Biogas upgrading – a technical review

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Presentation of myself

- Education:
  - M.Sc. Chemical Process Engineering
  - PhD Chemical Process Engineering, Production of ethanol from softwood

- Work:
  - Process Engineer, Process Manager at Malmberg Water, biogas upgrading and water treatment 2014-2016
  - Research Area Director Transportation and Fuels at Energiforsk, the Swedish Energy Research Centre since Feb 2016

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Presentation of Energiforsk

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Who was SGC?

- SGC – the Swedish Gas Technology Centre
- Vision: Catalyzing energy gas development for sustainable solutions
- Mission:
  - Reference point for gas research in Sweden
  - Coordinate research and development in the area of gas technology with focus on renewable gases
  - Support for commercialization of sustainable technical solutions

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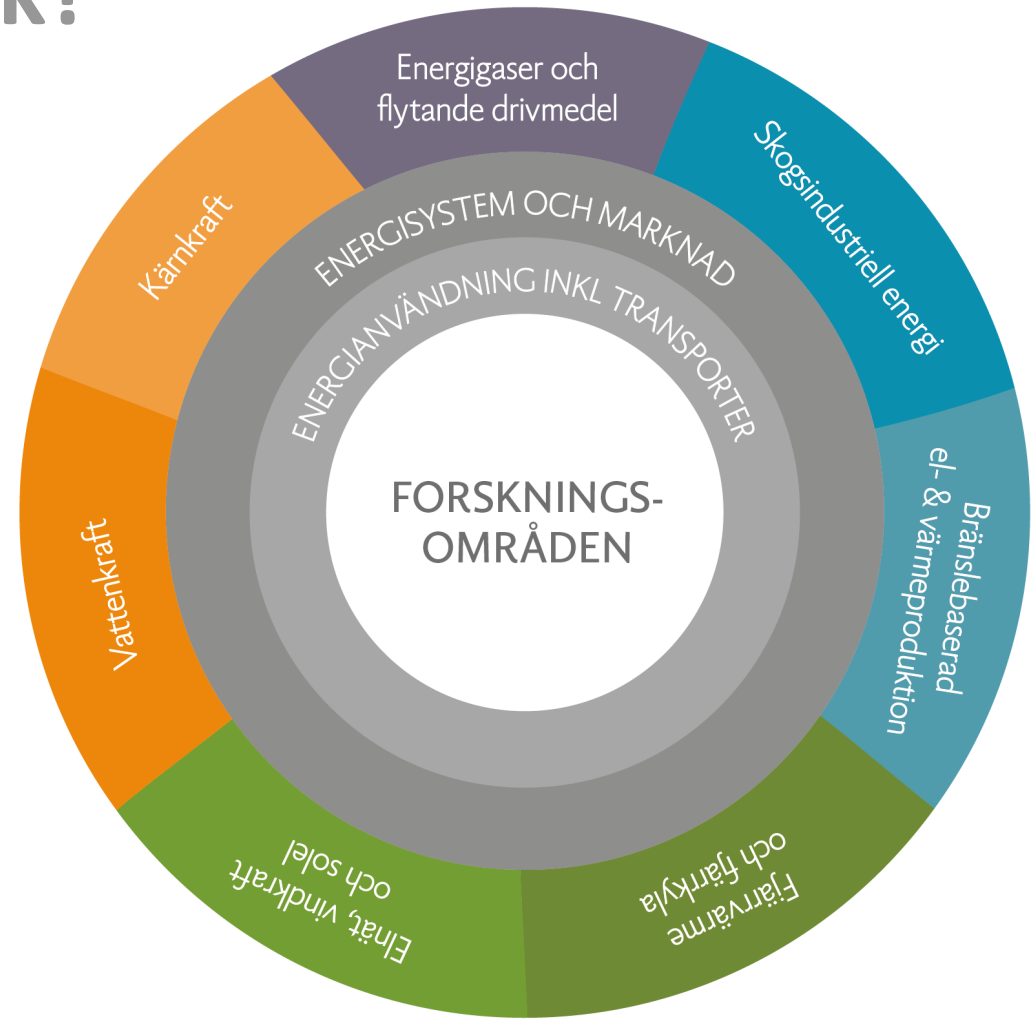
Who is Energiforsk?

- Research areas:
  - Transportation and fuels
  - Energy in the forest industry
  - Fuel bases production of electricity and heat
  - District heating and cooling
  - Electricity nets, wind and solar electricity
  - Water power
  - Nuclear power

  - Energy systems and markets
  - Energy use incl. transportation



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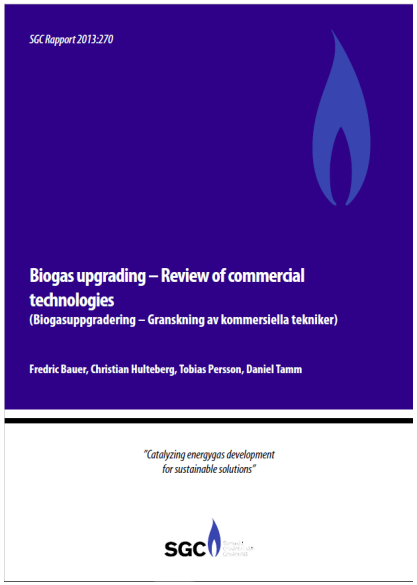
Reports on biogas upgrading



- Water scrubber and PSA main technologies
- Amine scrubber start to take significant market share
- Membrane upgrading, organic physical scrubbers and cryogenic distillation considered upcoming technologies

- ”Biogas upgrading – a technical review”
- Energiforsk 2016:275

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Content

- Report ”Biogas upgrading – a technical review”:
  - Biogas upgrading techniques
  - Comparison between biogas upgrading techniques
    - Impurities
    - Cost (investment, operational)
  - Gas treatment, removal of impurities
  - Product gas quality (requirements in different European countries)
  - Different uses of product gas, biomethane
  - Different uses of carbon dioxide as a byproduct

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Content

- Report ”Biogas upgrading – a technical review”:
  - **Biogas upgrading techniques**
  - **Comparison between biogas upgrading techniques**
    - **Impurities**
    - **Cost (investment, operational)**
  - Gas treatment, removal of impurities
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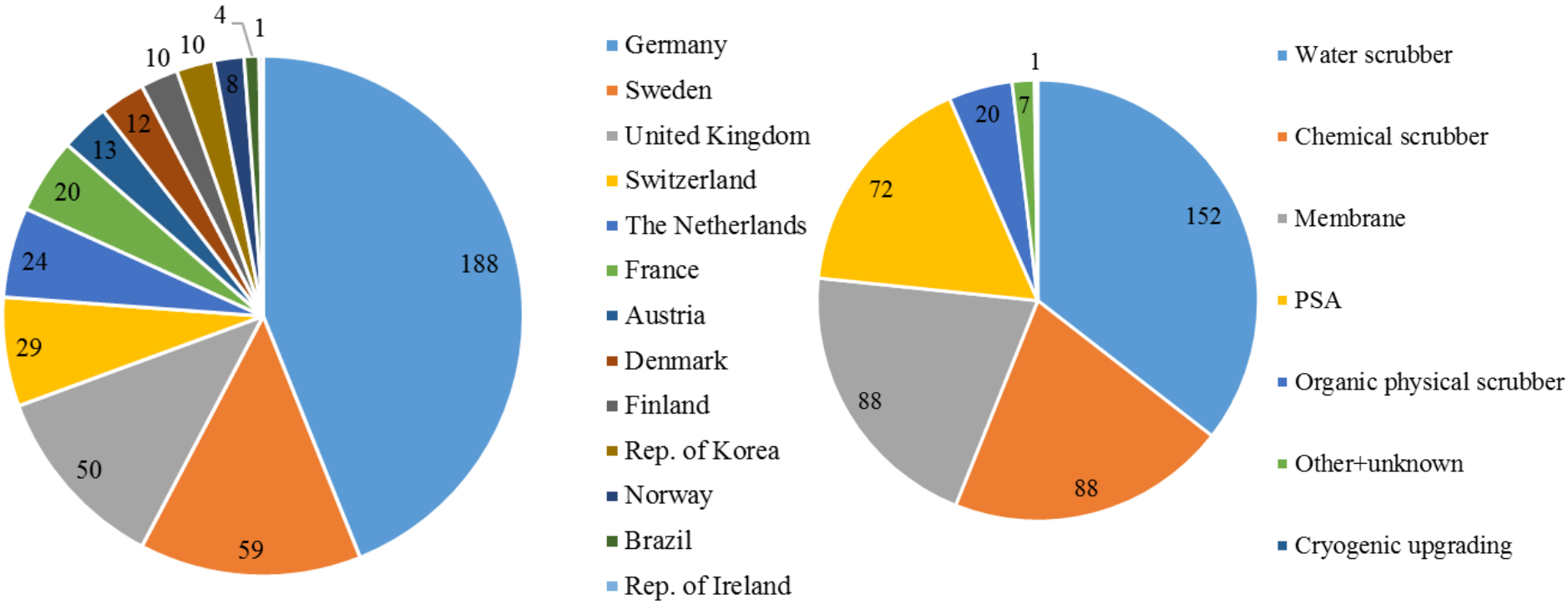
Biogas upgrading, plants in operation 2015

IEA Task 37, statistics on operational biogas upgrading plants among IEA Task 37 member countries, data from 2015



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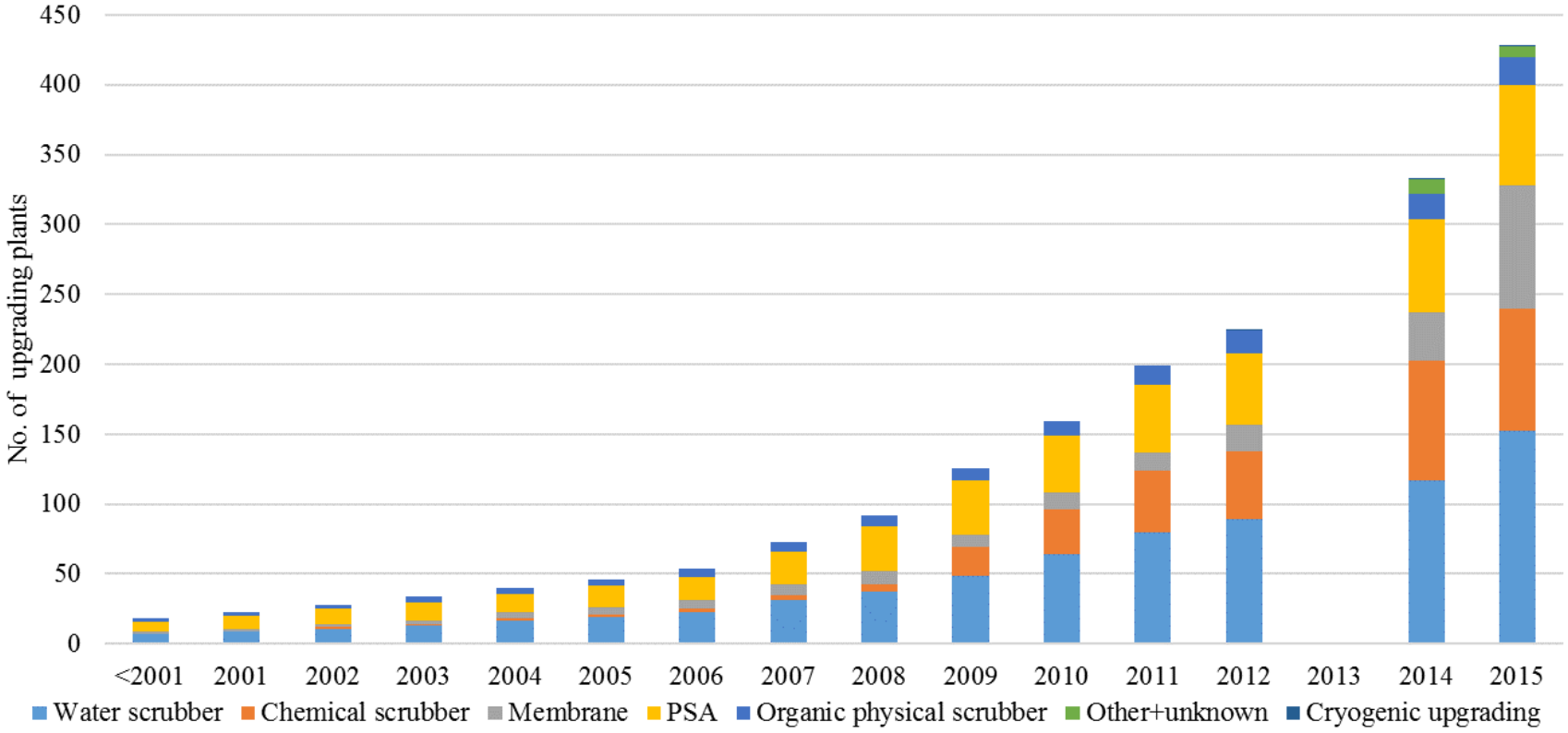
Biogas upgrading plants over time



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Biogas upgrading techniques

- Pressure swing adsorption (PSA)
  - CO_2 and CH_4 adsorb differently on a surface at different pressures.

- Water scrubber
- Amine scrubber
- Organic physical scrubber
  - CO_2 and CH_4 dissolve differently in solvents such as water, amines and organic solvents.

Organic physical scrubber in Wolfshagen, Germany from BMF Haase

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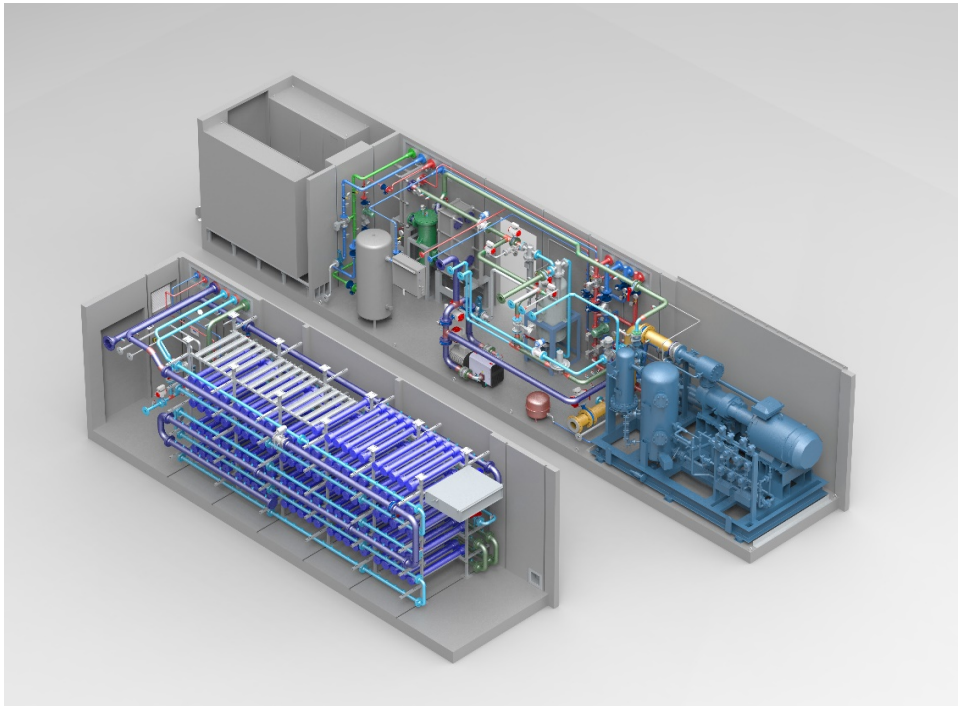
Biogas upgrading techniques

- Membrane separation
  - CO_2 passes through a semi permeable membrane while CH_4 does not.
- Cryogenic upgrading
  - Distillation of CO_2 and CH_4 at low temperatures.



Layout av membrananläggning från EnviTec

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What comes onto the biogas upgrading process?

- Except methane and carbon dioxide:

H_2S N_2 H_2O O_2 H_2 Volatile organic carbon (VOC) siloxanes

- The amount of these depend on the substrate…
  - More VOC in biogas from household waste/food waste
  - More siloxanes in biogas from sewage sludge

- … as well as operation of the anaerobic digestion
  - Less H_2S with dosage of iron chloride or iron oxide

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Gas cleaning

- Desulphurization
- Siloxane removal
- Ammonia removal
- Oxygen removal
- VOC/BTEX removal
- Methane removal in side streams

- Important to consider the sequence of these purification methods!
- Gas cleaning in raw gas, product gas or side stream (stripper air, CO_2 stream)?

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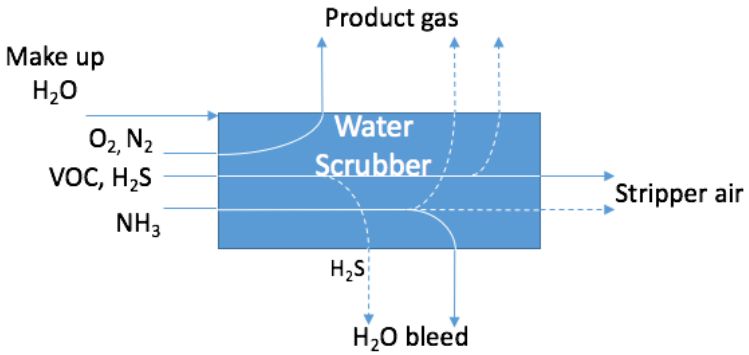
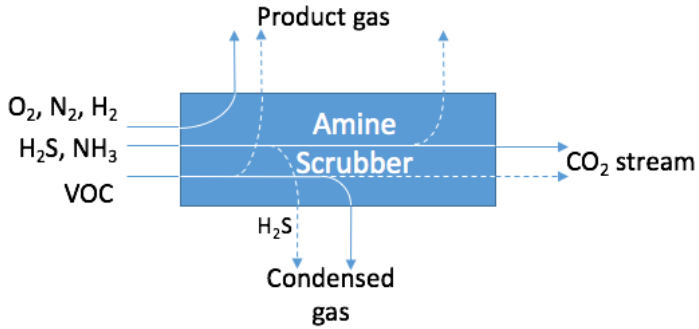
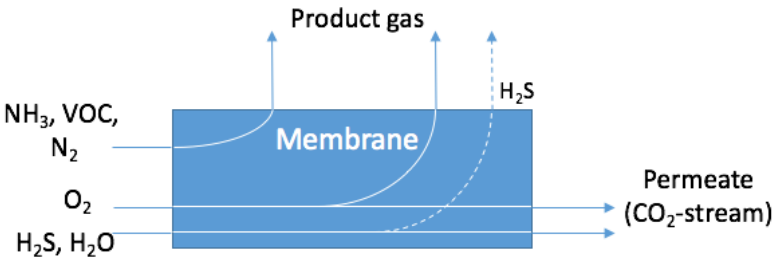
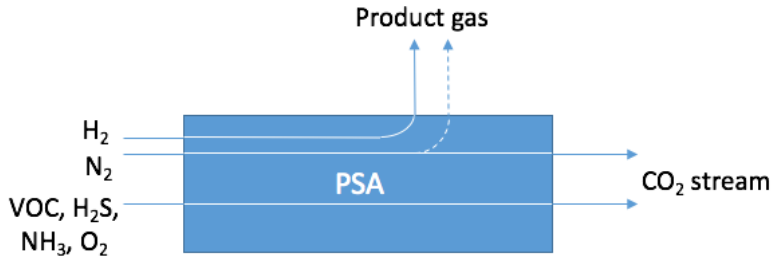
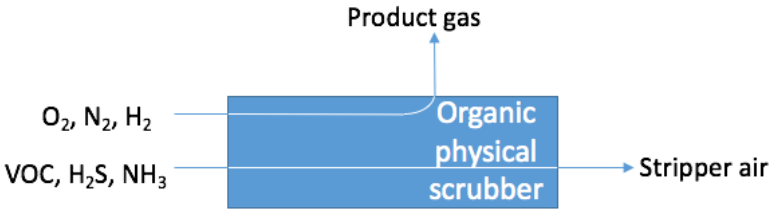
Where do these compounds go?











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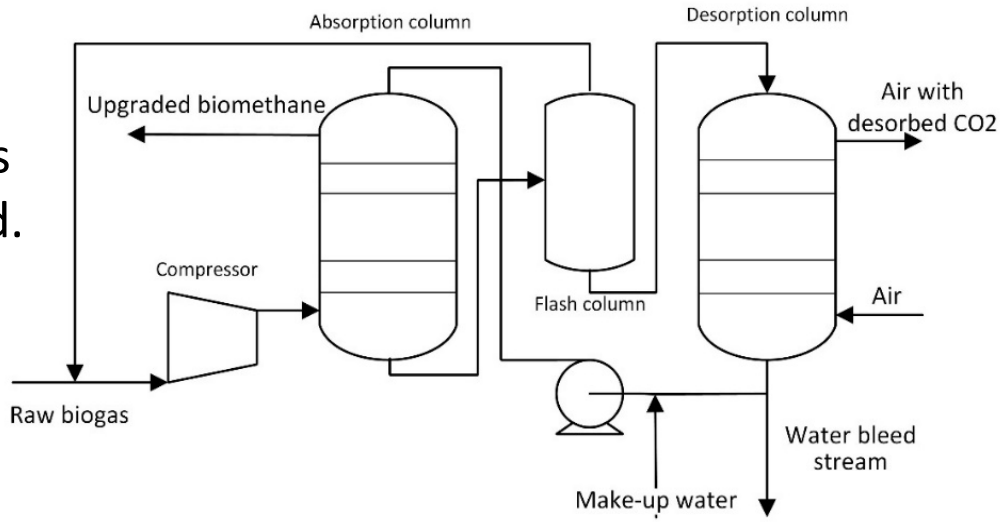
Water scrubber

- Biogas pressurized
- Absorption column: CO_2 dissolves in the water
- Biomethane dried
- Flash column
- Desorption with air: CO_2 desorbs from the water which is recycled.



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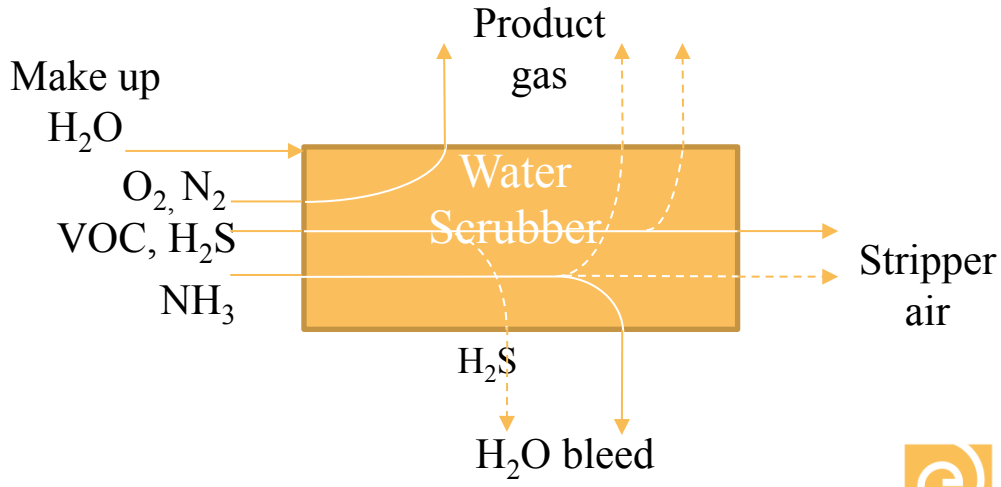
Water scrubber

- H_2S, NH_3 → stripper air, water bleed
- VOC → gas condensate, stripper air
- O_2, N_2 → product gas / biomethane
- Drying of product gas needed
- Traces of CH_4 in stripper air



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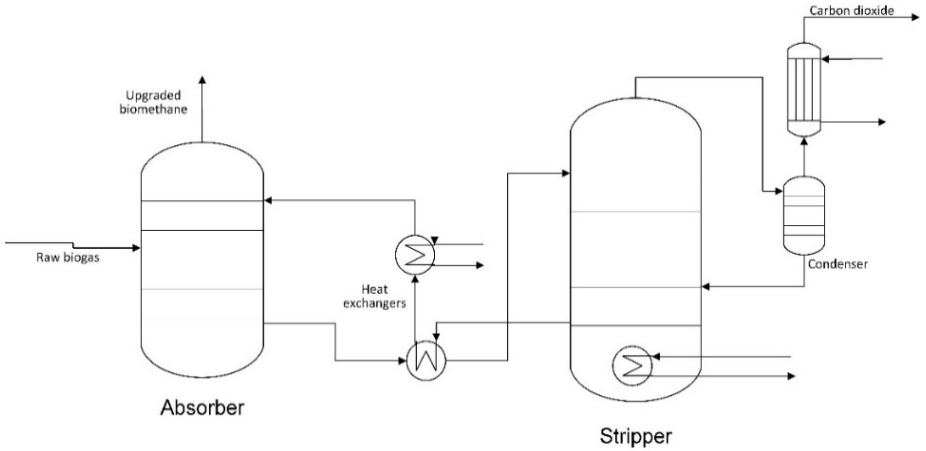
Amine scrubber

- Absorption column: CO_2 reacts with amine and is transferred to the solution
- Desorption with heat
- Biomethane dried
- Works at low pressure.



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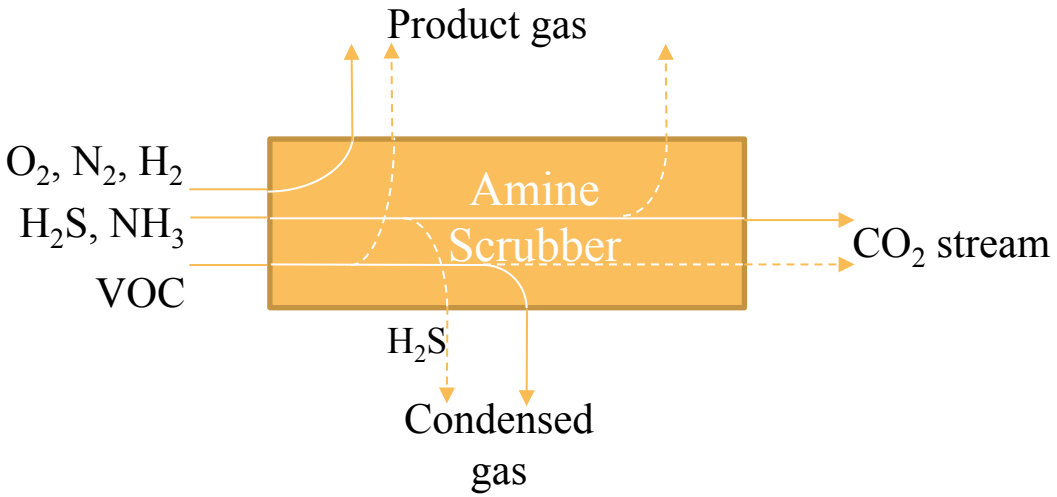
Amine scrubber

- $H_2S \rightarrow CO_2$ stream (At high H_2S concentrations in the raw gas, a polish filter in the product gas may be needed for amine scrubbers.)
- VOC, $NH_3 \rightarrow$ gas condensate, CO_2 stream
- O_2, $N_2 \rightarrow$ product gas / biomethane
- Drying of product gas needed
- Very pure CO_2 can be produced.



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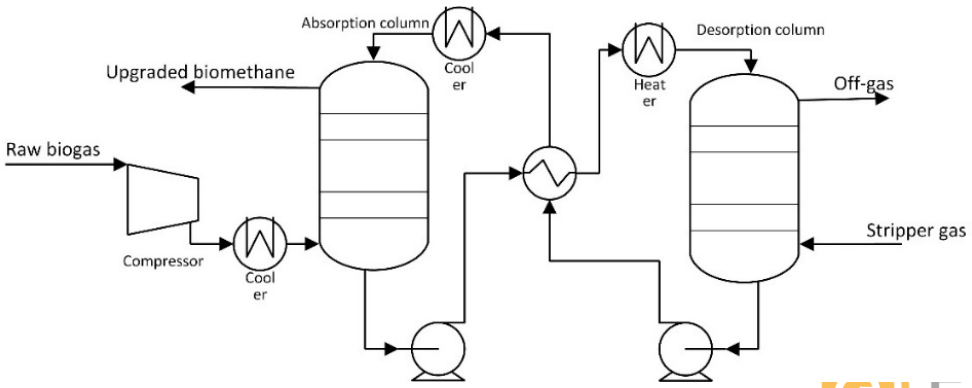
Organic physical scrubber

- Biogas pressurized
- Absorption column: CO_2 dissolves in the organic solvent
- Biomethane may need drying (has a dewpoint around -20 ˚C at 1 bar(a)).
- Desorption with air: CO_2 desorbs from the solvent which is recycled.



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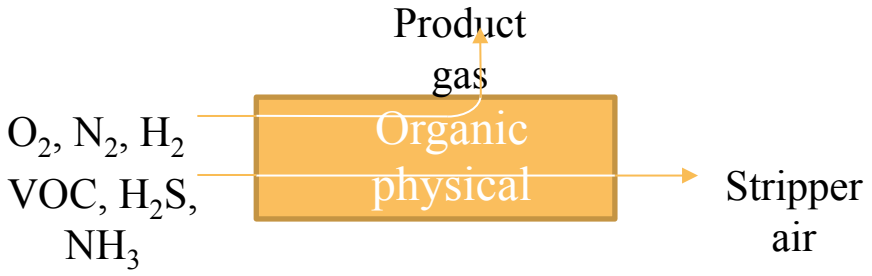
Organic physical scrubber

- H_2S, NH_3, → stripper air
- VOC → gas condensate, stripper air (Water insoluble VOCs are concentrated in the solvent and can be removed by an additional cleaning step.)
- O_2, N_2 → product gas / biomethane
- Product gas will have a dew point around -20 ˚C at 1 bar(a).
- Traces of CH_4 in stripper air



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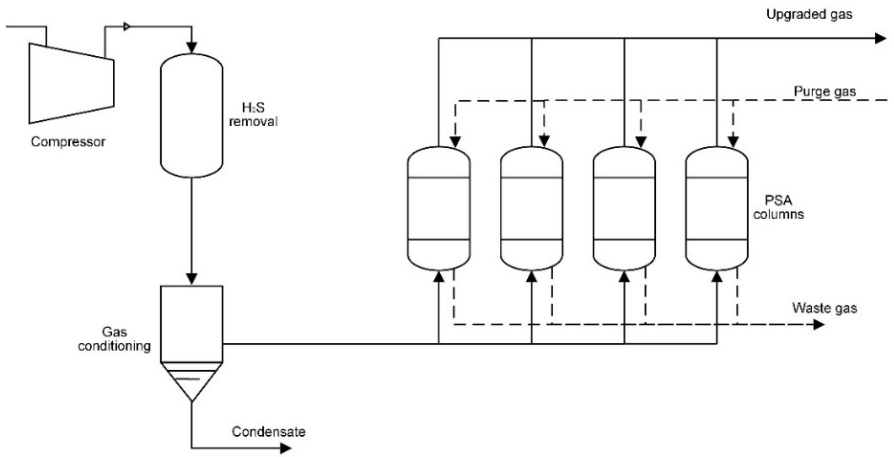
PSA – pressure swing adsorption

- Biogas pressurized
- Adsorption column: CO_2 retained
- Pressure released when column saturated → CO_2 released
- Several columns needed for continuous operation
- Columns filled with activated carbon, zeolites, silica gels or carbon molecular sieves (CMS)



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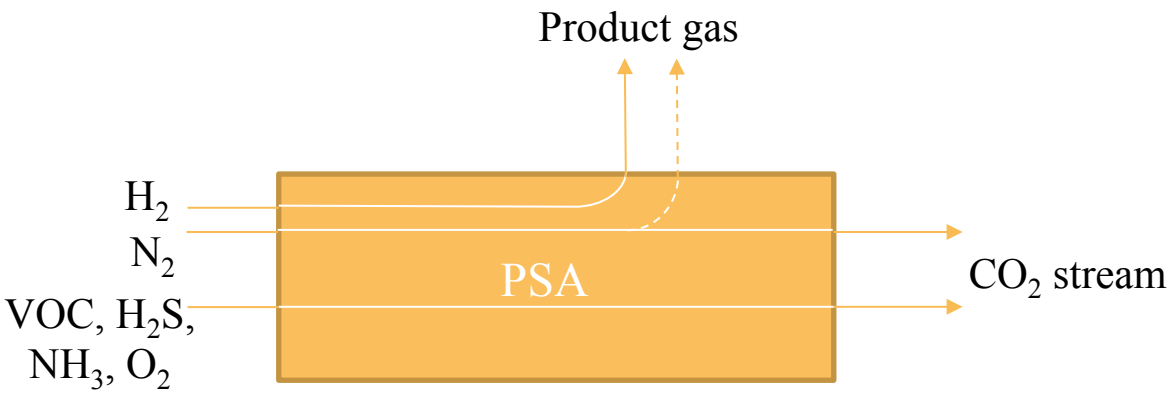
PSA – pressure swing adsorption

- H_2S, VOC, NH_3, O_2, N_2 → CO_2 stream BUT H_2S needs to be removed in pretreatment due to irreversible binding to the adsorbent! Also VOC and NH_3 need to be removed in pretreatment.
- H_2 → product gas / biomethane
- No drying of product gas needed



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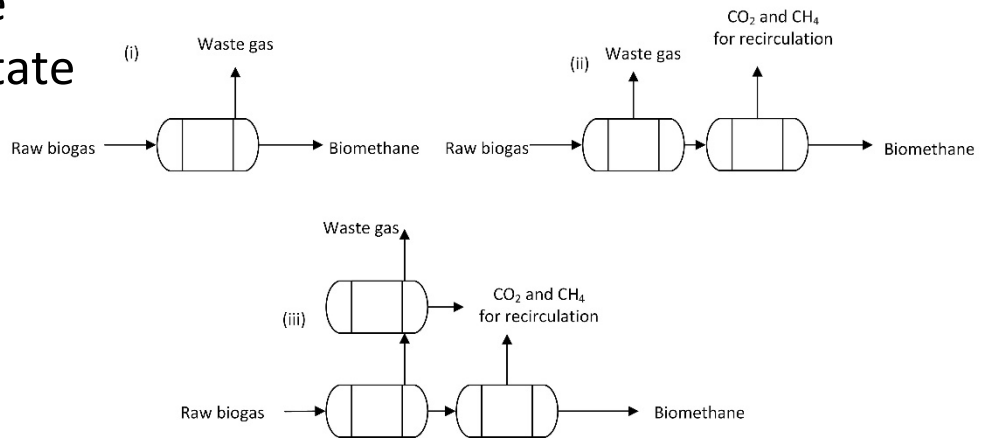
Membrane separation

- Biogas pressurized to 10-20 bar(a)
- Membrane: CO_2 passes through the membrane to the permeate side, CH_4 retained on the retentate side
- Several membrane steps to optimize product quality and minimize methane slip



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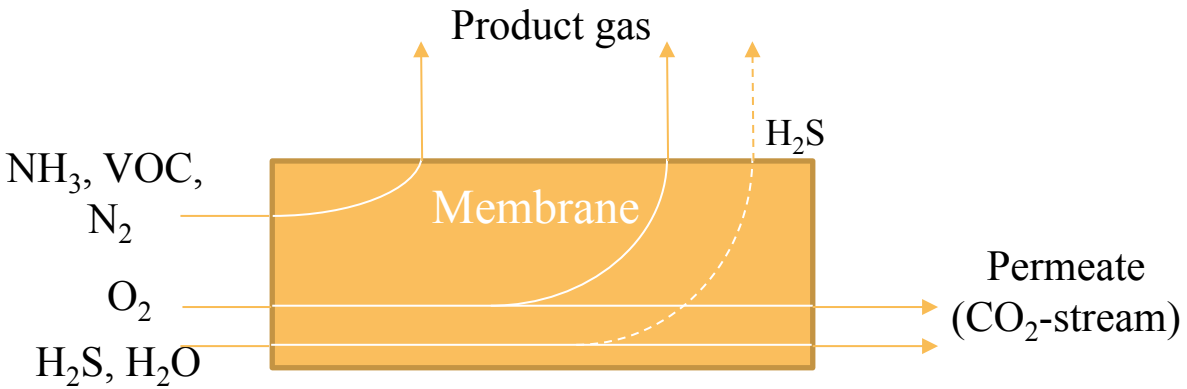
Membrane separation

- $H_2S \rightarrow CO_2$ stream, significant amount to product gas (commonly removed in pretreatment to avoid acid condensation on membranes)
- N_2, VOC → product gas BUT certain VOCs damage the membrane fiber and VOCs are commonly removed in pretreatment
- NH_3 → gas condensate in pretreatment drying
- $O_2 \rightarrow CO_2$ stream and product gas
- No drying of product gas needed
- Most membranes sensitive to liquid water, oil and particles



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Comparison of techniques

Data for specific investment cost and energy consumption collected from biogas upgrading suppliers for a standard case.

	Raw gas specifications	Product gas requirements
Pressure:	20 mbar(g)	> 4 bar(g)
Methane concentration	60 vol%	> 97 vol%
Sulphur concentration	200 ppm H_2S	< 20 mg/Nm^3 (excl. odorisation)
Water concentration	Saturated with water at 40 ˚C	Dew point -10 ˚C at 200 bar(g)
Other requirements	Max. 0.1 vol% O_2 and 0.4 vol% N_2, no siloxanes, max. 100 ppm NH_3	

Also: 1% methane slip, containerized solution, no heat recovery, annual average

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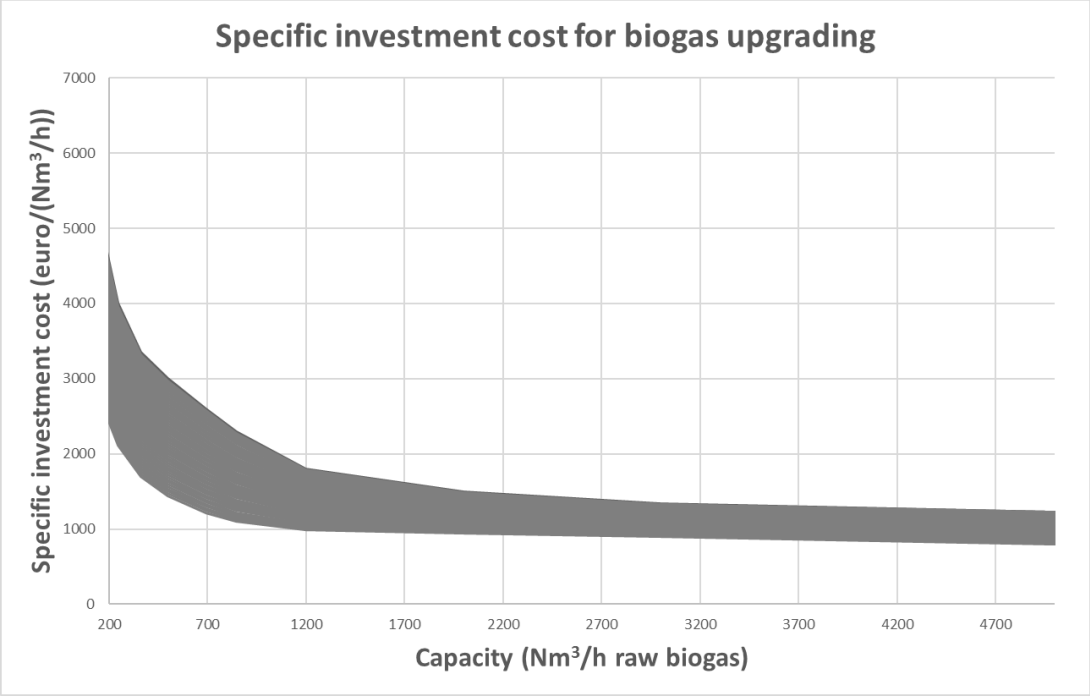
Comparison of techniques

- Investment cost (euro/(Nm^3 raw gas/h))



Specific investment cost for biogas upgrading, data from different suppliers.

- Lower specific investment cost with higher capacity, especially above 1000 Nm^3/h.
- Distribution between suppliers but no general trend concerning techniques.
- Largest distribution between suppliers at low capacities.
- Economy of scale most dominant for membranes at low capacities and for scrubbers at higher capacities.

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Comparison of techniques

- Energy consumption
  - 0,2-0,3 kWh/Nm^3 biogas for all techniques (electricity except for amine scrubbers where electricity consumption is lower but also heat is needed)
  - No significant difference between techniques has been shown by the collected data.

- Methane slip
  - Amount of methane which is found in side streams and this not present in the product gas (% of methane in the raw gas)

	Methane slip
Pressure swing adsorption (PSA)	1-1.5%
Water scrubber	1%
Amine scrubber	<0.1%
Membrane separation	0.5%
Organic physical scrubber	1-2%
Cryogenic upgrading	No data

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Thanks to…

Reference group:

- Air Liquide
- Ammongas
- Biofrigas
- BMF Haase
- Carbotech
- DMT
- DVGW
- Envitec
- Greenlane Biogas
- Malmberg Water
- NeoZeo
- Pentair Haffman
- Purac Puregas
- Scandinavian Biogas
- Sysadvance

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DGC, Danish Gas Technology Centre
Stockholm Gas

The Swedish Water & Wastewater Association (Svenskt Vatten)

SVGW (Swiss Gas Industry)

Project partner:

Hulteberg
CHEMISTRY & ENGINEERING

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Report

Want to know more?

The report ”Biogas upgrading – technical review” and many more reports on biogas can be found at

http://www.energiforsk.se/rapportsok/

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