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PEM FUEL CELLS
To be sure.

New Energy World JU
fuel cells & hydrogen for sustainability

30,000 hours of PEMFC system operation at a chlor-alkali plant

Stayers: effect of feed contaminants

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Jorg Coolegem, Hakan Yildirim, Frank de Bruijn

We are dedicated to designing and producing the best value for money PEM fuel cell stacks in the market.

Stationary PEM fuel cells with lifetimes beyond 5 years

<u>Goal</u>:
> 40.000 hours stationary operation lifetime of PEM fuel cell

<u>Motivation</u>:
lower replacement frequency PEMFC stacks over economic lifetime Power Plant
→ lower cost of ownership PEMFC Power Plant

Development & Commercialization:

Membrane → MEA → Stack → System integrators → End users

Testing + modeling:

Research topics STAYERS project

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A	Components Investigated / Developed (I/D):	STAYERS	Presentation
1	membrane	D	
2	MEA	D	X
3	catalyst/electrode	D	
4	GDL	I	
5	cell plates	D	
6	seals	D	
7	BOP	I	X

STAYERS 1 2 3 4 5

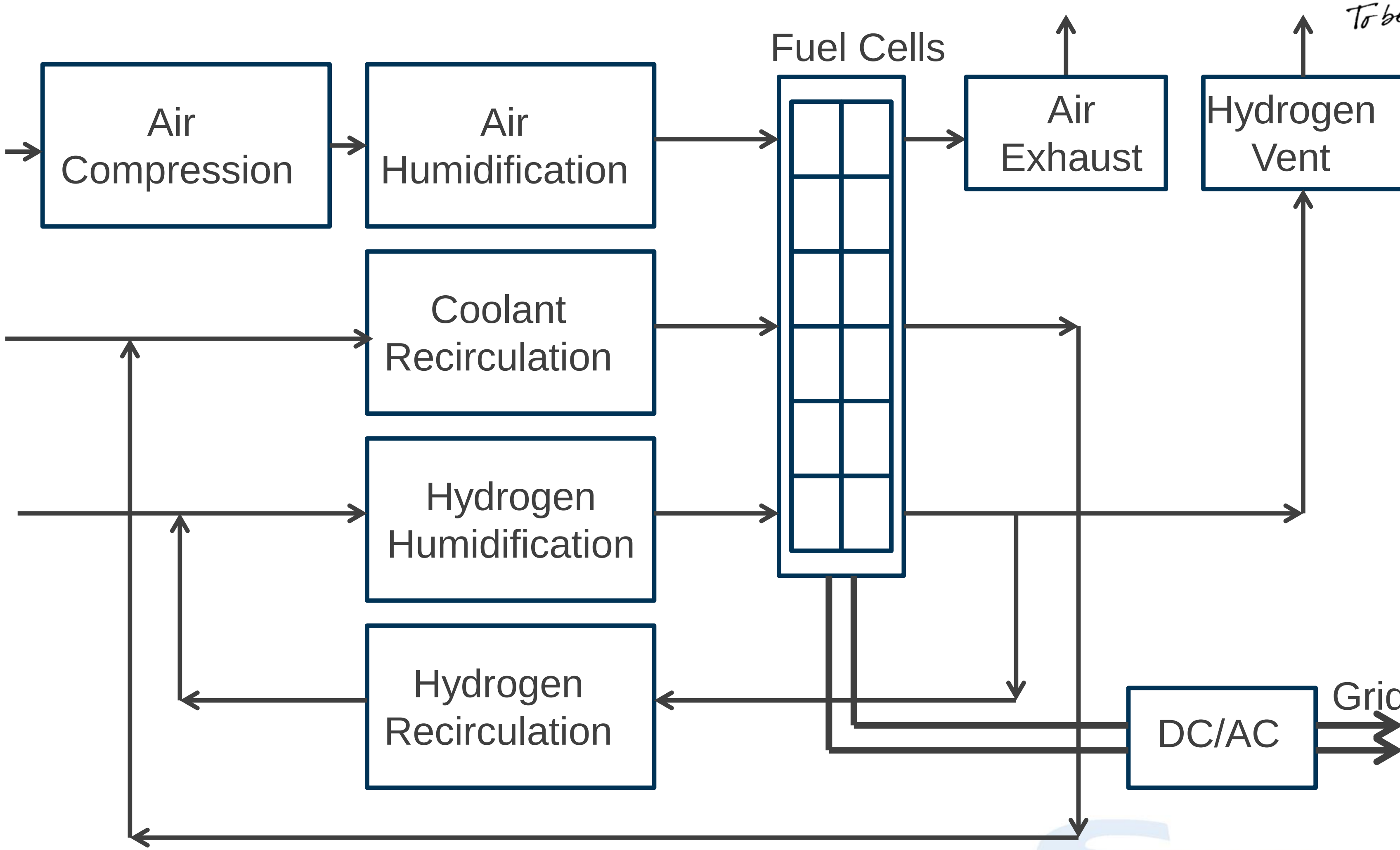
Set up & conditions stack duration test at a chlor-alkali plant

- Tower of 2x6 stacks
- 75 cell/stack, 900 cells
- Avg output: 100 A / 600V: 60 kW
- Start: April 2007
- March 2013: Total hours to grid >33.000

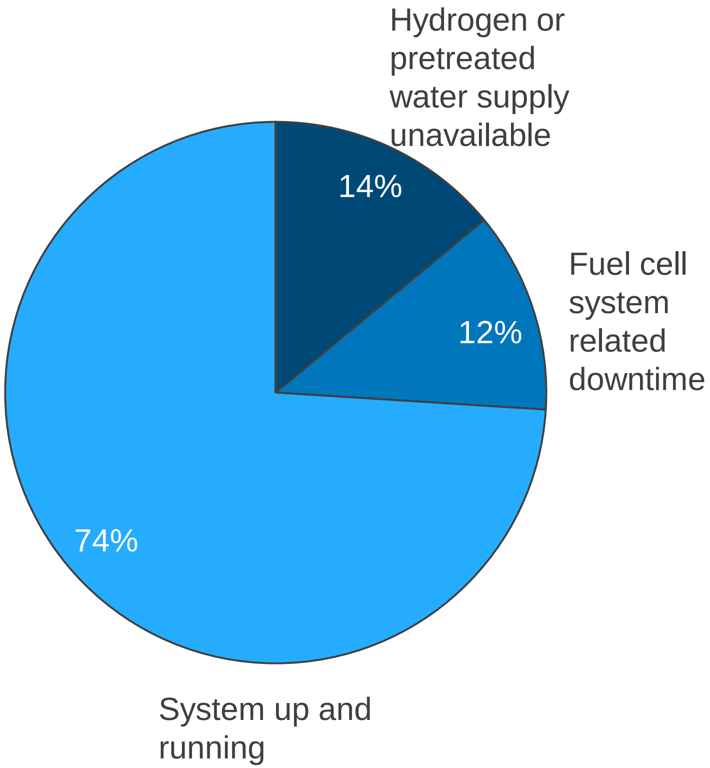
Operation conditions favorable for durability:

System	J [A/cm2]	Stoich. ratio Cathode	Stoich. ratio Anode	T stack [deg. C]	RH cathode [%]	RH anode [%]
Power plant Delfzijl	0,5	3.3	2.4	65	85	85

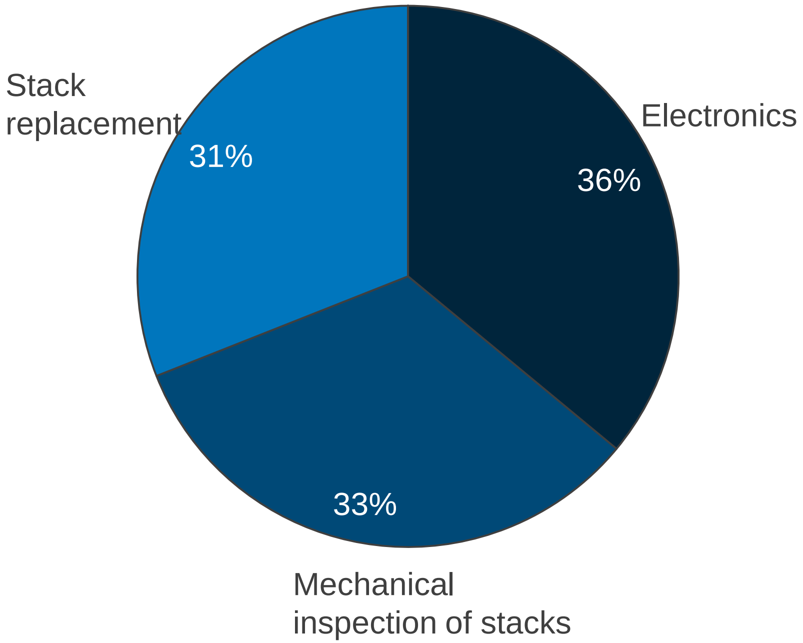
System layout



System uptime over period September 2010 – January 2013



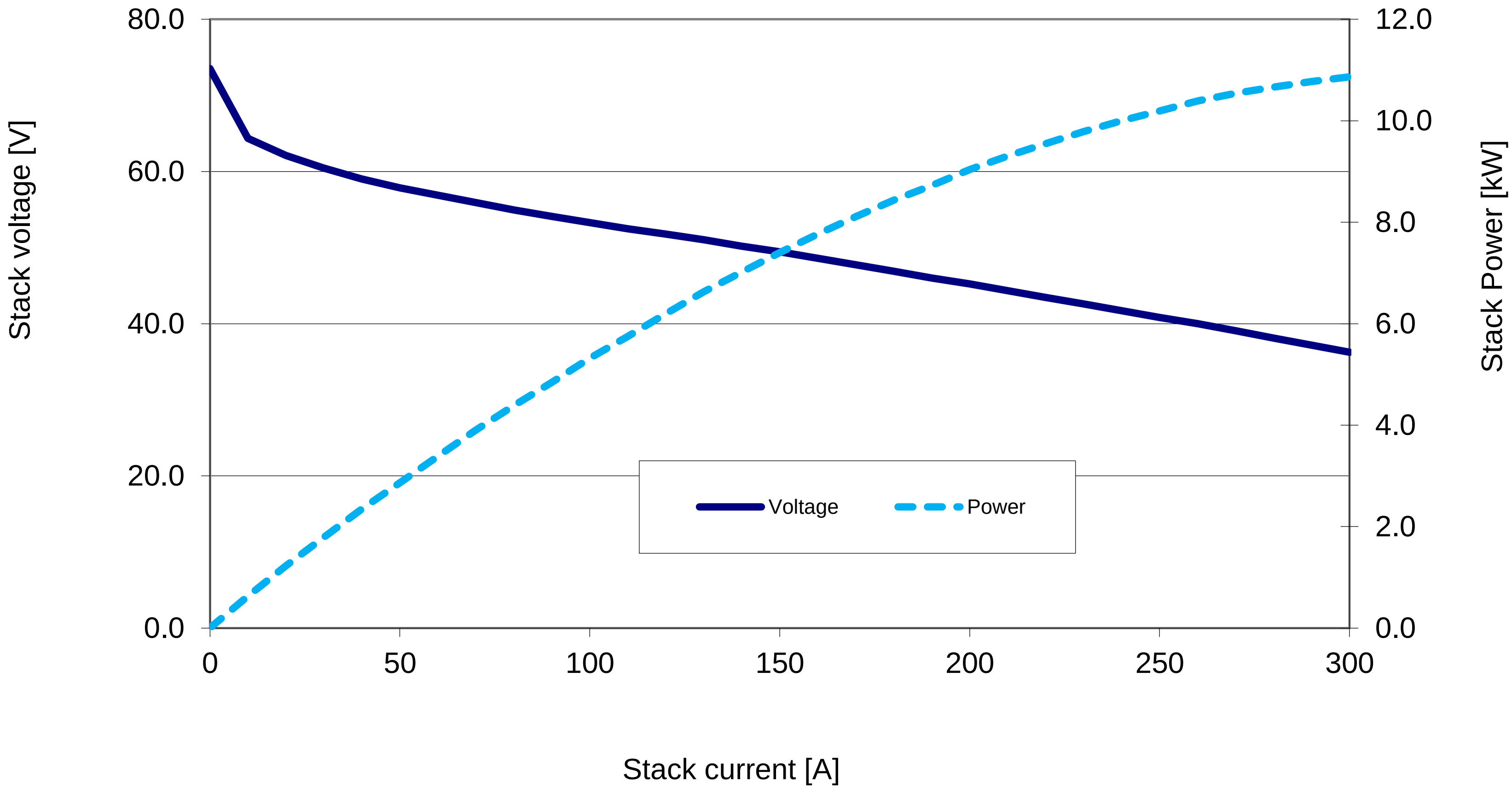
System uptime



System related downtime

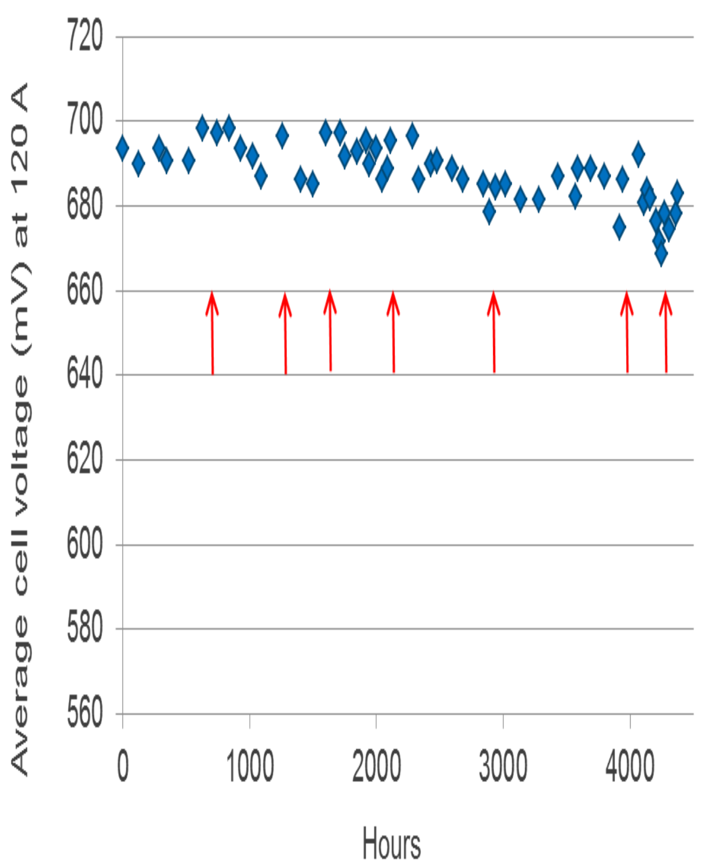
Compare recent data: uptime 2013 = 97%
BOP very reliable!

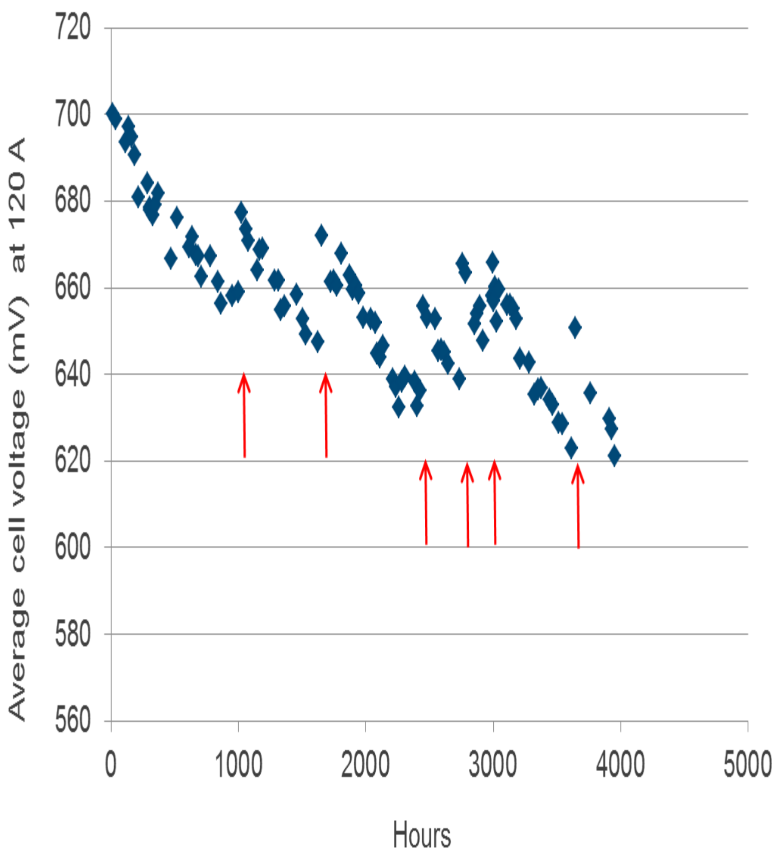
Stack characteristics



T stack = 65 °; RH anode and cathode = 80%; P = 1 bara; Stoichiometry H_2/air = 1.25/2

MEA with low vs. high reversible decay

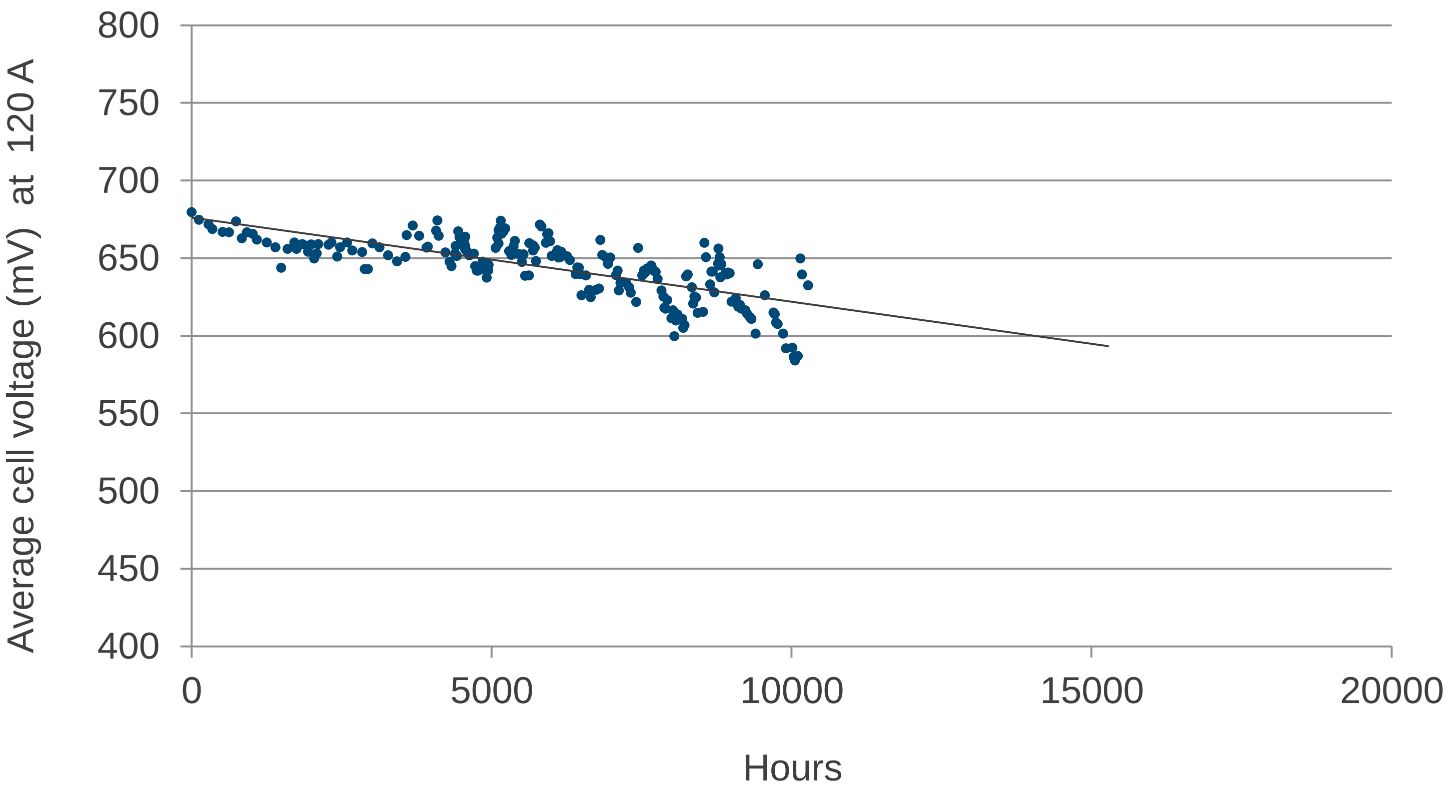




Widespread lifetimes of various MEAs tested in Pem Power Plant

MEA	Number of stacks tested	Typical lifetime (hrs before stack voltage has reached low voltage limit)	Linear cell voltage decay rate (µV/h)
under 5k MEAs	63	< 5,000	15 to 60
6k MEAs	2	6,000	11 ± 0.3
8k MEAs	9	8,000	6.2 ± 1.3
16k+ MEAs*	8	> 16,000	2.5 ± 0.5

Cell voltage versus time for 8k MEAs



Nedstack's XXL stacks using 16 k+ MEAs can operate for more than 20,000 hours

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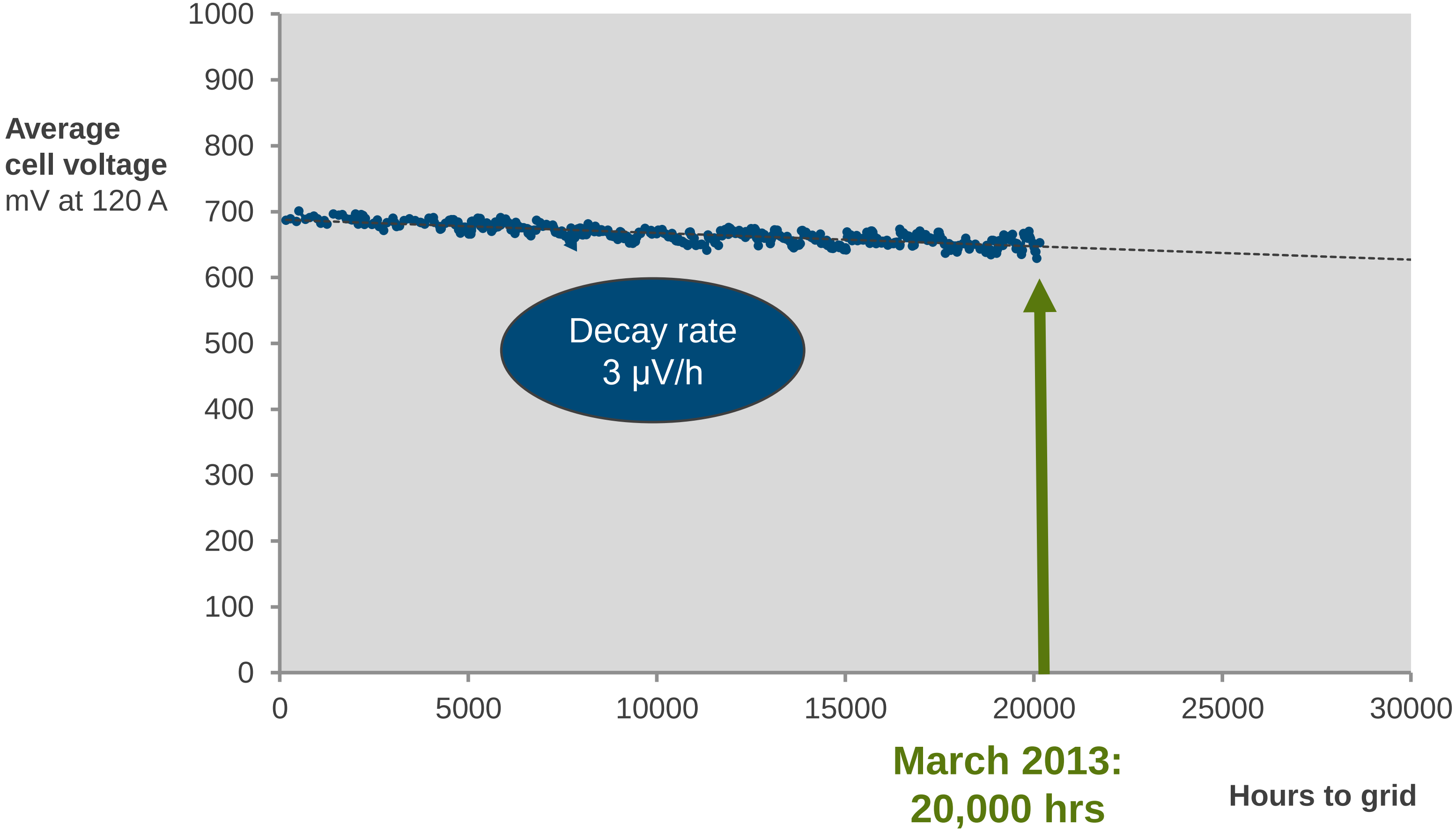

Conclusions – good news

1. System is in operation for > 33,000 hours without replacement of Balance of Plant Components

2. Fuel cell related downtime < 10% readily achievable

3. MEA and stack technology is capable of lasting > 20,000 hours

Conclusions - degradation

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1. In the PEM Power Plant, conditions are relatively mild:
   - Stationary operation, no load cycles, no air/air starts
   - Gases are wet (80% RH at inlet)
   - Temperature is low (65 °C)

2. Still, many MEAs do not exceed 5,000 hours of operation

3. Reversible decay mainly linked to contaminants
   - Accumulation in recycle and long runtimes make even ppb levels of contaminants relevant

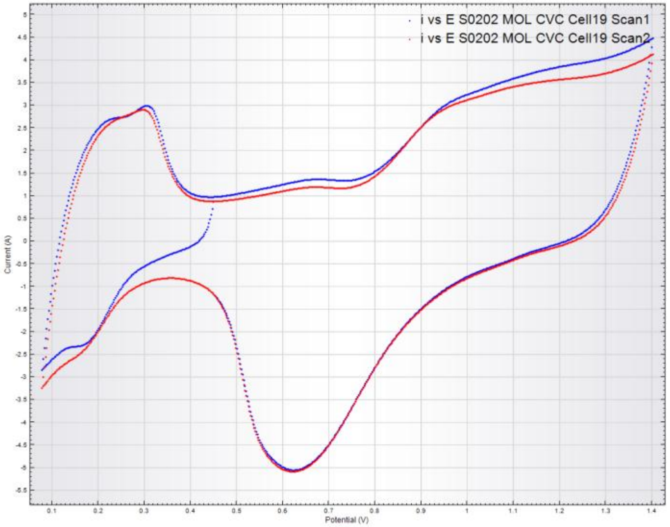
4. Irreversible decay linked to multiple causes:
   - Loss of cathode ECSA
   - Loss of water removal capability
   - Irreversible adsorption of contaminants

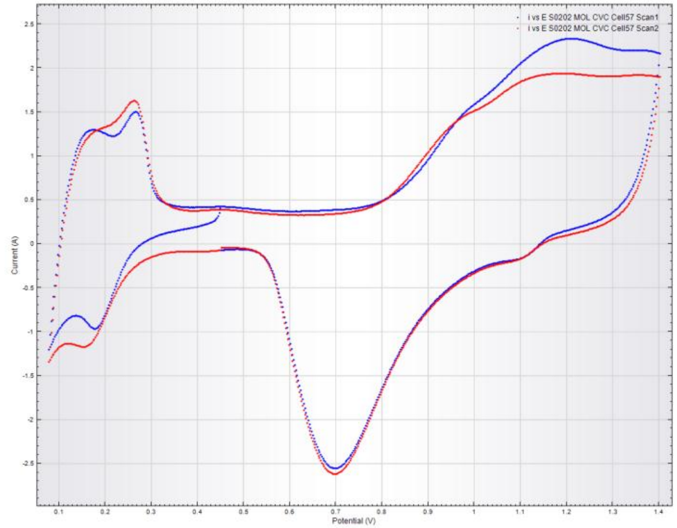
Contamination determined in air

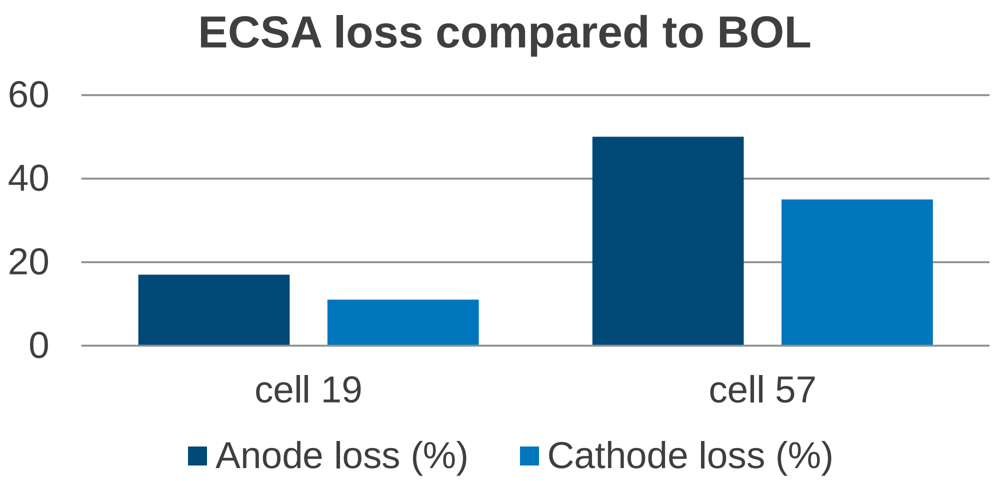
All in ppb (V)	Air (Outside)	Air (Filter)
NOx	15	15
SO2	1	1
Ammonia	<10	<10
Hydrocarbons	<10	<10

Remarks:
- NOx difficult to remove
- SO2 also (partially) removed in humidifier/scrubber

SO2 determined in Rainbow-2







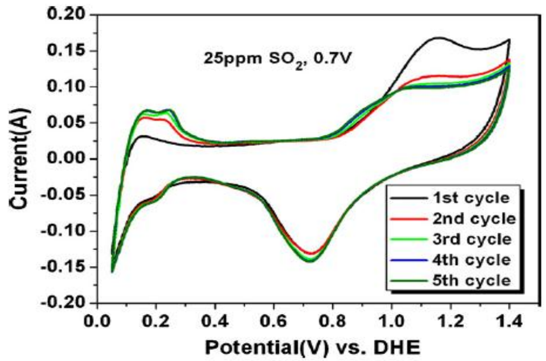


Fig. 14. CV spectra of first 5 cycles after the cathode being poisoned by 25 ppm SO_2 for 5 h at 0.7 V. T_{cell} = 70 °C, humidification temperatures of the anode and the cathode: 70 °C.

Cyclic voltamograms of two cells with different MEA's in same stack
Cathode ECSA reduction seems to correspond with Anode ECSA reduction

Contamination determined in H2 feed

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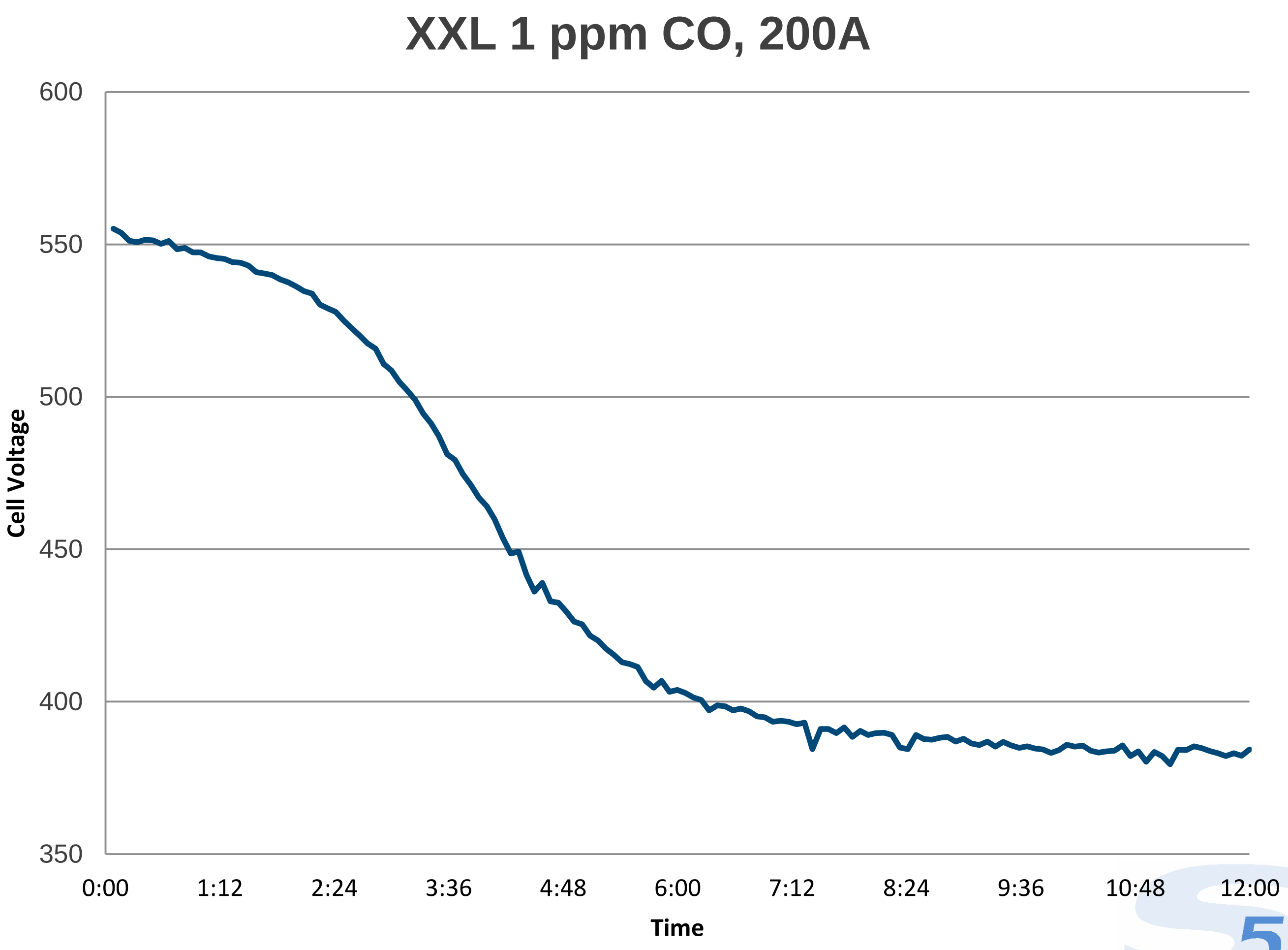
All in ppb (V)	H2 Feed A	H2 recirculation A	H2 Recirculation B
CO	100	70-140	320
CH4	100	170	X
Hydrocarbons	X	X	<10
Chlorine	X	X	<20
S	X	< 1	X

A, B different analytical labs and different sample moments
X: not checked

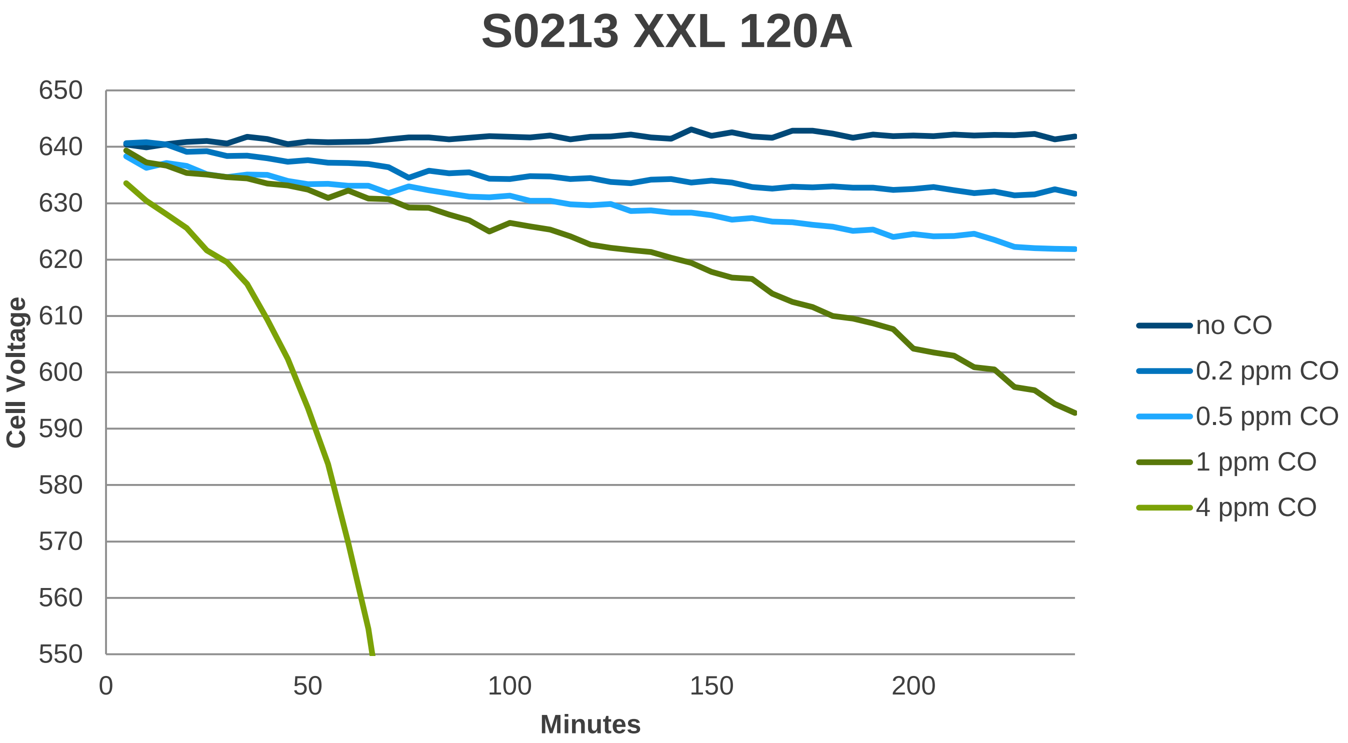
Conclusions:

- Presence of CO may result in substantial reversible decay
- No accumulation of CO in recirculation loop?
    - $CO_{(g)} + H_2O_{(v)} \rightarrow CO_{2(g)} + H_{2(g)}$?
- Origin of CH4?
    - Stable component inside recirculation loop?

Cell voltage loss with 1ppm CO @ 200 A



Cell voltage loss at various CO concentrations @120A



Conclusions

Ranking suspected degradation mechanisms:

1. Cathode loss of active surface area; irreversible
2. Anode loss of active surface area by poisoning; reversible
3. Cathode loss of active surface area by poisoning; reversible
4. Cathode increase of proton resistance; irreversible

Order and extent largely depend on MEA / catalyst formulation

Acknowledgements

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See also:

Adriaan J.L. Verhage, Jorg F. Coolegem, Martijn J.J Mulder, M. Hakan Yildirim, Frank A. de Bruijn, 30,000 h operation of a 70 kW stationary PEM fuel cell system using hydrogen from a chlorine factory, Int. Journal of hydrogen energy 38 (2013), 4714-4724