Exploring the Possibilities of SOFC Systems Operated with Biogas

- In Light of Results from Operation of a 5 kW CHP Unit

Lars Hedström & Maria Saxe[1]

Markku Rissanen[2], Göran Lindbergh[3], Bengt Ridell[4]

[1]***KTH - Energy processes***, *SE-100 44 Stockholm, Sweden*

[2]***ABB AB, Corporate Research***, *SE-721 78 Västerås, Sweden*

[3]***KTH - Applied Electrochemistry***, *SE-100 44 Stockholm, Sweden*

[4]***Grontmij AB, Energy Systems***, *SE-212 09 - Malmö, Sweden*

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Background

- GlashusEtt in Hammarby sjöstad - An information centre in a residential area with an environmental profile.
- The SOFC supplied by one of the SECA partners, Acumentrics.
- The first high-temperature fuel cell installation in Sweden and one of the first systems from Acumentrics operated on biogas.

Scope of the evaluation

- Third-party evaluation of a 5 kW combined heat and power (CHP) SOFC system.
- The system was evaluated by looking at the energy balance, degradation and operation behaviour

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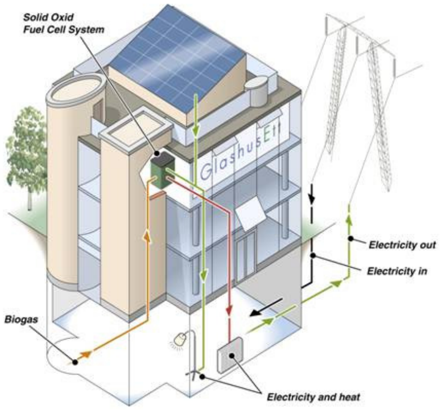

Background - The biogas used

- Upgraded biogas, (or bio-methane), available in the residential area for use in gas stoves
- Production at Henriksdal wastewater treatment plant
- Biogas produced via Anaerobic Digestion Process- ADP
- Upgraded by water-scrubbing
- Supplied to vehicles, complies with the standards set for vehicular biogas fuel in Sweden

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Gas composition	
Methane (CH_4)	97 ± 2 %
Carbon dioxide (CO_2)	1,5± 0.5 %
Nitrogen (N_2)	< 1.0 %
Oxygen (O_2)	< 0,2 %
Hydrogen Sulfide, H_2S	< 0,05 ppm
Tetrahydrotiofen, C_4H_8S (odorant)	< 10 ppm

The Solid Oxide Fuel Cell system

- 5 kW combined heat and power SOFC
- Hybrid system with 4 batteries
- POX & Sulphur trap
- 4 fuel cell stacks, each containing 12 manifolds
- A manifold holds six anode-supported tubular cells

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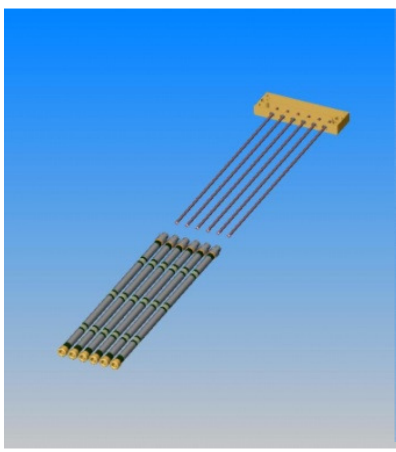
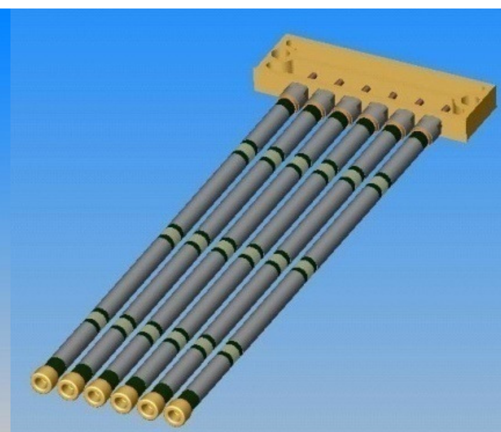
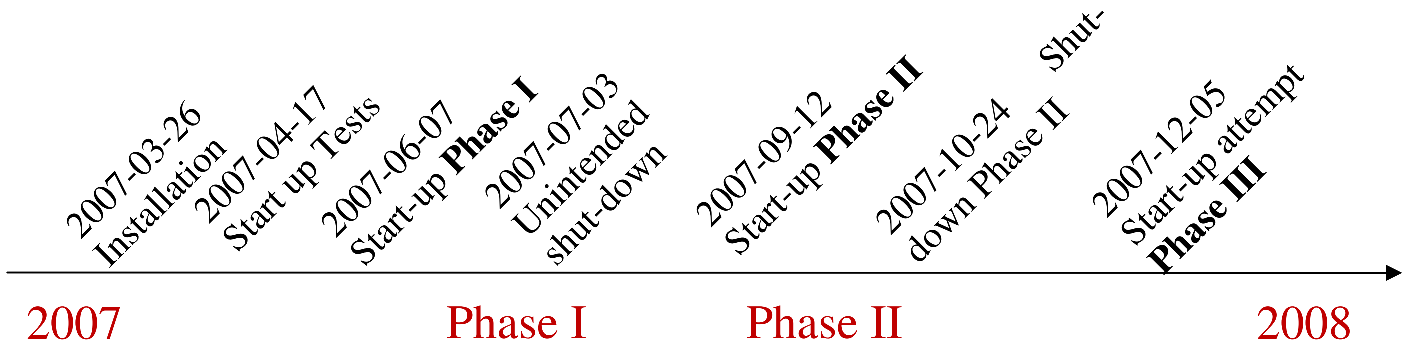




Operation and Evaluation



- Phase I: 619 h
  - Stable operation, unintended but controlled shut down
- Phase II: 1009 h
  - Occational instable operation, rapid degradation
- Phase III – only warm up
  - One cell below minimum voltage levels

Operation and Evaluation

- The current and power were measured as a total from the fuel cell stacks.
- The voltage was measured as stack average but also on individual manifolds.
- Stack temperatures were measured below, in the middle of and above each stack.

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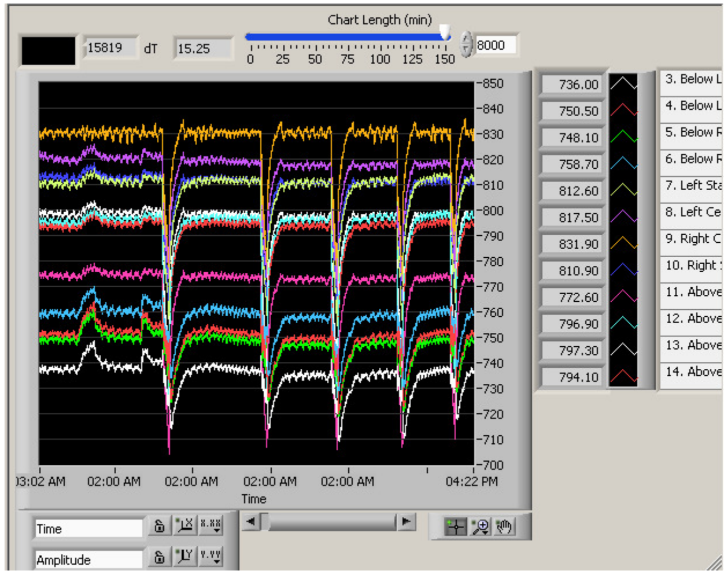

Results from Phase I

- During phase I the system was operated for 619 h
- In phase I there was an unintended, but controlled, shut-down because of stack and battery control.
- About 2 kW was constant load and 1 kW was varying loads

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Min, max and average values of some key parameters from Phase I

	Min	*Av.*	*Max*
P_{DC} [kW]	2.5	3.2	3.5
I_{stack_avg} [A]	67.7	87.6	97.4
U_{stack_avg} [V]	34.9	36.0	38.1
η_{SOFC} [%]	27.0	33.7	40.6
Q_{CW} [kW]	1.4	1.8	2.4
η_{CHP} [%]	44.3	47.7	51.2
T_{stack_avg} [°C]	765.2	805.2	877.4
ΔT_{stack} [°C]	42.6	54.3	63.9

Results from Phase II

- During phase II the system was operated for 1006 h
- Instable operation during periods in the beginning
- Rapid degradation

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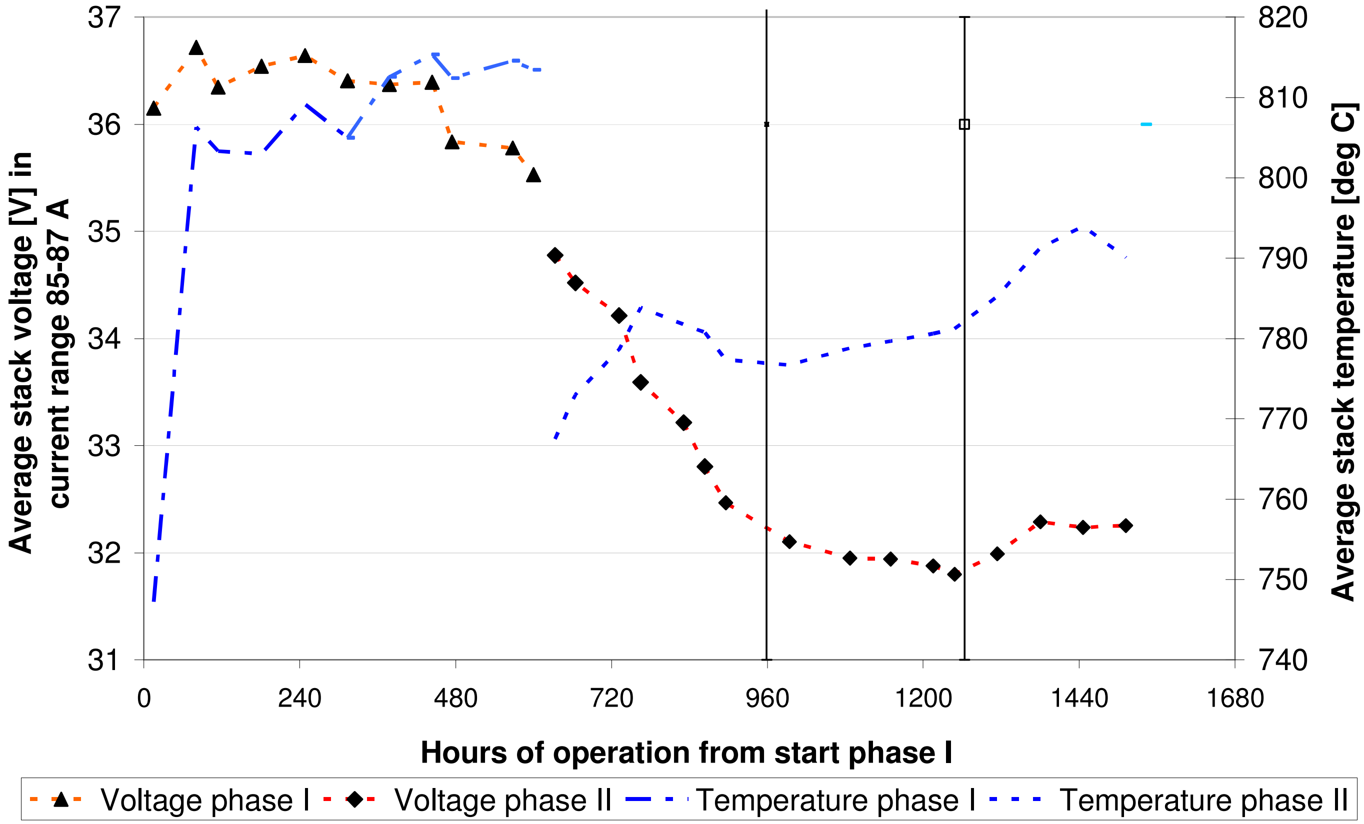
Min, max and average values of some key parameters from Phase II

	Min	*Av.*	*Max*
P_{DC} [kW]	0.25	2.8	3.1
I_{stack_avg} [A]	7.5	80.2	95.9
U_{stack_avg} [V]	29.8	33.2	45.5
η_{SOFC} [%]	2.8	29.7	37.7
Q_{CW} [kW]	0.4	1.5	6.8
η_{CHP} [%]	17.5	46.8	61.3
T_{stack_avg} [°C]	736.2	783.0	808.9
ΔT_{stack} [°C]	52.6	88.1	104.6

Degradation

- The degradation is studied by analysing the decrease in open circuit voltage (OCV) and average stack voltage within the interval 85-87 A.



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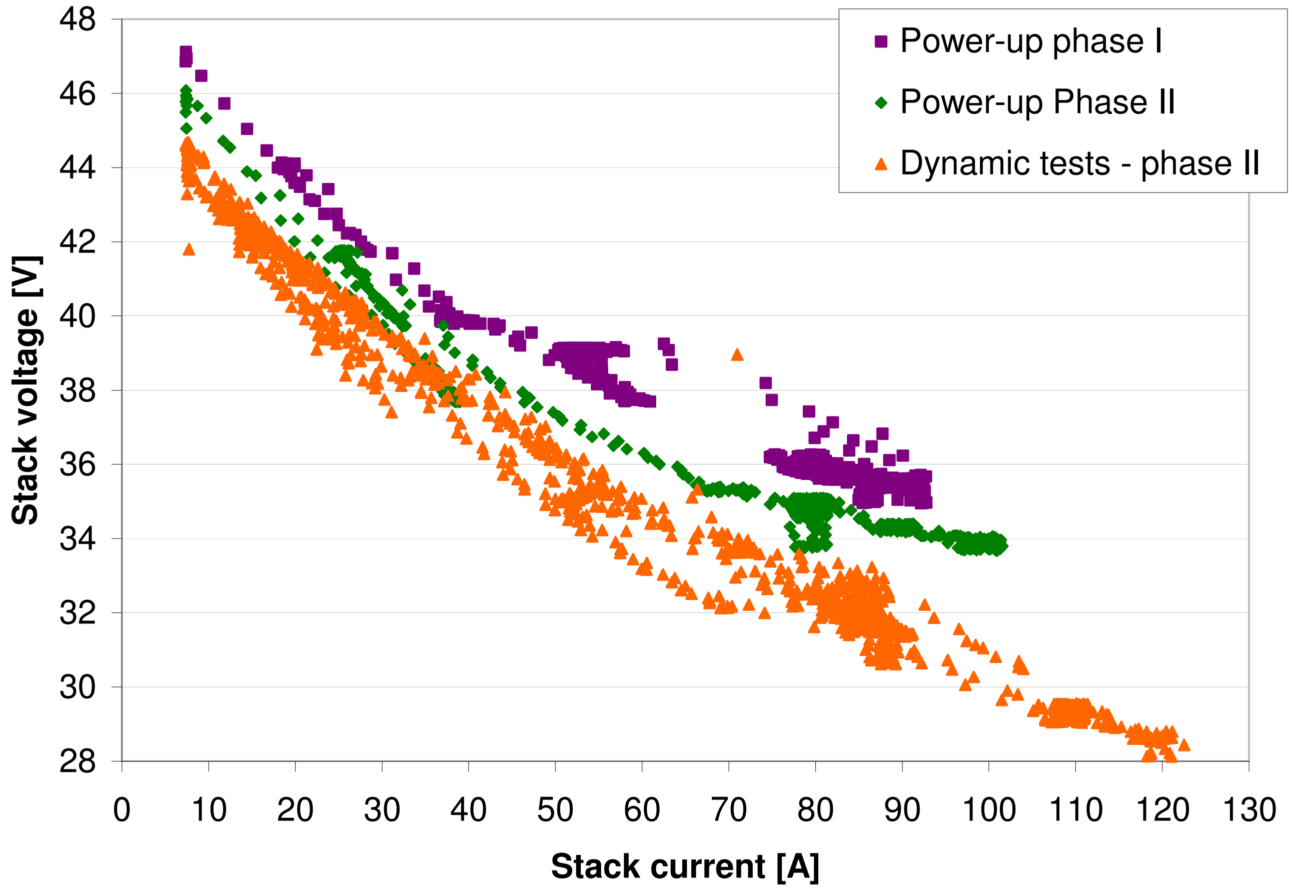
Degradation - Polarisation curve



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Degradation - OCV

Max and average open circuit voltage for the FC system

	Start Phase I	*Start Phase II*	*Start Phase III*
OCV_{stack}	49	48.5	47

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- 1.5 V (out of 2 V) is caused by degradation of all manifolds
- About 0.5 V is caused by forceful degradation of a few manifolds. 0.24 V (1), 0.12 V (1) and 0.06 V (4)
- One cell is performing below the minimum voltage level in the control system

Cause of degradation

- The main mechanisms for degradation are
  - Material breakdown, such as micro cracks
  - Delamination and interconnect detachment
  - Morphology change or blocking of electro-active reaction sites.

- Possible contaminants in the reactants?

- Sulphur can affect the cells by adsorption on the electro-active reaction sites or by reacting with the nickel catalyst
- Siloxanes can form SiO_2 at anodes.
- Other possible contaminants are chlorine and chromium
  - Chlorine can be present in the fuel or in the air and affects mainly the anode side.
  - Chromium can be released from stainless steel components (interconnects) within the system and is mainly affecting the cathode side of the cells.

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Conclusions

- After **1600 hours** of operation, **7 starts and stops** and **50 load cycles** the SOFC unit showed a **degradation of 8.7 %**
- The **cell-stack efficiency** was on average **30%** (fuel to DC) and within the range stated for the system supplier
- The total **combined heat and power efficiency** (fuel to heat and DC) was on average about **50%.**

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- The system can not handle high power demands (only 3.5 kW possible).
- Improving the control system and heat management is important.
- More research has to be done to evaluate if biogas is a suitable fuel for SOFCs and/or which gas cleaning measures are necessary.

Considerations from a Market perspective

- A very interesting and valuable research project
- At this stage of development focus should be technical design for durability, instead of various costumer demands
- Today much focus is directed to different applications, if focus would be on technical design aimed at durability, then the applications would follow.
- When durability is achieved niche-applications will open up were the added value compensates the higher cost.

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Technical design for durability?

- Examples
  - Temperature gradients
    - Thicker insulation
    - More temperature measurement points
  - Thorough gas cleaning of inlet gases – or inlet gases consisting of as few components as possible
  - Indicators for example when the sulphur trap is full or dysfunctional
  - Control system
    - Reduce the amounts of insecure parameters
    - Slow or no dynamics for the stack
    - Individual cell measurements
    - Gas composition measurements
    - Allow no or very small temperature gradients

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Thank you for your attention!