Innovation Center Iceland

Results of some projects on geothermal gases at Innovation Center and IceTec

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Composition of geothermal gas

	Svartsengi	Nesjavellir	Bjarnarflag, BJ-12
Compound	Content (vol%)	Content (vol%)	Content (vol%)
CO_2	98,09	50,8	39,4
H_2S	1,14	21,5	30,1
H_2	0,4	21,1	36,7
N_2	0,34	6,3	0,6
CH_4	0,03	0,3	0,2

Quantity of geothermal gas in 2010

Power Plant	Capacity (MW)	CO_2 (t/year)	CO_2 (kg/kWh)	H_2S (t/year)	CH_4 (t/year)
Nesjavellir	120	28 936	0.027[b]	13 340	111
Hellisheiði	213[a]	41 722	0.022[b]	9 384	46
Svartsengi	75	47 974	0.073[b]	903	3.7
Reykjanes	100	26 102	0.029	880	2.1
Krafla	60	54 116	0.103	4 100	151 [c]
Bjarnarflag	3	1 200[c]	0.046	568	12 [c]

[a] Capacity increase by 90 MW in October 2011 is not included
[b] Hot water for district heating is also produced, but here have all the CO_2 emissions been attributed to the electricity production.
[c] Estimated from data in Table 7 by using published data on H_2S emission

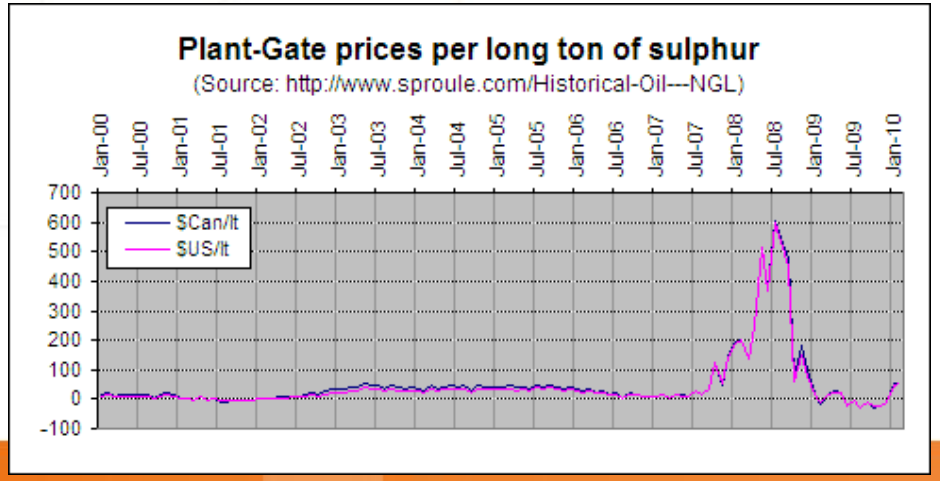
0.02 – 0.1 t CO_2/MWh

Hydrogen sulphide (H_2S)

- Sources
  - Natural gas
  - Desulfurisation of oil products in oil refineries
- Always converted to sulphur (S) or sulphuric acid (H_2SO_4)
- Uses
  - Inorganic sulfur compounds
  - Precipitate metals from solution (NiS, CuS)
- LHV (lower heating value)
  - 15 MJ/kg for H_2S (product SO_2)
  - 42 MJ/kg for diesel
    - Hydrogen sulfide fuel cells have been considered
- Hydrogen from hydrogen sulphide
  - $H_2S = H_2 + S$
    - Less energy needed than for $2H_2O = 2H_2 + O_2$

Sulphur (S)

- Production in 2010
  - 68 million tonnes (Mt)
    - 1 tonne S gives 3.1 tonnes of H_2SO_4
- Canadian stockpile
  - 11.9 Mt in Alberta, Canda
- Prices
  - 170 USD/t CFR Tampa, Florida, September 2012
  - 200 USD/t CFR North Africa, September 2012
  - 109 CAD/lt, Alberta, March 2013



Sulphuric acid (H_2SO_4)

- Production in 2012
  - 234 million tonnes (Mt)
    - From S
      - $S + H_2O + 1{,}5O_2 = H_2SO_4$
    - Byproduct acid
- Supply and demand
  - 4 – 6 Mt deficit from 2012 to 2015
  - Europe net exporter of H_2SO_4
- Prices
  - 0 – 800 USD/tonne last five years
  - 70 - 80 USD/t CFR NW Europe, September 2012

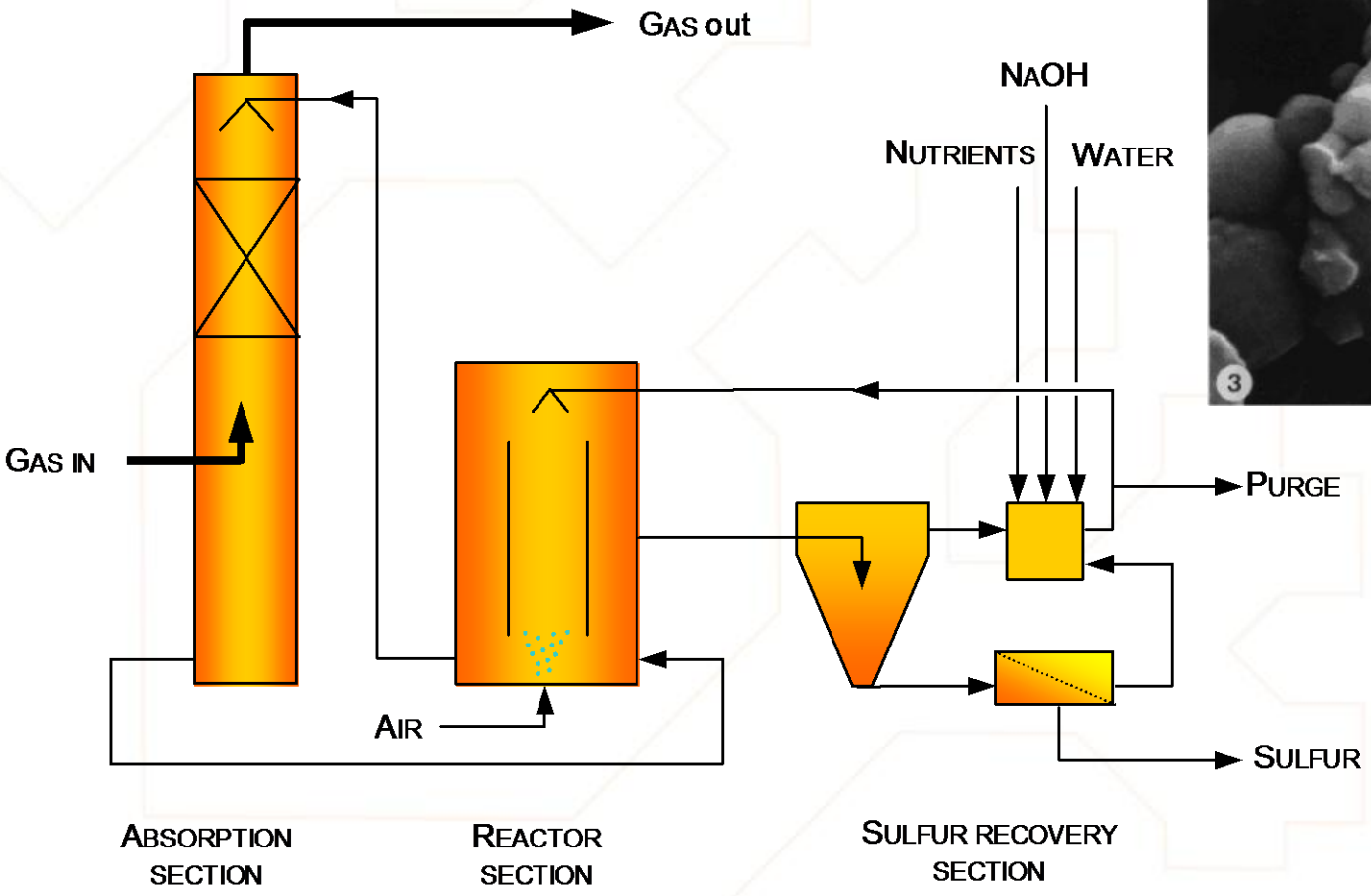
Hydrogen (H_2)

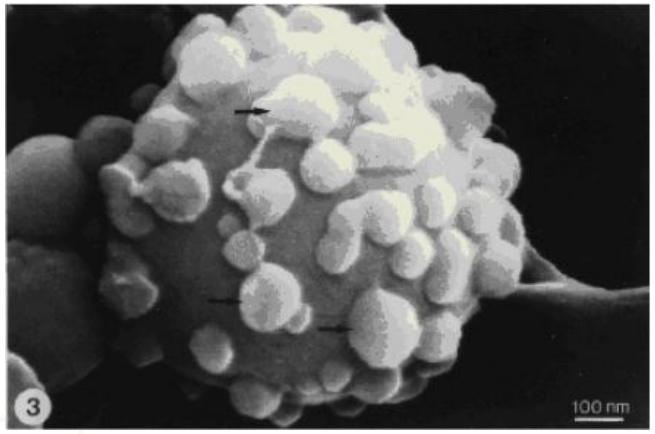
- Most hydrogen is made from natural gas
  - Price of hydrogen determined by price of natural gas.
- In Iceland production by water electrolysis can be considered
  - $2H_2O = 2H_2 + O_2$
  - Electricity consumption: 56 MWh/t
    - Hydrogen at 120 bar
  - Costs
    - Electricity cost: 1960 USD/t
      - Electricity price 35 USD/MWh
    - Total cost: 2800 USD/t
- Value of 100 t/year hydrogen
  - Max 0.28 million USD

Purification of CO_2 from Svartsengi 1999 - 2000

- Different methods for H_2S removal compared
- Most economic method is bacterial oxidation of H_2S to S (Thiopaq process)
  - H_2S absorbed in basic solution
    - $H_2S + OH^- = HS^- + H_2O$
  - Thibaccilus bacteria oxidise HS^- to elemental sulfur (S^0) and base is regenerated
    - $HS^- + 1/2O_2 = S^0 + OH^-$
  - 10 ppm H_2S in CO_2 after treatment
- Cost of purification 6 USD/t CO_2
  - Cost of H_2S removal 600 USD/t S (600 tonnes S obtained)

Thiopaq process for removal of H_2S from gas





Sulfur particles on bacteria

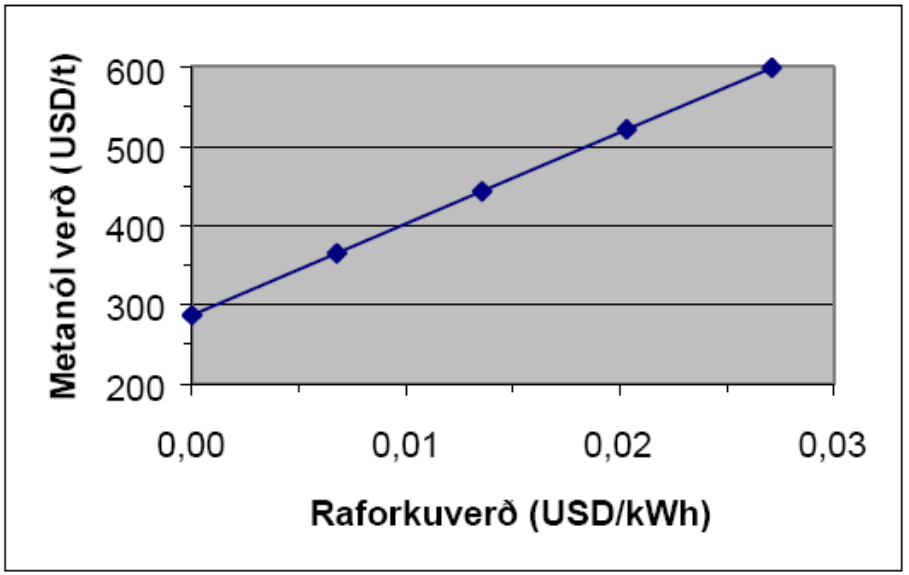
Use of purified CO_2

- Sufficiently pure for use in greenhouses
  - Ideal location for a large greenhouse is next to a geothermal power plant
- Food grade CO_2 by further purification
  - Dry ice and liquid CO_2
    - Be carefull to remove all H_2S before drying the gas
      - $H_2S + CO_2 = COS + H_2O$
- Methanol production
  - After further purification to 0,1 ppm H_2S

Production of methanol from CO_2

- $CO_2 + 3H_2 = CH_3OH + H_2O$
  - 56 MWh/t hydrogen
  - 11 MWh/t methanol
  - 8 MWh to „fix“ 1 kg CO_2
    - Coal fired power plants: 1 t CO_2 per MWh

- Storage of H_2



HYSIS project

- 2006 – 2007, Cooperation between UI, OR and IceTec
- Electrolysis to produce hydrogen and sulfur

$$H_2S = H_2 + S$$

  - $H_2S + 2Fe^{3+} = 2Fe^{2+} + S$
  - $2Fe^{2+} + 2H^{+} = 2Fe^{3+} + H_2$
- 10000 t of H_2S could give 590 t of hydrogen and 9419 t of sulphur (S)
- Electricity demand for hydrogen production less than when producing hydrogen by water electrolysis

Cost of different methods at Nesjavellir for 6000 t/year of S

Method	Cost per t S removed (USD)	Products per year
WSA	440	H_2SO_4= 19 000 t, steam 60000 t
LO-CAT	800	S = 6000 t, gas with H_2 and CO_2
Thiopaq	300	S = 6000 t, gas with H_2 and CO_2
Electrolysis	210	S = 6000 t, H_2 = 360 t, gas with H_2 and CO_2

Gas after H_2S removal

- 40 vol% H_2
- 60 vol% CO_2
- 550 Nm^3/h of H_2 = 49 kg/h = 380 t/year
  - Value 1 million USD

CO_2 Electrofuels
Nordic ongoing project

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Ea Energy Analyses

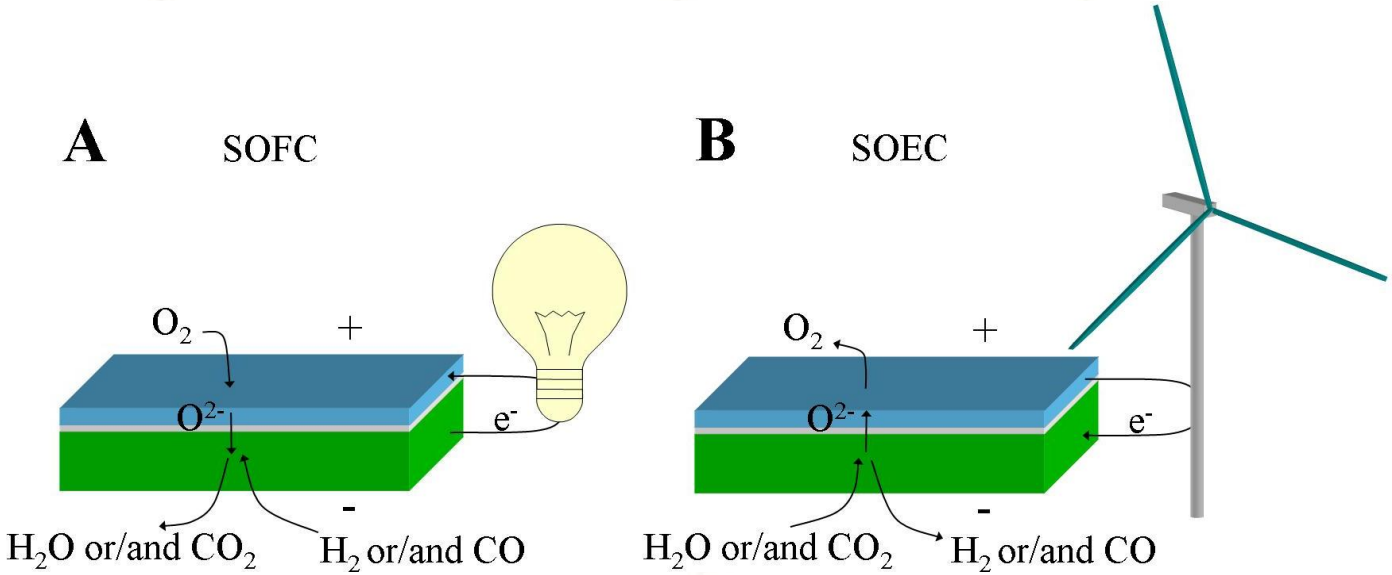
HALDOR TOPSØE

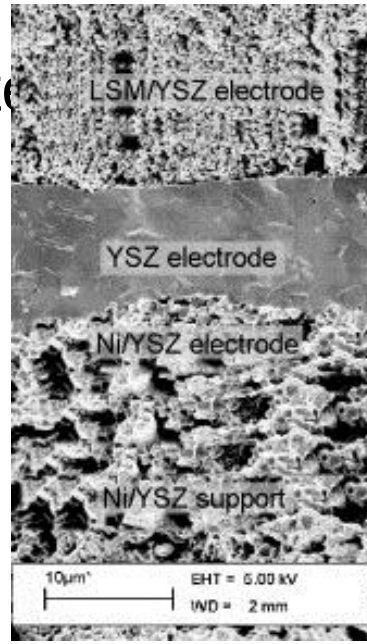
DTU

Is CO_2 electrofuels a viable and competitive technology for the Nordic countries?

New method for producing hydrogen

- Cost of hydrogen from solid oxide electrolysis lower than for conventionalk alakline electrolysis
  - Electric energy consumption about 30 % lower
  - Investment cost lower



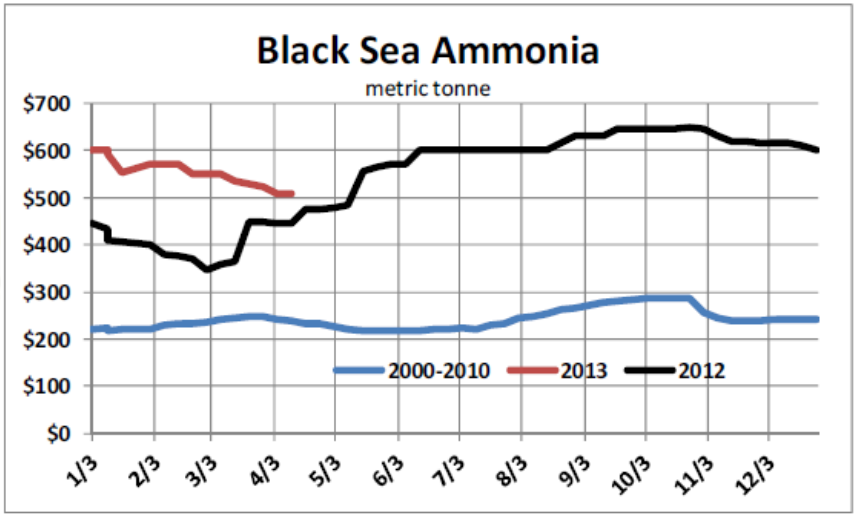


Methane from CO2

- $CO_2 + 4H_2 = CH_4 + 2H_2O$
- Technology has been developed
- Electric energy consumption
  - 17,2 kWh/Nm^3 with alklaline electrolysis
  - 12 kWh/Nm^3 with SOEC
- Electricity cost at 35 USD/MWh
  - 99 ISK/Nm3 for alkaline electrolysis
  - 69 ISK/Nm3 for SOEC
  - Retail price 119 ISK/Nm^3
- 20.000 t/year CO_2 could give 10 Million Nm^3 per year
  - 22 MW of power required

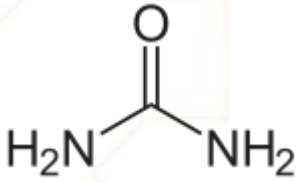
What can be done with sulphuric acid?

- Inorganic sulphates
  - $FeSO_4$
  - $Al_3(SO_4)_2$
  - Etc.
- $(NH_4)_2SO_4$ (AMS)
  - Often produced from waste acid and ammonia
- 180 kg of H_2 needed to make 1 tonne ammonia (NH_3)
- Hydrogen cost per tonne ammonia 500 USD
  - 35 USD/MWh
  - 30% lower cost with SOEC



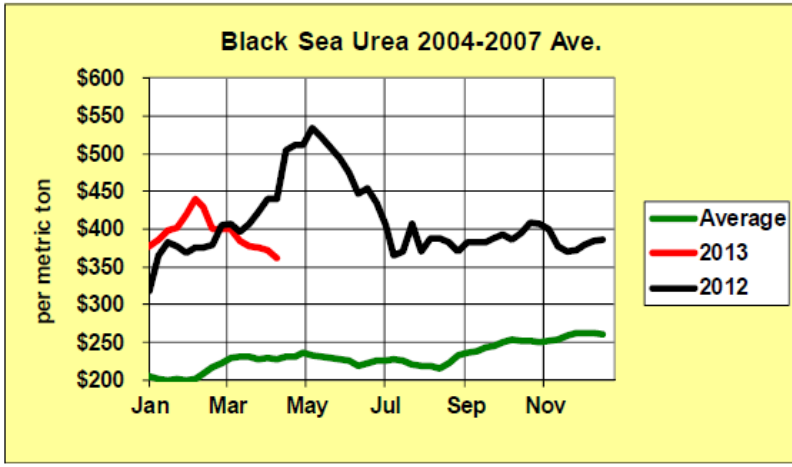
Fertiliser from CO_2

- Urea



- $2NH_3 + CO_2 = NH_2CONH_2 + H_2O$

- 60000 t/year CO_2 and 46500 t/year NH_3
  - 82000 t/year Urea
  - 60 MW for hydrogen production
- Hydrogen cost per tonne urea
  - 282 USD/t
  - 30% lower cost with SOEC

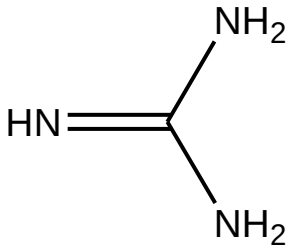


Fertiliser from H_2SO_4 and CO_2

- 60 000 t/year CO_2 and 60 000 t/ year H_2SO_4 with
- 67 500 t/year ammonia
  - Small ammonia plant
  - 85 MW of electric power used for H_2 production
- Products
  - 62 000 t/year urea
  - 81 000 t/year ammonium sulphate
- Could be economical if price of ammonia increases
  - Could the price be higher than that of products from natural gas?
  - Couls SOEC make this economial

Guanidine

- Guanidine
  - From carbon dioxide and ammonia
    - $CO_2 + 3NH_3 = CN_3H_5 + 2H_2O$
  - Solid
    - M.p. 50° C
    - Can be used as a fertiliser
  - Reaction of guanidine with water at 200 - 300° C
    - $CN_3H_5 + 2H_2O = CO_2 + 3NH_3$
    - $2NH_3 = N_2 + 3H_2$
    - Ammonia content of guanidine 54%
    - Hydrogen content 9.5 %



guanidine

Thank you