*EFC 17069*

# DEMCOPEM-2MW COGENERATIVE PEM FUEL CELL UNIT FOR HYDROGEN RECOVERY FROM CHLOR-ALKALI INDUSTRY IN CHINA: FIRST MONTHS OF OPERATION AND PRELIMINARY DATA ANALYSIS


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**12-15 December 2017 – Naples (Italy)**

# SUMMARY

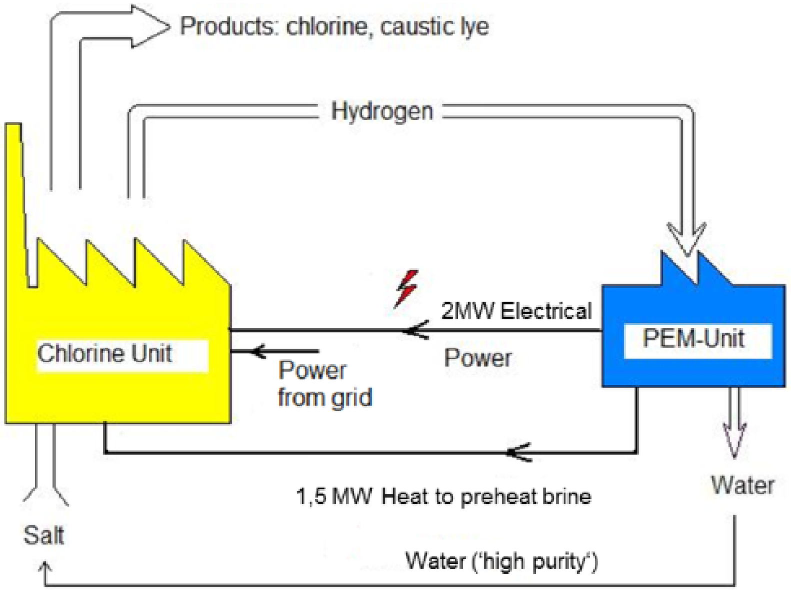
- ✓ DEMCOPEM-2MW PROJECT
- ✓ MW-SCALE COGENERATIVE PEM UNIT
- ✓ FIRST MONTHS OF OPERATION
- ✓ MODELLING AND ENERGY BALANCES OF THE PLANT
- ✓ CONCLUSIONS

# DEMCOPEM-2MW EU PROJECT

Design, construction and demonstration of a combined heat and power (CHP) PEMFC power plant (2MW$_{DC\ el}$)

*and*

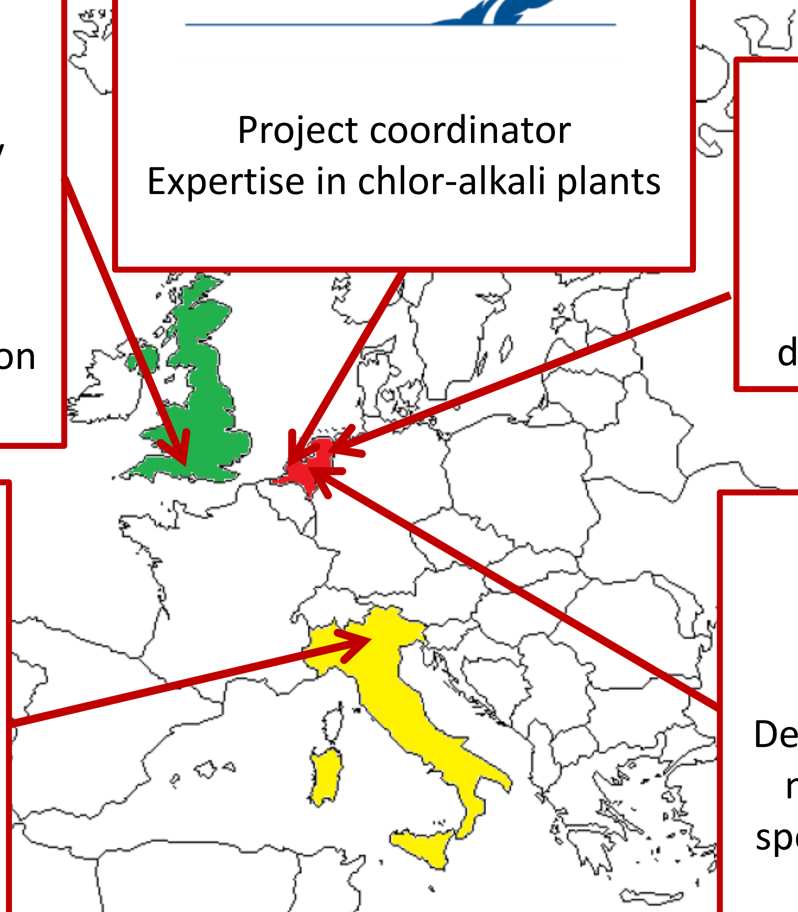
integration into a chlor-alkali industrial plant recovering byproduct hydrogen




## *OBJECTIVES (2015-2019)*

- **High net conversion efficiency** (50% electric and 85% total)
- **Long lifetime** of system and fuel cells (16,000 h up to 40,000 h target)
- Development of **large-volume manufacturing process** for high-quality MEAs
- **Economical plant design** (< 2500 €/kW$_e$)
- Fully **automated operation**
- Ensure plant reliability by developing protocols for **fuel cells monitoring and rapid replacement** of faulty stacks (on-stream availability of > 95%)
- Contribute to the general goals of the FCH-JU for installed fuel cell capacity

# PROJECT PARTNERS



**Johnson Matthey Fuel Cells** – *the power within*

High quality MEA assembly
Manufacturing process development
Performances, robustness, lifetime and costs optimization

**AkzoNobel**

Project coordinator
Expertise in chlor-alkali plants

**Nedstack** PEM FUEL CELLS – *To be sure.*

PEM fuel cell stack development and production

**POLITECNICO MILANO 1863**

Power plant simulation model development, calibration and validation
Analysis of experimental measurements

**MTSA TECHNOPOWER**

Development, production and maintenance of customer-specific equipment for energy processes

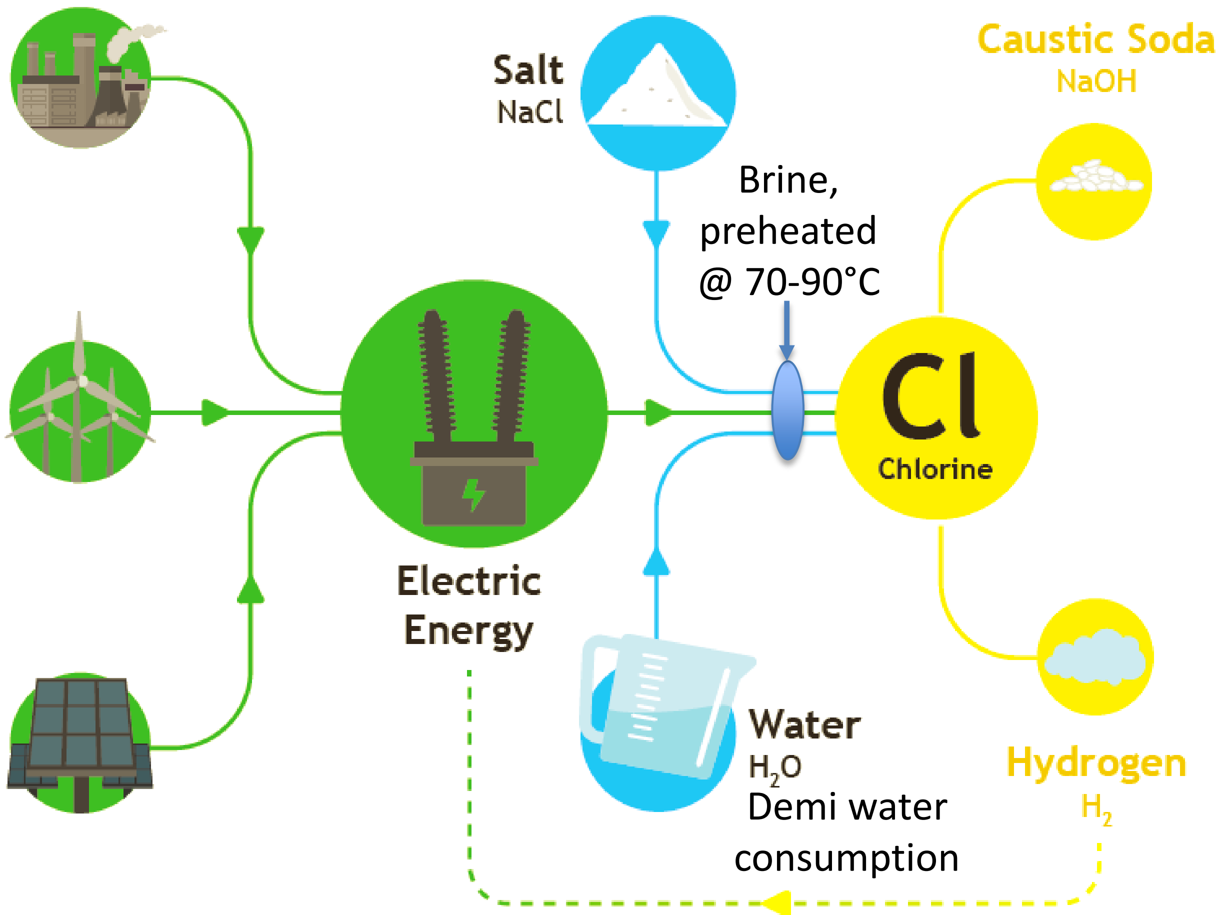
# PROJECT ACTIVITIES

| PEM CELLS AND STACKS DEVELOPMENT<br>LARGE SCALE INDUSTRIAL PRODUCTION | PEM SYSTEM INTEGRATION, OPERATION and LIFETIME MAINTEINANCE | SYSTEM MODELLING and DATA ANALYSIS |
| --- | --- | --- |
| Development of large-volume manufacturing process for high-quality MEAs.<br>Improvement of MEAs and stacks according to on-field experience. | Optimization of operating conditions and system development.<br>Mainteinance and operation in relevant industrial environment. | Modelling of system operating conditions and performances for measured data validation, identification of possible issues and further optimization. |
| Johnson Matthey Fuel Cel; Nedstack | Nedstack; MTSA Technopower | Politecnico Milano 1863 |

**COORDINATION / DISSEMINATION / COMMUNICATION / EXPLOITATION**

AkzoNobel

The Chlor-alkali process is suitable for integration with low temperature fuel cells




**Up to 50% of chlorine production cost is due to electrical energy**

**Excess hydrogen (**340 $Nm^3H_2/ton_{Cl}$**) can efficiently feed a fuel cell plant**

Source: EuroChlor, "Chlorine industry review 2015-2016", Brussels, 2015

# PREVIOUS PROJECTS: PEMFC PLANTS SCALE-UP

Installation is in **China:**

- high electricity price
- issues with electricity supply shortages
- large chlor-alkali plants market - ca. 180 plants – >1000 $MW_{el}$ PEM potential

Scale-up based on previous experiences (Nedstack & MTSA)

- **70 $kW_{el}$** PEM Power Plant at AkzoNobel (Delfzijl, NL, 2007)
- **1 $MW_{el}$** PEM Power Plant at Solvay (Antwerp, BE, 2011)

# PLANT OPERATION

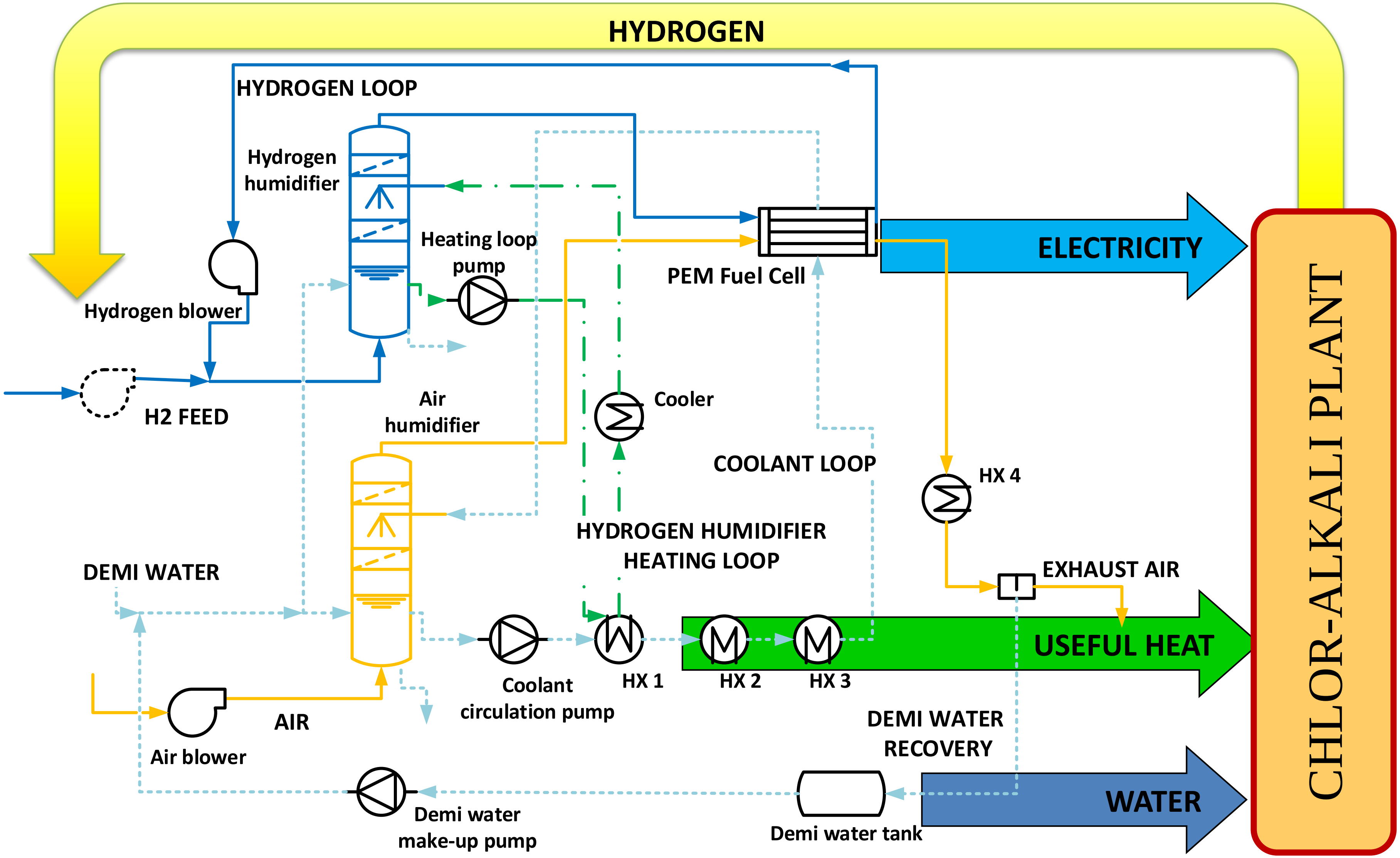
**Construction and shipment** of the plant in mid 2016 from MTSA factory (NL)

https://www.youtube.com/watch?v=W8QE8iEXAyM


**Opening ceremony** on 14 October 2016 at plant location of Ynnovate Ltd in Yingkou, China

- More than one year of plant operation: **data analysis**

# PLANT STRUCTURE

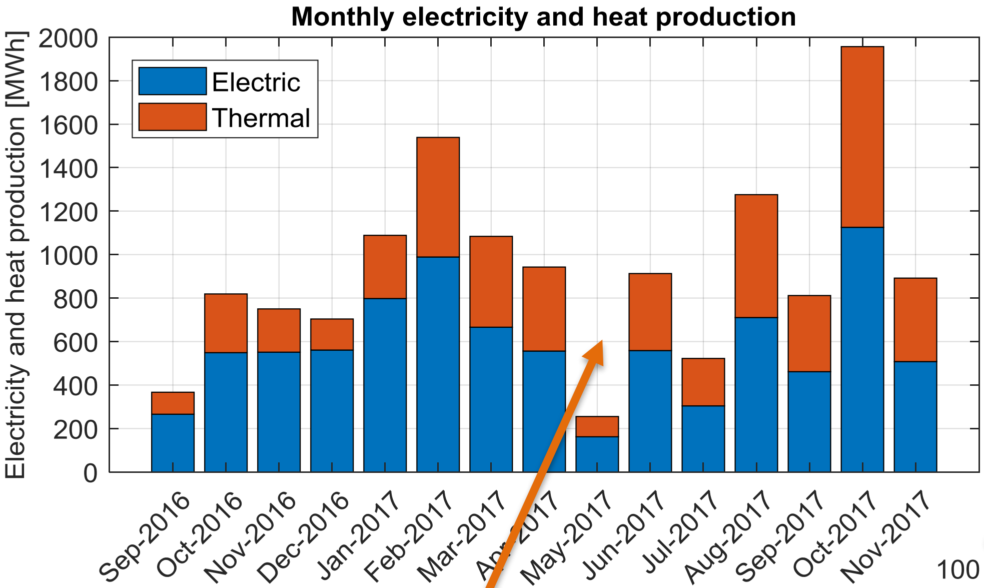


# Plant structure




The previously described plant is arranged in three containers units, resulting in the world largest stationary PEM fuel cell system in operation (2 $MW_{el}$).

# PLANT GLOBAL PERFORMANCES

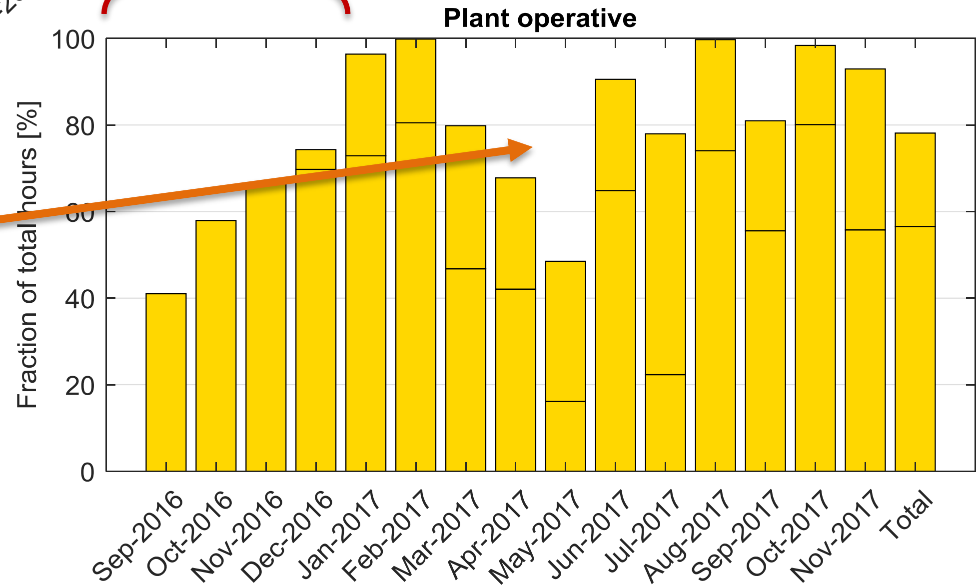



The plant has been operative since September 2016 and reached full-load capacity in January 2017.

The plant has been active for more than 8400 hours (vs. 10400 calendar hours).

**Initial plant operation with some limitations**

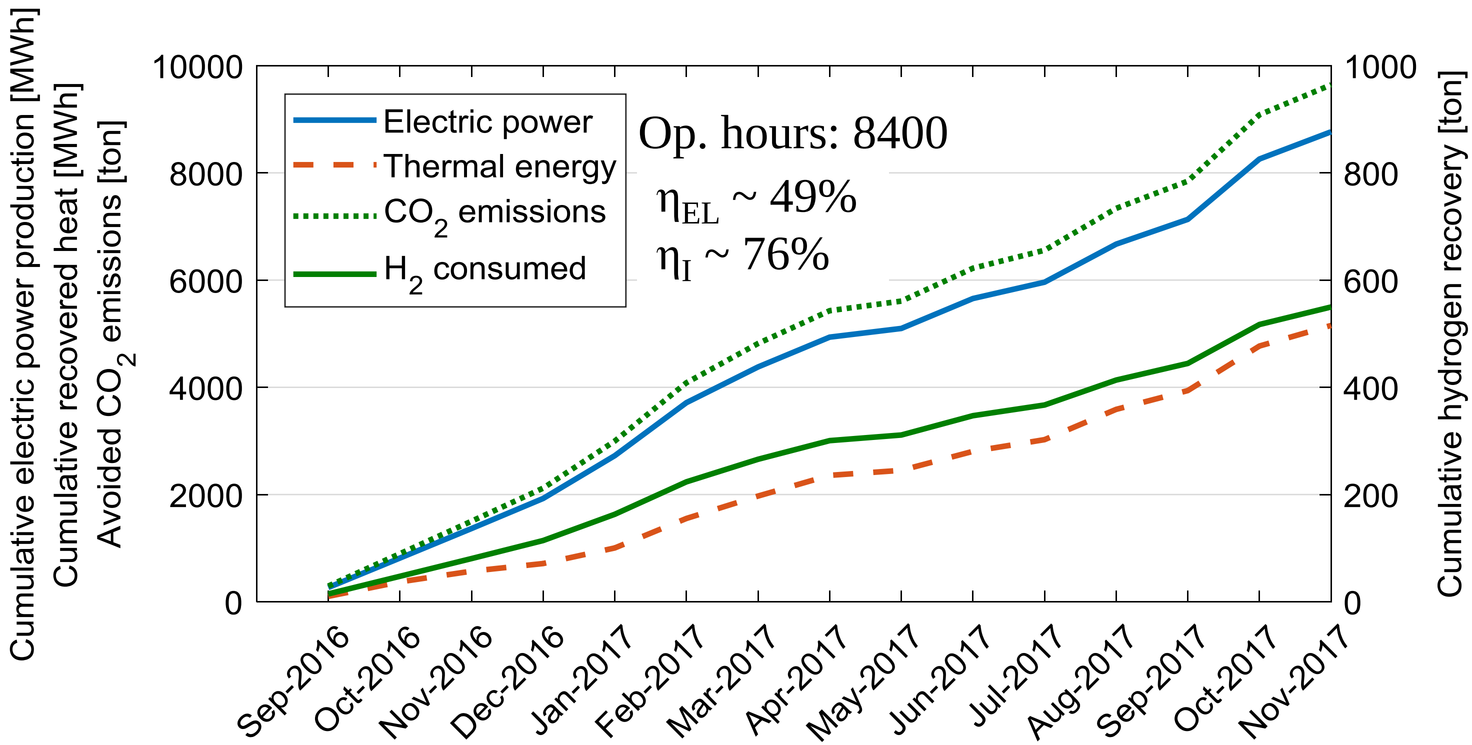
**Plant is often operated at part load (not all modules running) depending on hydrogen availability**




Thermal energy is calculated from measurements - although currently not recovered by the chlor-alkali plant.

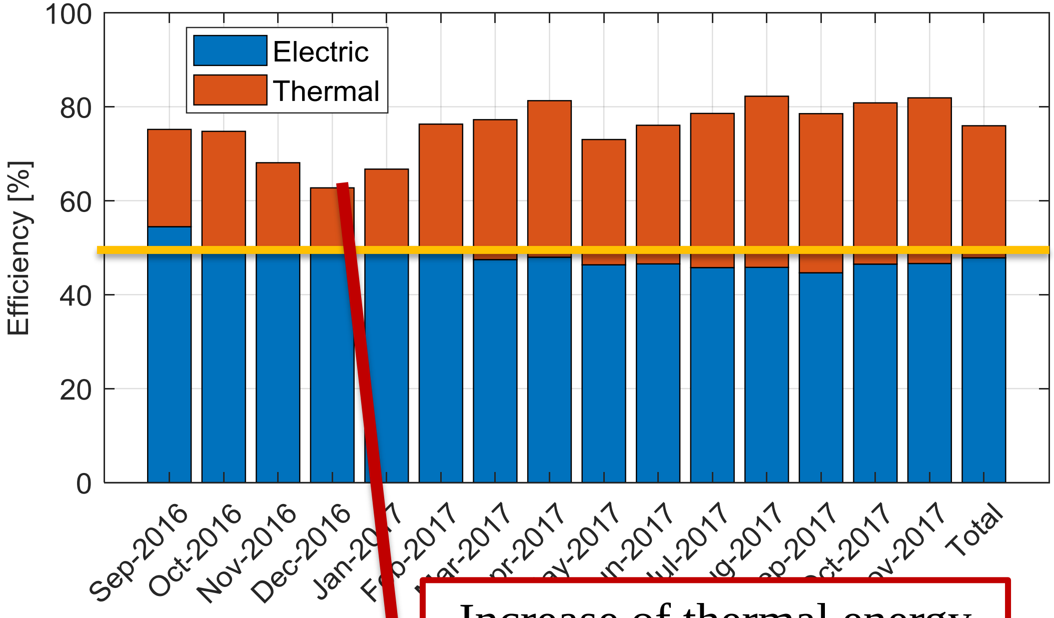
# PLANT GLOBAL PERFORMANCES

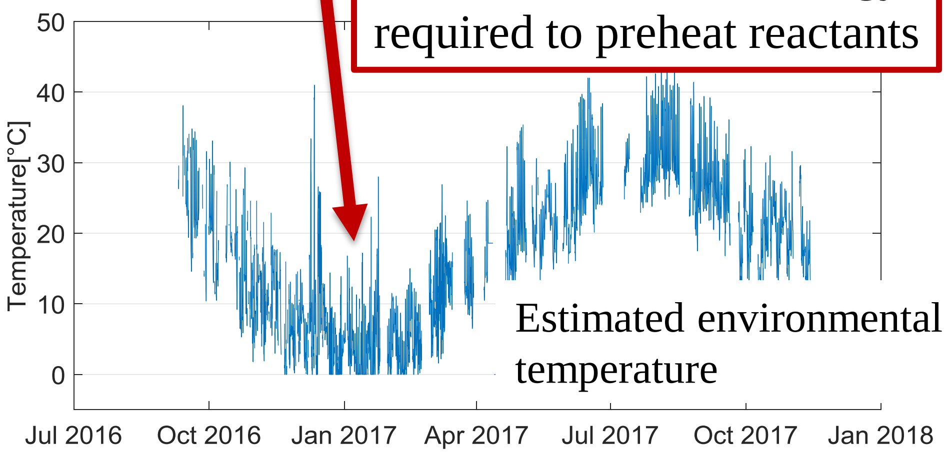
Globally, the plant produced about 9 GWh wihtout significant interruptions, making available 5 GWh of thermal energy at about 65°C.




Hydrogen is a byproduct from the industrial plant. More than 500 tons of hydrogen otherwise lost have been recovered, with an average electric efficiency of ~49%$_{LHV}$.

# PLANT GLOBAL PERFORMANCES



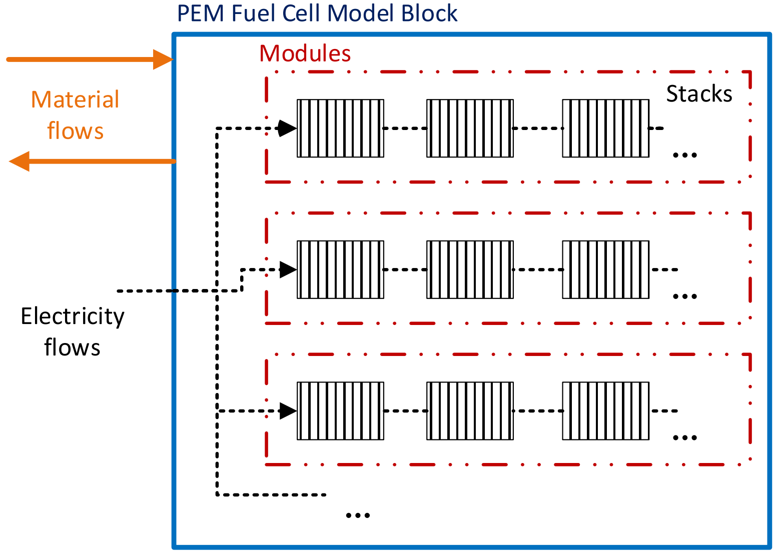

The measured **BOL electric efficiency** was 55%$_{LHV}$ and during the first year of operation the **average net electrical efficiency** has been ~49-50%$_{LHV}$ (56-57%$_{LHV}$ gross).

Additional 26%$_{LHV}$ (average) could be recovered as **thermal energy** leading to a global first law efficiency of nearly 76%$_{LHV}$ (peaks over 80%)

**Thermal energy recovery is strongly influenced by the harsh winter climate in Yingkou, China. Thermal efficiency ranges from 32% to 12%.**

- ➢ Average performances are aligned with the project expectations.

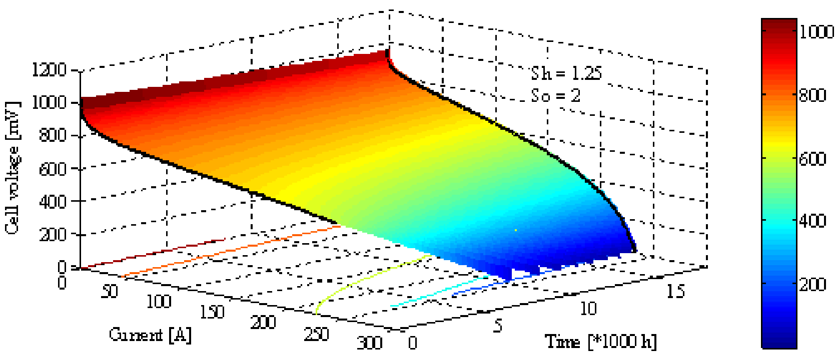
# PEM FUEL CELL MODEL




Lumped model developed in Aspen Custom Modeler, for integration with the balance of plant in Aspen Plus.

**Modular modelling approach reproduces the layout of the plant**:

STACKS ➔ MODULES ➔ GROUPS



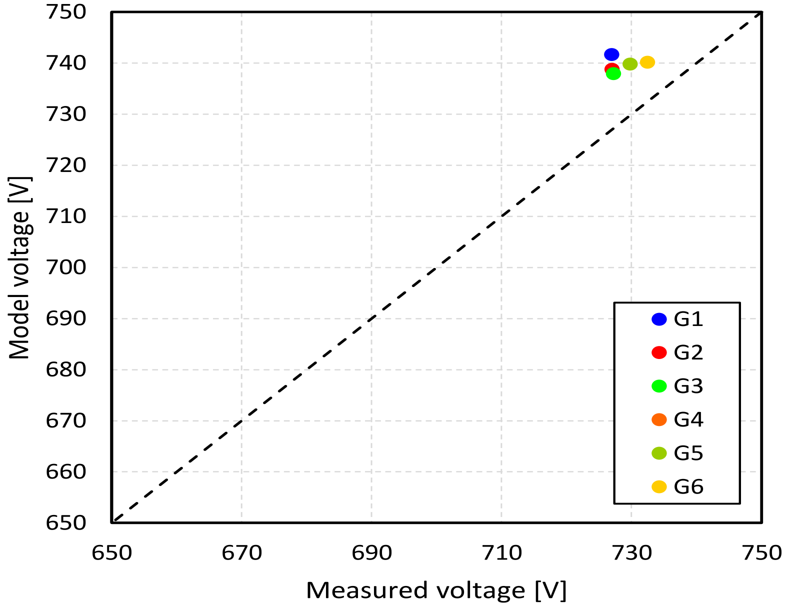

**Empirical formulation of the i-V curve, validated against experimental data**

- Considers reactants stoichiometry ($x_{H2}$, $x_{O2}$), exchange and limit current density ($i_0$, $i_L$), linear long-period voltage decay ($t_{BoL}$-$t_{EoL}$)
- In its first version, neglects T and RH effects: stacks at constant T and RH thanks to the cooling water circuit and humidifiers

$$V(i, x_{H2}, x_{O2}) = \left[A + B\ln\left(\frac{x_{H2}}{x_{H2,st}}\right) + C\ln\left(\frac{x_{O2}}{x_{O2,st}}\right) + Di + E\ln\left(\frac{i}{i_0}+1\right) + F\ln\left(1-\frac{i}{i_L}\right)\right] - G\,t(t_{BoL}, t_{EoL})$$

The complete PEMFC **power plant model is compared with field data.**

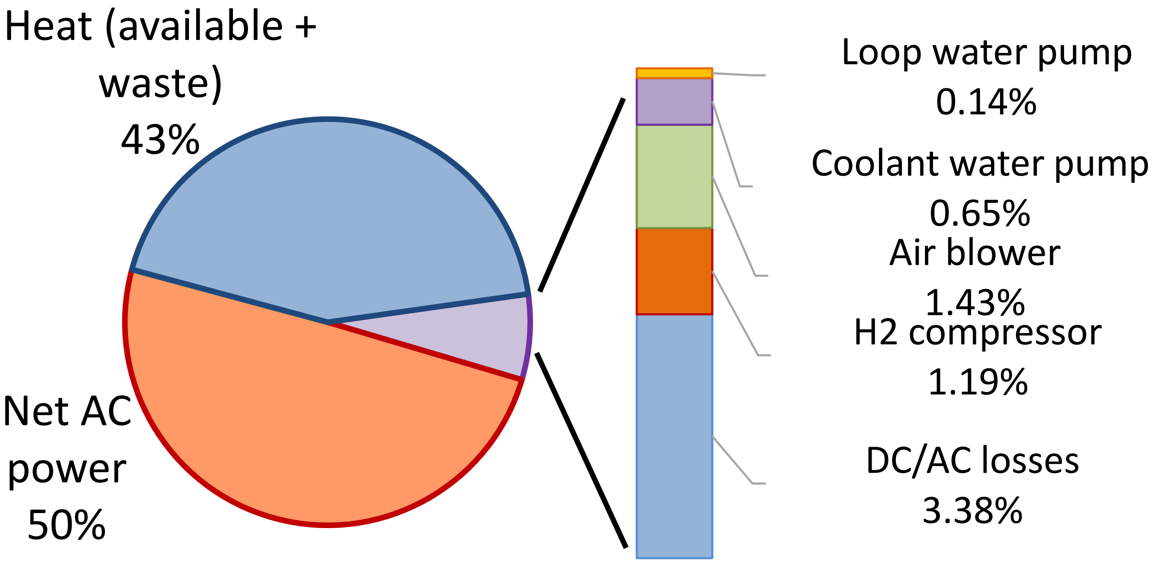
Voltage deviation at plant start-up




| **Property** | **Model-Measurements deviation [%]** | | |
|---|---|---|---|
| Date | 15 Sep 16 | 19 Sep 16 | 13 Oct 16 |
| Active groups | 5/6 | 4/6 | 5/6 |
| Current [A] | -1.8% | -3.4% | -6% |
| Voltage [V] | +1.8% | +3.4% | +6.3% |
| Auxiliaries power [kW] | -1.2% | +9.7% | +6% |
| Coolant flowrate [$m^3/h$] | -0.6% | -0.5% | +0.1% |
| Stack temp. [°C] | -1.3% | -1.4% | -2.6% |

- Good agreement at Beginning of Life
- Limited agreement after 1 month of operation, mainly due to an initial settlement of voltage and to the  effect of reversible decay in each operating run (not included in the model)

## *Plant energy balance at BOL*




A large quantity of low temperature heat (@ ~63°C) could be exploited by an external user. The amount is dependent on environmental temperatures due to system heat losses.

Compression and DC/AC conversion are the most significant losses.

- From long-term operation estimations, based on plant simulation, the electric efficiency loss during lifetime (about 6%) is partially recovered as additional heat.

- Results of modelling activities for BOL have been positively validated on on-field data.

# Conclusions & Outlook

The coupling of a large scale PEM fuel cell system with a chlor-alkali industrial plant for byproduct hydrogen recovery is under demonstration with satisfying results.

- The DEMCOPEM 2MW plant has been built on time and is currently in operation.
- BOL performances are aligned with the expectations (net electric efficiency over 50%, large thermal recovery capability) and plant availability is high.
- Part load operation and forced standby are mainly due to hydrogen availability, a situation which has recently been solved.
- Modelling activities yield results which are aligned with measured data.

*Next steps:*

- Analysis of plant performance data during the second year of operation and analysis of reversible decay phenomena
- Partial substitution of stacks with improved versions (MEAs development)
- Analysis of options for efficiency improvement (including thermal energy usage, not currently performed due to requirements of the industrial plant).

# Thank you for your attention!

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