

# Merits of the key current technologies for biogas to bio-methane gas upgrading

Michael Harasek

TU Wien

Institute of Chemical Engineering

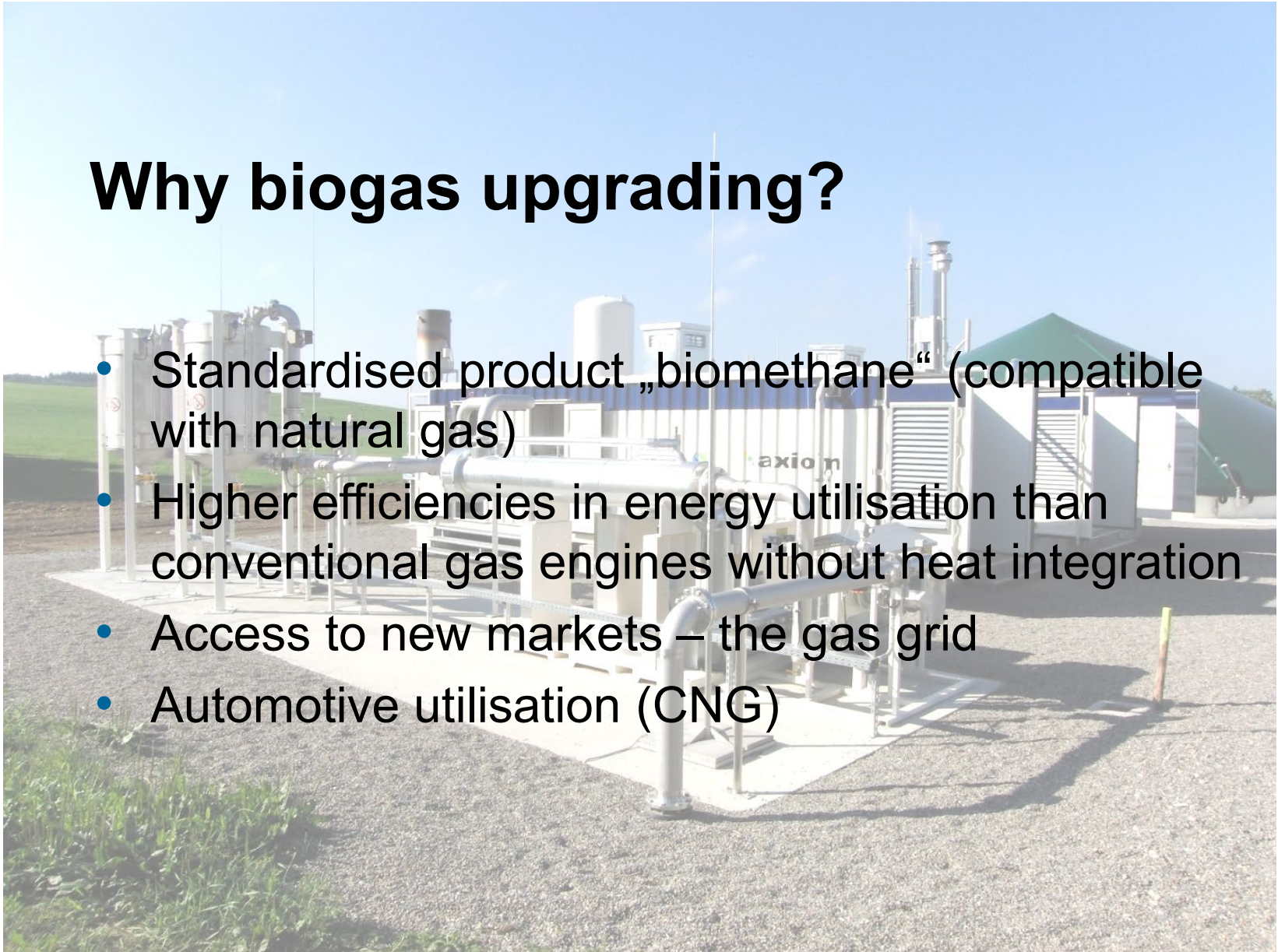
[michael.harasek@tuwien.ac.at](mailto:michael.harasek@tuwien.ac.at)

**Czech Austrian Summerschool – June 2023**

- Characteristics of biogas
- Upgrading biogas
  - Preconditioning / pretreatment
  - Desulphurisation
  - Compression
  - Upgrading = CO<sub>2</sub> + H<sub>2</sub>O separation
  - Final conditioning, offgas treatment
- Energy consumption and costs
- Biomethane Calculator
- Other environmentally related aspects
  - Economy of scale
  - Energy efficiency
- Summary & conclusions

## Why biogas upgrading?

- Standardised product „biomethane“ (compatible with natural gas)
- Higher efficiencies in energy utilisation than conventional gas engines without heat integration
- Access to new markets – the gas grid
- Automotive utilisation (CNG)



- Directive 2003/55/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in natural gas and repealing Directive 98/30/EC.

**Preamble:** Member States should ensure that, taking into account the necessary quality requirements, **biogas and gas from biomass or other types of gas** are granted nondiscriminatory access to the gas system, provided such access is permanently compatible with the relevant technical rules and safety standards. These rules and standards should ensure, that these gases can technically and safely be injected into, and transported through the natural gas system and should also address the chemical characteristics of these gases.

# European targets

- **European Green Deal - RePowerEU**
- **Biomethane Industrial Partnership – Biomethane Action Plan to get 35 billion m<sup>3</sup>/a biomethane into the gas grid by 2030 (!)**

## Introducing the Task Forces Teaming up to achieve 35 bcm of sustainable biomethane



**Task Force 1**  
National biomethane targets, strategies and policies



**Task Force 2**  
Accelerated biomethane project development



**Task Force 3**  
Sustainable potentials for innovative biomass sources



**Task Force 4**  
Cost efficiency of biomethane production and grid connection



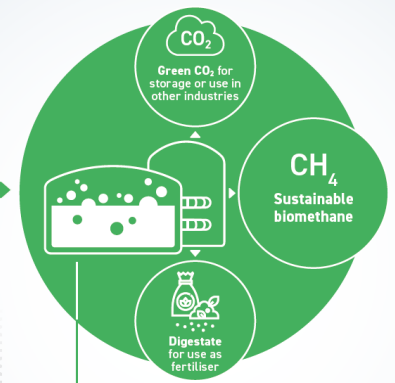
**Task Force 5**  
Research, Development and Innovation needs

## OUR VISION FOR BIOMETHANE



- Increases **soil carbon and biodiversity** by applying sustainable agricultural practices, such as cover crops and application of biogas digestate to fields
- Increases **rural employment**, providing additional market and income opportunities for farmers
- Provides an attractive and efficient **waste management** solution, supporting resource circularity
- Promotes **energy self-sufficiency and security**

- Sequential crops\*
- Plant by-products
- Animal by-products
- Biowaste from households
- Industrial and municipal organic wastes and sludges
- Woody by-products



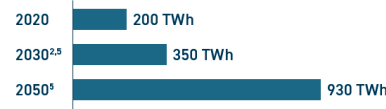
- Replacing natural gas with biomethane for decarbonisation of buildings with hybrid heat pumps
- Biomethane provides high temperature heat and climate neutral carbon for industrial processes
- Future power system requires dispatchable power. Biomethane provides flexibility and high value
- Decarbonisation of maritime and heavy long-distance road transport

FEEDSTOCKS

CONVERSION

END USE

### BIOMETHANE POTENTIAL IN EUROPE



### SELECTED CASE STUDIES

**Consorzio Italiano Biogas (CIB)** develops greener and efficient low carbon farming practices that integrate multicropping systems, smart nutrient recycling approaches and sustainable soil management with the production of biomethane. The CIB calls this Biogasdoneright, an approach that demonstrates how production can be increased while sustainability actually improves. Biogasdoneright can be replicated across Europe and become a cornerstone in sustainable biomethane production scale-up.

Danish company **Nature Energy** focuses on local food waste, industrial waste and agricultural waste to produce biogas and biomethane close to where the feedstock arises, thereby contributing to rural development. Technical innovations allow Nature Energy to increase scale and decrease costs. With 12 plants currently in the EU, Nature Energy have ambitious growth plans to invest 4.7 billion Euros by 2030 on additional plants in Europe and abroad to enhance the green transition. Nature Energy trades and markets the biomethane across Europe to both utilities and industry.

Biomethane finds application in many end-use sectors including long haul heavy transport. **Scania** the Swedish truck and bus company, has long been developing trucks and buses running on alternative energy, like biomethane. Many international transport operators, and several major cities, operate Scania biogas vehicles. Scania aims to have 50% of all Scania EU heavy-duty gas trucks and buses biomethane powered by 2030.

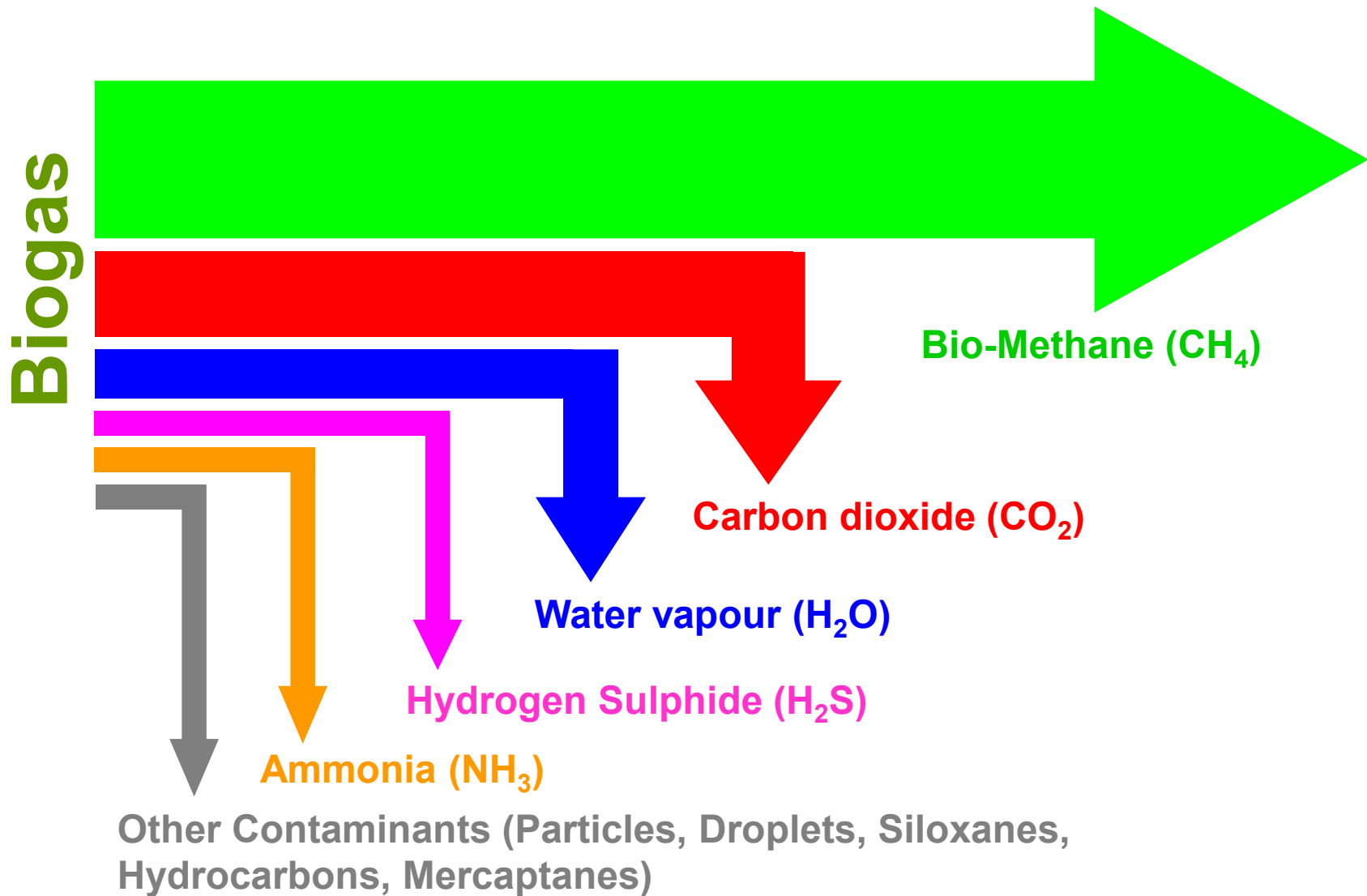
# Biogas Composition and Natural Gas Standards

	Biogas yield (l/kg VS*)	Methane content (%)
Fat	1000–1250	70–75
Protein	600–700	68–73
Carbohydrate	700–800	50–55

\*VS = Volatile Solids

[Wellinger et al., IEA Task37 (2009)]

Parameter	Biogas	Specification according to ÖVGW G31	Unit
methane	50 bis 70	-	[mole %]
carbon dioxide	25 bis 45	$\leq 2,0$	[mole %]
ammonia	up to 1.000	technically free	[mg/m <sub>N</sub> <sup>3</sup> ]
hydrogen sulfide	up to 2.000	$\leq 5$	[mg/m <sub>N</sub> <sup>3</sup> ]
oxygen	up to 2	$\leq 0,5$	[mole%]
nitrogen	up to 8	$\leq 5$	[mole %]
water vapour (dewpoint)	up to 37 @ 1 bar	$\leq - 8 @ 40 \text{ bar}$	[°C]
<b>upper heating value</b>	6,7 - 8,4	10,7 - 12,8	kWh/m <sub>N</sub> <sup>3</sup>
<b>Wobbe-Index</b>	6,9 - 9,5	13,3 - 15,7	kWh/m <sub>N</sub> <sup>3</sup>



# Biogas Upgrading Steps

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- Preconditioning / pretreatment
- Removal of particles, droplets, siloxanes, other trace components

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- Biogas desulphurisation

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- Compression

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- Biogas upgrading
- Separation of CO<sub>2</sub> and H<sub>2</sub>O

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- Final conditioning
- Dewpoint control, adjustment of heating value, offgas treatment



- ✓ **Particles, droplets:** use filter, demister
- ✓ **Siloxanes:** use carbon adsorption (water dewpoint control needed - place a chiller + reheater in front of the carbon adsorption tower)
- ✓ **Halogenated hydrocarbons, other hydrocarbons, fatty acids, terpenes:** use carbon adsorption (water dewpoint control needed - place a chiller + reheater in front of the carbon adsorption tower)

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- ✓ **Various technologies available:**
  - ✓ In-situ desulphurisation
  - ✓ Air injection
  - ✓ External biological desulphurisation
  - ✓ Chemical oxidation
  - ✓ Adsorptive removal (iron oxide, zinc oxide)
  - ✓ Catalytical oxidation and carbon adsorption (KI/I<sub>2</sub> – impregnated carbon, needs stoichiometric amount of oxygen)
  - ✓ Combined with upgrading: water/amine absorption
- ✓ Ask, if there is a desulphurisation currently used or implemented
- ✓ Check the H<sub>2</sub>S concentration and feedstock related fluctuations

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## Compatible:

- External biological desulphurisation in combination with pure oxygen injection
- In-situ desulphurisation using iron salts
- **External chemical scrubber with oxidation using NaOH/H<sub>2</sub>O<sub>2</sub>, recommended for fluctuating H<sub>2</sub>S concentrations in the biogas**
- Adsorptive desulphurisation technologies with low excess of O<sub>2</sub> (impregnated activated carbon adsorbents)

## Not suitable / incompatible:

- Air injection
- External biological desulphurisation with air injection



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- ✓ **Various types of compressors available:**
  - ✓ Piston compressors
  - ✓ Screw compressors
  - ✓ Water ring pumps
  - ✓ Blowers
- ✓ Check range of load/capacity variation
- ✓ Check delivery pressure requirements
- ✓ Consider correct conversion volume flow to operating conditions (temperature, pressure), add recycle if needed
- ✓ Do not forget to account for water content / humidity
- ✓ Design for worst case and check turn-down ratio of compressor
- ✓ Check corrosion resistance, service intervals and lifetime
- ✓ Prefer oil-free systems (gear box lubrication only)
- ✓ Check cooling requirements – prefer water cooled systems

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- ✓ **Various technologies available**
  - ✓ Pressure swing adsorption
  - ✓ Water scrubbing
  - ✓ Selexol absorption
  - ✓ Amine absorption
  - ✓ Membrane separation
  - ✓ Cryo separation
  - ✓ Hybrid systems
- ✓ **Decide for suitable technology primarily NOT by investment costs – remember: cheap can be expensive!!**
- ✓ Select suitable technology according to:
  - ✓ upgrading capacity
  - ✓ turn-down ratio
  - ✓ shut-down / start-up performance and ease of operation
  - ✓ product quality needed
  - ✓ Chemicals and energy consumption

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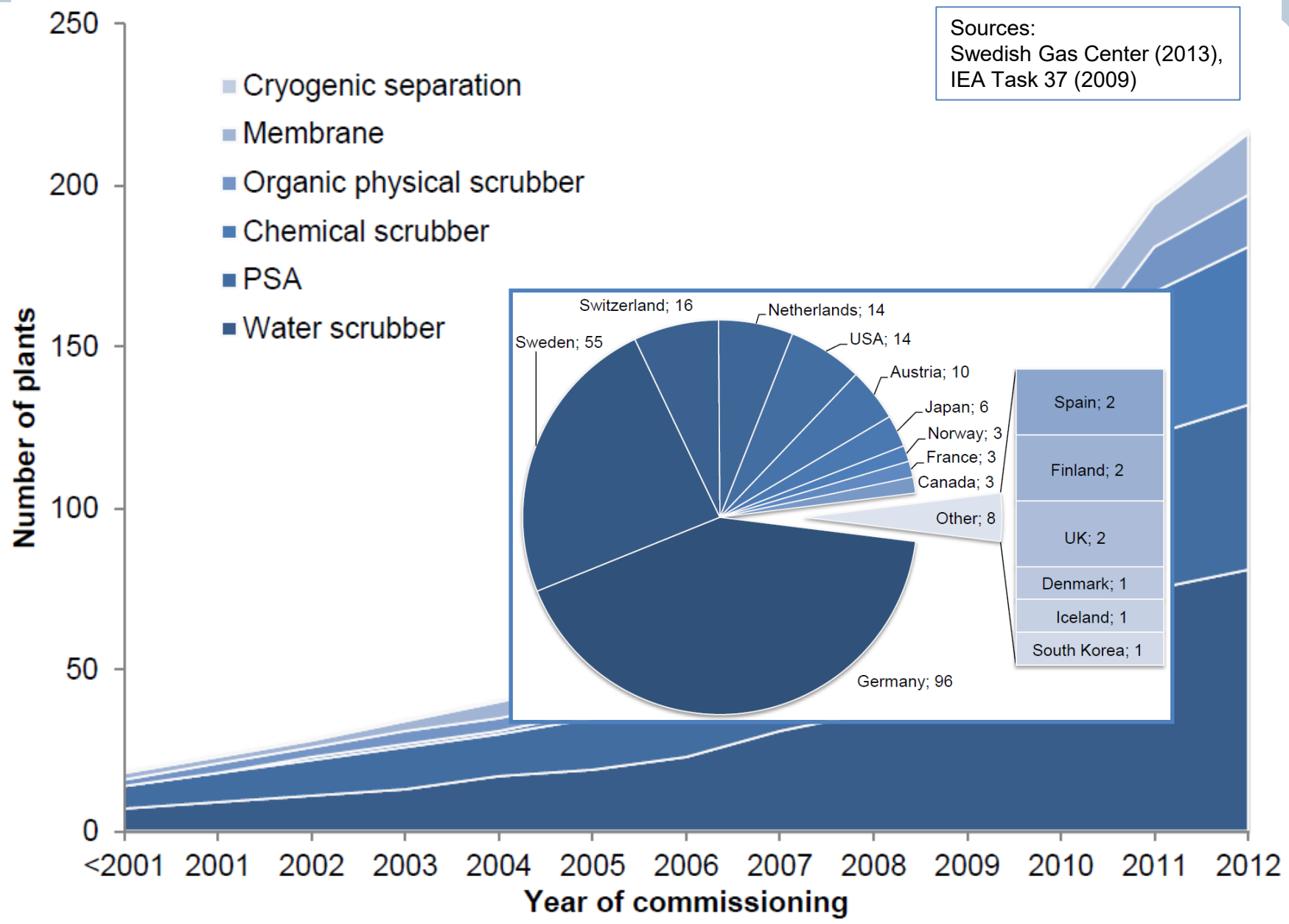
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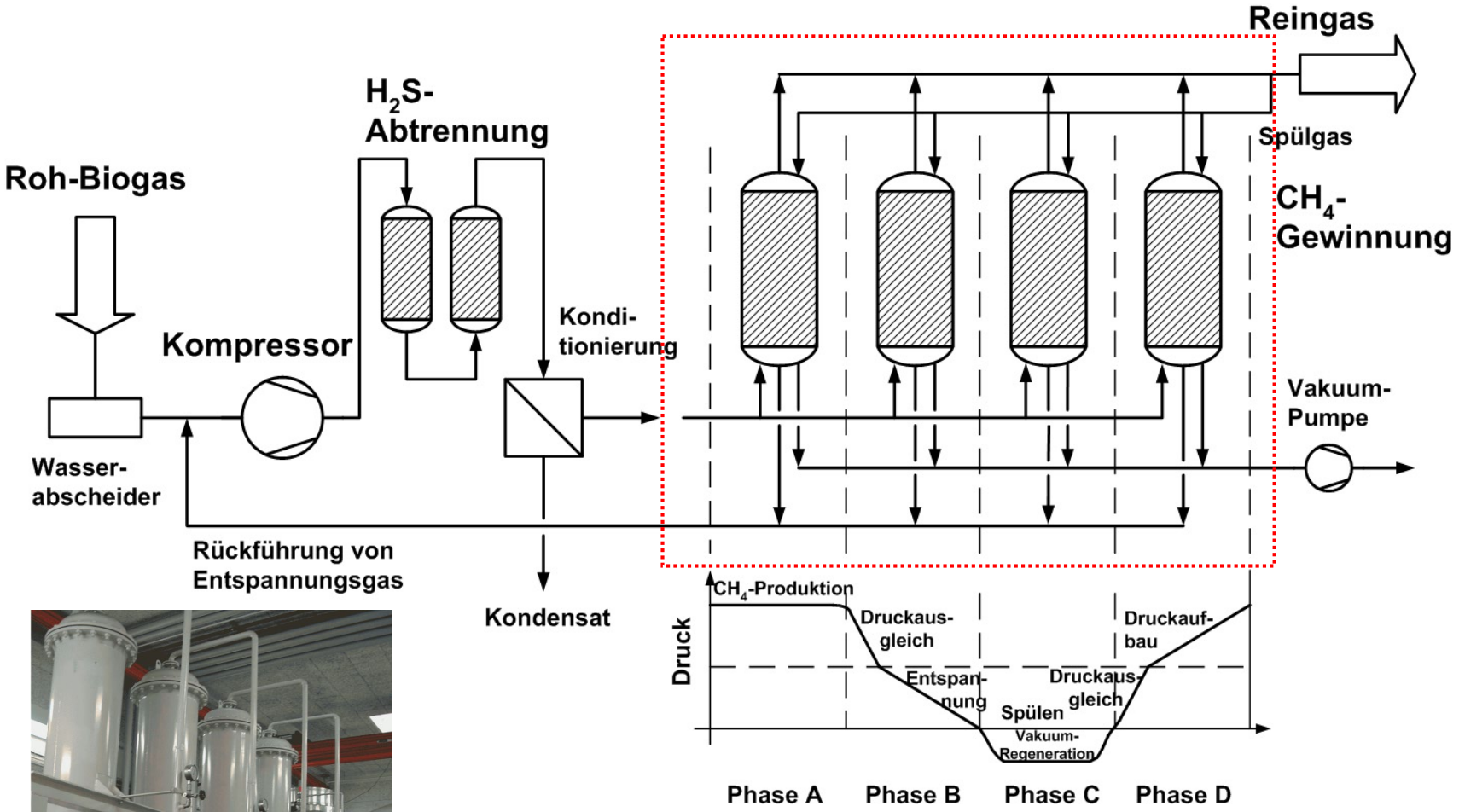
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# Identified Biogas Upgrading Plants (IEA Task 37)

Sources:  
 Swedish Gas Center (2013),  
 IEA Task 37 (2009)



# Pressure Swing Adsorption



- Cyclic operation
- Many valves, precise timing needed

# Project Pucking - Pressure Swing Adsorption (PSA)

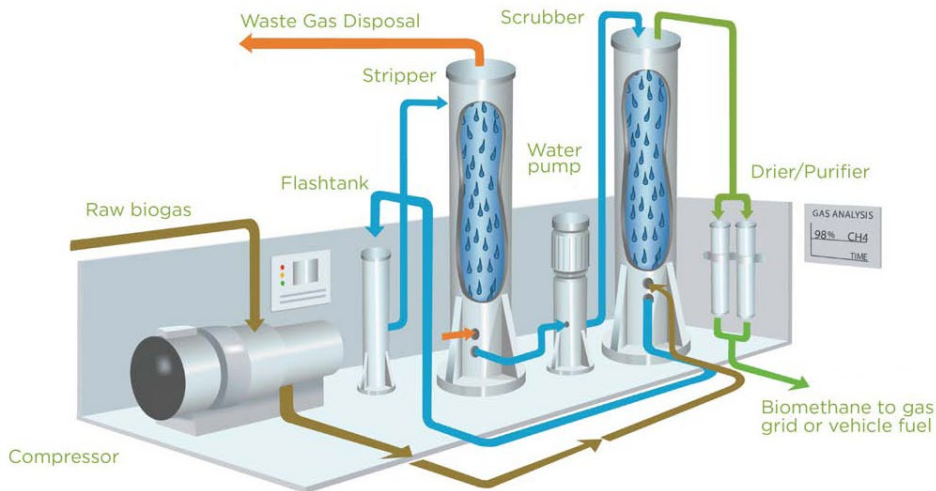
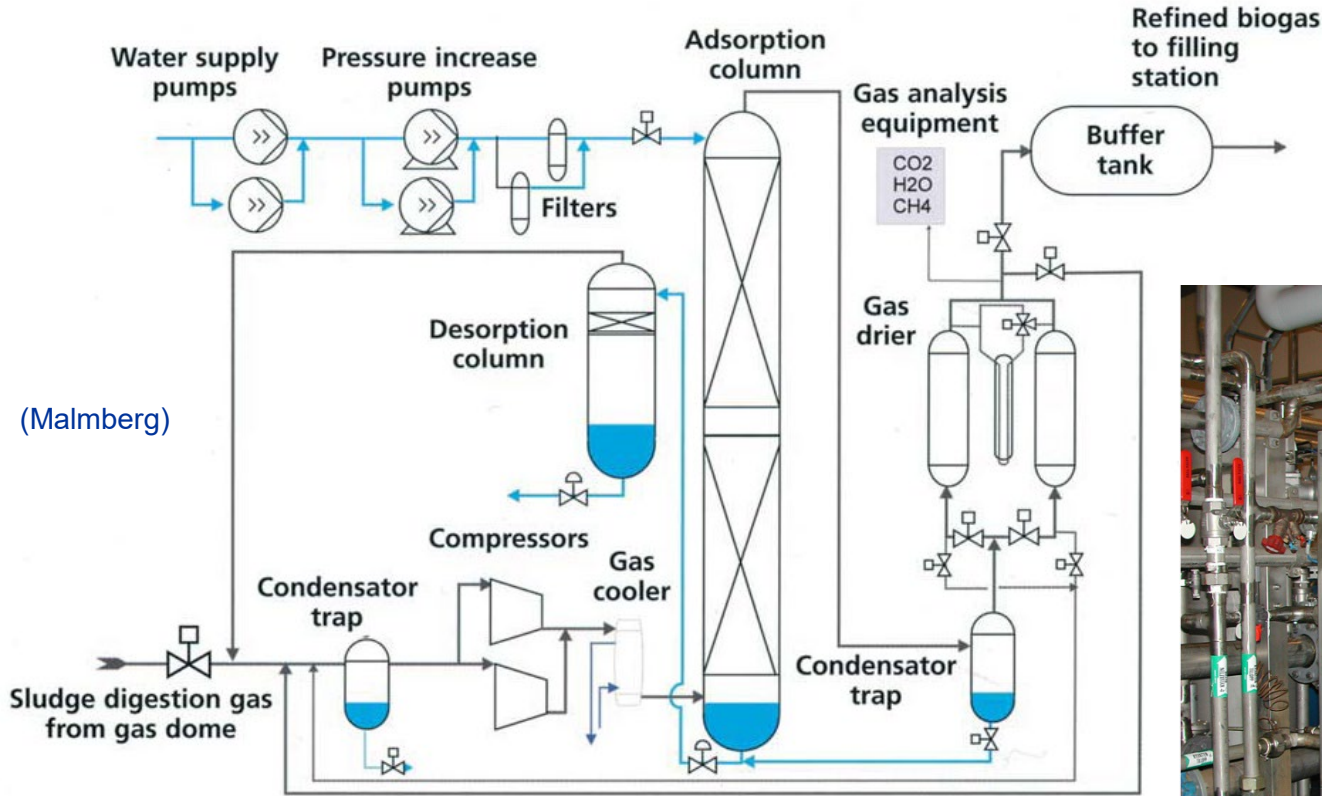


(Photos: M.Harasek)



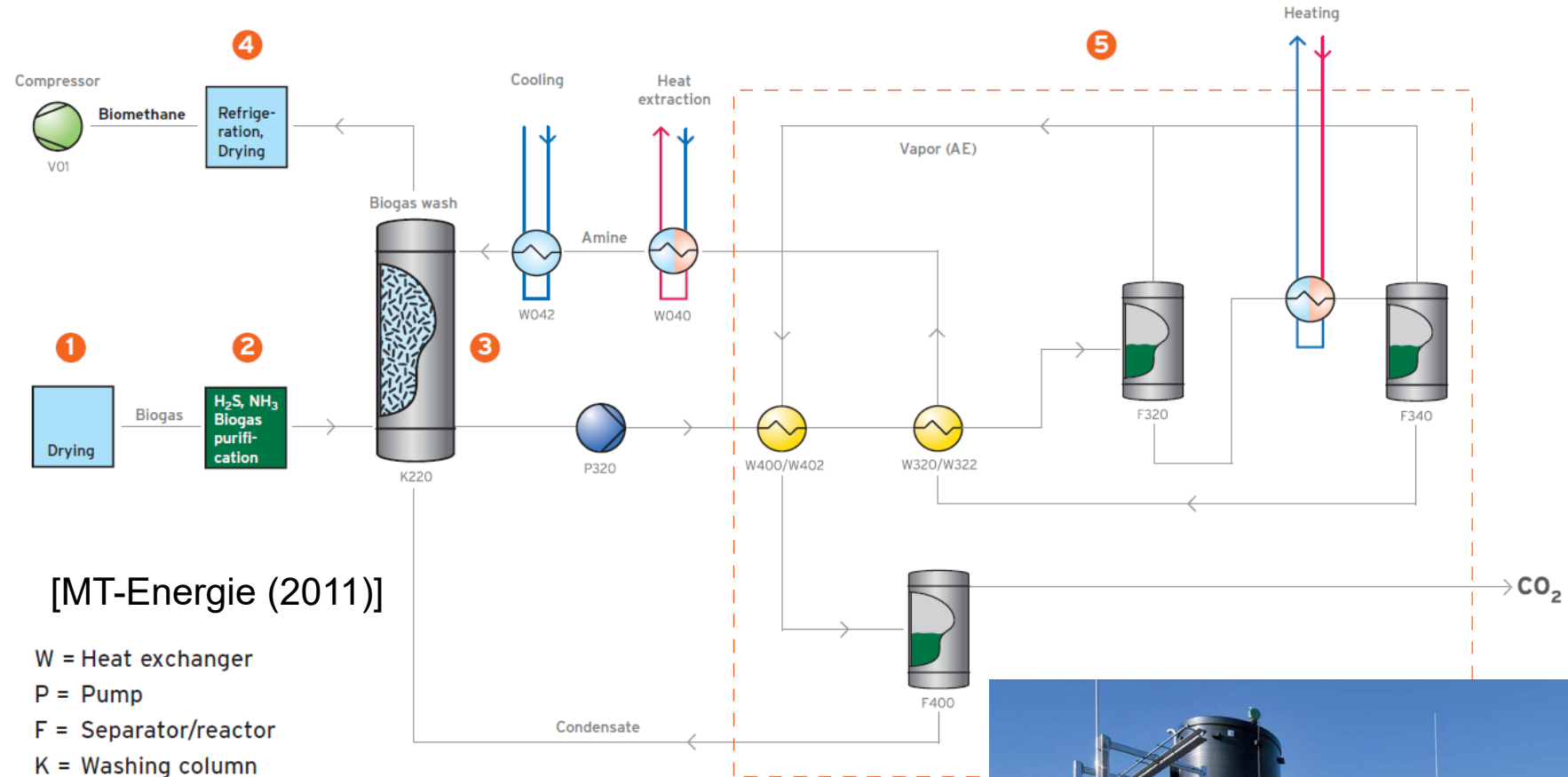


# Water Scrubbing / Absorption





- Waste water treatment plant Asten (near Linz)
- Malmberg – water scrubber (800 m<sup>3</sup>/h biogas)



- Alkanol amines (MEA, DEA, MDEA) used for  $CO_2$  absorption
- High desorption temperatures in recycle loops
- Low pressure operation possible

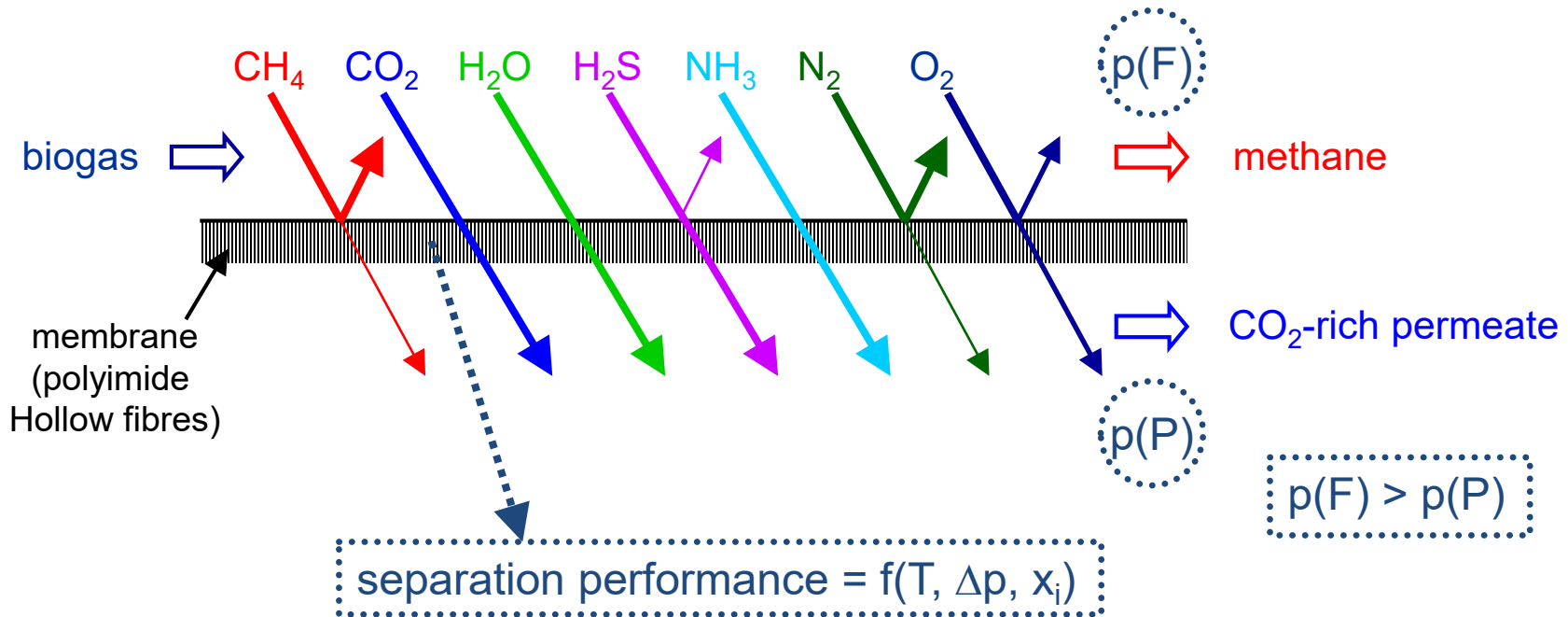




- Capacity 1,000.000 m<sup>3</sup> Bio-methane / a
- BCM (MT-Energie) amine scrubber

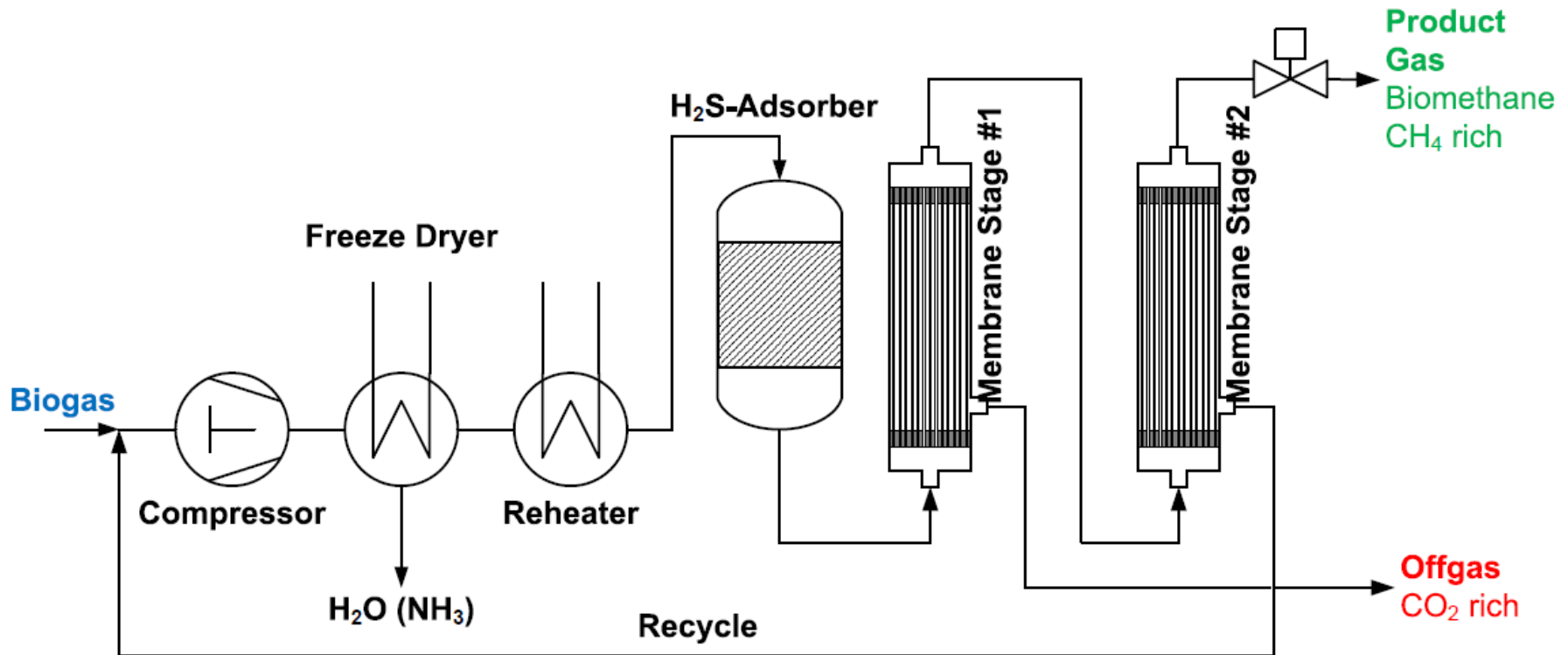
# Upgrading of biogas using gas permeation (GP)

- Separation principle: different permeabilities of methane and components to be separated.
- Important parameter: permeability ratio = selectivity.
- After compression biogas is fed to membrane modules.

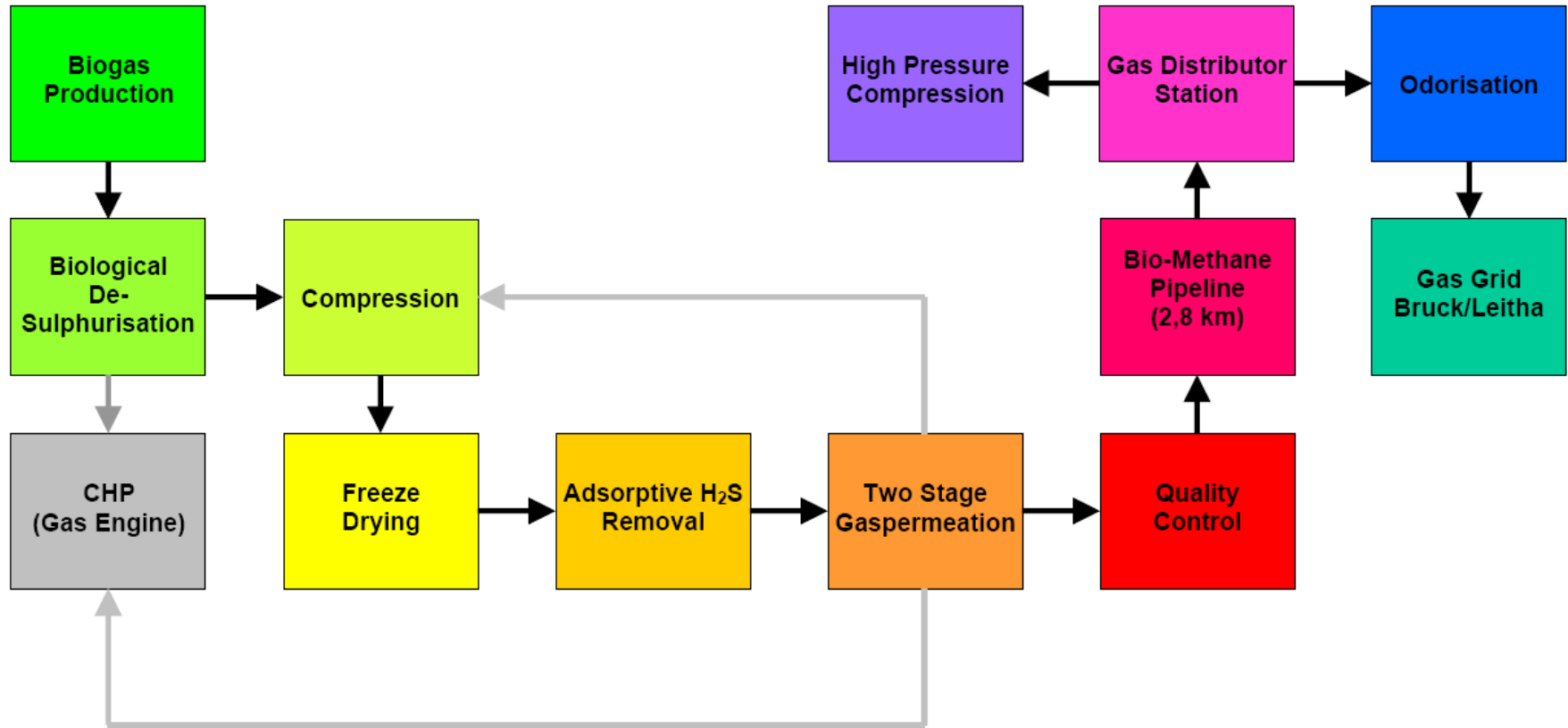


# Process Scheme of a Two-stage Membrane System

- **Two-stage separation process** with recycle and a single compressor



# Process Integration (Two-stage design)



- **Biological desulphurisation prior to membrane treatment**
- **Permeate is recycled to CHP plant – „zero methane“ emission of upgrading system**

Bruck/Leitha plant as reference...

Utilization of approx. 34 000 t/a of organic waste

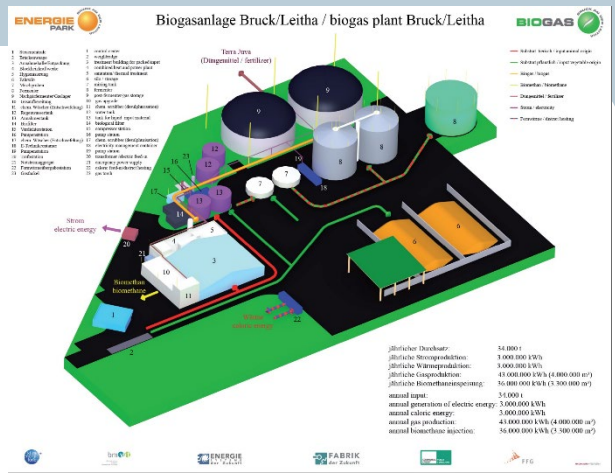
Pre-treatment of the waste by pasteurization (1h at 70°C)

3 digesters (3000 m<sup>3</sup> each), 2 post-digesters (5000 m<sup>3</sup> each)

1000 m<sup>3</sup>/h raw biogas

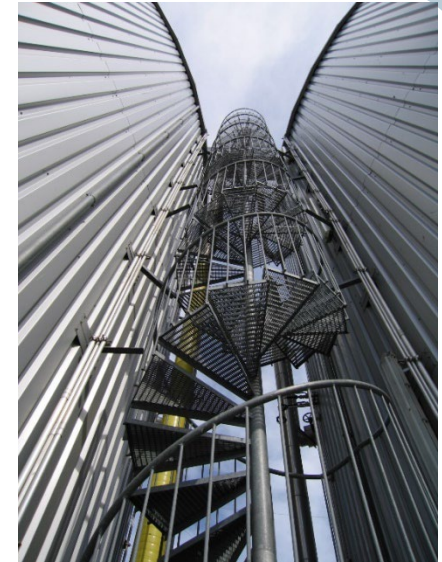
2 CHP gas engines (summing up to 1362 kW) for own supply

Biogas upgrading plant (3.300.000 m<sup>3</sup>/a biomethane) – 400m<sup>3</sup>/h bio-methane

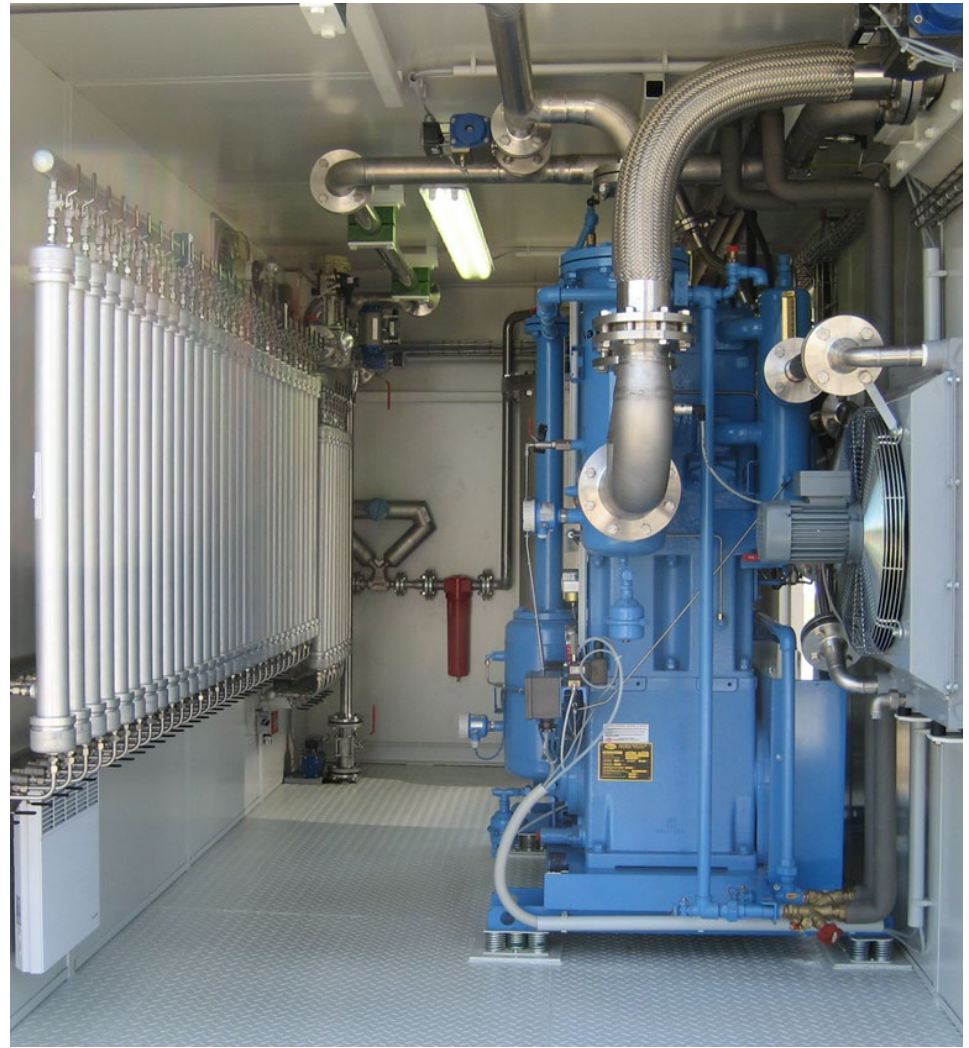




# Biogas plant Bruck/Leitha (Austria)



# Upgrading plant in Bruck/Leitha

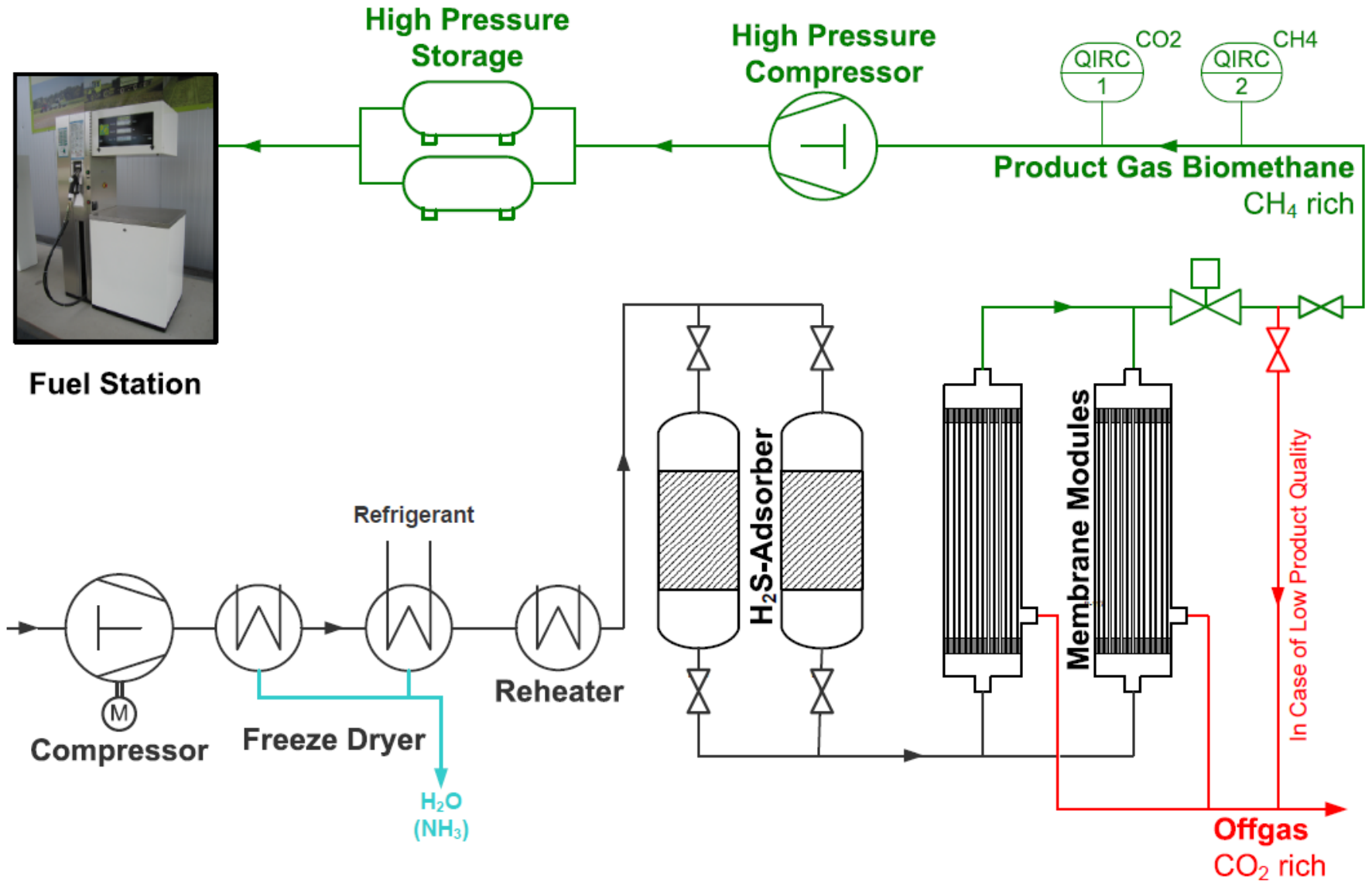


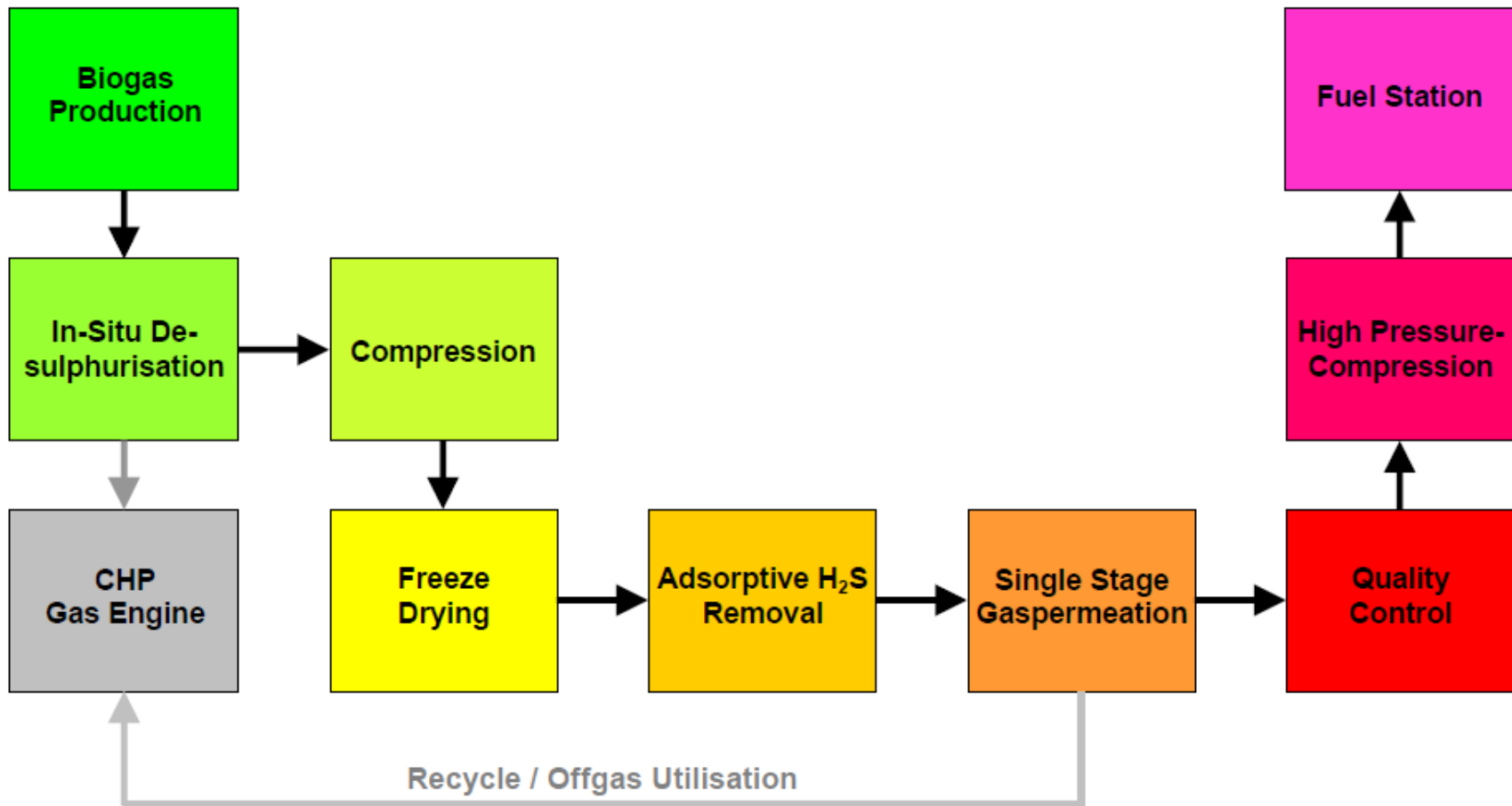
180 m<sup>3</sup>/h biogas / 100 m<sup>3</sup>(STP)/h biomethane @ 6 bar  
 Details: <http://www.virtuellesbiogas.at>

# Biomethane Fuel Station: Single Stage Upgrading



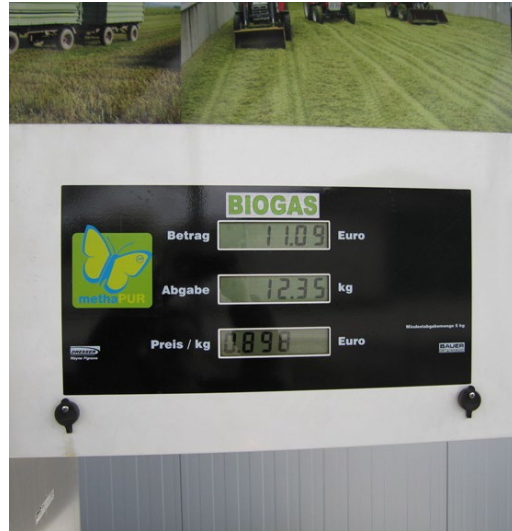
Fuel Station





- In-situ desulphurisation (addition of iron salts into the fermentation broth to catch sulphides)
- Permeate is recycled to CHP plant – „zero methane“ emission of upgrading system

# Bio-CNG with on-site fuel station



- Capacity: 500 kg/d bio-methane
- Bio-methane as fuel alternative (tractors, harvesting)



- Capacity: 220 (300) m<sup>3</sup>/h biogas
- Axiom – Membrane separation

# Membrane Biogas Upgrading Plant in Kisslegg (GE)



Membrane modules

# Biogasupgrading V2.0 in Bruck

- Start of plant and building construction and building end of 2013
- Start-up and grid feed-in October 2014
- Total investment @ plant location €3.900.000
- Investment cost biogas upgrading plant €1.865.000

## Plant data:

- Biogas 1000 m<sup>3</sup>/h
- Bio-methane 657 m<sup>3</sup>/h
- CH<sub>4</sub> > 98,2%
- CH<sub>4</sub> recovery 99,5%
- kWh/Nm<sup>3</sup><sub>biogas</sub> < 0,235





# Biogasupgrading V2.0 in Bruck



Compressors & Gas upgrading



Production hall

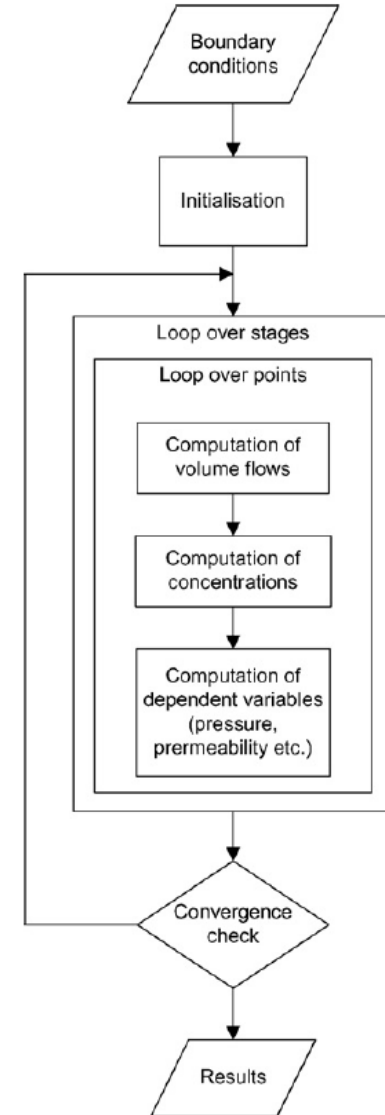
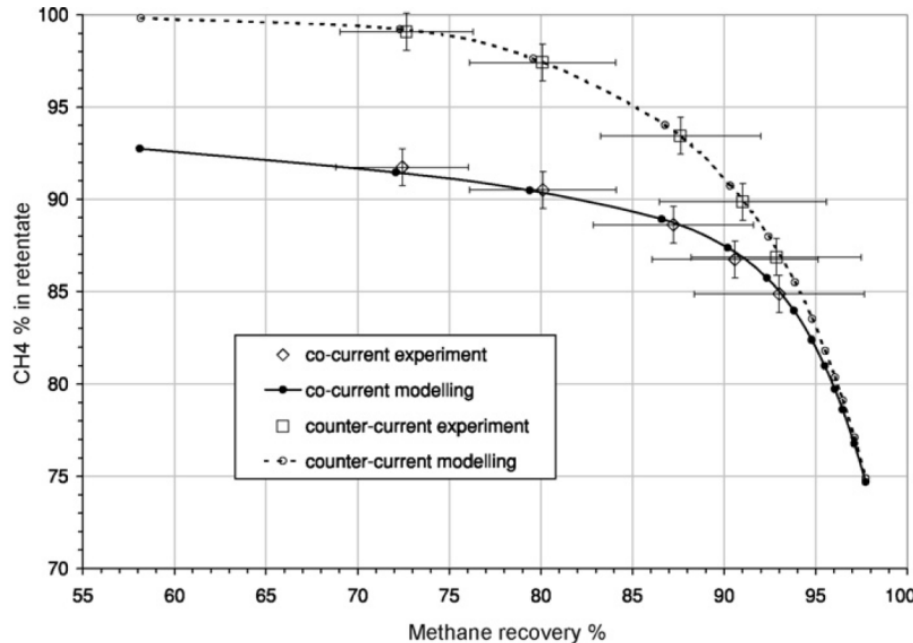


Desulphurization

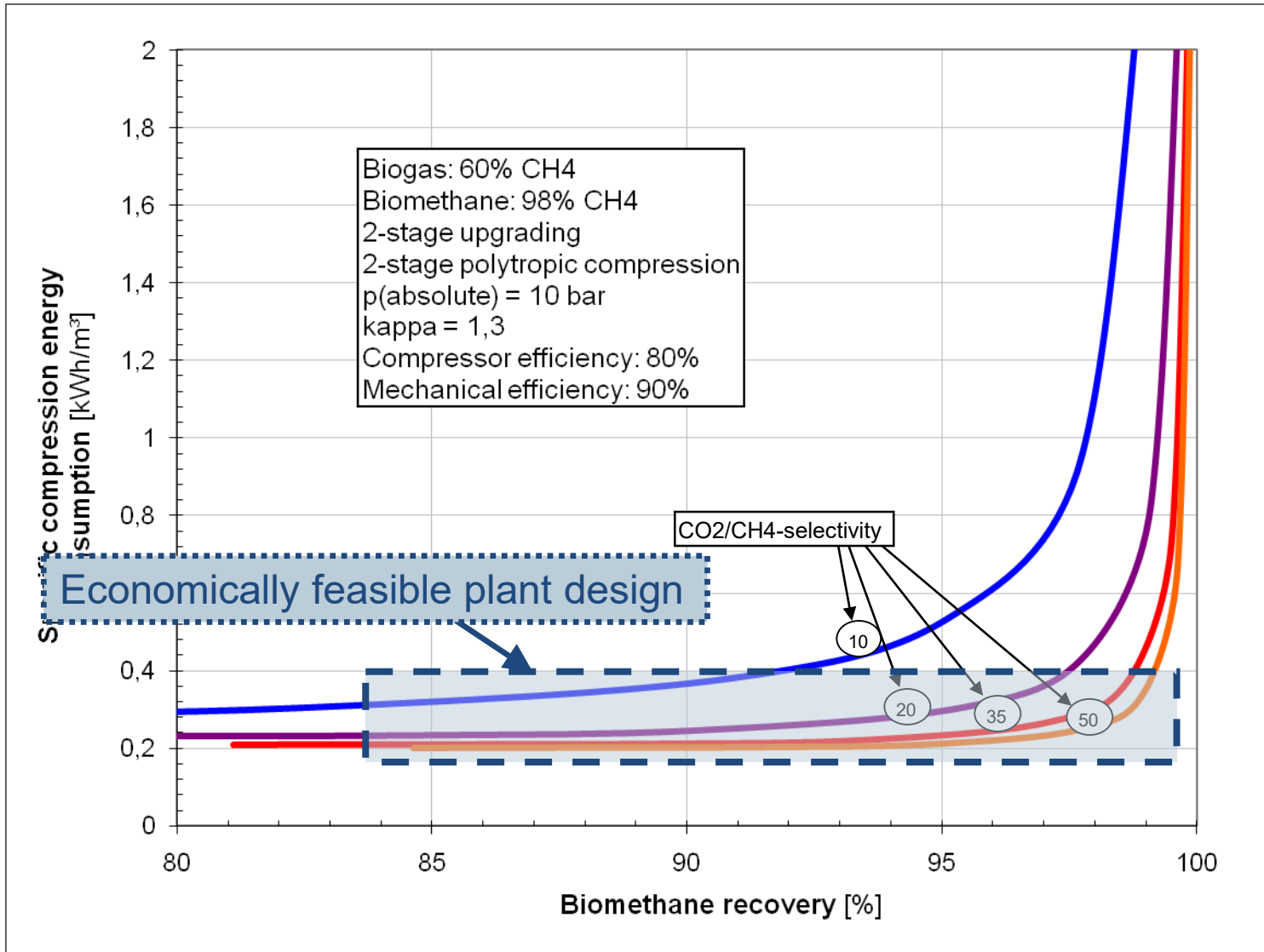
 **axiom**  
**BIOGAS**  
**ENERGIE**  
**PARK**



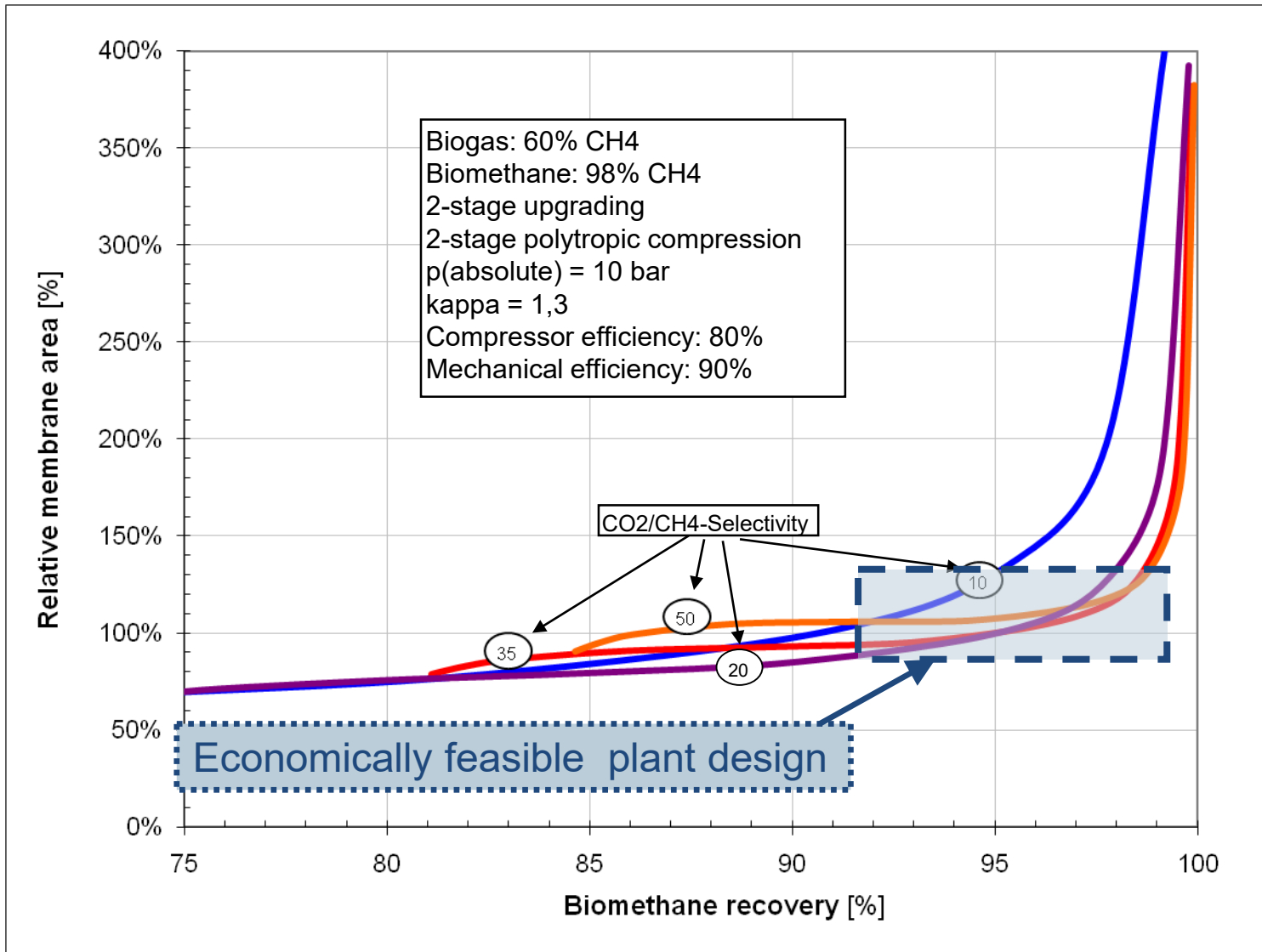
- Discrete solver for the modelling of multicomponent gas permeation systems
- Conservation equations in membrane permeation are discretised using finite difference method in one-dimension and solved using Gauß-Seidel approach (Makaruk & Harasek, J.Membrane Science 344 258-265)
- Modelling results were validated and provided good agreement with experimental results:



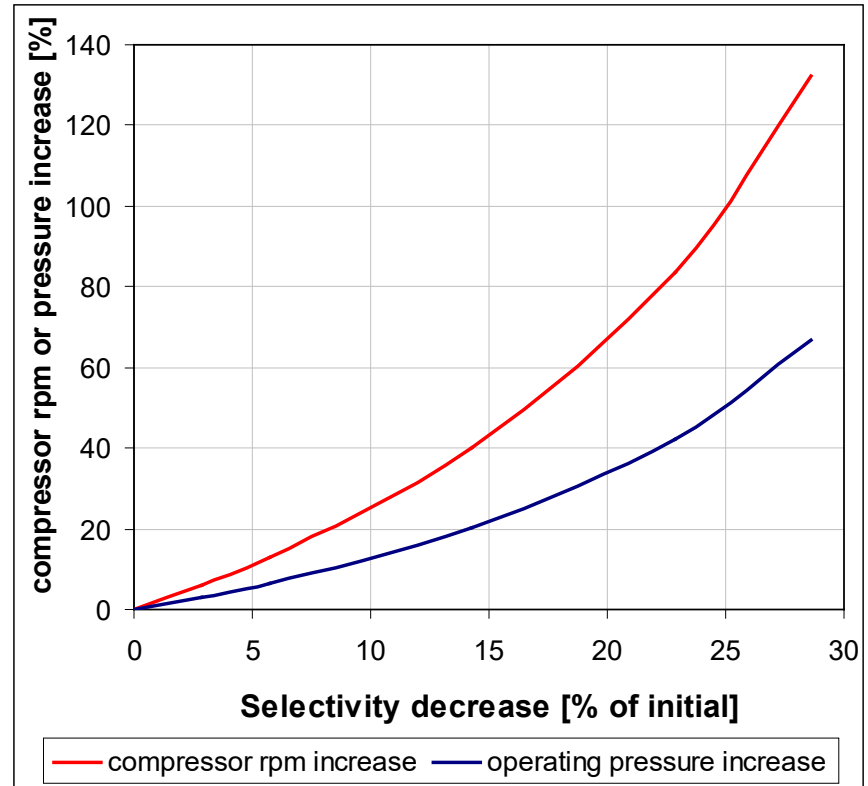
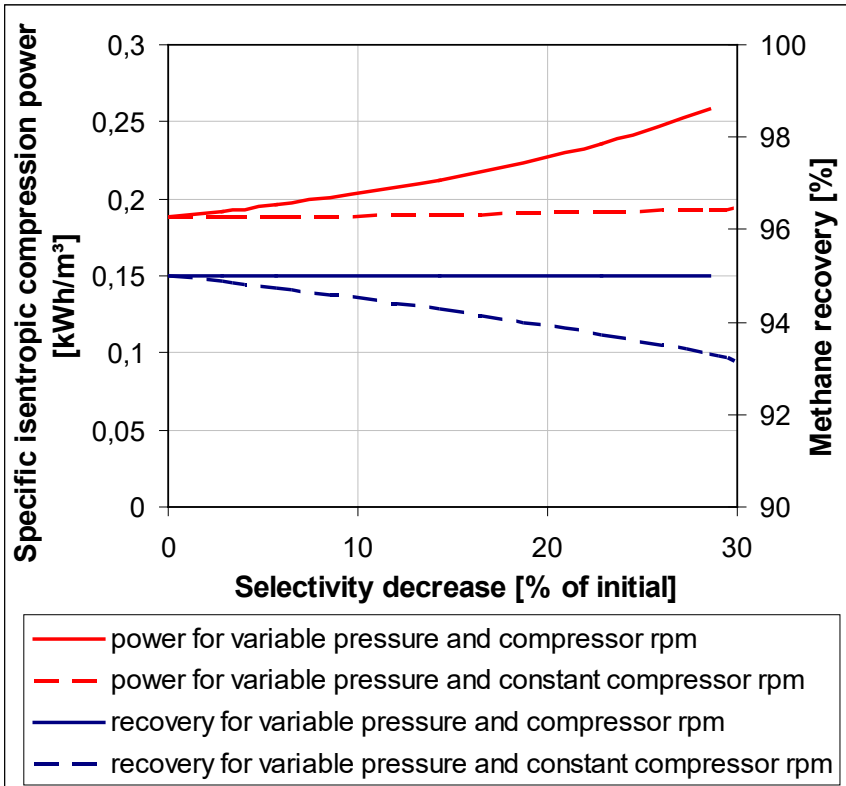
# Compression Energy Consumption per m<sup>3</sup> Product



# Membrane Area as Function of Recovery

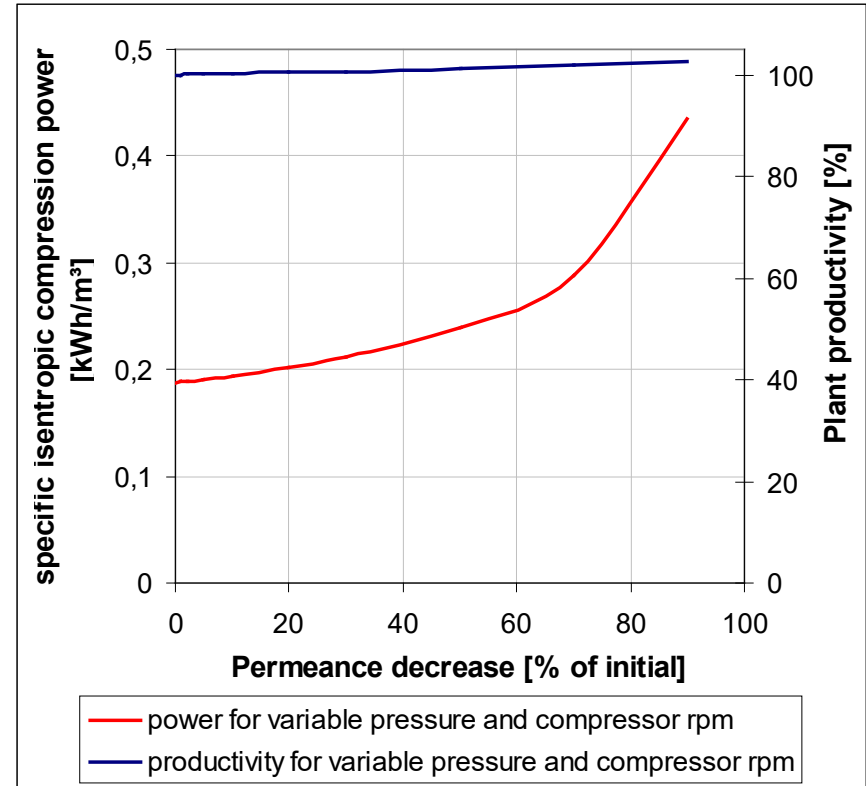
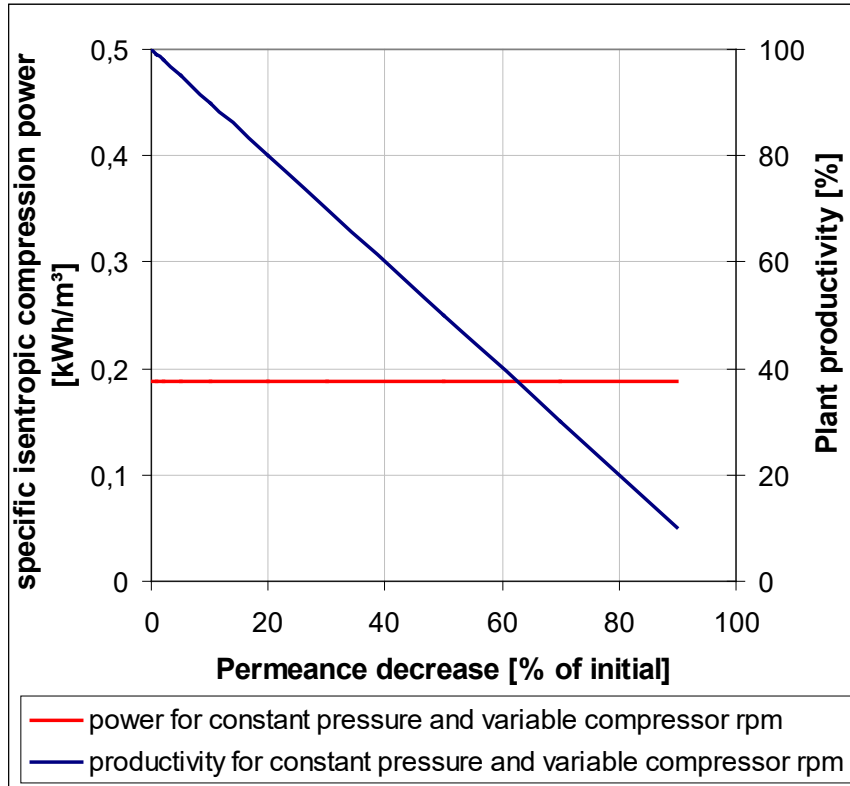


# Simulation – Change of Membrane Selectivity



- Selectivity decline results in a reduction of methane recovery, the operating pressure must be adjusted to maintain the gas purity
- If methane content and methane recovery are to be invariable to the selectivity reduction, both pressure and compressor RPM need to be adjusted (higher specific energy consumption)

# Simulation – Change of Membrane Performance



- Permeance decline leads to a decrease of plant productivity as the compressor volume flow has to be reduced to maintain the product gas methane content .
- If a constant productivity is to be maintained, the plant operating pressure needs to be increased while the compressor RPM may remain constant

- ✓ **Final conditioning needs depend on upgrading technology and requirements of gas grid or fuel use:**
  - ✓ All absorption based upgrading technologies (water scrubbing, selexol absorption, amine absorption) need gas drying by glycol scrubbing or molecular sieve adsorption
  - ✓ PSA may need mixing buffer tank to level out product concentration fluctuations
- ✓ Heating value correction: propane dosing to adjust heating value – consider need for gas quality and product gas flow measurement for dosing control
- ✓ Delivery pressure adjustment: pressure reduction or increase depends on feed-in conditions
- ✓ Odor dosing: e.g. THT (tetrahydrothiophene) or similar dosing equipment and control
- ✓ Gas quality measurement: local regulations and agreements may require continuous quality measurement (e.g. process gas chromatography – consider calibration needs!)

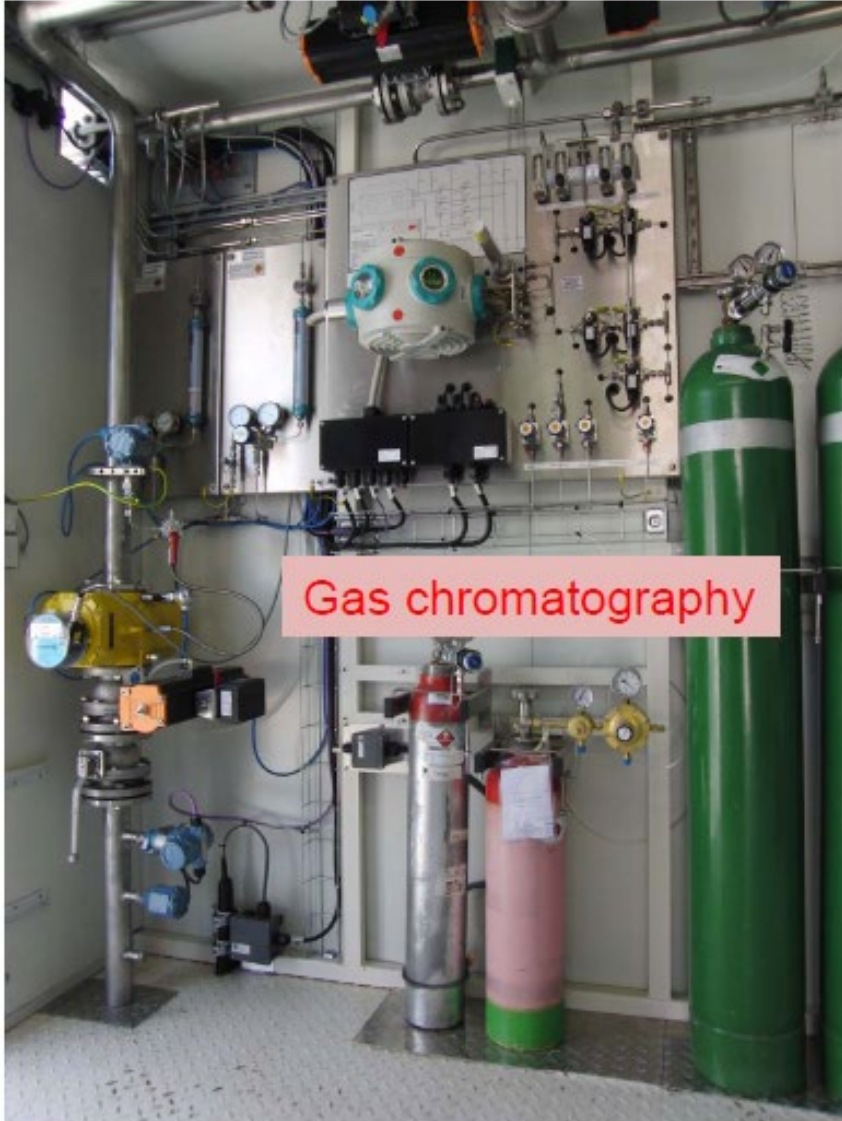
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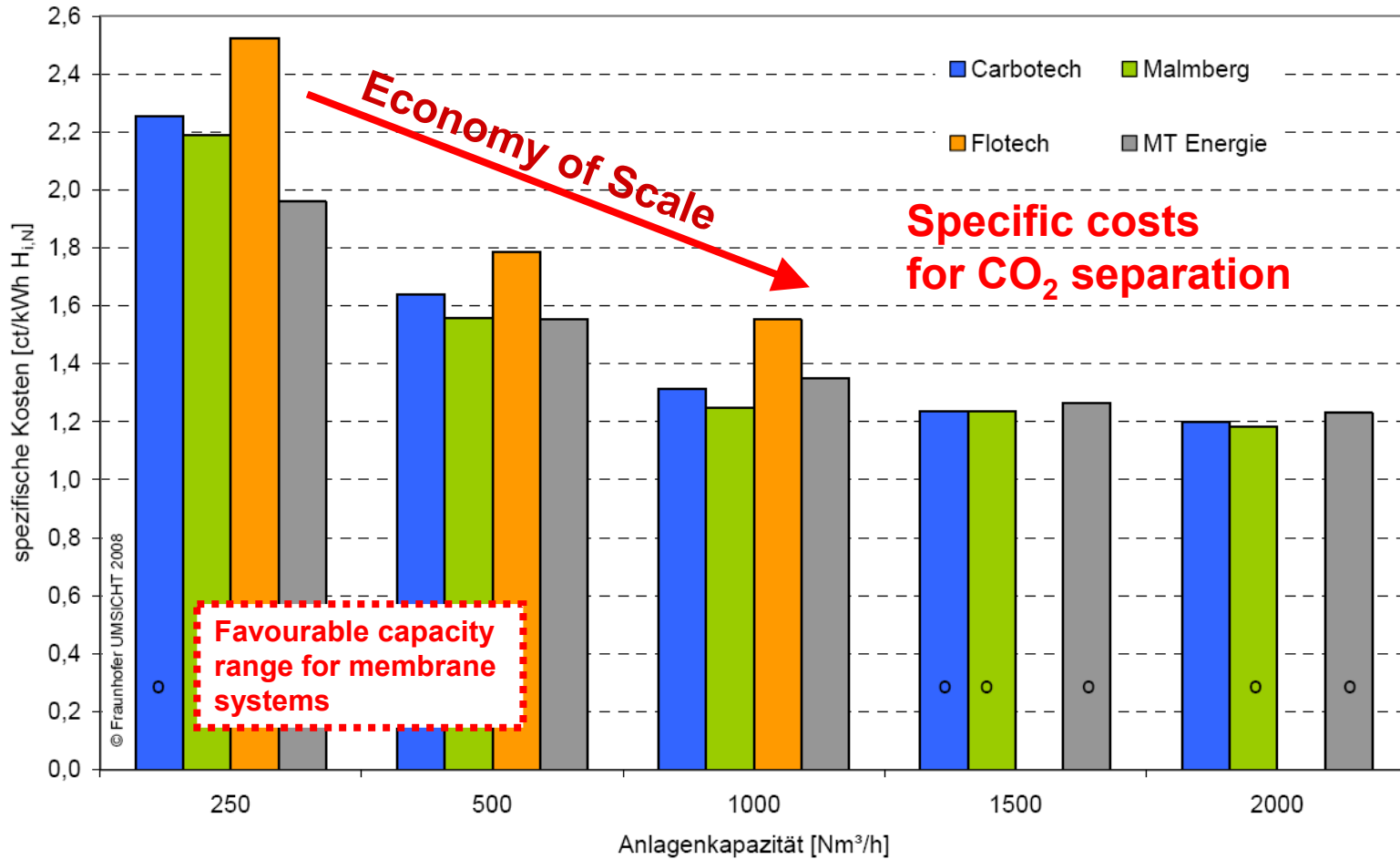
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Calculations by Fraunhofer Institut UMSICHT (2008)



- Pipe the biogas to a central location
- Build a mobile upgrade plant

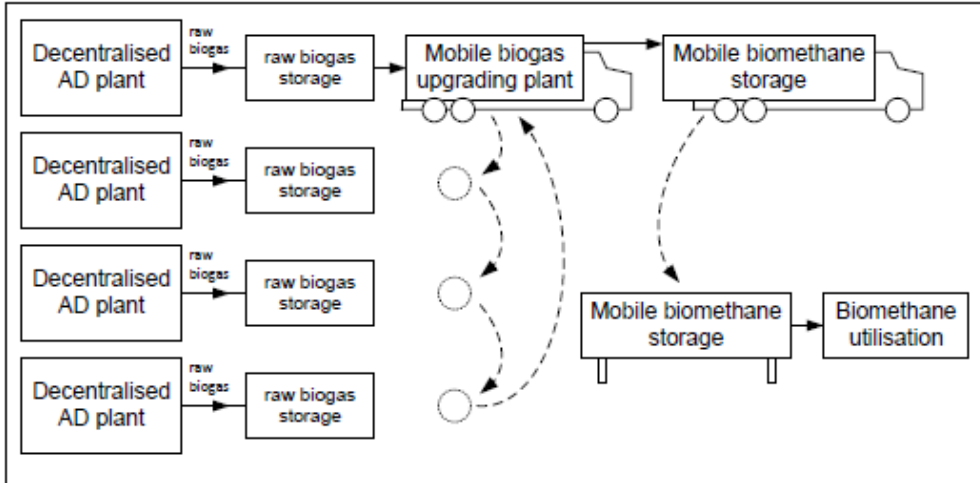


Figure 2: One possibility of mobile biogas upgrading for cooperative biomethane production applying mobile biomethane storage tanks; Source: Vienna University of Technology

## 20-foot standard-container (6058mm)

Horizontal projection:

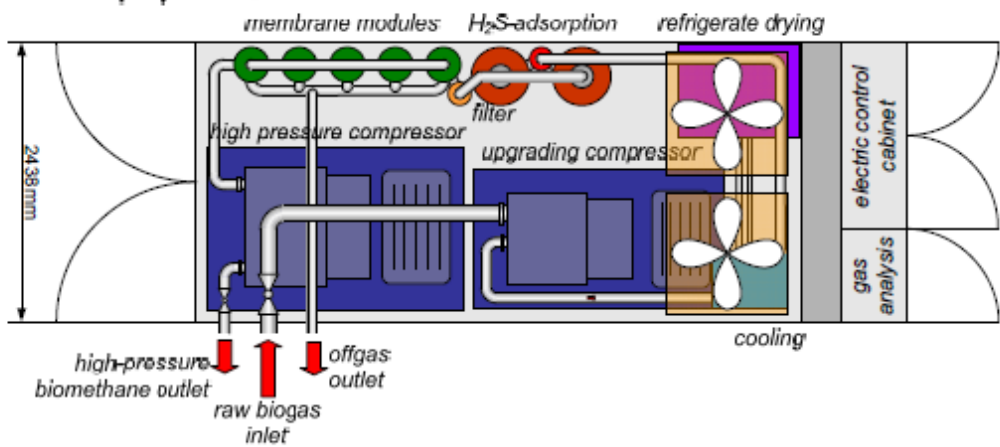


Figure 3: Scheme of a mobile biogas upgrading unit with a capacity of 300m<sup>3</sup>/h raw biogas using gaspermeation mounted in a 20-foot standard container; Source: Vienna University of Technology

**GUIDE TO COOPERATIVE BIOGAS TO BIOMETHANE DEVELOPMENTS**

PRODUCED BY

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Vienna University of Technology

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VIENNA UNIVERSITY OF TECHNOLOGY (AUSTRIA),  
Institute of Chemical Engineering  
Research Division Thermal Process Engineering and Simulation

AS PART DELIVERY OF:

**BIOMETHANE REGIONS**

Promotion of bio-methane and its market development through local and regional partnerships  
A project under the Intelligent Energy - Europe programme

Contract Number: EE/10/130  
Deliverable Reference: Task 3.1.2  
Delivery Date: December 2012

**Biomethane-Calculator**

File Settings Help

**Biomethane-Calculator**

BIO-METHANE REGIONS

INTELLIGENT ENERGY EUROPE FOR A SUSTAINABLE FUTURE

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**Biomethane-Calculator**

**Biomethane-Calculator**

Welcome Raw biogas Gas upgrading unit Biomethane/Ofgas Plant parameters Economics

Thank you for using Biomethane-Calculator

This tool has been developed during the IEE-project BioMethane Regions. It is designed to be used for pre-feasibility studies regarding new bio-methane facilities. Check frequently for updates of this tool at:

[bio.methan.at](http://bio.methan.at)

Biomethane-Calculator comprises the technological aspects of upgrading raw biogas to produce biomethane. If also the production of raw biogas has to be assessed, we recommend to use Biogas-Calculator in addition to this tool. It can be downloaded at:

[www.energie-zentrum.com](http://www.energie-zentrum.com)

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**Perform computation!**

**Free download @ <http://bio.methan.at>**

**Biomethane-Calculator**

File Settings Help

**Biomethane-Calculator**

WELCOME | Raw biogas | **Gas upgrading unit** | Biomethane/Offgas | Plant parameters | Economics

**Gas upgrading unit and additional components**

Gas upgrading technology: Gaspermeation (medium recovery)

Include additional raw biogas desulphurisation  Yes  No

Include low pressure biomethane pipeline  Yes  No Length of biomethane pipeline [m]: 100.0

Include gas transfer station for grid injection  Yes  No

Include high pressure compression  Yes  No Level of high pressure [bar(g)]: 60.0

Include gas odorisation  Yes  No

Include conditioning by propane dosing  Yes  No Propane dosing related to biomethane flow [%]: 1.0

**Perform computation!**

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**Biomethane-Calculator**

File Settings Help

**Biomethane-Calculator**

Welcome | Raw biogas | Gas upgrading unit | Biomethane/Offgas | Plant parameters | Economics

**Technical parameters of upgrading plant**

Methane recovery [%]:	<input type="text" value="95"/>	Biomethane pressure [bar(g)]:	<input type="text" value="6"/>	Annual amount of biomethane [m³(STP)/a]:	<input type="text" value="1.050.974"/>
Methane slip [%]:	<input type="text" value="5"/>	Stripping air volume flow [m³(STP)/h]:	<input type="text" value=""/>	Annual amount of raw biogas [m³(STP)/a]:	<input type="text" value="2.146.200"/>

**Perform computation!**

Free download @ <http://bio.methan.at>

**Biomethane-Calculator**

File Settings Help

**Biomethane-Calculator**

Welcome | Raw biogas | Gas upgrading unit | Biomethane/Offgas | Plant parameters | **Economics**

**Investment and operational costs, specific production costs**

Investment costs [€]:	<input type="text" value="1.349.425"/>	Specific costs per m <sup>3</sup> raw biogas [ct/m <sup>3</sup> (STP)]:	<input type="text" value="20.51"/>
Annual capital costs [€/a]:	<input type="text" value="138.941"/>	Specific costs per m <sup>3</sup> methane in raw biogas [ct/m <sup>3</sup> (STP)]:	<input type="text" value="41.02"/>
Annual operational costs [€/a]:	<input type="text" value="207.425"/>	Specific costs per kWh methane in raw biogas (Hs) [ct/kWh]:	<input type="text" value="3.72"/>
Annual raw biogas costs [€/a]:	<input type="text" value="0"/>	Specific costs per kWh methane in raw biogas (Hi) [ct/kWh]:	<input type="text" value="4.13"/>
Annual propane costs [€/a]:	<input type="text" value="92.564"/>	Specific costs per m <sup>3</sup> biomethane [ct/m <sup>3</sup> (STP)]:	<input type="text" value="41.89"/>
Annual chemicals costs [€/a]:	<input type="text" value="1.297"/>	Specific costs per m <sup>3</sup> methane in biomethane [ct/m <sup>3</sup> ]:	<input type="text" value="43.18"/>
Annual overall costs [€/a]:	<input type="text" value="440.225"/>	Specific costs per kWh methane in biomethane (Hs) [ct/kWh]:	<input type="text" value="3.92"/>
		Specific costs per kWh methane in biomethane (Hi) [ct/kWh]:	<input type="text" value="4.35"/>

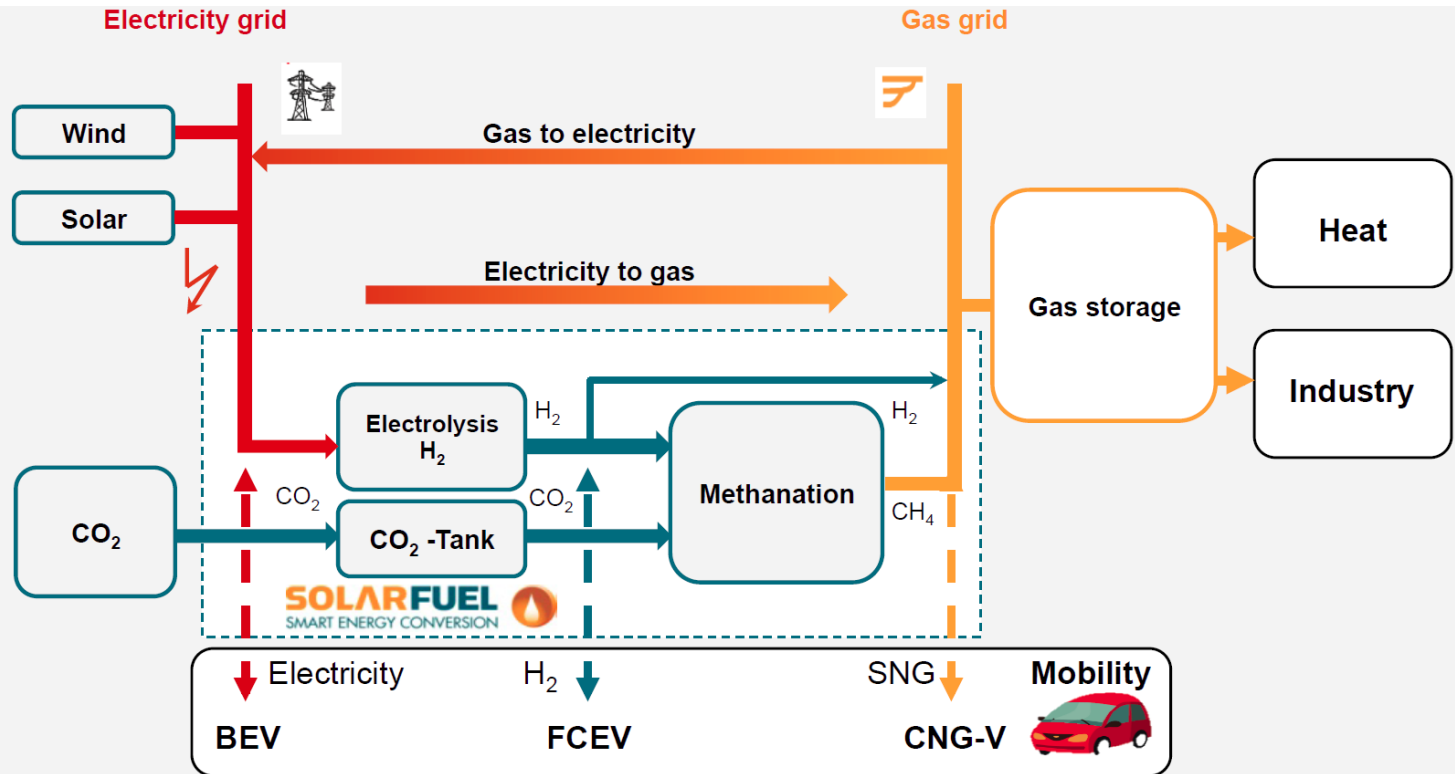
(Hs ... Upper heating value    Hi ... Lower heating value)

**Perform computation!**

Free download @ <http://bio.methan.at>

# Power-to-Gas – Energy Storage & Fuels

- Production fluctuations of wind and photovoltaics
- Water electrolyzers & methanation
- Energy storage => hydrogen, methane



CNG-V = Compressed Natural Gas Vehicle

FCEV = Fuel Cell Electric Vehicle

BEV = Battery Electric Vehicle

## Rightsizing ...

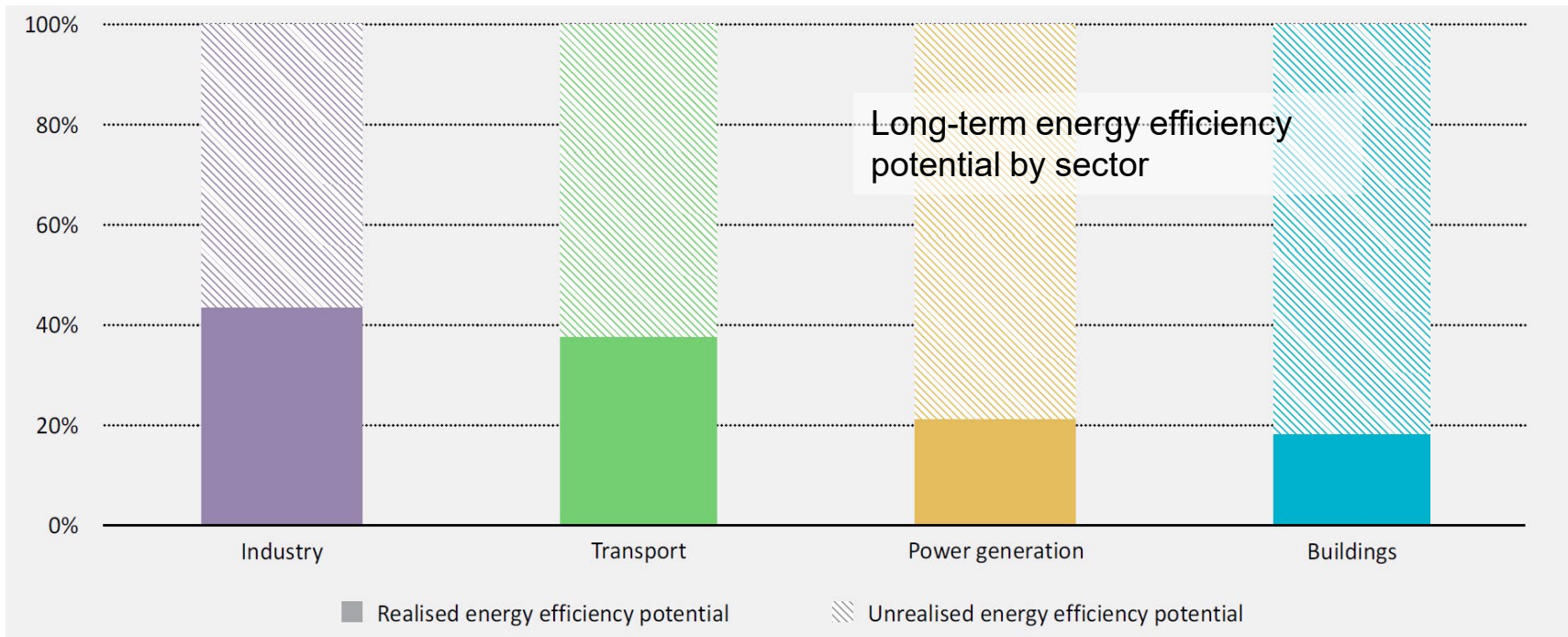




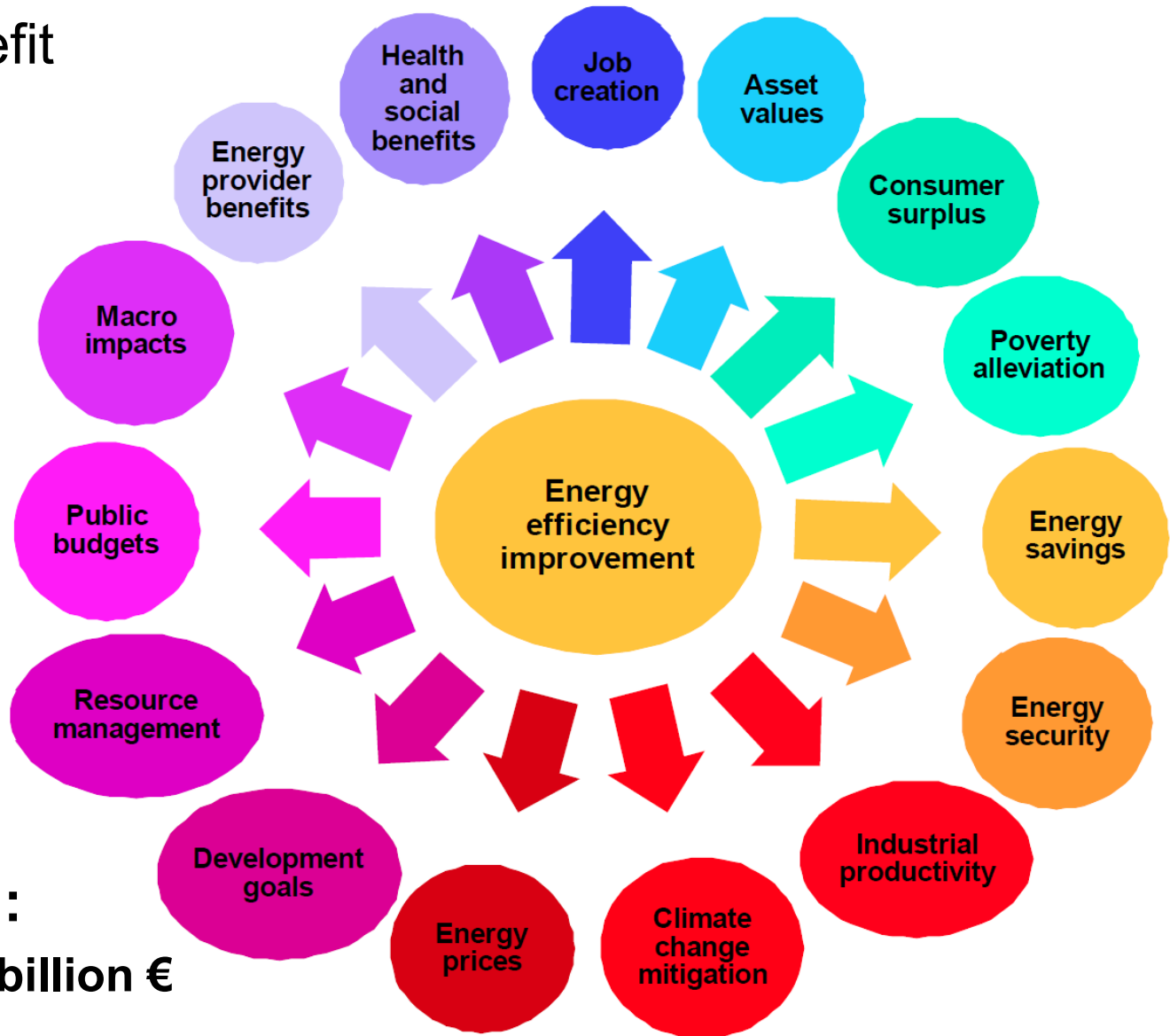
# Bigger and BIGGER...



- Largest “primary energy” potential of all sources!
- Many barriers contribute to the limited uptake of energy efficiency opportunities
- Main obstacle is the lack of attention paid to energy efficiency investment opportunities by stakeholders in both the private and government sectors relative to supply-side opportunities, including new resources such as shale gas and oil [IEA, 2014]

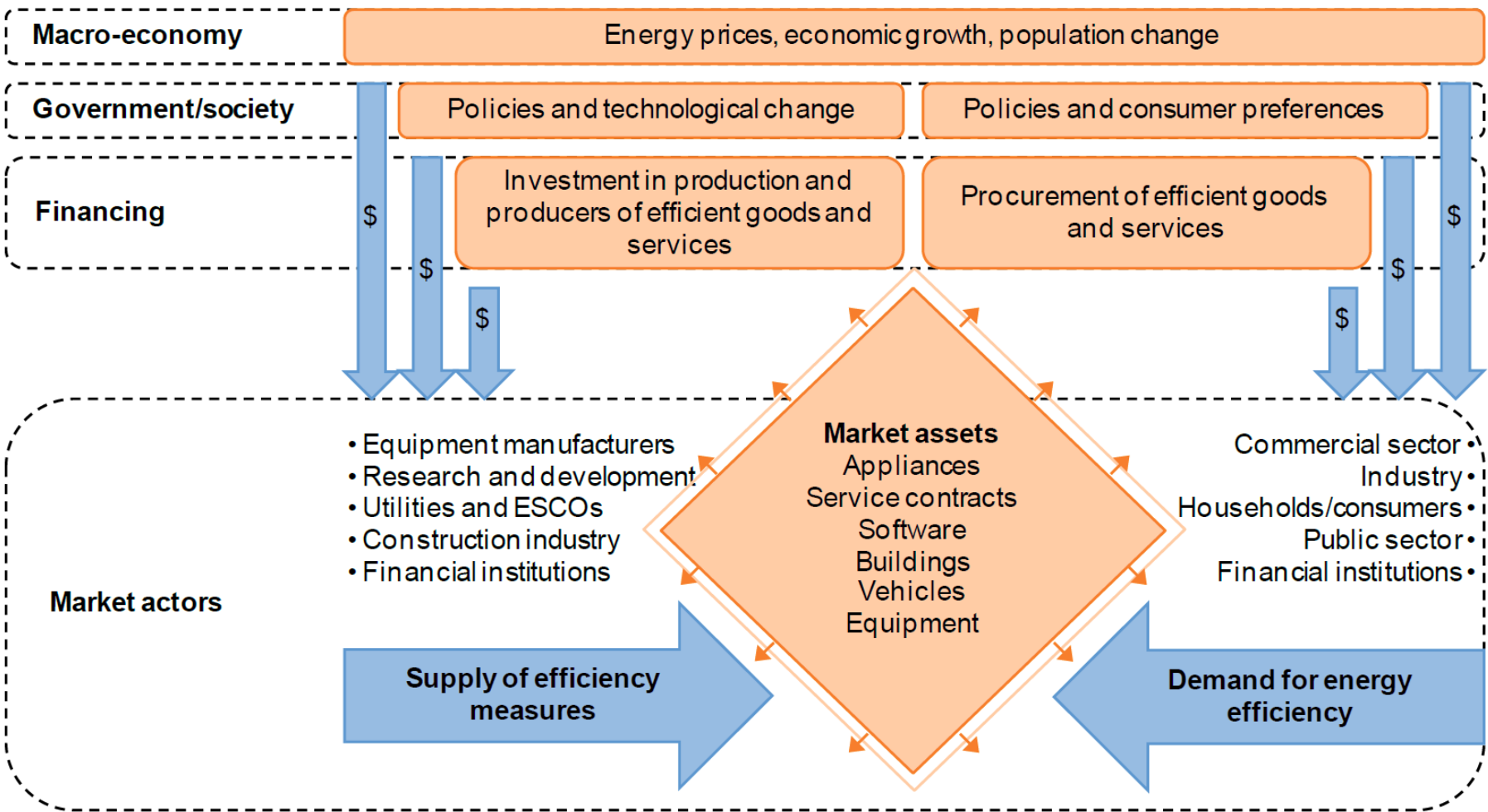


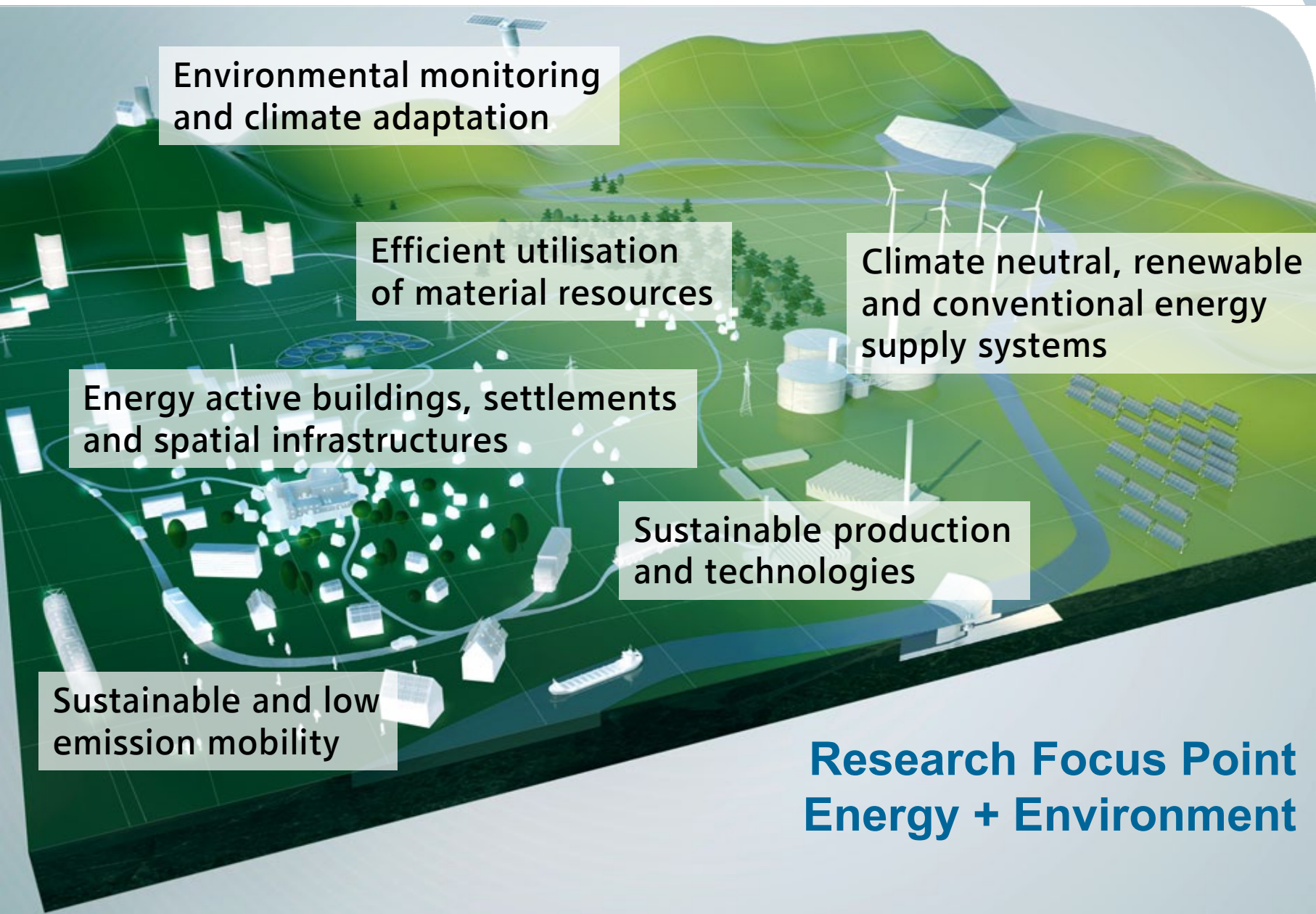
Multiple benefit approach



**EU potential:**  
 20% of a 1600 billion €  
 energy market

# The Market for Energy Efficiency





Environmental monitoring and climate adaptation

Efficient utilisation of material resources

Climate neutral, renewable and conventional energy supply systems

Energy active buildings, settlements and spatial infrastructures

Sustainable production and technologies

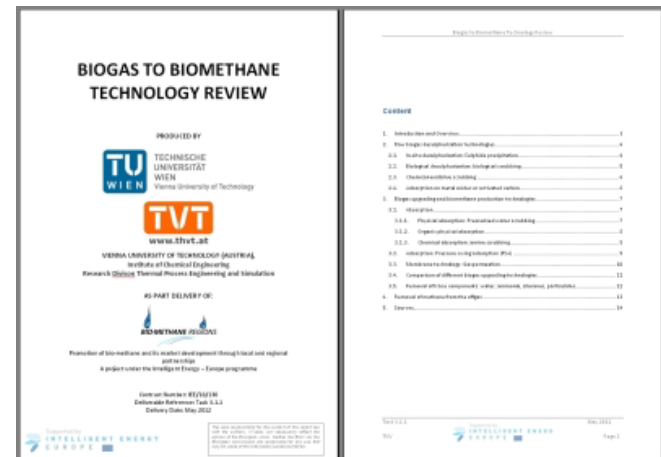
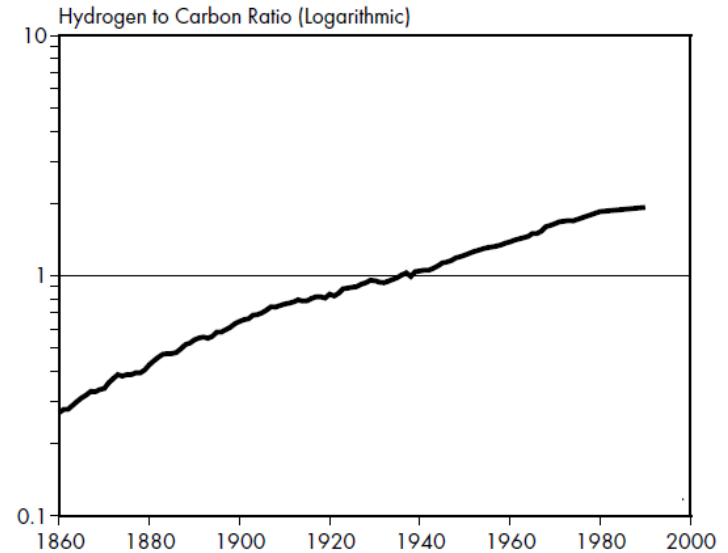
Sustainable and low emission mobility

**Research Focus Point  
Energy + Environment**



- Various upgrading technologies available – choose according to your process needs!
- Define your upgrading tasks early & know your biogas composition early!
- Biogas upgrading is expensive and should therefore operate at design capacity for best economic results
- Fully automated systems available, but customised pretreatment design decides between success and failure!

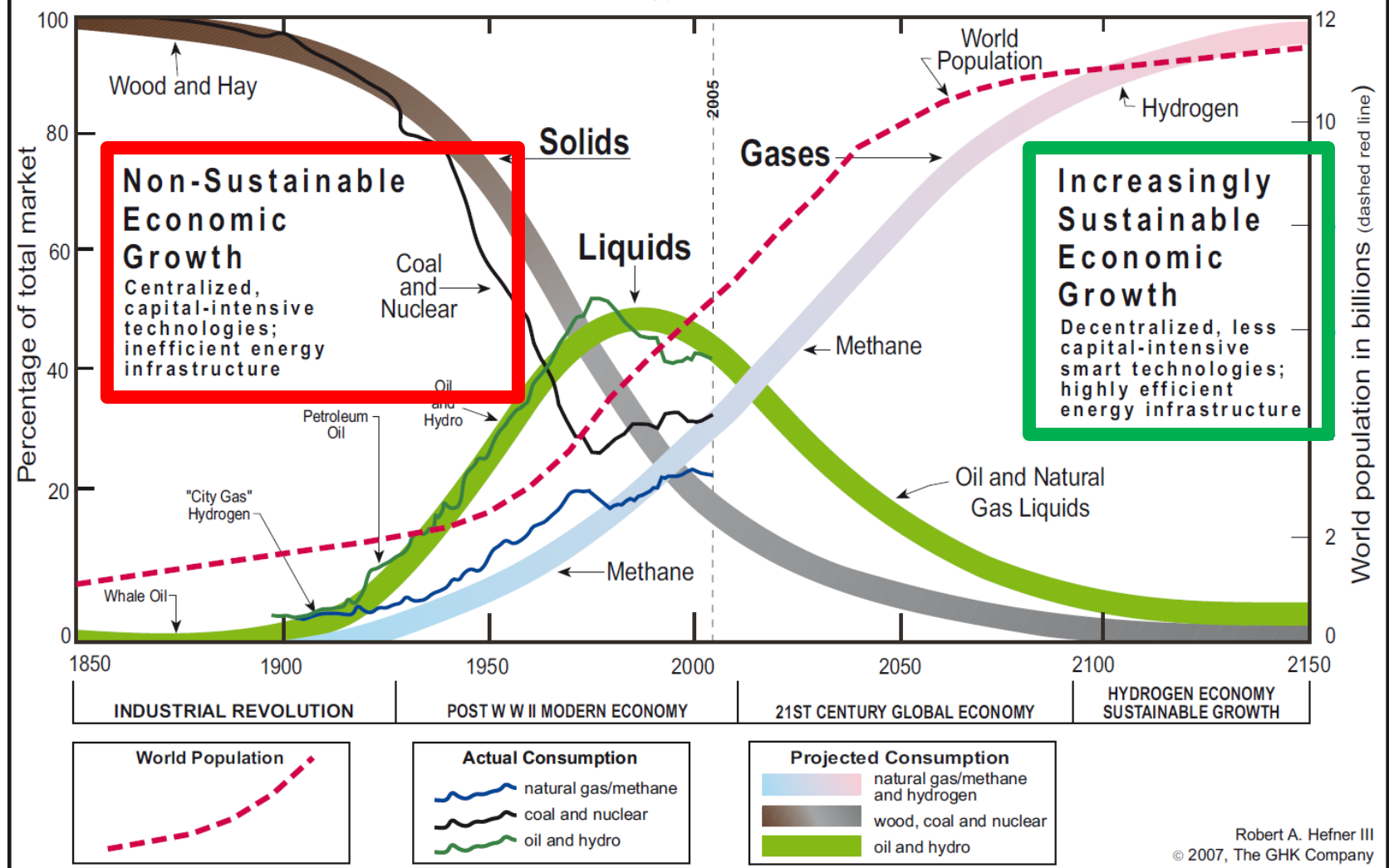
**Hydrogen-Carbon Ratio, World Energy Mix, 1860–1990**



Available upon request

# What are the drivers ?

## The Age of Energy Gases Global Energy Transition Waves



**Thank you very much for your Interest!**

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