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Modeling of 2-MW co-generative PEM fuel cell for hydrogen recovering from Chlorine industry

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SUMMARY

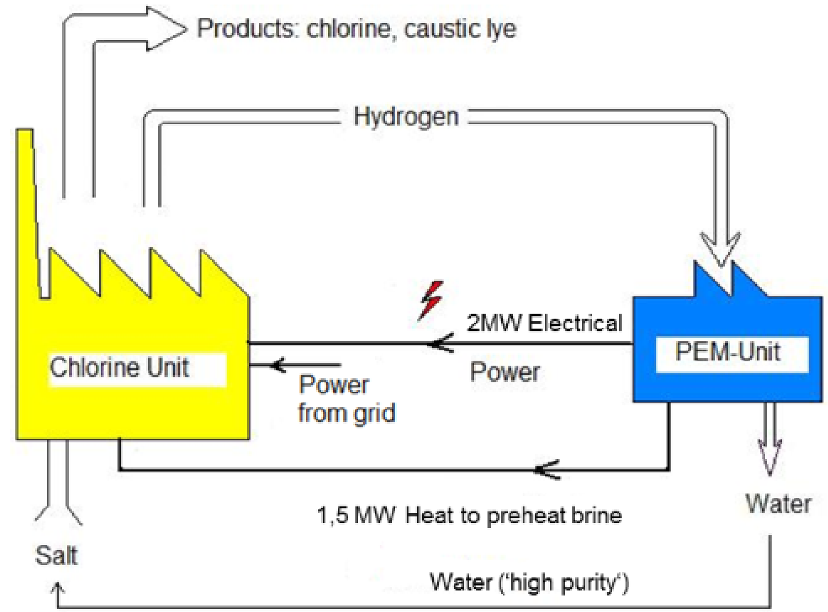
- ✓ DEMCOPEM-2MW PROJECT OUTLINE
- ✓ PLANT MODELLING
  - ✓ REFERENCE PLANT LAYOUT
  - ✓ FUEL CELL MODELING AND VALIDATION
  - ✓ SIMULATION RESULTS
  - ✓ ALTERNATIVE PLANT OPTIONS (POST-COMBUSTION)
- ✓ CONCLUSIONS & FUTURE WORK

DEMCOPEM-2MW EU PROJECT

DESIGN, CONSTRUCTION AND DEMONSTRATION OF A COMBINED HEAT AND POWER PEM FUEL CELL POWER PLANT (2MW_{EL}, 1.5 MW_{TH})

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)
- Develop a capable **volume manufacturing process** for high quality MEAs
- Fully **automated operation and remote control**
- **Economical plant design** (< 2500 €/kW_e)
- 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

DEMCOPEM 2MW

Johnson Matthey Fuel Cells
the power within

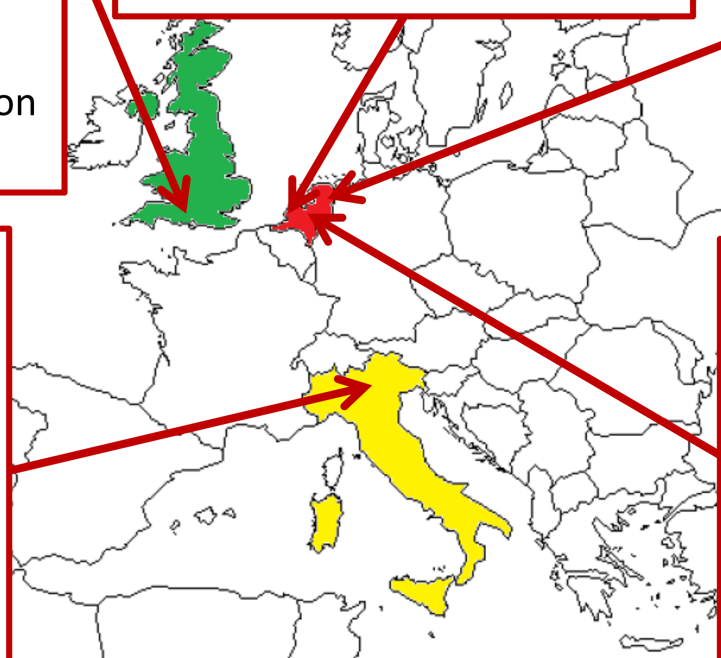
High quality MEA assembly
Manufacturing process development
Performances, robustness, lifetime and costs optimization

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

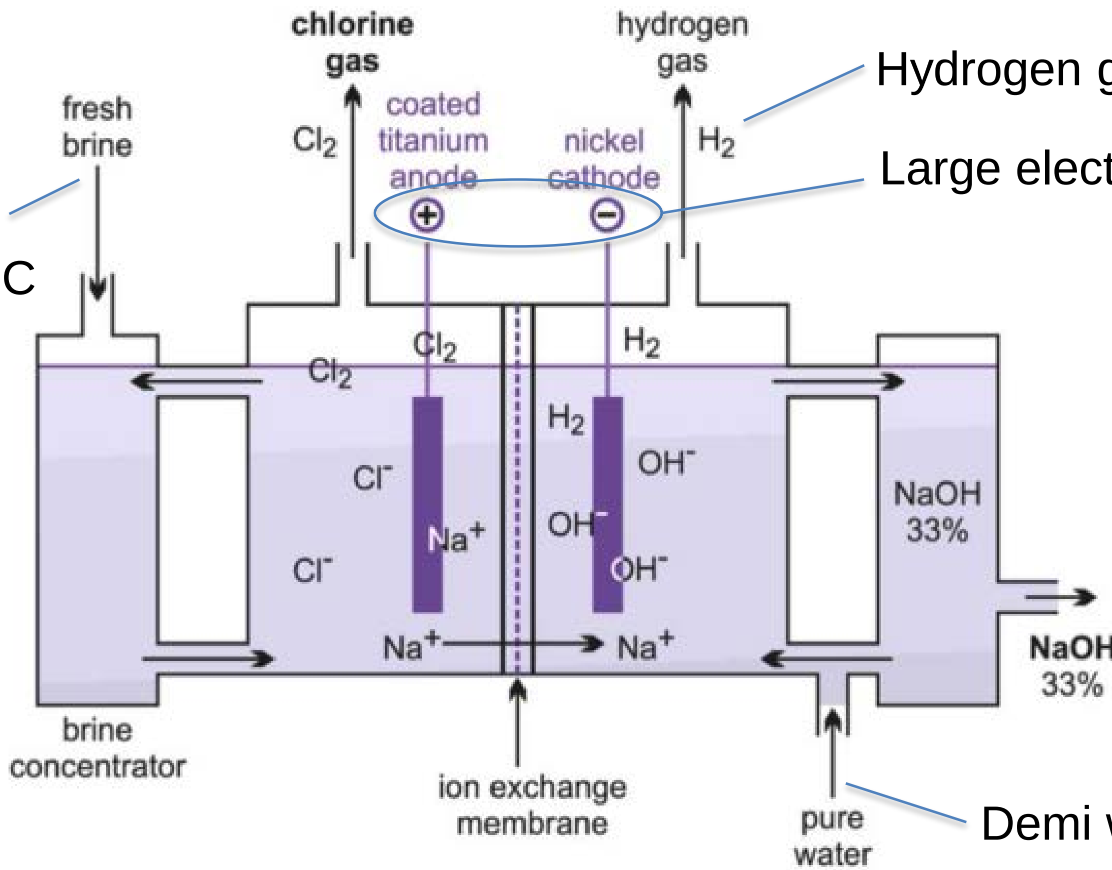
The Chlor-alkali process is suitable for integration with low temperature fuel cells

Reactants pre-heating: cells work at about 70-90°C

Hydrogen generated as byproduct

Large electricity consumption (DC)

Demi water consumption



DEMCOPEM-2MW EU PROJECT

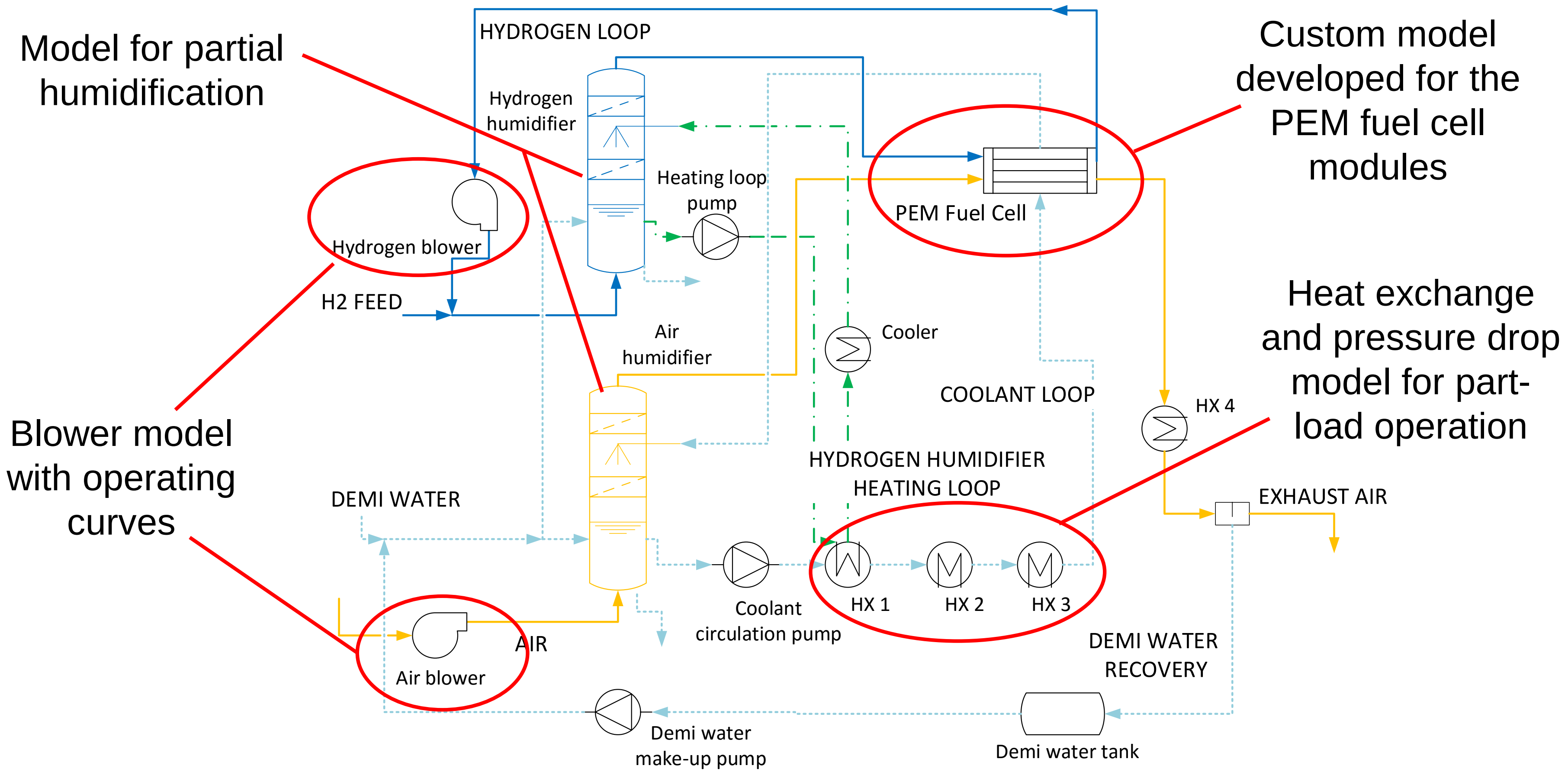
Demonstration will be in Northern **China** (high electricity price, issues with supply shortages, large Chlor-alkali plants market - ca. 180 plants)

SCALE-UP BASED ON PREVIOUS EXPERIENCES (Nedstack & MTSA)

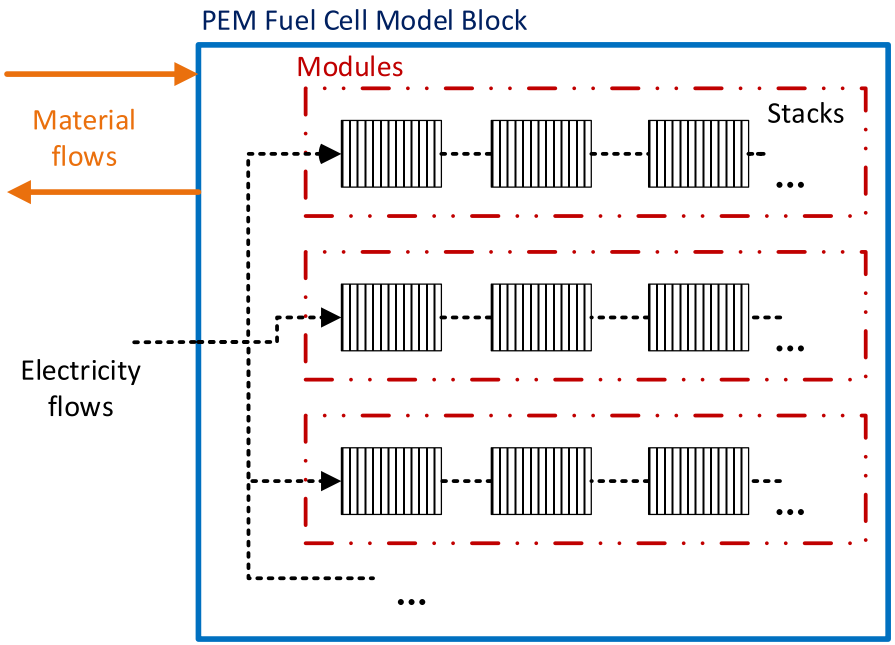
- 70 kWe PEM Power Plant at AkzoNobel (Delfzijl, NL, 2007)
- 1 MWe PEM Power Plant at Solvay (Antwerp, BE, 2011)

MODEL FEATURES

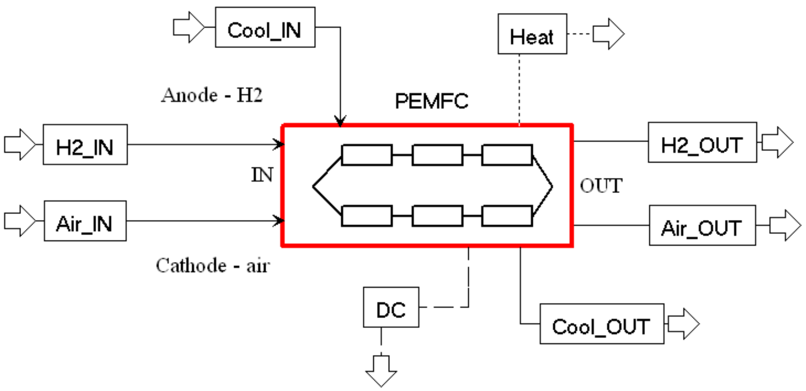
- Model implemented in Aspen PLUS for full load and part-load analysis
- First phase validation vs. 1 MW plant layout and performance data



PEM FUEL CELL MODEL

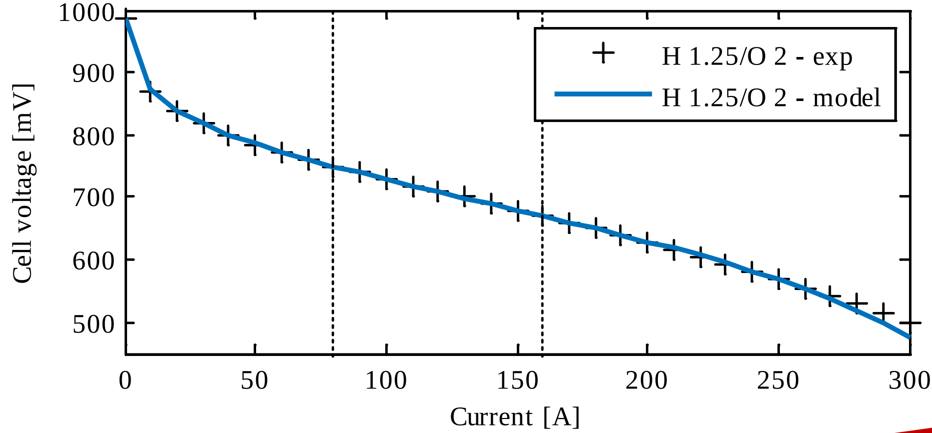


Development of a specific custom model, lumped (0D) type



- The model considers **polarization curves, mass and energy balances, heat exchange** (either at constant temperature, heat duty or heat exchange coefficient)
- **Pressure drop** correlations are also included
- The fuel cell can be controlled in current, power or reactants excess
- The FC **operating temperature** is controlled through the coolant flow

PEM POLARIZATION CURVES

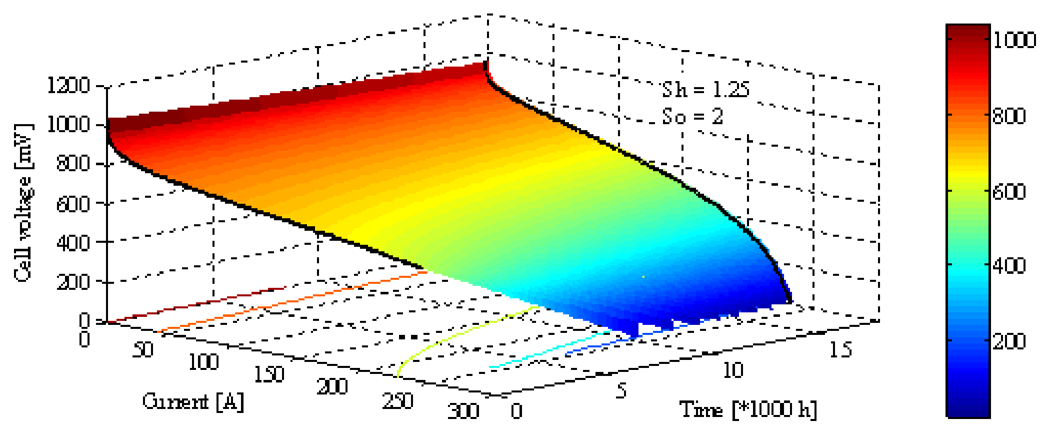


Temperature effects on the PEM are not taken into account (the FC is expected to work at ~ constant temperature thanks to the cooling loop)

Reactants ratio to stoichiometry, exchange and limiting current effects are included

$$V(i, x_H, x_O) = A + B \ln\left(\frac{x_{H2}}{x_{H2,st}}\right) + C \ln\left(\frac{x_{O2}}{x_{O2,st}}\right) + Di + E \ln\left(\frac{i}{i_0} + 1\right) + F \ln\left(1 - \frac{i}{i_L}\right)$$

- Both Beginning of life (BOL) and End of Life (EOL) polarization curves are regressed vs. experimental datasets
- Intermediate conditions (mid of life, MOL) are found assuming a linear decay (i.e. constant decay rate)



POLARIZATION CURVES - VALIDATION

The model is checked against data available for single modules provided by Nedstack, leading to acceptable errors on voltage prediction @ BOL and EOL

BOL

Clear linear behavior in the main current operating range

RMSD 4.33 mV

0.6% max error on V in operating range

(5% error at very high currents - out of operating range)

EOL

Evidence of non-linear losses especially in the high current operating range
Higher uncertainty in test conditions and operational history

RMSD 15.35 mV

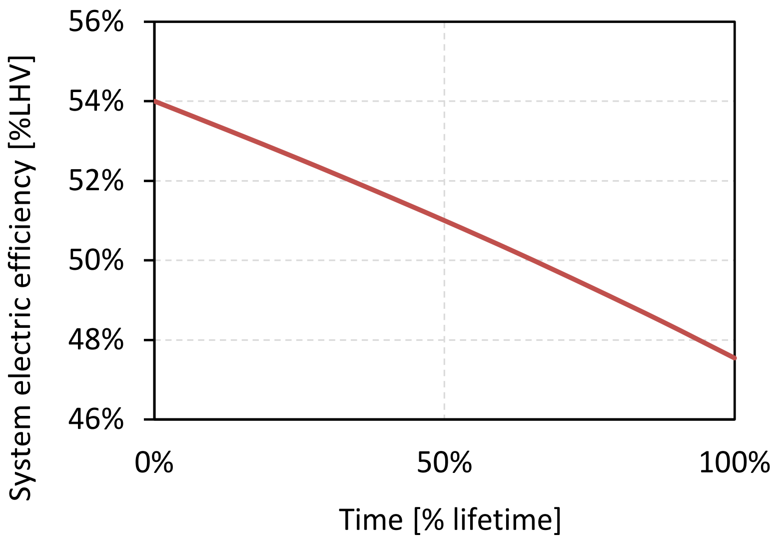
3.5% max error on V in operating range

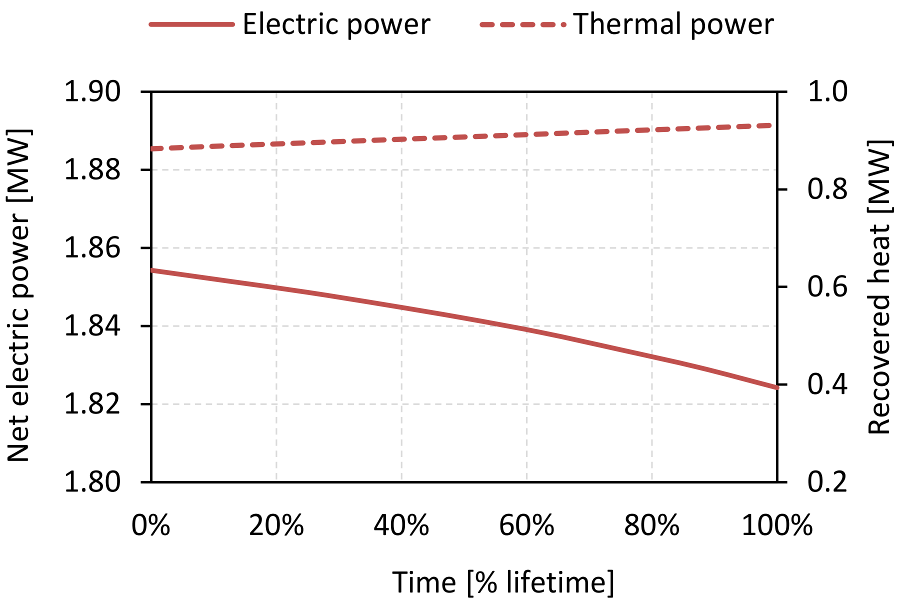
(larger error at very high currents - out of operating range)

- Impact on final estimation of power production is <1% (comparable to typical stack performance variations due to different production lots)

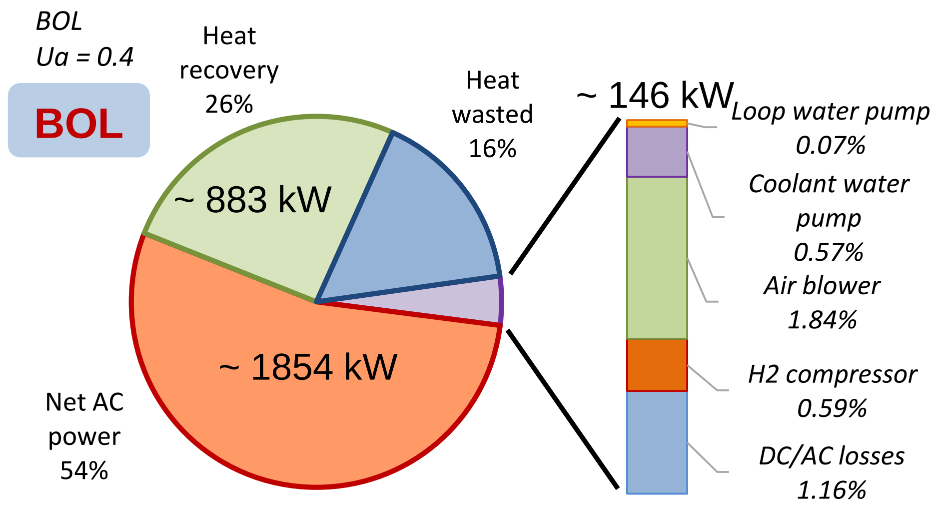
2 MW PLANT SIMULATION – EFFICIENCY AND POWER VS. TIME

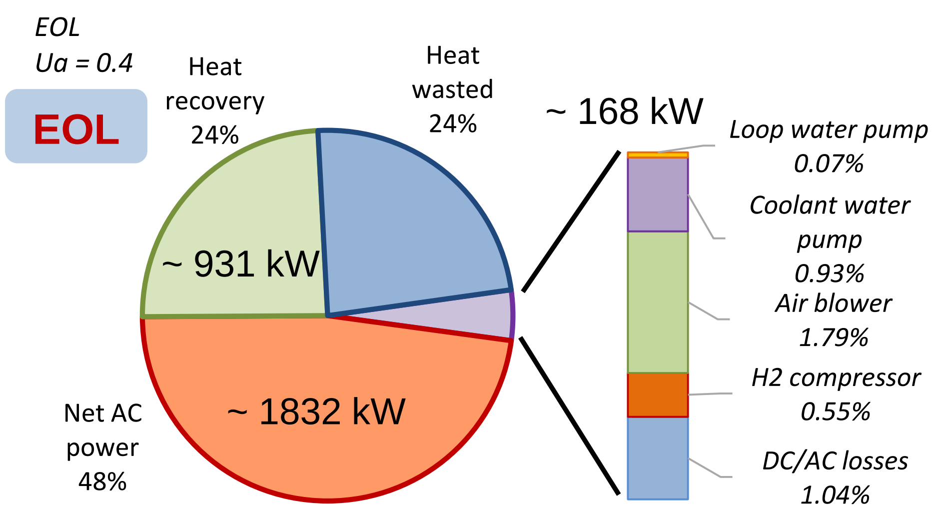
- The analysis is carried out here with a *constant DC power output control*
- During lifetime, stack voltage decay influences the whole plant: a reduction of about 6% in el. efficiency is expected if no compensating actions is adopted
- Possible compensating action have been investigated: variable reactant stoichiometry control (e.g. switch to lower utilization during lifetime)
- Significant impact on net electric power production and recovered thermal power: the electricity-to-heat ratio decreases from 2.1 to 1.9





2 MW PLANT SIMULATION – ENERGY BALANCES



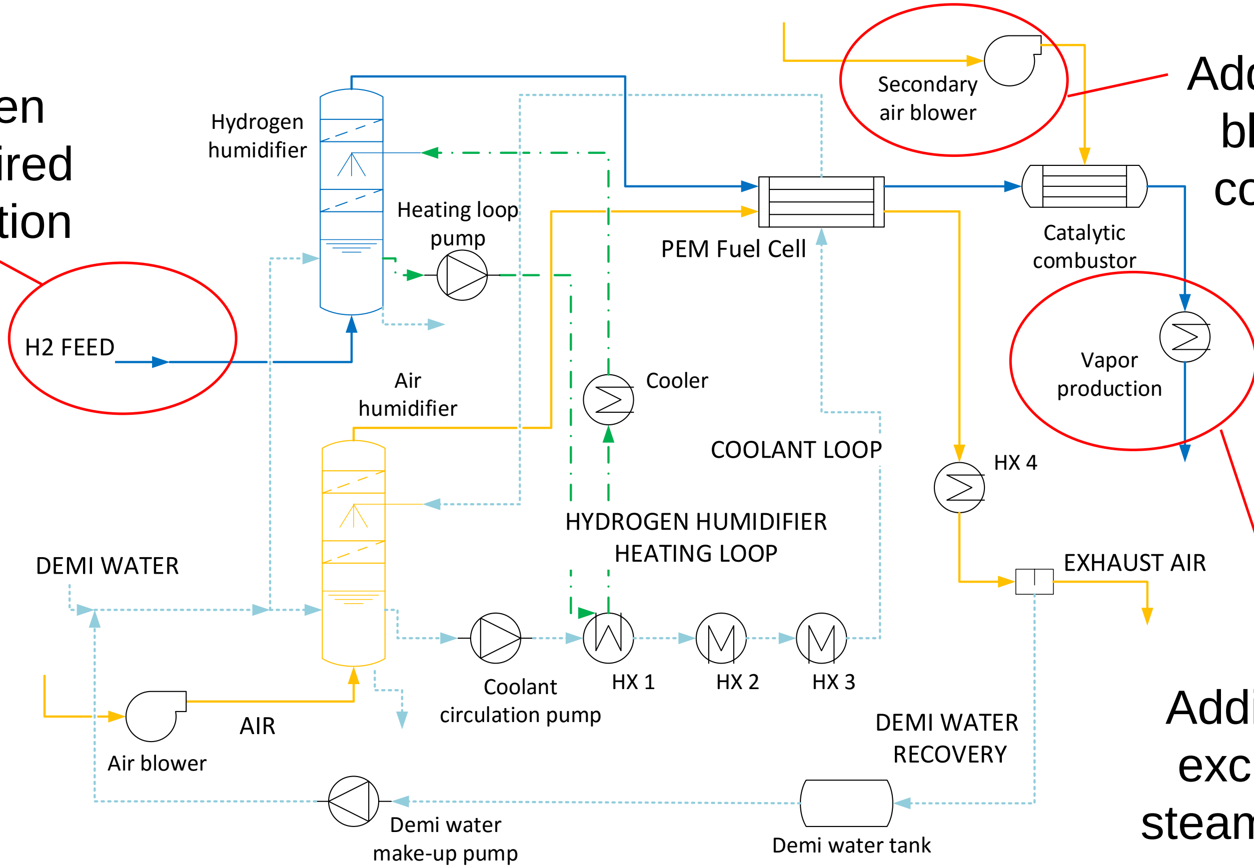


- FC voltage decay at EOL is compensated with an increased hydrogen input (~10%) to keep the same DC electric production
- Increase of available heat for recovery
- Auxiliary consumptions are mainly related to air blower; cooling water pump has the higher increase from BOL to EOL (nearly double)
- Alternative operational strategies:
  - constant H_2 input / change operating point of FCs (resulting in a net reduction of electric output)
  - change of reactants excess (resulting in lower available heat, but increased efficiency)

ALTERNATIVE LAYOUT : POST-COMBUSTION

- ✓ The plant can produce 'industrial quality' steam @200°C, 10 bar
- ✓ Net electric efficiency is reduced to 28÷31%, while total (heat+electricity) efficiency is between 88% (constant DC output @ 2 MW, Q_{rec}=4.3 MW_{th}) and 98% (constant H_2 input @ 3.4 MW_{LHV} , Q_{rec}=2.4 MW_{th})

No hydrogen blower required for recirculation



Additional air blower for combustor

Additional heat exchanger for steam production

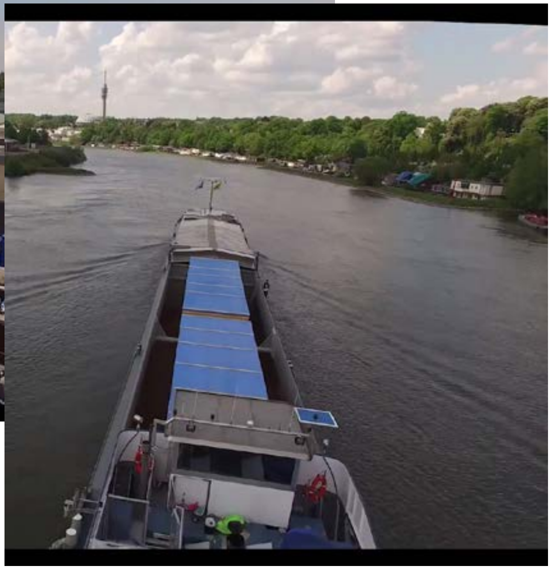
CONCLUSIONS

- We developed the simulation of DEMCOPEM 2 MW plant with a specific plant and FC model
- Simulation results investigate the effects of expected FC performance decay during lifetime (i) at constant electric output and (ii) at constant hydrogen input; evidencing the changes in electric efficiency, heat production, total efficiency, H_2 input requirements / power output
- The analysis shows the opportunity of adopting corrective actions on plant operating point (i.e. changing reactants excess, temperatures…)
- The possibility of post-combustion instead of H_2 recirculation is also addressed (suitable when high temperature steam is required, but brings about a low (~30%) electric efficiency).
- Next steps: refine modelling with respect to decay evaluation and uneven flow distribution
- Once the plant is in operation, model will be validated on experimental measurements / exploited to define the optimal operational strategy vs. lifetime / identify possible improvement actions applicable to next generation large scale PEM fuel cell plants.

THE PLANT IS ON HIS WAY…

Images from "Droneshots transport energiecentrale MTSA", Triggerfilm NL, https://www.youtube.com/watch?v=W8QE8iEXAyM

After successful Factory Acceptance Tests, the plant is now travelling to China and launching ceremony is foreseen in Q4, 2016
@ Ynnovate Ltd in Yingkou, Liaoning province, China



A dedicated panel will be held at the ***International Conference on Applied Energy (ICAE)*** in Beijing , October 8-11, 2016

Thank you for your attention!

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