26th World Gas Conference

1 – 5 June 2015, Paris, France

Thematic Workshop WOC 5.4/TT1
Renewables: Technological and economic aspects for power to gas and upgrading of biogas to natural gas quality.

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Content of Workshop

Chair and co-chair: Aksel Hauge Pedersen and Koen G. Wiersma

- Presentation of WOC 5-4 report, and papers.

1. Introduction and Technology aspects – Aksel Hauge Pedersen,
2. Economic aspects – Koen G Wiersma,
3. Contributed papers – next slide
4. Q&A and concluding remarks

Contributed papers

Paper Title	Author	Company/Country
Power to Gas	Peter Klingenberger	E.ON/ GERMANY
TECHNOLOGICAL AND ECONOMIC ASPECTS OF BLENDING HYDROGEN INTO NATURAL GAS PIPELINE NETWORKS: DETERMINATION OF KEY ISSUES FOR A SELECTED GAS PIPELINE IN IRAN	Sohrab Fathi	Kermanshah University/ IRAN
Coupling of Biomass Based Processes with PtG – Methanation Technologies, Process Concepts, and Economics	Frank Graf	DVGW/GERMANY
GENEVA BIOGAS PURIFICATION PLANT	Caoline Mazzoleni/ Julien Andre	Service Industriels De Genève/SWIT-ZERLAND
GAYA Demonstration project -Towards industrialization of an innovative and integrated 2nd generation bioSNG pathway	Olivier Guerrini	GdF-SUEZ, FRANCE

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WOC 5.4 - Study group report – **"Technology aspects".**

1. Global status for upgrading of biogas (2013)
2. Electrolyzing technologies (2013)
3. Injection of Hydrogen into the Natural Gas System (2014)
4. Economic aspect of Power to Gas (2015)

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Global status for upgrading of biogas to methane (2013) - through removal of CO_2 (table from tech. review Vienna, 2012)

Parameter	Water Scrubbing	Organic scrubbing	Chemical Scrubbing (Amine)	PSA	Membrane	Cryogenic
Methane cont. - vol%	95,0-99,0	95,0-99,0	> 99,0	95,0-99,0	95,0-99,0	
Methane recovery - %	98	96	99,96	98	80 - 99,5	
Methane slip -%	2,0	4,0	0,04	2,0	20-0,5	0,037
Delivery pressure - bar	4-8	4-8	0	4-7	4-7	
Power consumption - kWh/m^3 biomethane	0,46	0,49 - 0,67	0,27	0,46	0,25 - 0,43	0,5 - 1,12
Capex - €/(500 m^3 biomethane/ h)	3500	3500	3500	3500	3500-3700	13000
OPEX - ct/m^3 biomethane at 500 m^3/h	9,1	9,0	11,2	9,2	6,5-10,1	

Methanation: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
"reuse" of CO_2 – still under development .

- Chemical methanation (temperature level 200 – 500 deg. C).
  - Sabatier reaction
  - Haldor Topsoe's TREMP process
  - Methanation at PSI

  etc.

- The Biological methanation (temperature level 40 – 70 deg. C)
  - Electrocheae – biological catalysis
  - Enzymatic upgrading of biogas (Akermin)

  etc.

Electrolyzing technologies (2013) - Alcaline

Cathode: $4H_2O(l) + 4e^- \rightarrow 2H_2(g) + 4OH^-(aq)$

Anode: $4OH(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$

In total: $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

AEC - state of the art - 2013		
Parameter	State of the art	Potential
Capacity (Nm^3/h)	1 - 1000	Up to 3000
System Price €/Nm^3/h (€/kW @ 5 kWh/Nm^3)	7000 - 8500 (1400 - 1800)	2000
Power consumption kWh/Nm^3	4,8 - 5,5	3,9 - 4,6
Increase in power cons. due to degradation	2-4% per year	2 - 4%
Outlet pressure	32 bar	Up to 100 bar
Lifetime for stack (hours)	40.000	40.000
System lifetime (years)	10	10

Manufactures of alkaline electrolyzers				
Manufacturer	**Country**	**Capacity range m^3 H_2/h**	**Pressure bar**	**kWh/Nm^3 H_2**
Hydrogenics	CA/US/EU	1 - 60	10 - 25	4,2
Teledyne	US	2,8 - 150	4,2 - 16	5,6 - 6,1
NEL/Norks Hydro	N	0 - 485	0 - 12	4,1 - 4,8
IHT (Lurgi/Barmag syst))	CH	3 - 760	0 - 32	3,9 - 4,6
Accagen	CH	1 - 100	10 - 200	4,4 - 6,3
Idroenergy	IT	0,4 - 64	1,8 - 3,9	5 - 6

Electrolyzing technologies (2013) - PEM

Anode : $2H_2O \rightarrow 4H^+ + O_2 + 4e^-$

Cathode : $4H^+ + 4e^- \rightarrow 2H_2$

Cell : $2H_2O \rightarrow 2H_2 + O_2$

PEM electrolyzer - state of the art - 2013		
Parameter	**State of art**	**Potential (in 5 - 10 years)**
Capacity (Nm^3/h)	1 - 30	1-3000
System Price €/Nm^3/h (€/kW @ 5 kWh/Nm^3)	15000€/Nm^3/h (3000 €/kW)	2700 €/Nm^3/h (540 €/kW)
Power consumption kWh/Nm^3	6-6,5	3,6 - 4,4 (at elevated temperature - up 200 gr. C)
Degradation (increase in power consumption/year)	2 - 4%	2 - 4%
Outlet pressure	30 bar	200 bar
Lifetime stacks (hours)	5000	50.000

Manufactures of PEMFC				
Manufacturer	Country	Capacity range m^3 H_2/h	Pressure bar	kWh/Nm^3 H_2
Proton	US	0,2 - 30	1,5 - 4	6,8 - 7,3
Siemens	D			
CETH2	GB	5 - 160	14	5 - 5,2
Syslatech	D	0,09 - 2	?	?
Hydrogenics	US/CA/EU	1 - 2	0 - 8	6,7
ITM Power	GB	1 - 2	15	4,8 - 5

Electrolyzing technologies (2013) - SOEC

Cathode : $2H_2O \rightarrow 2H_2 + 2O^{--} + 4e^-$

Anode : $2O^{--} + 4e^- \rightarrow O_2$

Cell : $2H_2O \rightarrow 2H_2 + O_2$

SOEC - state of the art - 2013		
Parameter	State of art	Potential (in 5 - 10 years)
Capacity (Nm^3/h)	3	3000
System Price €/Nm^3/h (€/kW @ 5 kWh/Nm^3)	4000€/Nm^3/h (800 €/kW)	700 €/Nm^3/h (150 €/kW)
Power consumption kWh/Nm^3	3,3 - 3,7	3,2
Degredation (increase in power consumption/year)	8%	2%
Outlet pressure	8 bar	50 bar
Lifetime stacks (hours)	8000	40.000

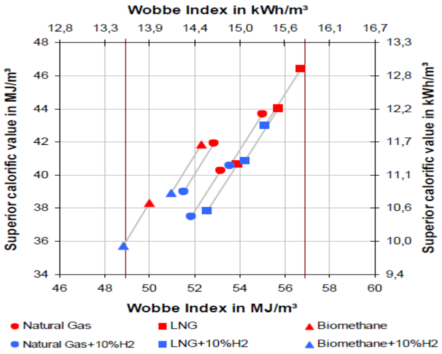
Manufacturers of SOEC				
Manufacturer	**Country**	**Capacity range m^3 H_2/h (kW)**	**Pressure bar**	**kWh/Nm^3 H_2**
Ceramatec	US (Idaho) - 2008	17 kW	?	?
Haldor Topsoe/DTU	DK - 2014	20 kW	?	?
Kier/HERC	Korea	? turbular stack	?	?
Kyocera	Japan	?	?	?
Acumentrics	US	?	?	?
Versa Power systems	Canada/US	2 - 10 kW	?	?
Delphi/PNNL	US	?	?	?
Sunfire	US	200 kW	30	

Injection of Hydrogen into the Natural Gas System – (2014)

Recommend limits for hydrogen injection to natural gas net.

- Max. 2 % - if connected to CNG filling station
- Max. 5 % - if not connected to CNG filling station, gas turbines and gas engines.
- Max. 10 % - if not connected to filling station, gas turbines and gas engines.

Not yet european/global standard.



Conclusion amongst experts from GERG are - injection of 10 % of H_2 in natural gas grids seems reasonable for domestic and commercial appliances. However it will be beneficial to initiate some additional tests to acquire more data.