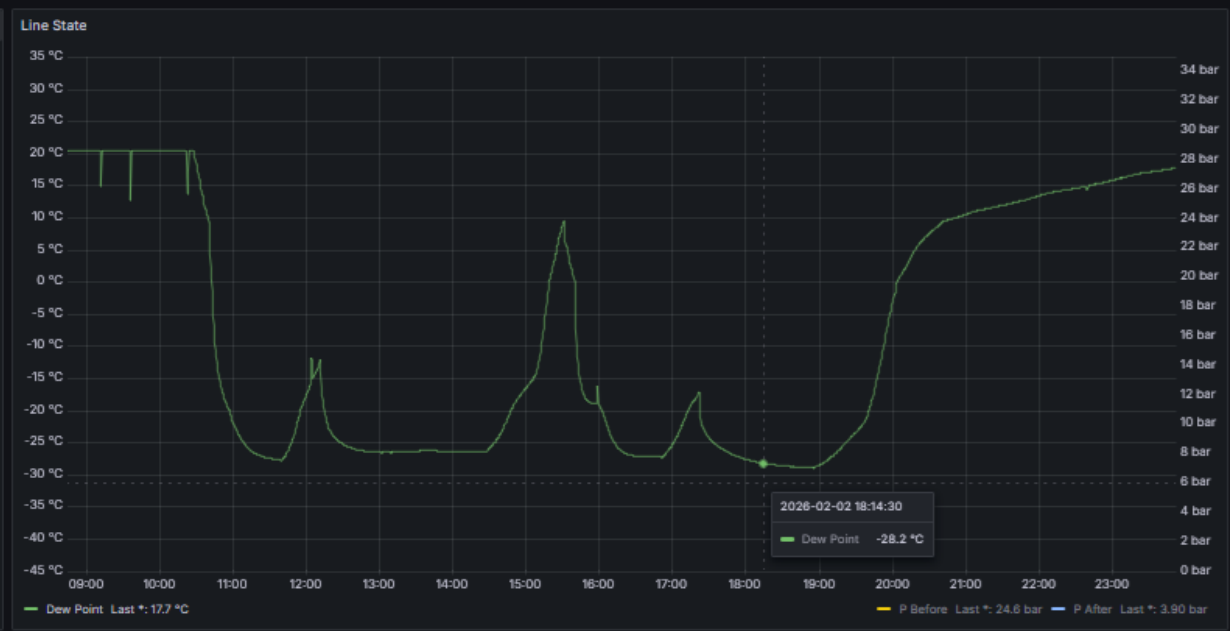
# Controls



# Controls



# Controls





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# Industrial hydrogen today

Global hydrogen production ~**100 Mt/yr**

More than **95% produced from fossil fuels**

Industrial use	Share
Ammonia ( $\text{N}_2 + 3\text{H}_2 \leftrightarrow 2\text{NH}_3$ )	~55%
Refining	~25%
Methanol ( $\text{CO} + 2\text{H}_2 \rightarrow \text{CH}_3\text{OH}$ )	~10%
Steel (direct reduced iron)	growing

Production route	Share	Cost (€/kg)
Steam Methane Reforming ( $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$ and $\text{CO} + \text{H}_2 \rightarrow \text{CO}_2 + \text{H}_2$ )	~75%	1–2
Coal Gasification	~20%	1–2
Electrolysis	<1%	4–10

Niche application: Seasonal energy storage in salt caverns,  $10^3$  ton  $\text{H}_2$  capacity, ~ 40–50 % round-trip efficiency

Ref: IEA Global Hydrogen Review: <https://www.iea.org/reports/global-hydrogen-review-2025>

# H<sub>2</sub> compression systems

Compressor technology	Max P (bar)	Advantages	Disadvantages
Reciprocating (pistons and turbines)	1000	Mature tech, large flows, high compression ratios	Moving parts, lubricants use
Diaphragm	900	Oil free, high gas purity	Limited flow rate, higher capex
Ionic liquid	700	Oil free, good efficiency	Limited industrial experience
Electrochemical	1000	No moving parts, very high purity gas	Low throughput, high capex
Metal hydride	300	No moving parts, very high purity gas	Low compression rate, thermal management

## Energy consumption

2 kWh/Kg (200 bar): 5%, 4 kWh/Kg (350 bar): 10%, 7 kWh/Kg (700 bar): 18%.