TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

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

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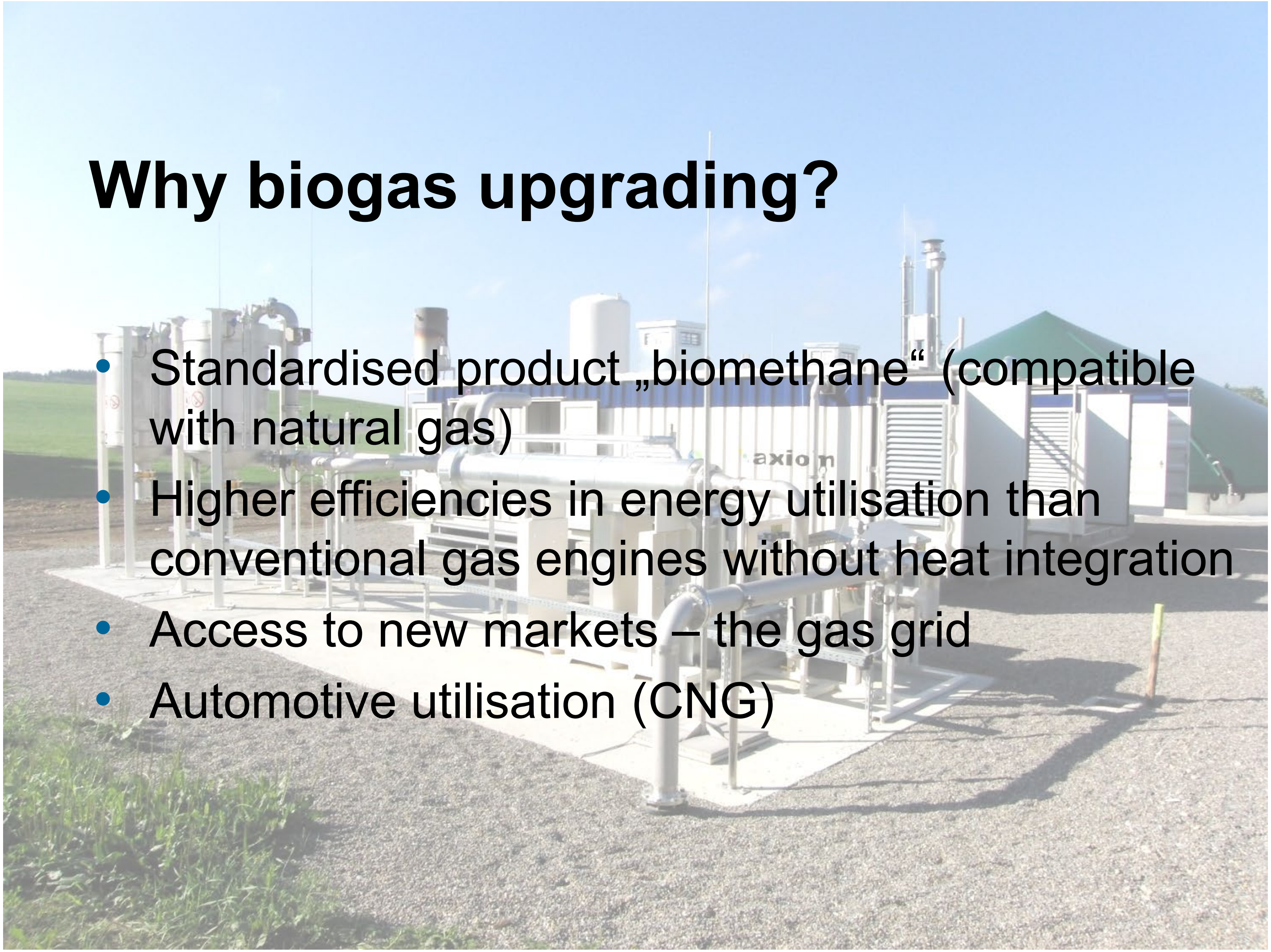
Agenda

- Characteristics of biogas
- Upgrading biogas
  - Preconditioning / pretreatment
  - Desulphurisation
  - Compression
  - Upgrading = CO_2 + H_2O 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)

EU Legislative Basis for Biomethane Access to Gas Grids

- 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.

Preambel: 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.

Biogas Composition and Natural Gas Standards

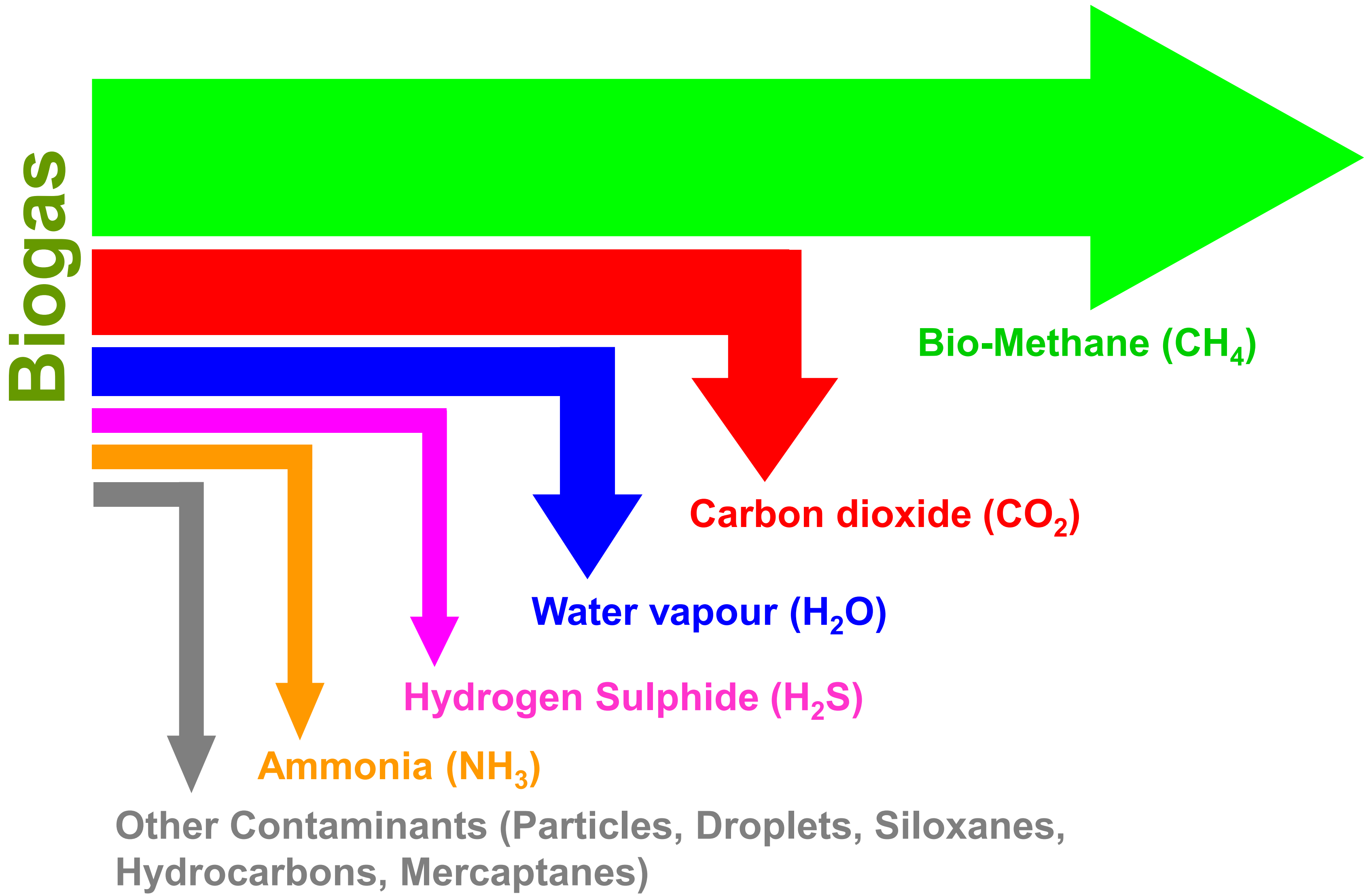
	Biogas yield (l/kg VS*)	Methane content (%)
Fat	1000–1250	70–75
Protein	600–700	68–73
Carbohydrate	700–800	50–55

*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	≤ 2,0	[mole %]
ammonia	up to 1.000	technically free	[mg/m_N^3]
hydrogen sulfide	up to 2.000	≤ 5	[mg/m_N^3]
oxygen	up to 2	≤ 0,5	[mole%]
nitrogen	up to 8	≤ 5	[mole %]
water vapour (dewpoint)	up to 37 @ 1 bar	≤ - 8 @ 40 bar	[°C]
upper heating value	6,7 - 8,4	10,7 - 12,8	kWh/m_N^3
Wobbe-Index	6,9 - 9,5	13,3 - 15,7	kWh/m_N^3

Biogas Upgrading – A Separation Problem



Biogas Upgrading Steps

1
- Preconditioning / pretreatment
- Removal of particles, droplets, siloxanes, other trace components

2
- Biogas desulphurisation

3
- Compression

4
- Biogas upgrading
- Separation of CO_2 and H_2O

5
- Final conditioning
- Dewpoint control, adjustment of heating value, offgas treatment

Preconditioning / Pretreatment

- ✓ **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)

1 2 3 4 5

Desulphurisation – Removal of H_2S

- **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_2 – impregated carbon, needs stochiometric amount of oxygen)
  - Combined with upgrading: water/amine absorption
- Ask, if there is a desulphurisation currently used or implemented
- Check the H_2S concentration and feedstock related fluctuations

Compatible desulphurisation technologies

Compatible:

- External biological desulphurisation in combination with pure oxygen injection
- In-situ desulphurisation using iron salts
- **External chemical scrubber with oxidation using $NaOH/H_2O_2$, recommended for fluctuating H_2S concentrations in the biogas**
- Adsorptive desulphurisation technologies with low excess of O_2 (impregnated activated carbon adsorbents)

Not suitable / incompatible:

- Air injection
- External biological desulphurisation with air injection

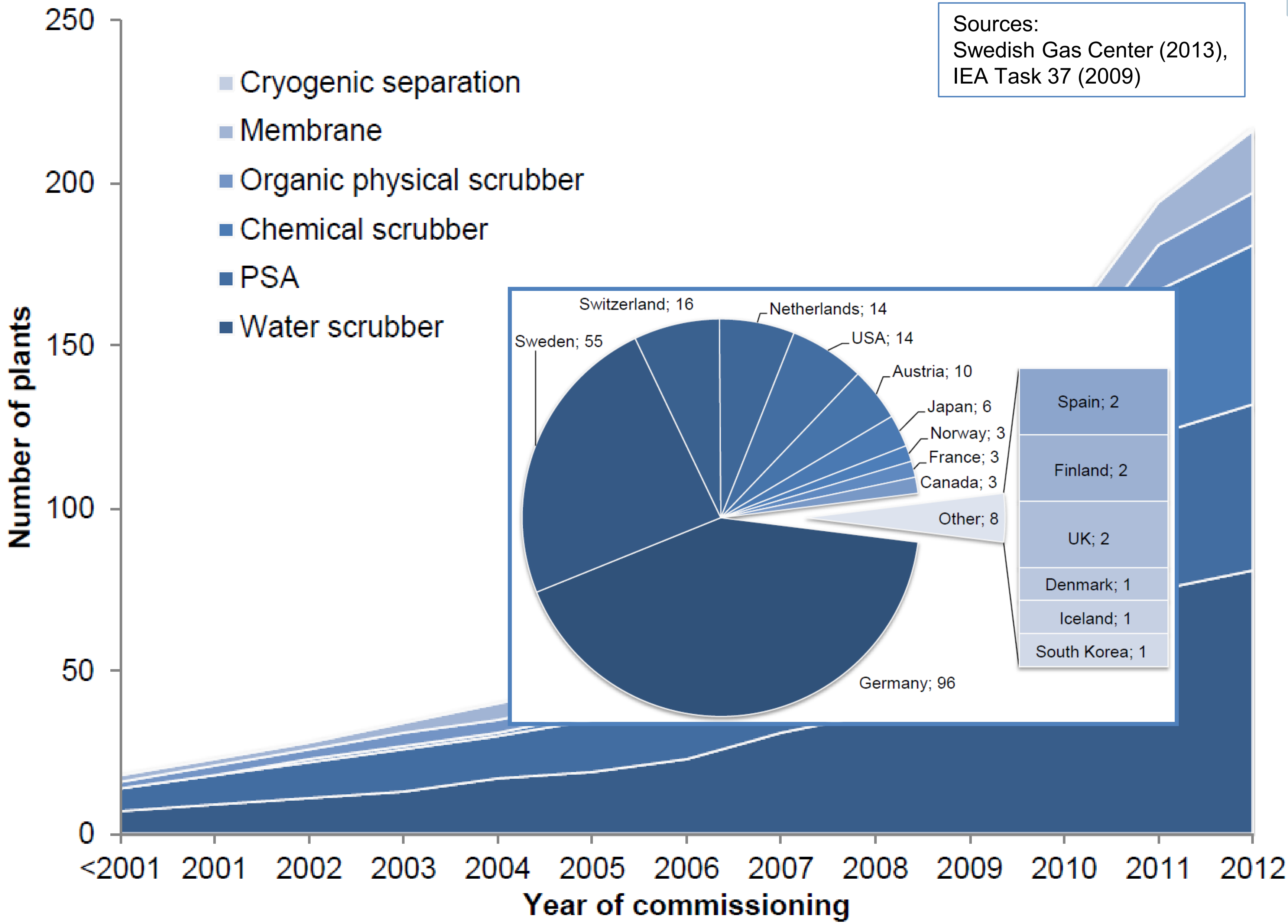
Compression

- ✓ **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

Biogas upgrading

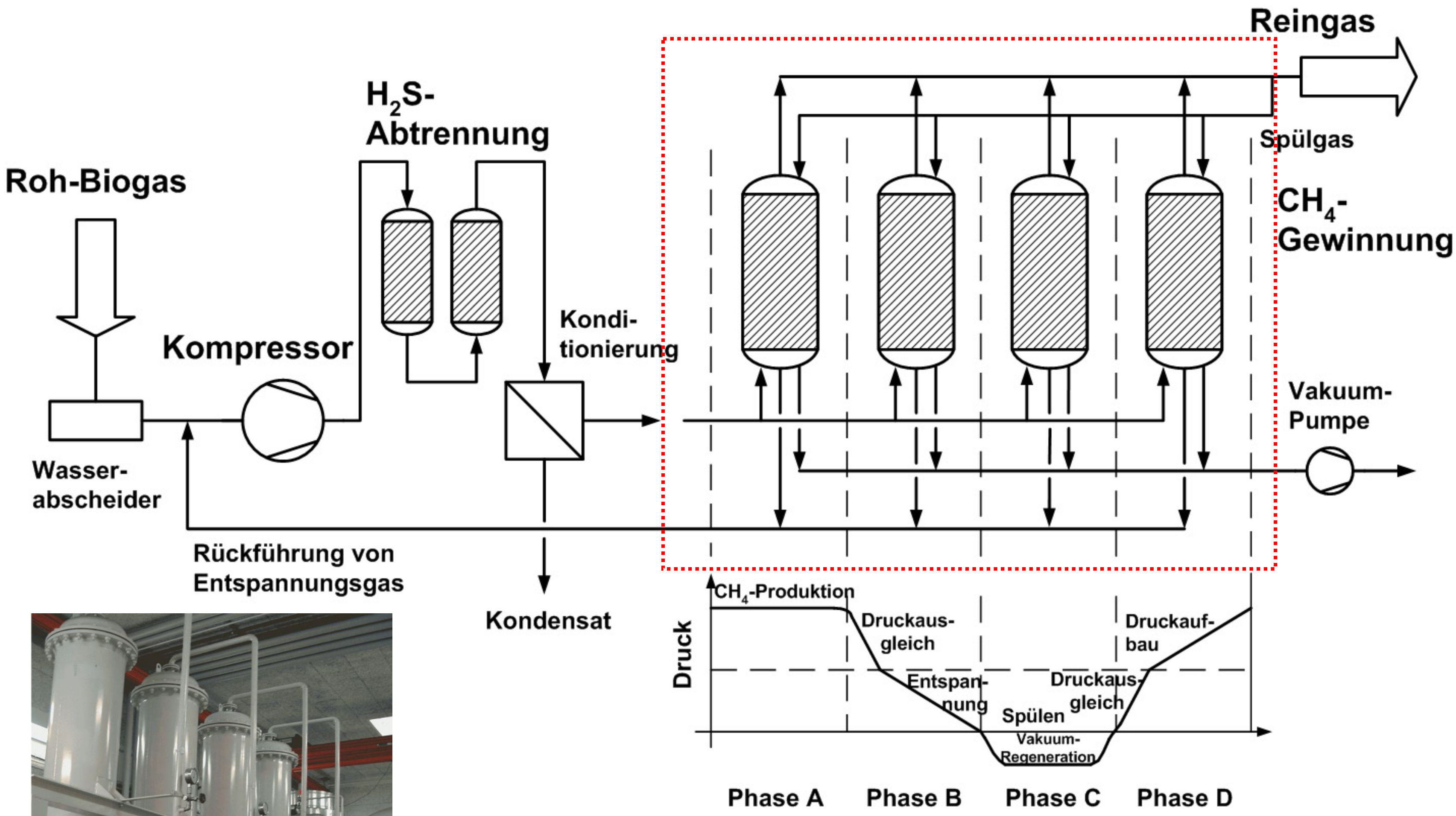
- ✓ **Various technologies available**
  - ✓ Pressure swing adsorption
  - ✓ Water scrubbing
  - ✓ Selexol absorption
  - ✓ Amine absorption
  - ✓ Membrane separation
  - ✓ Cryo separation
  - ✓ Hybrid systems
- ✓ **Decide for suitable technology primarily NOT by investment costs – remember: cheap can 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

Identified Biogas Upgrading Plants (IEA Task 37)



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

Pressure Swing Adsorption

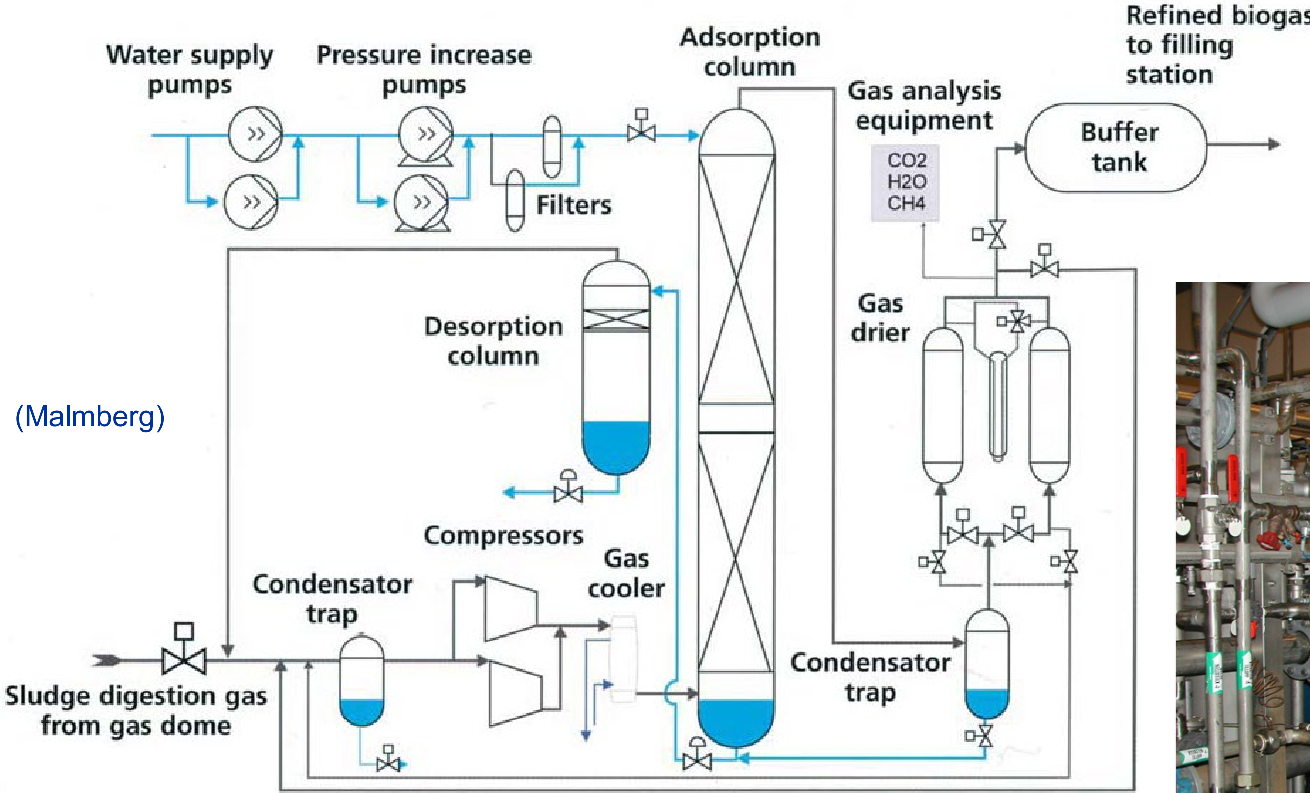


- Cyclic operation
- Many valves, precise timing needed

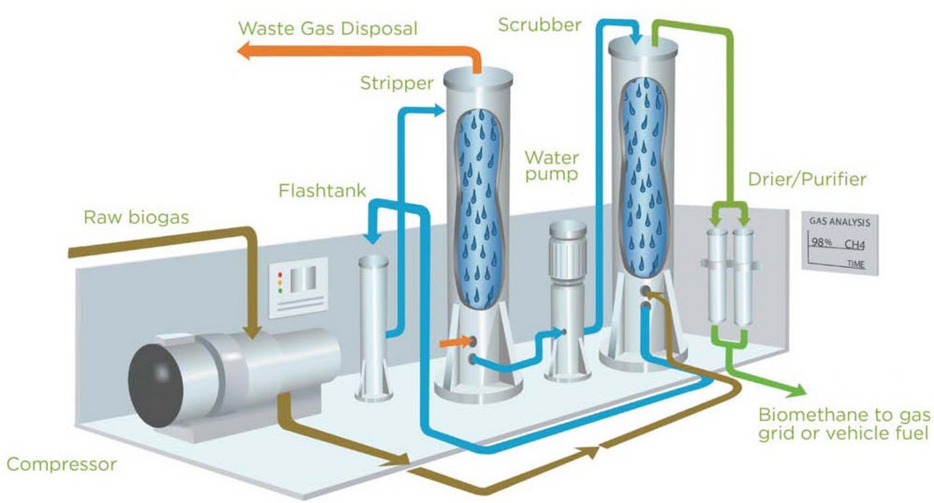
Project Pucking - Pressure Swing Adsorption (PSA)

(Photos: M.Harasek)

Water Scrubbing / Absorption



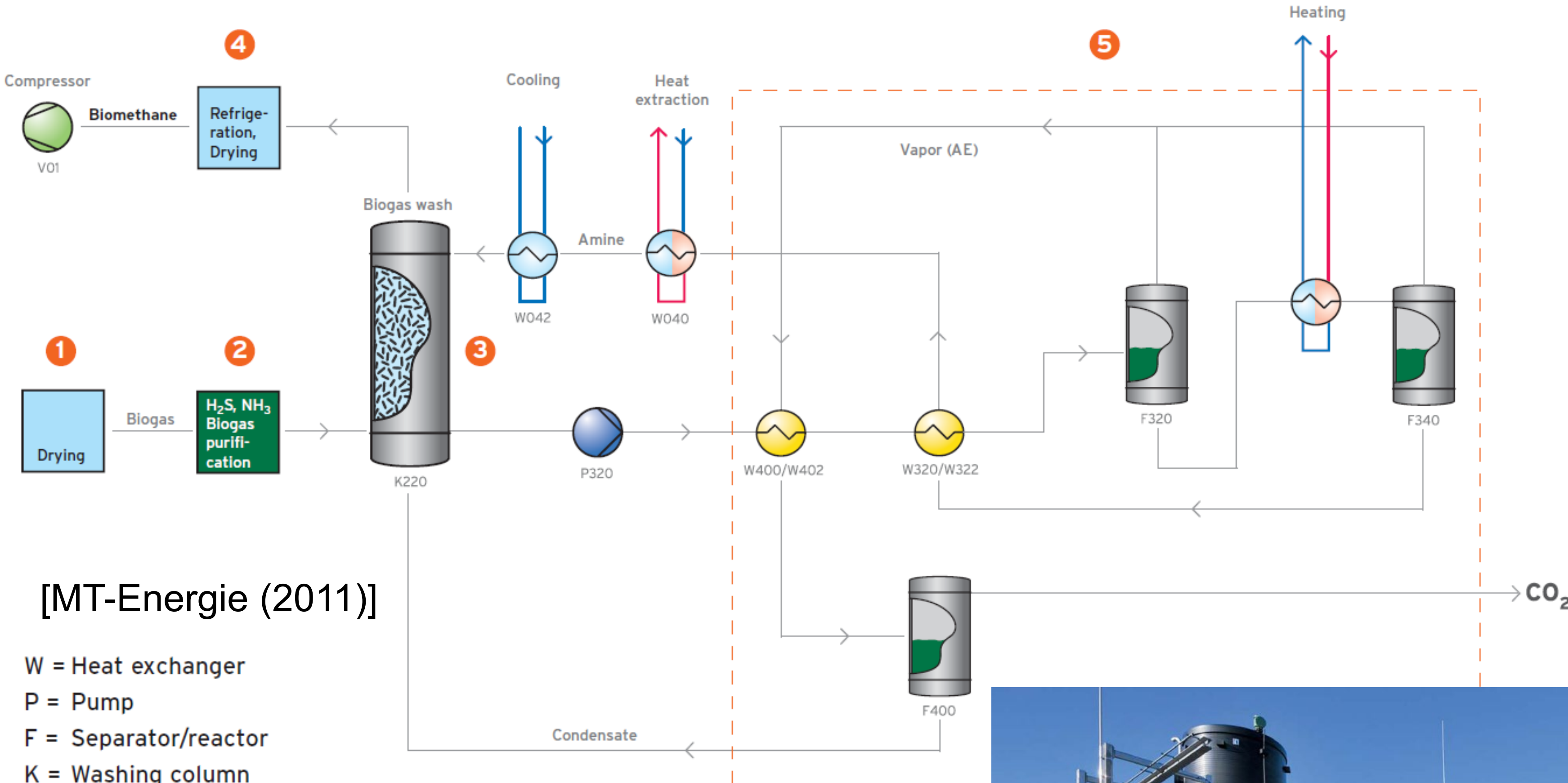
(Malmberg)



Austria's largest Upgrading Plant

- Waste water treatment plant Asten (near Linz)
- Malmberg – water scrubber (800 m³/h biogas)

Amine absorption



[MT-Energie (2011)]

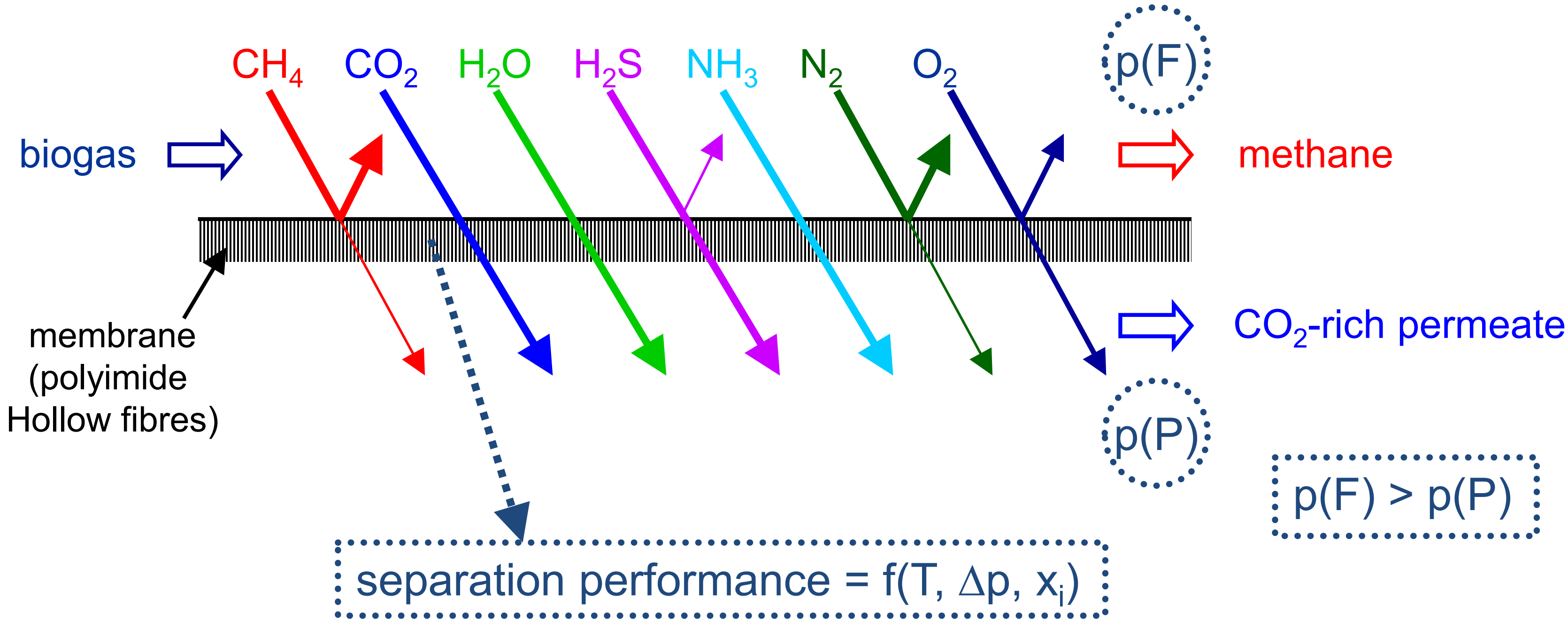
- Alkanol amines (MEA, DEA, MDEA) used for CO_2 absorption
- High desorption temperatures in recycle loops
- Low pressure operation possible

Biogas Engerwitzdorf – Grid injection

- Capacity 1,000.000 m³ Bio-methane / a
- BCM (MT-Energie) amine scrubber

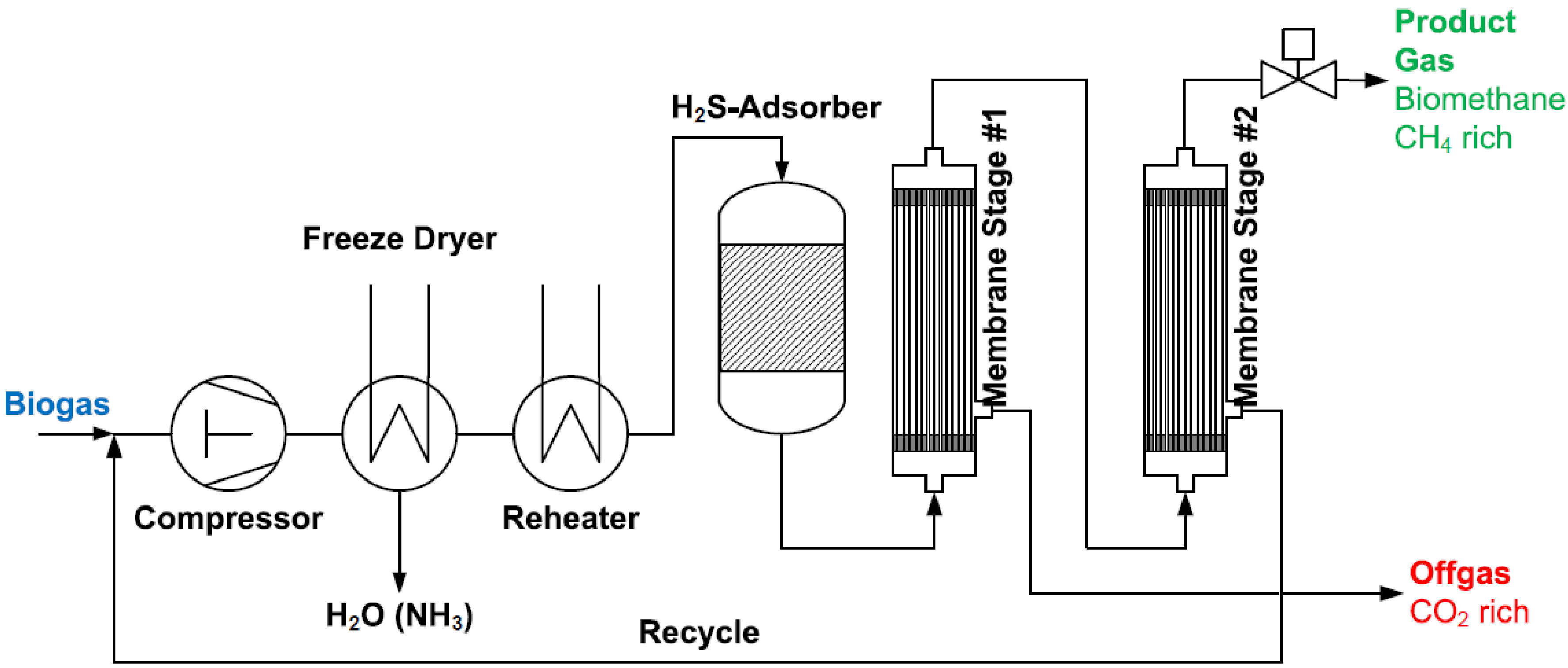
Upgrading of biogas using gas permeation (GP)

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

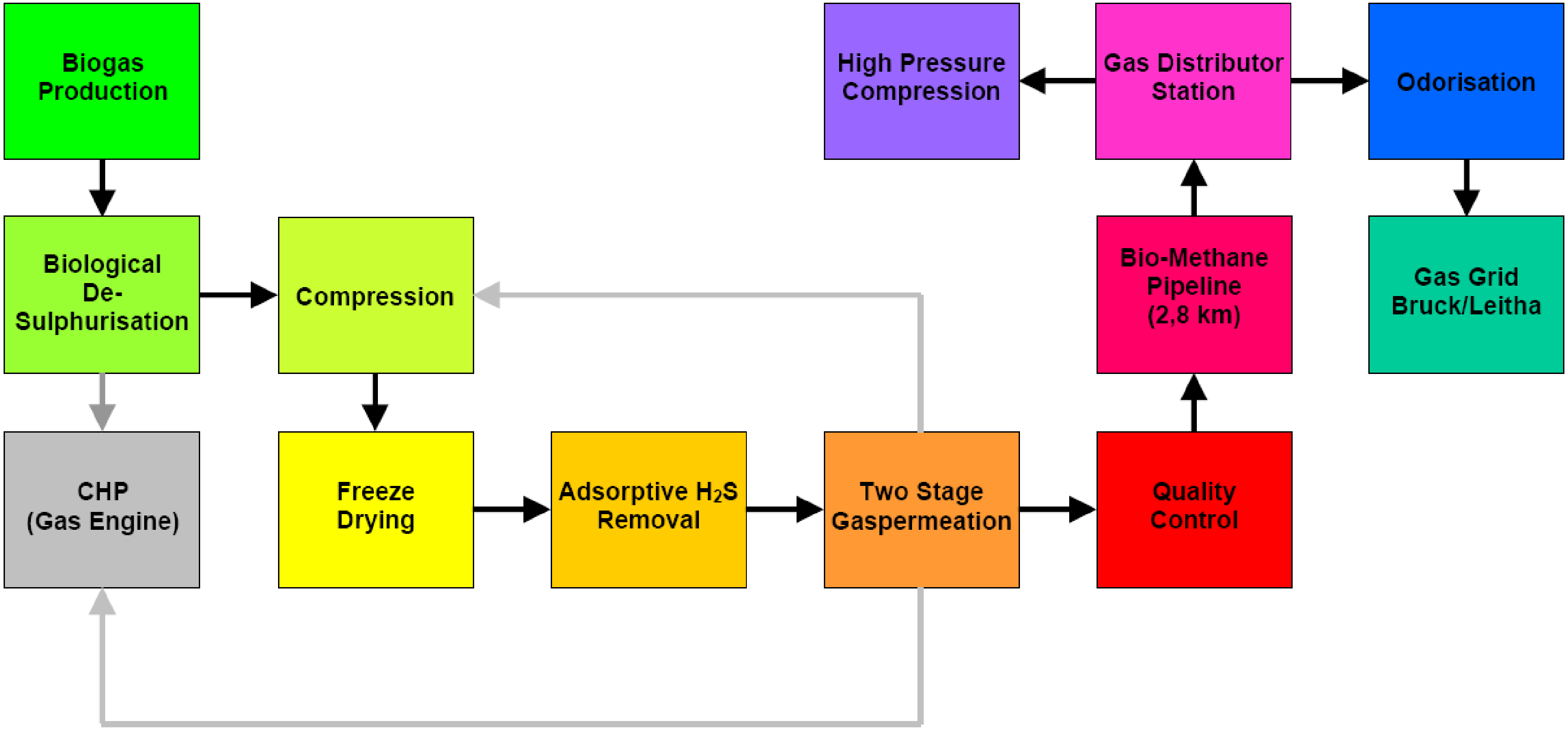


Process Scheme of a Two-stage Membrane System

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

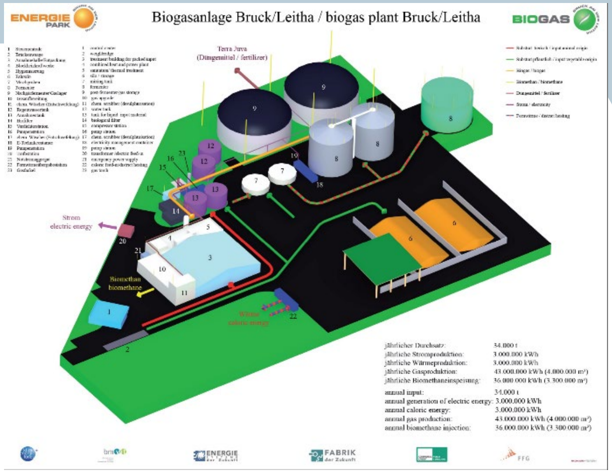


Process Integration (Two-stage design)



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

Biogas from waste feedstocks



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)

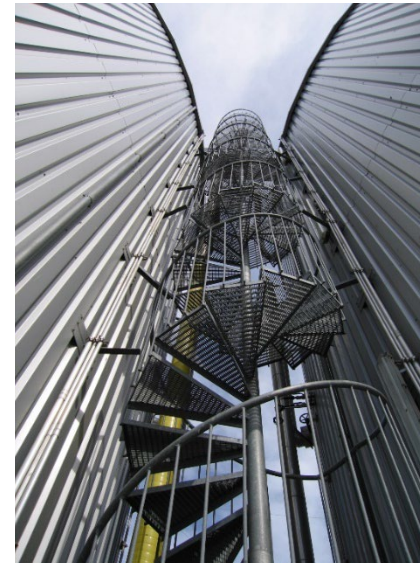
3 digesters (3000 m³ each), 2 post-digesters (5000 m³ each)

1000 m³/h raw biogas

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

Biogas upgrading plant (3.300.000 m³/a biomethane) – 400m³/h bio-methane

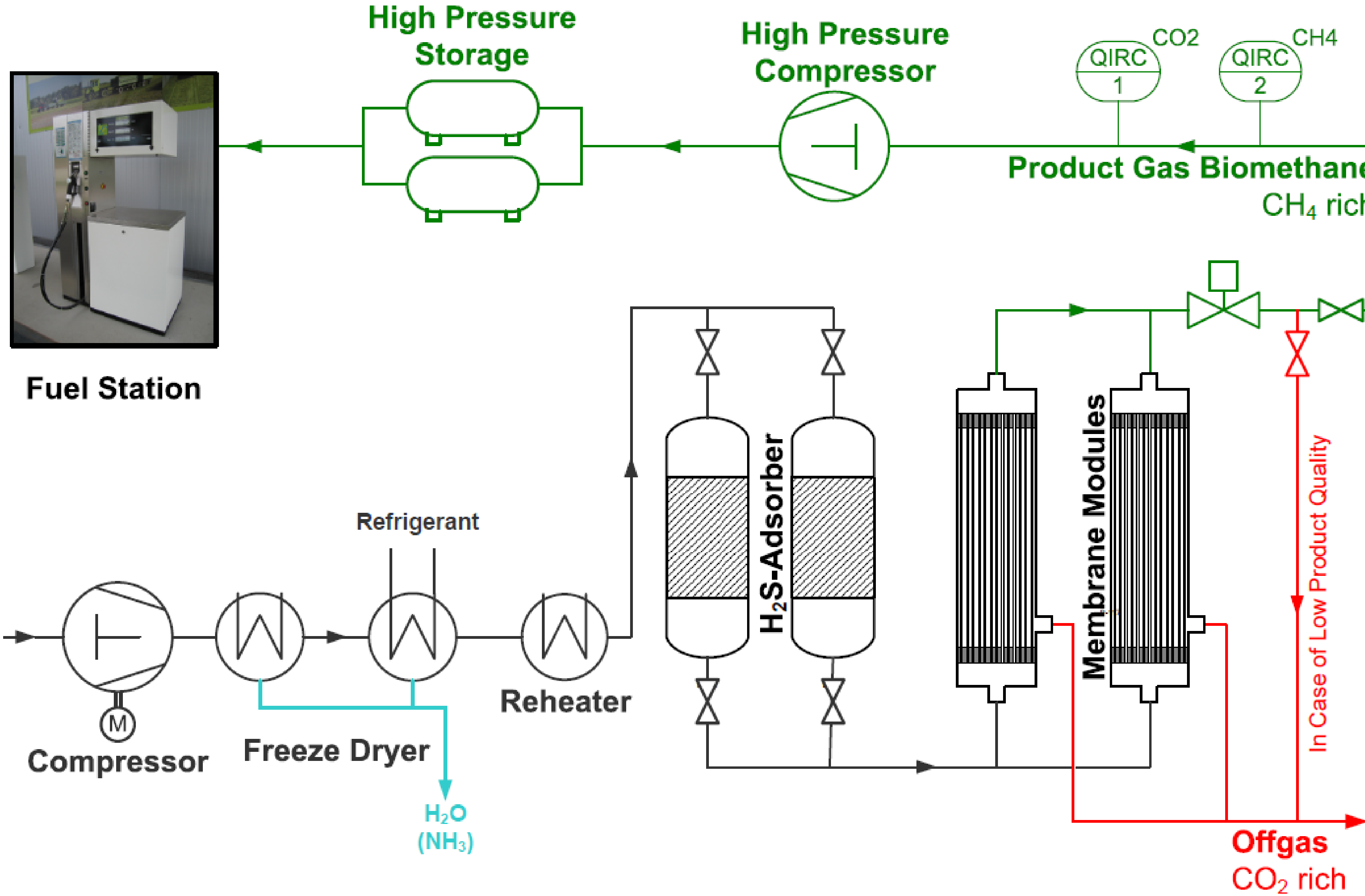
Biogas plant Bruck/Leitha (Austria)



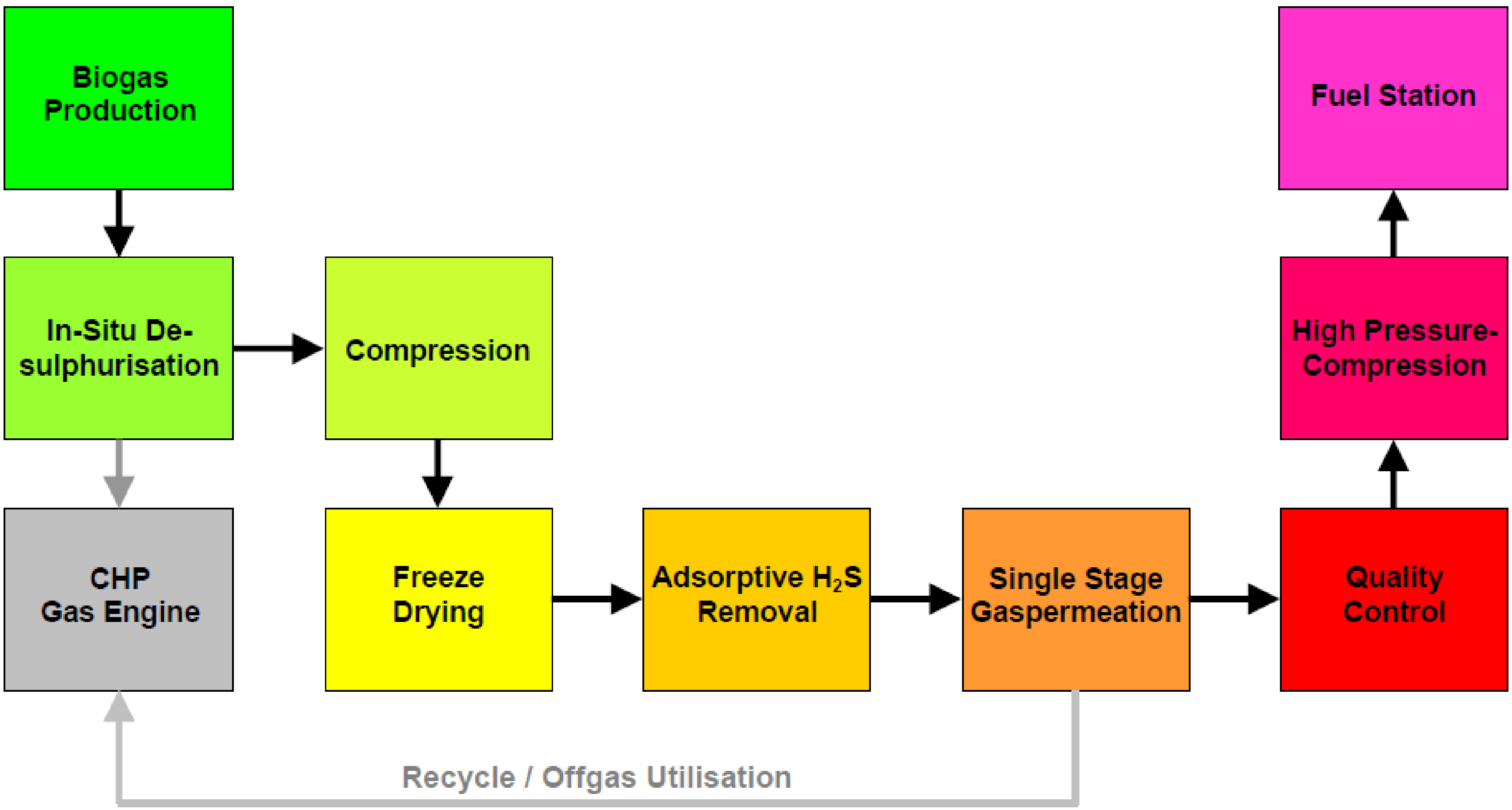
Upgrading plant in Bruck/Leitha

180 m³/h biogas / 100 m³(STP)/h biomethane @ 6 bar
Details: http://www.virtuellesbiogas.at

Biomethane Fuel Station: Single Stage Upgrading



Process Integration (Margarethen am Moos)



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

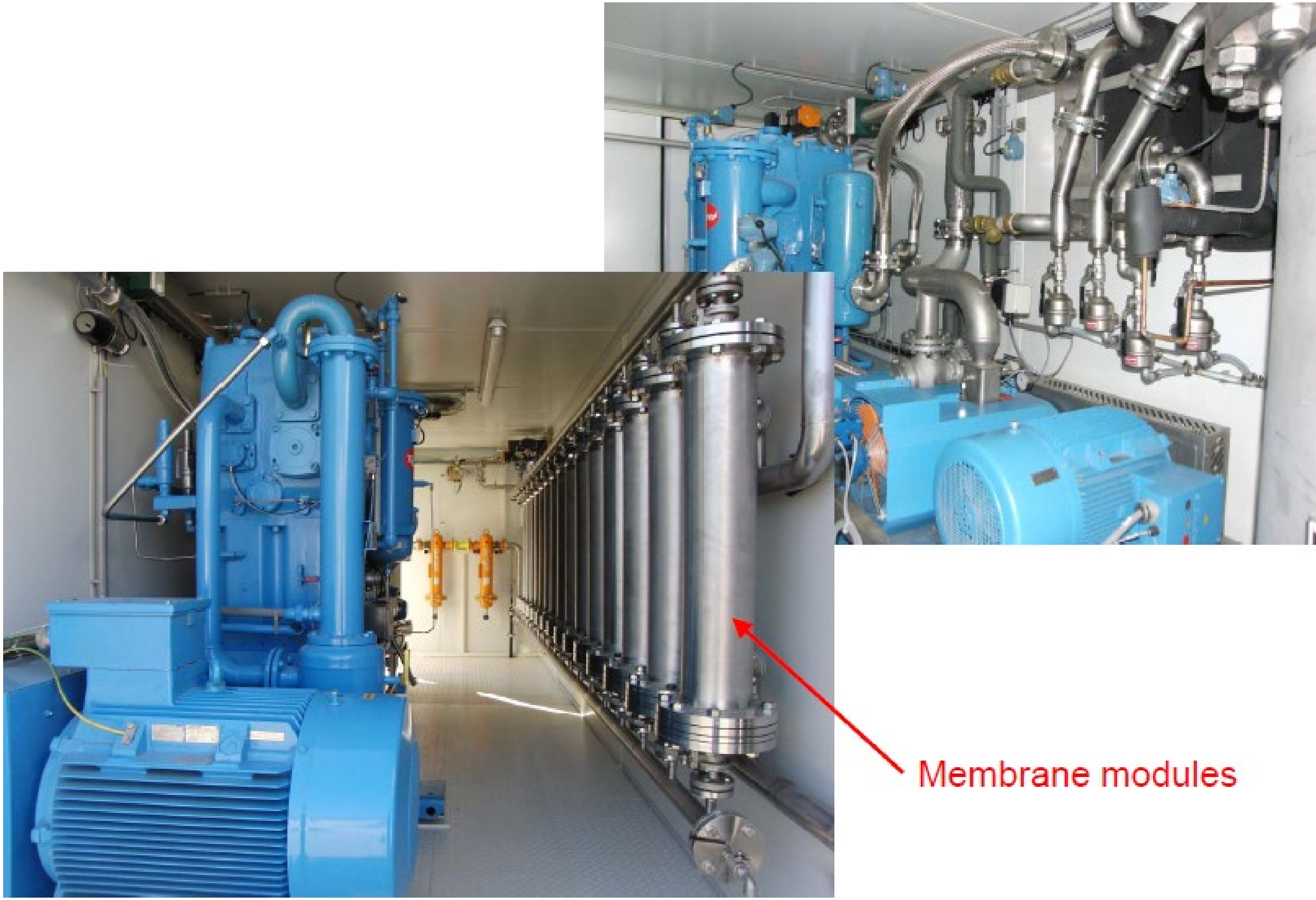
Bio-CNG with on-site fuel station

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

Bio-methane Wiener Neustadt

- Capacity: 220 (300) m³/h biogas
- Axiom – Membrane separation

Membrane Biogas Upgrading Plant in Kisslegg (GE)



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

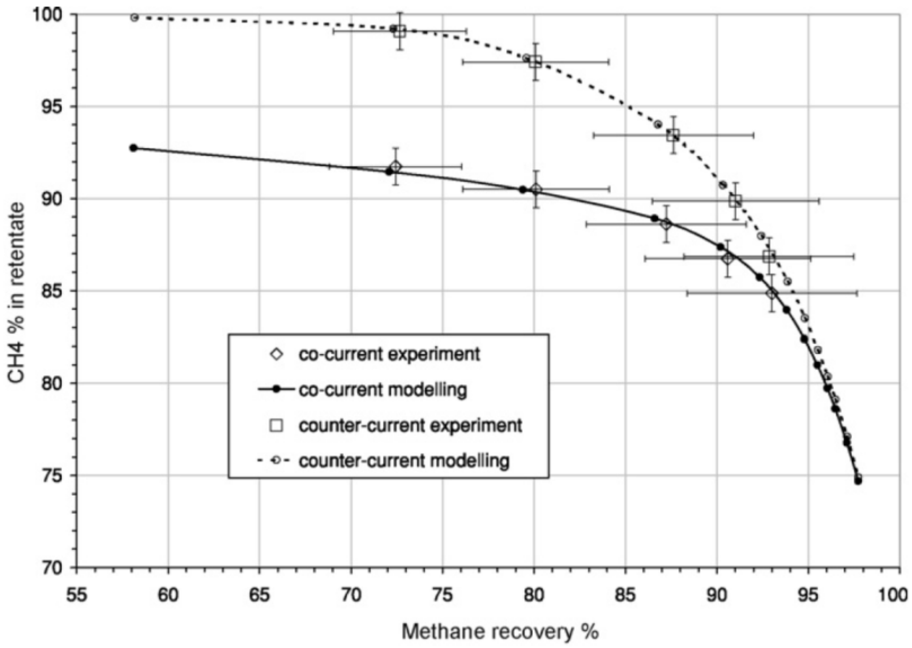
<u>Plant data:</u>

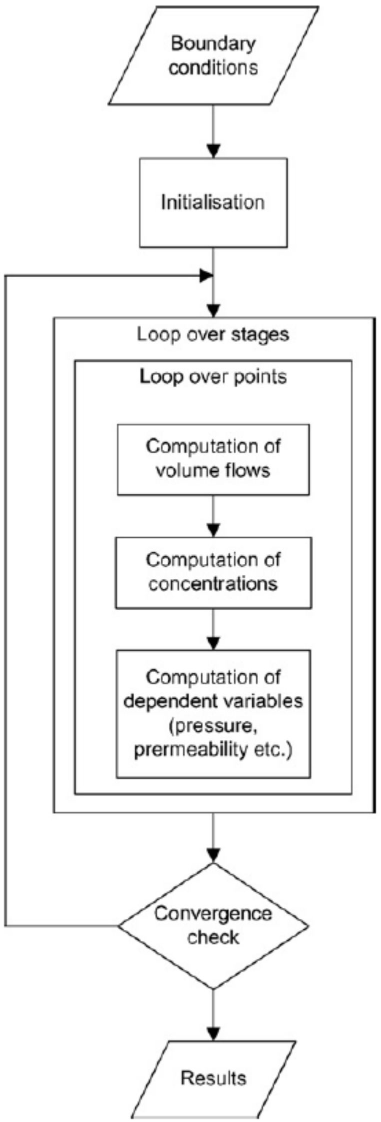
- Biogas 1000 m^3/h
- Bio-methane 657 m^3/h
- CH_4 > 98,2%
- CH4 recovery 99,5%
- kWh/Nm^3_{biogas} < 0,235

Biogasupgrading V2.0 in Bruck

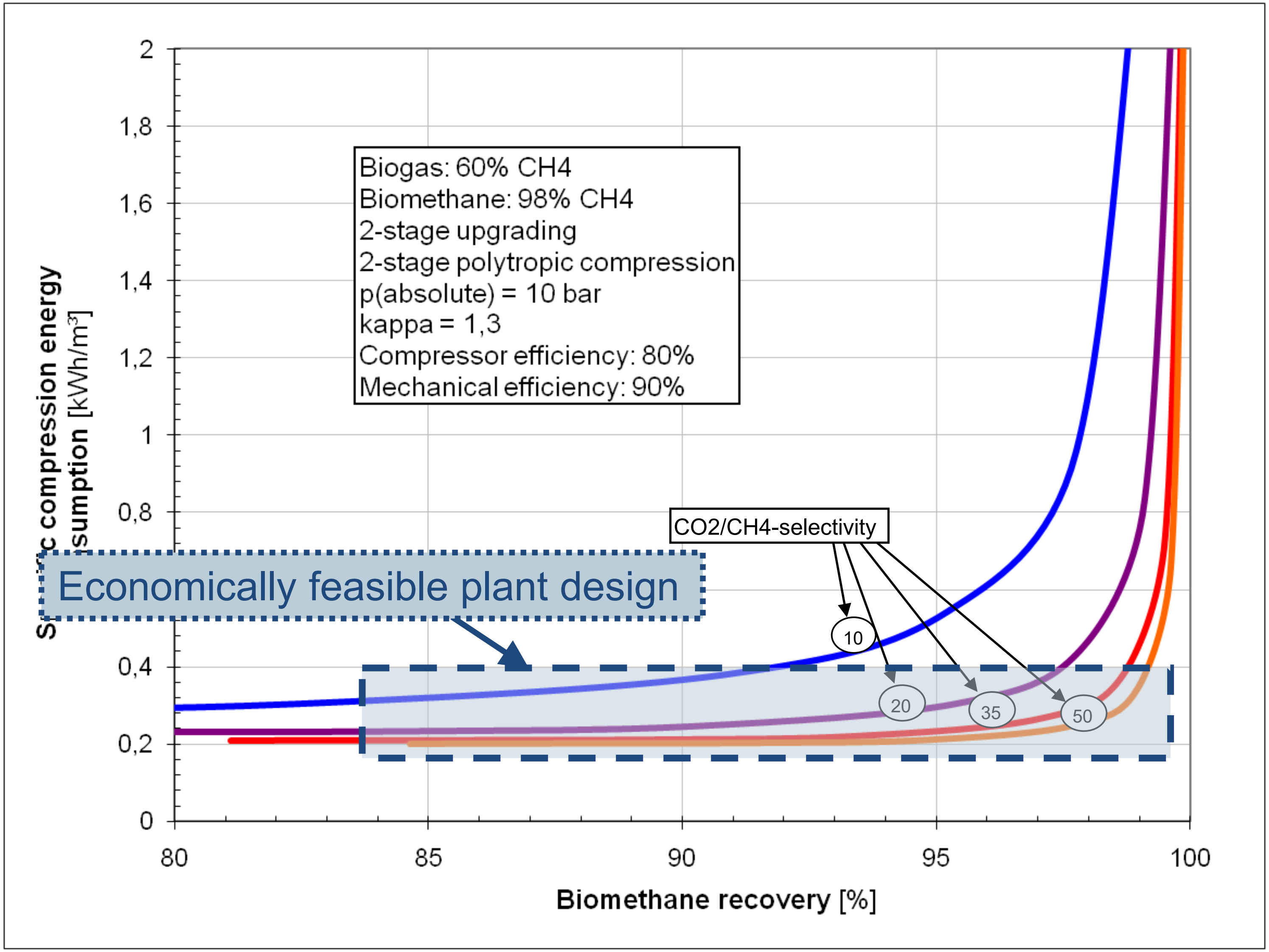
Process modelling of biogas upgrading

- 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:

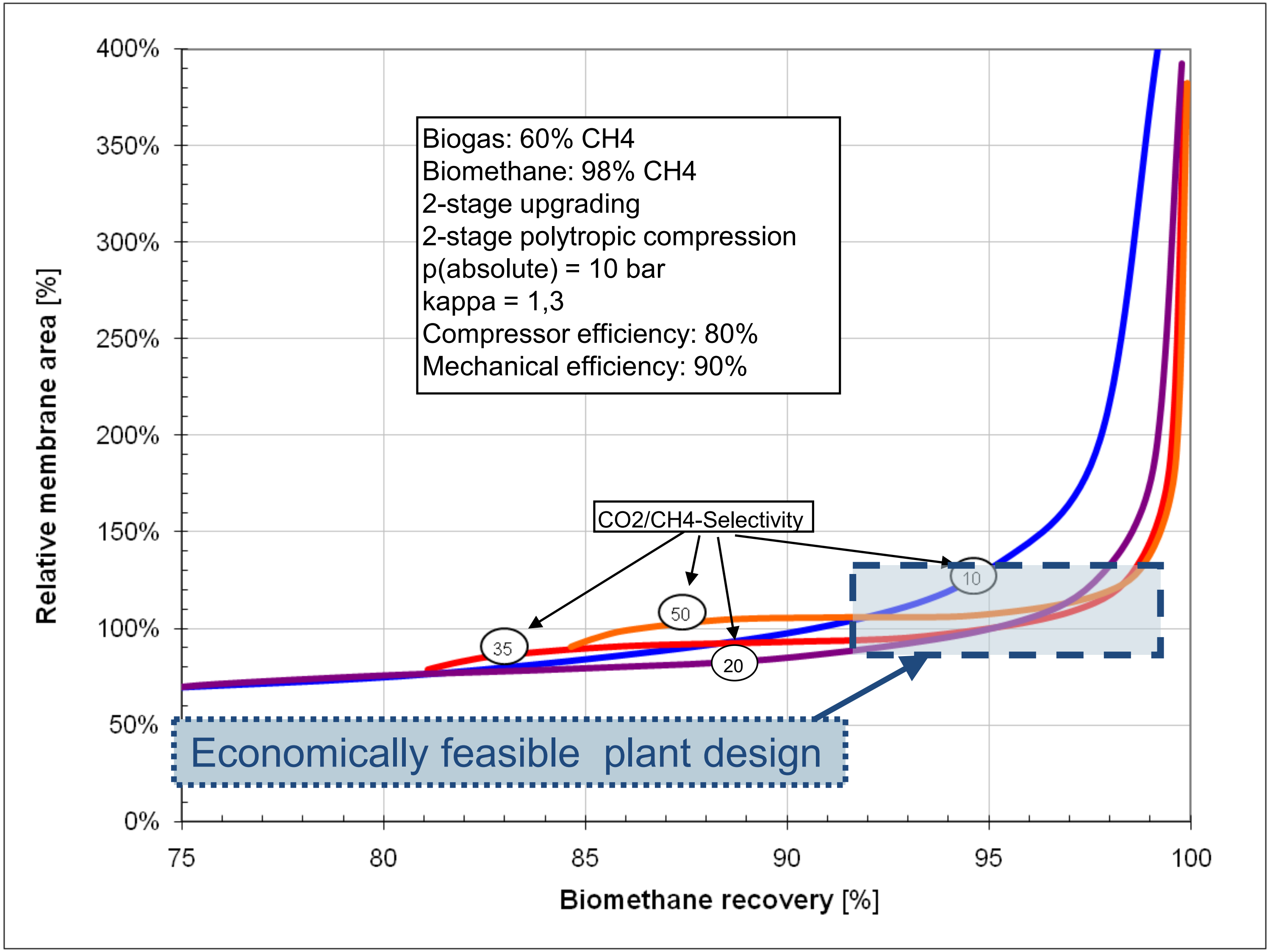




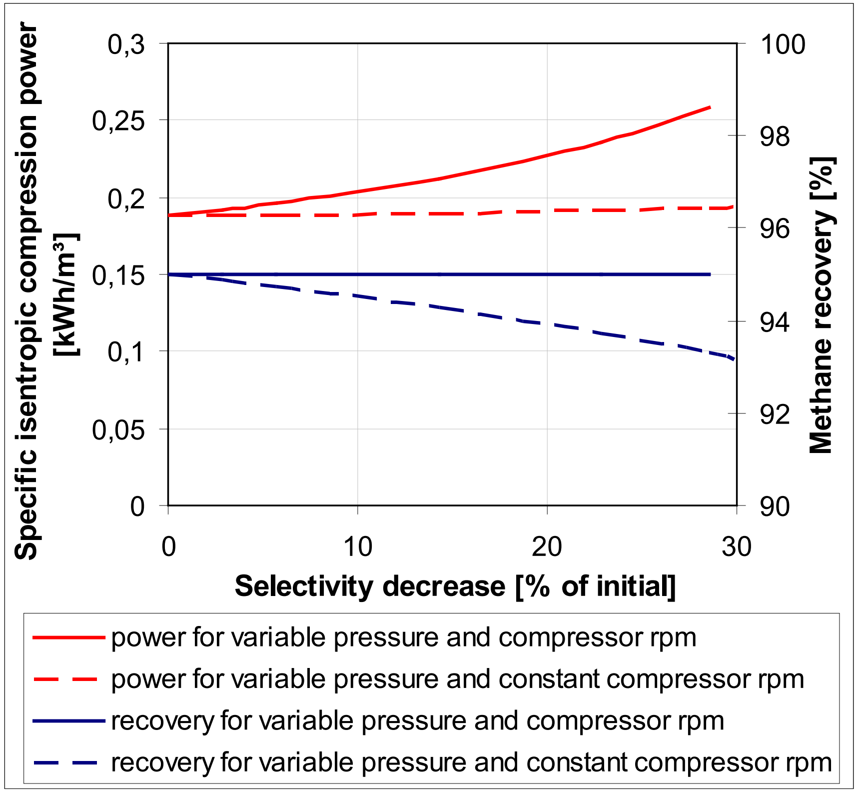
Compression Energy Consumption per m³ Product

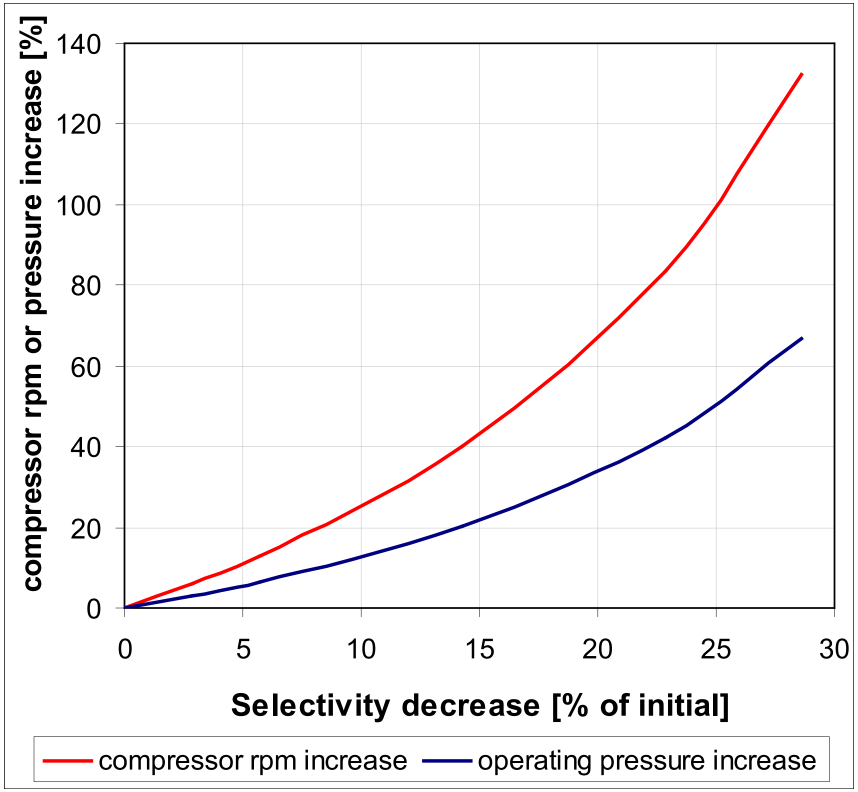


Membrane Area as Function of Recovery



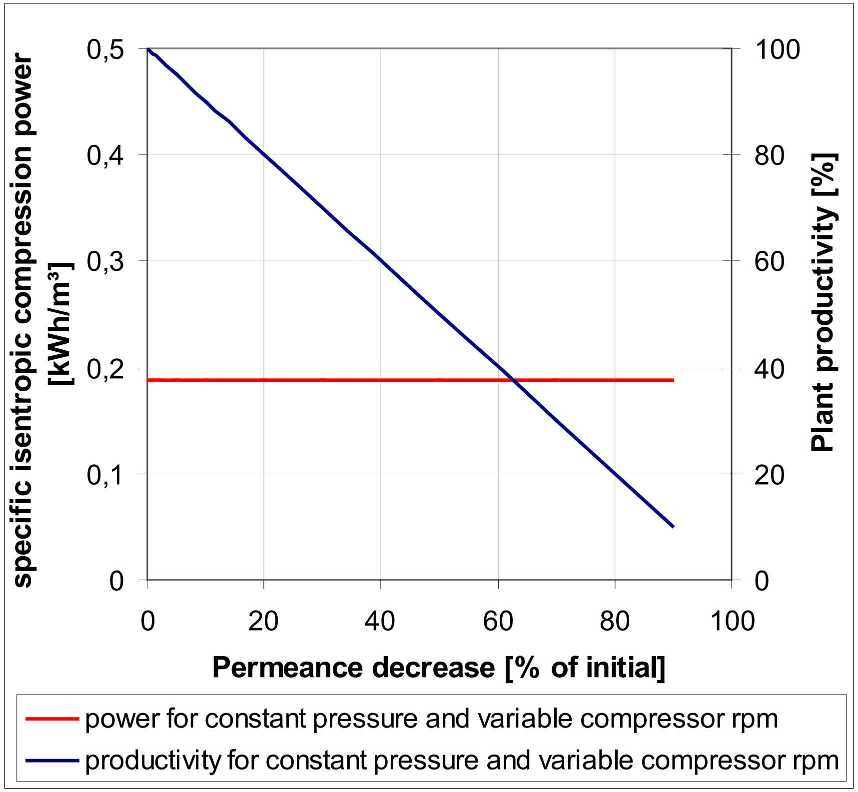
Simulation – Change of Membrane Selectivity

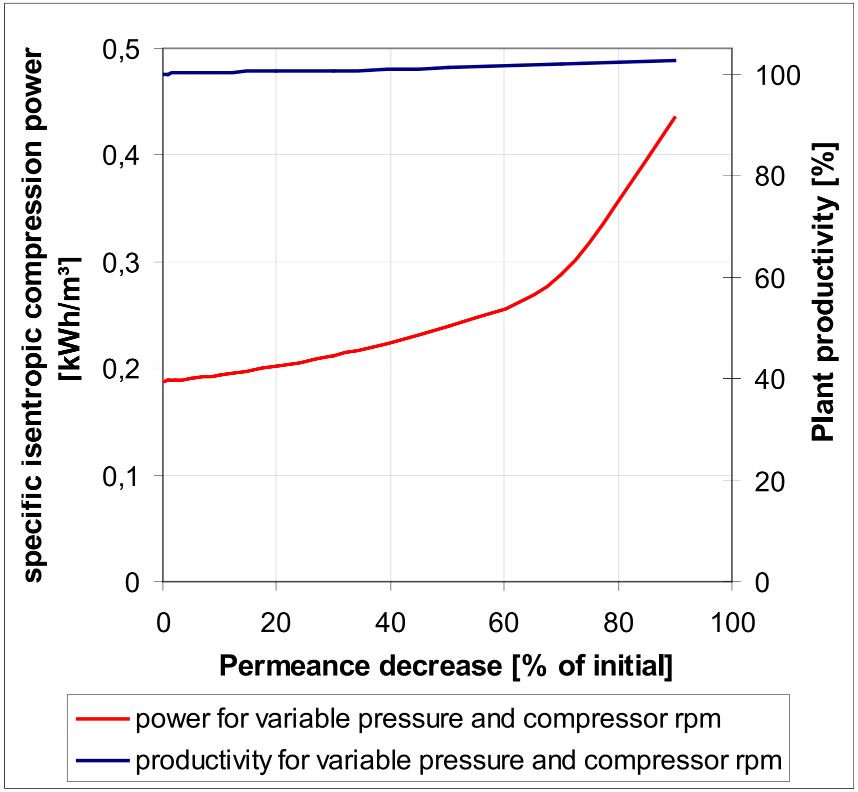




- Selectivity decline results in a reduction of methane recovery, the operating pressure must be adjusted to maintain the gas purity
- If methane content and methane recovery are to be invariable to the selectivity reduction, both pressure and compressor RPM need to be adjusted (higher specific energy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

- **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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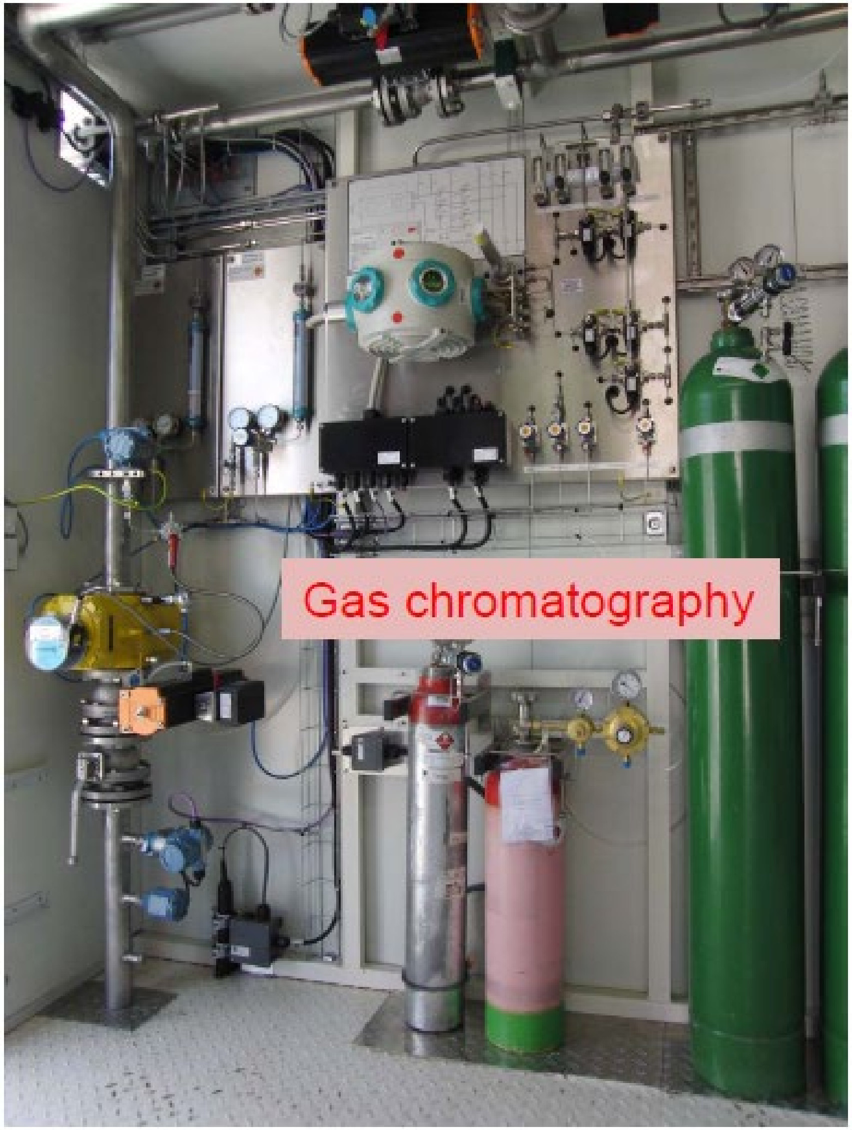
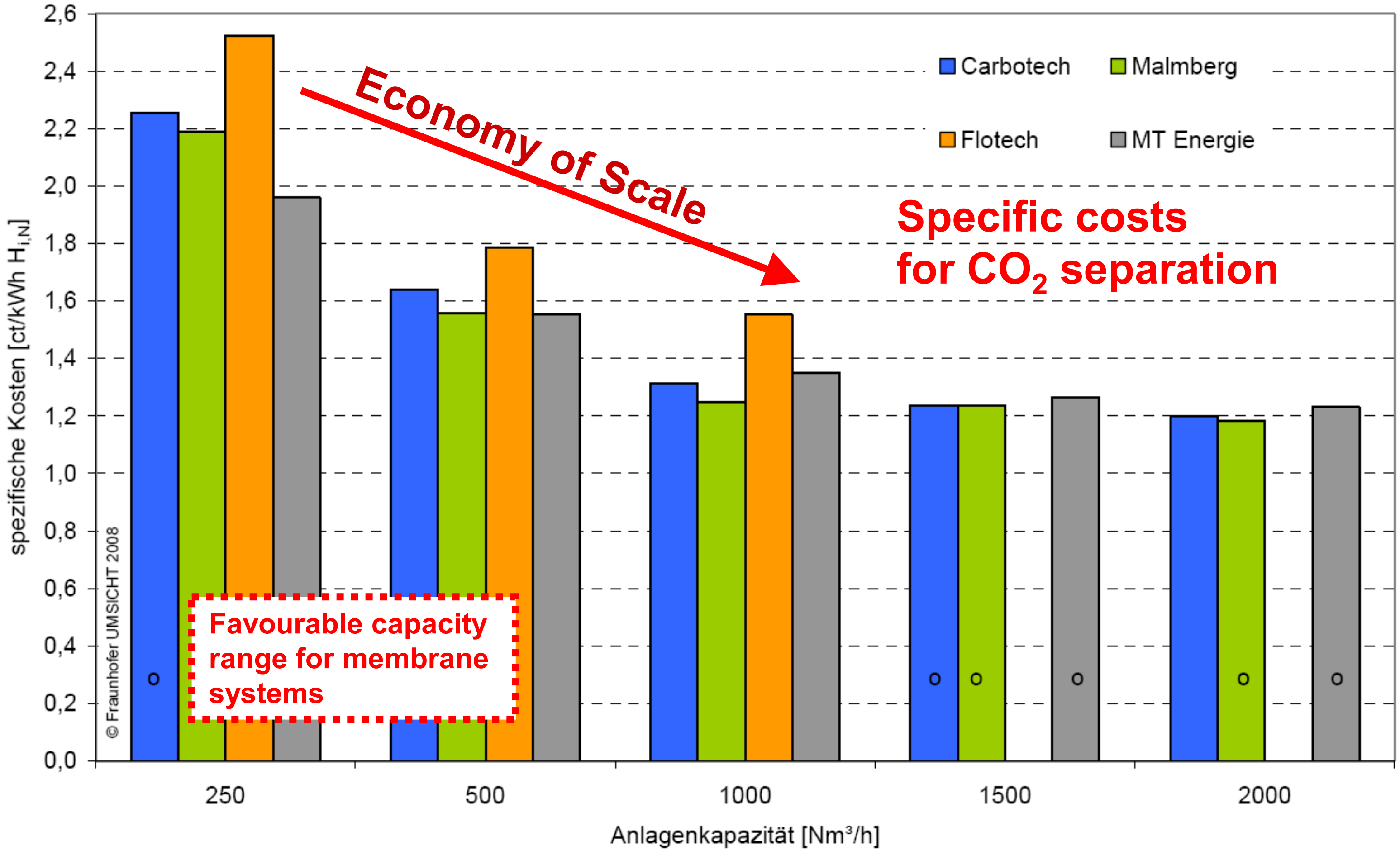
Gas quality Measurement / Offgas Treatment



Costs for CO_2 Separation

Calculations by Fraunhofer Institut UMSICHT (2008)



Cooperative Biogas Upgrading

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

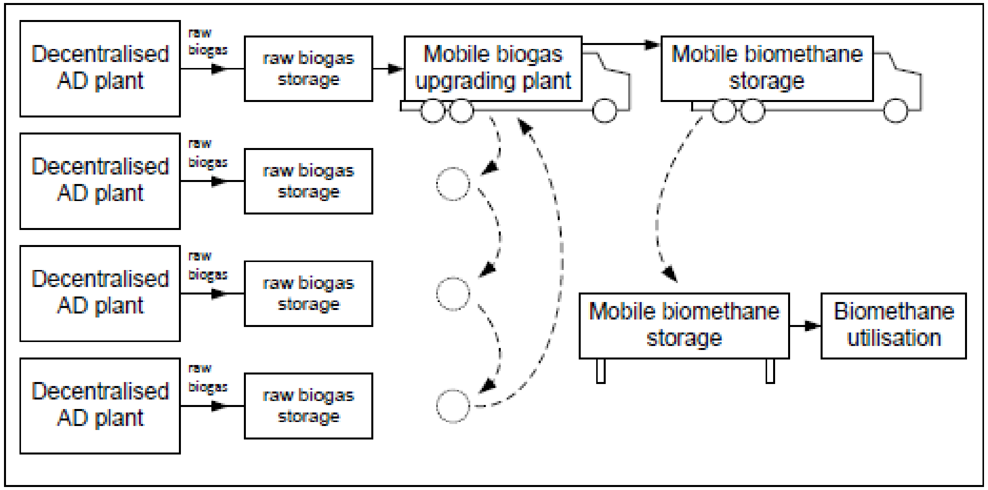


Figure 2: One possibility of mobile biogas upgrading for cooperative biomethane production applying mobile biomethane storage tanks; Source: Vienna University of Technology

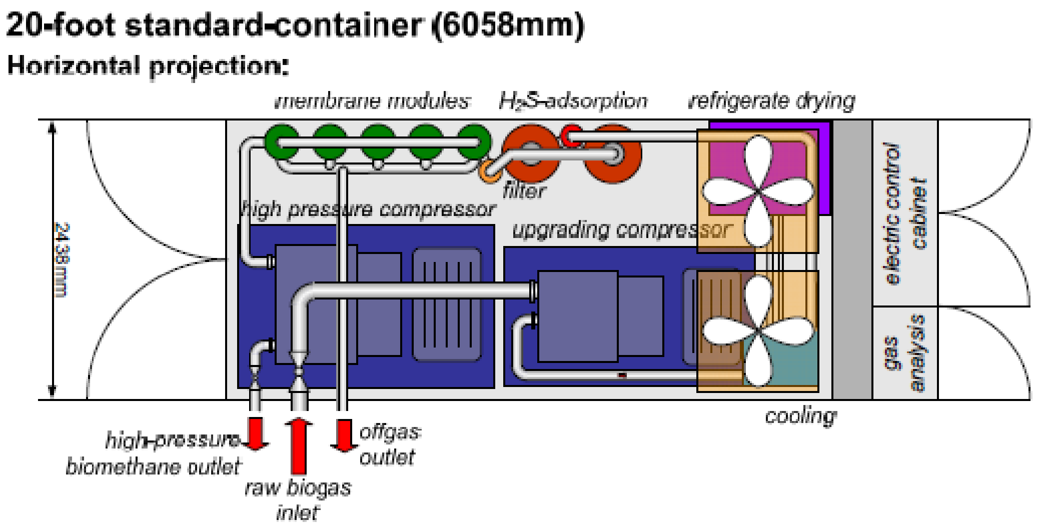


Figure 3: Scheme of a mobile biogas upgrading unit with a capacity of 300m³/h raw biogas using gaspermeation mounted in a 20-foot standard container; Source: Vienna University of Technology


GUIDE TO COOPERATIVE BIOGAS TO BIOMETHANE DEVELOPMENTS

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Research Division Thermal Process Engineering and Simulation

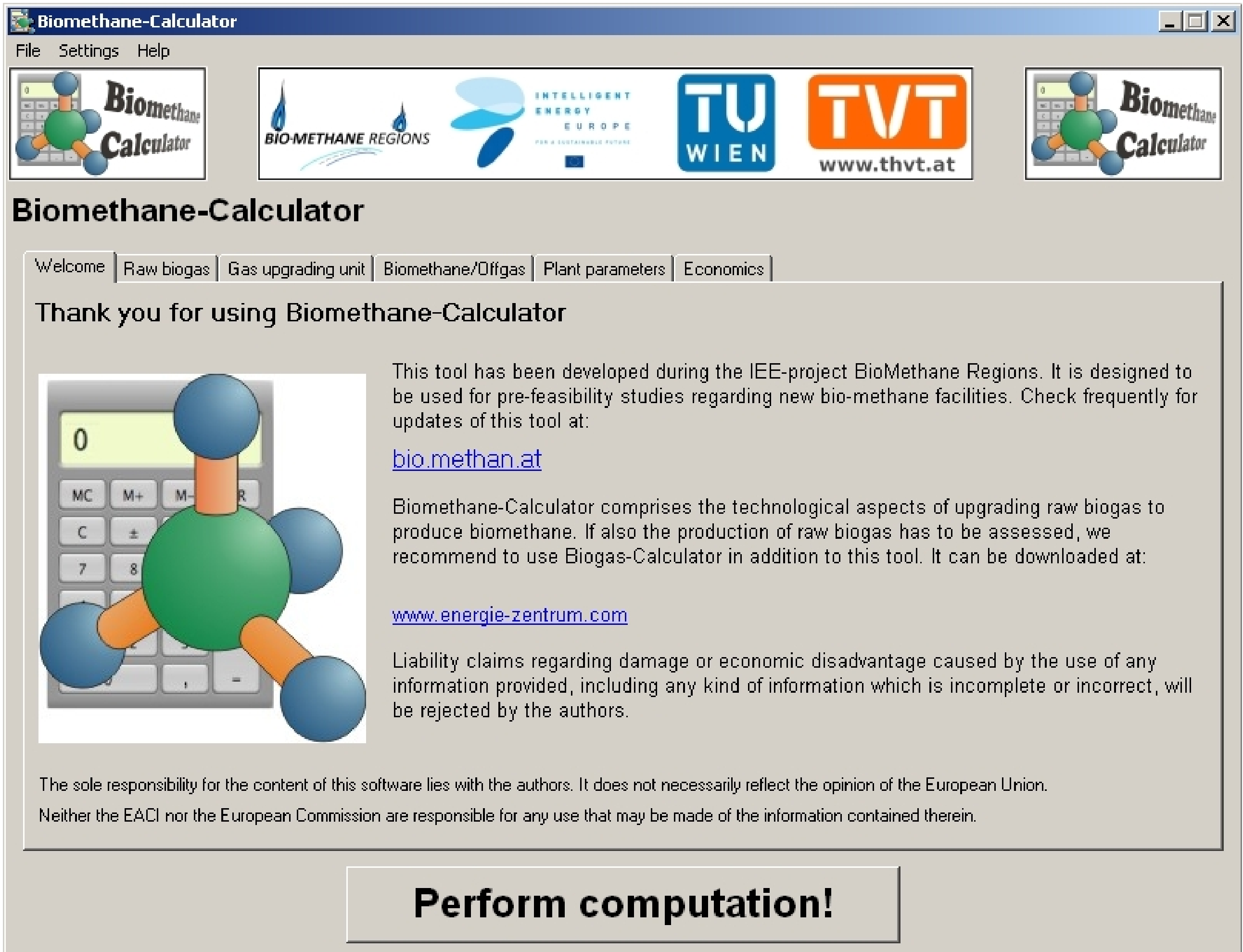
AS PART DELIVERY OF:

BIO-METHANE REGIONS

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

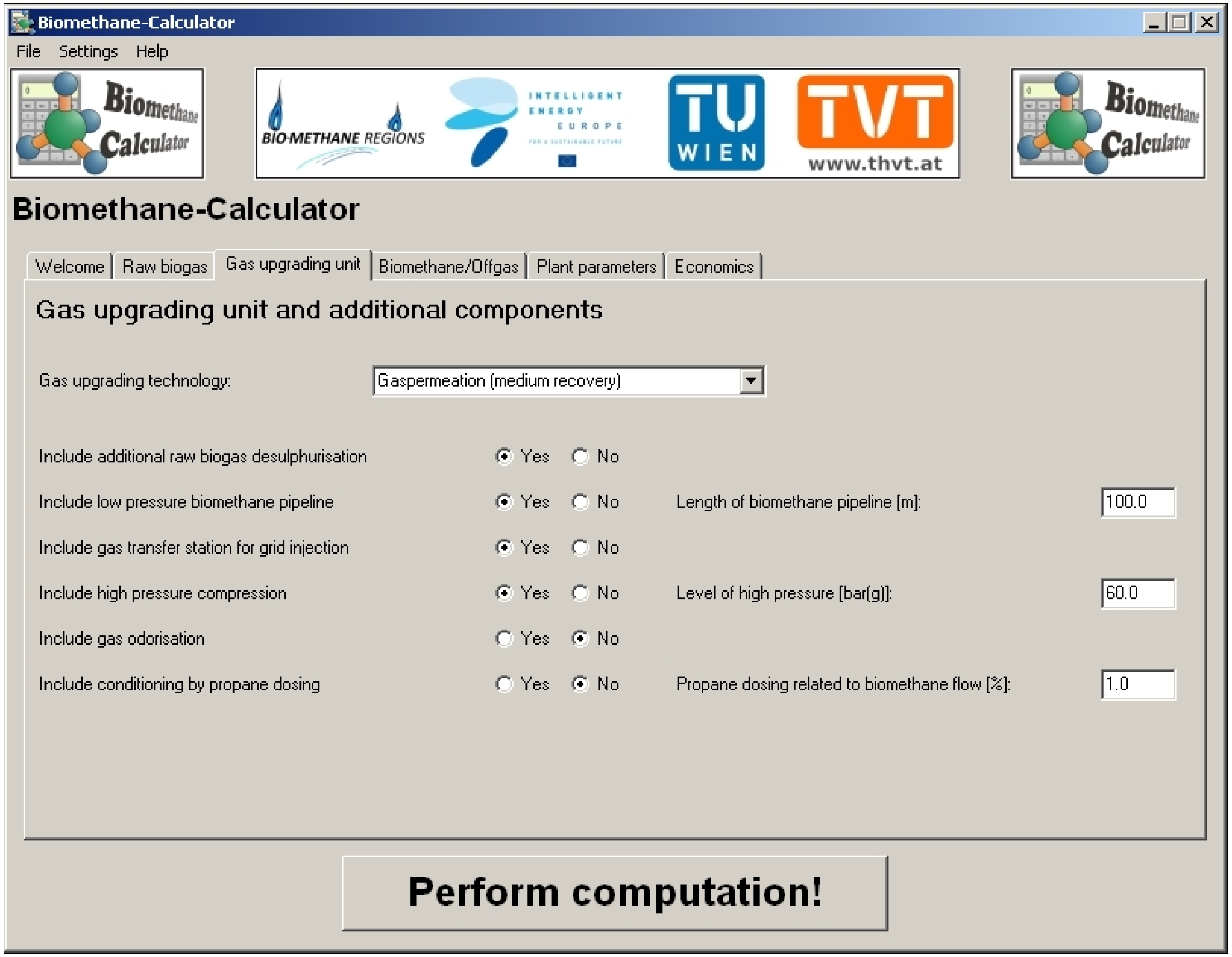
Contract Number: IEE/10/130
Deliverable Reference: Task 3.1.2
Delivery Date: December 2012

Biomethane Calculator



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

Biomethane Calculator



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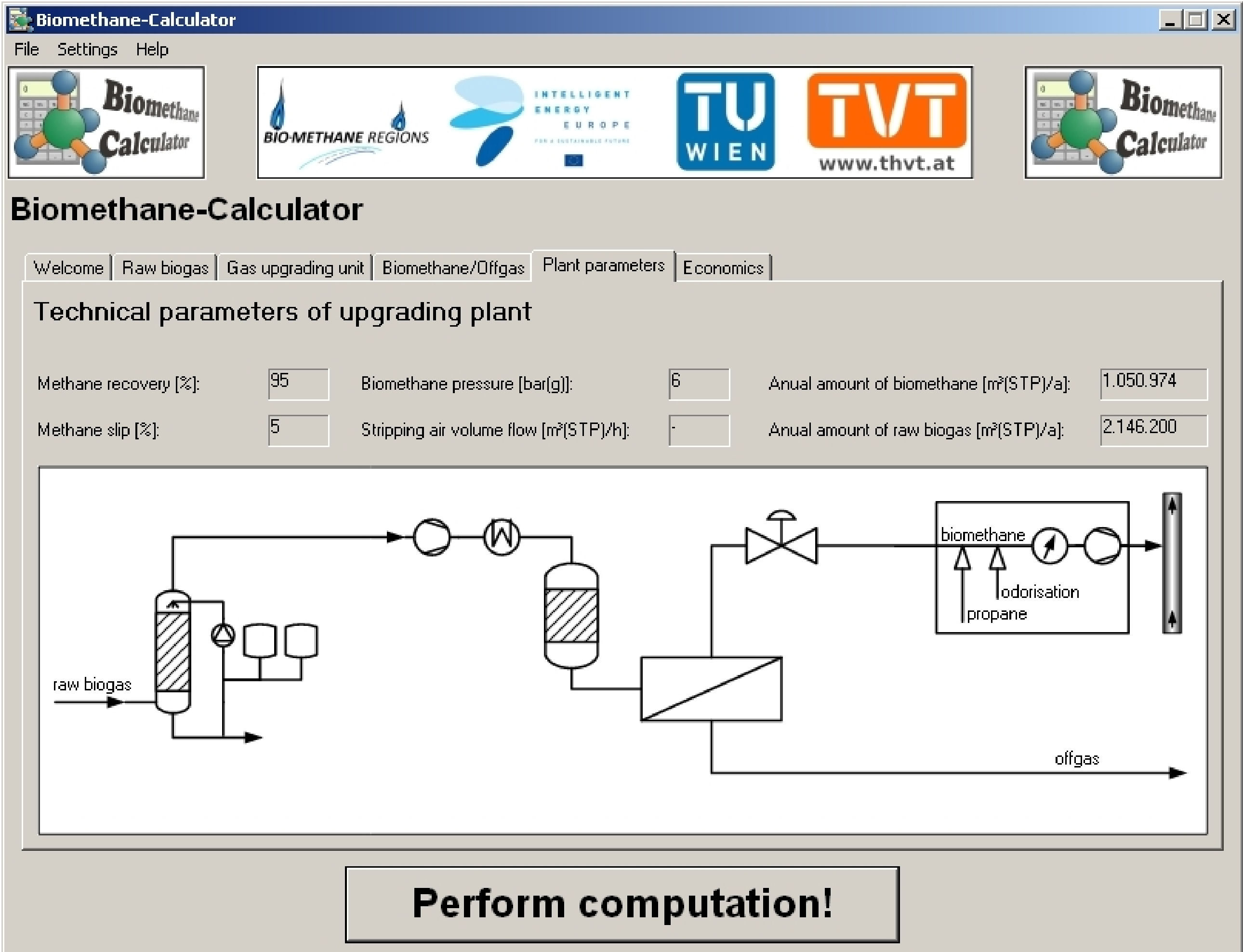
Biomethane Calculator



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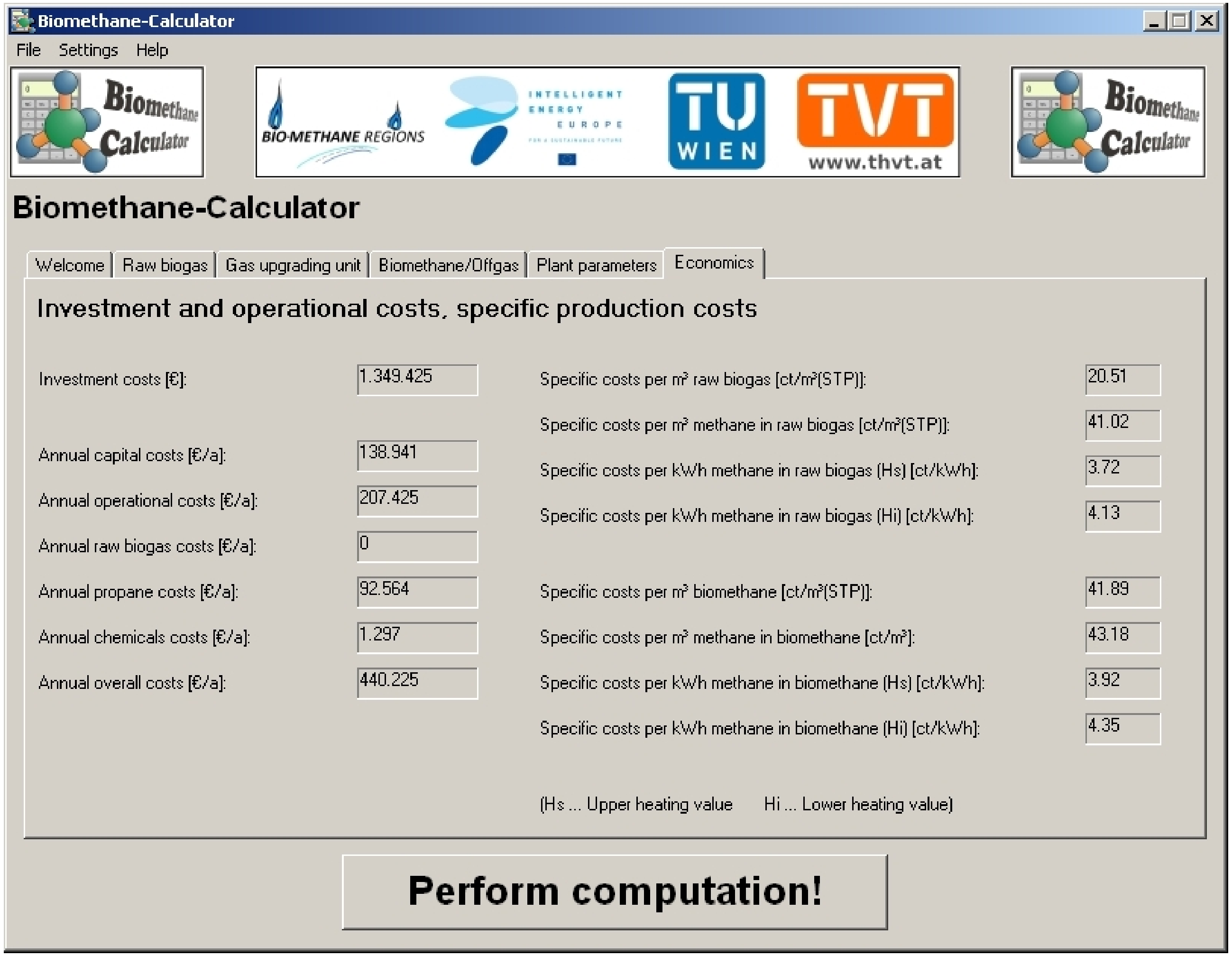
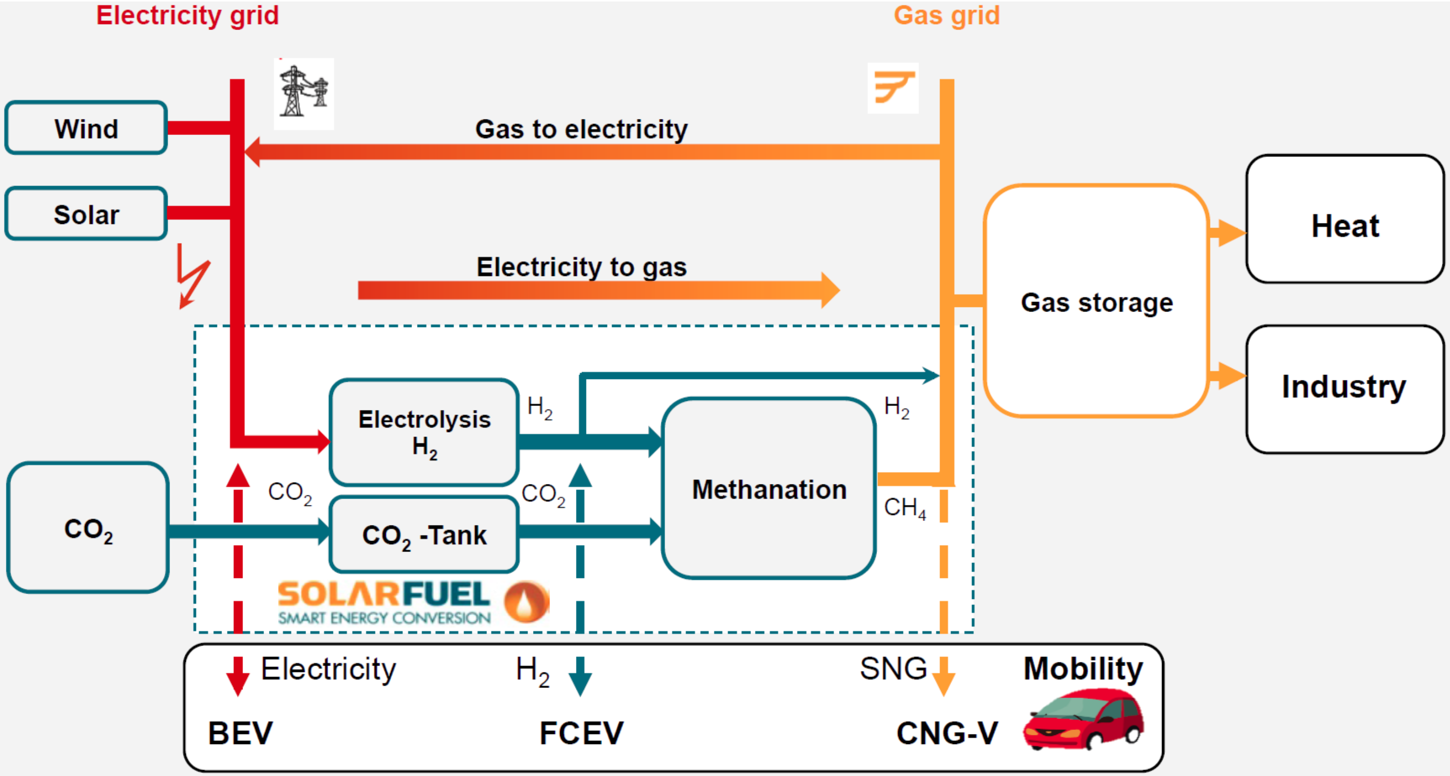
Biomethane Calculator



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



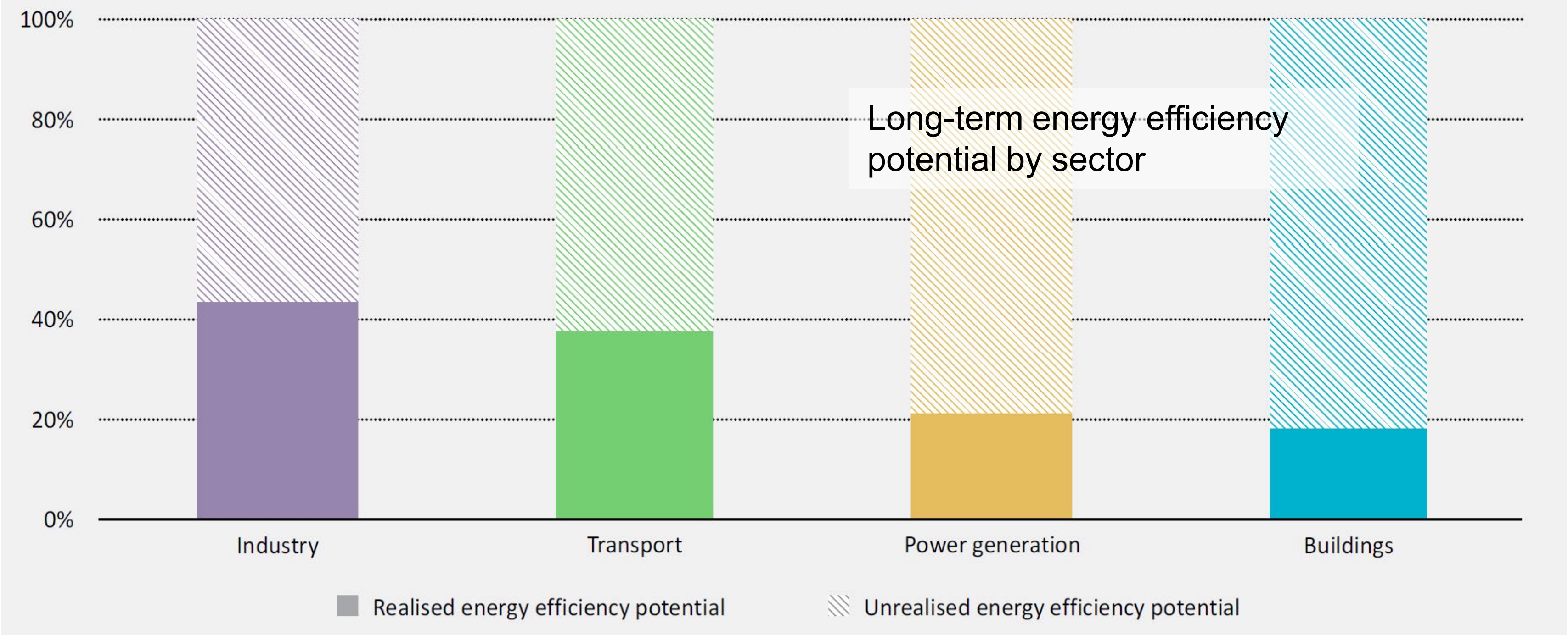
CNG-V = Compressed Natural Gas Vehicle **FCEV** = Fuel Cell Electric Vehicle **BEV** = Battery Electric Vehicle

Rightsizing …

Bigger and BIGGER…

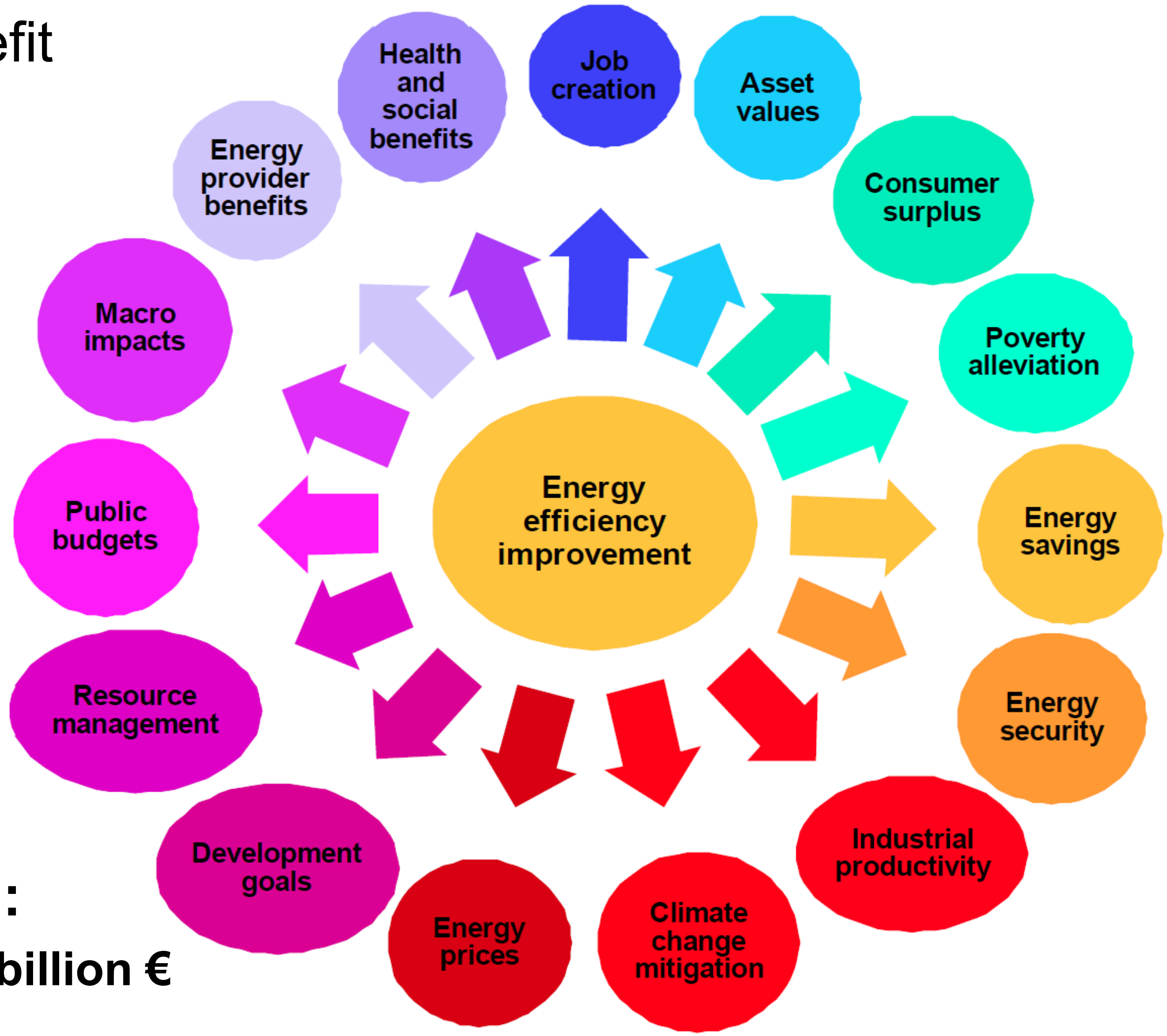
Energy Efficiency

- 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]



Energy Efficiency and Energy Savings

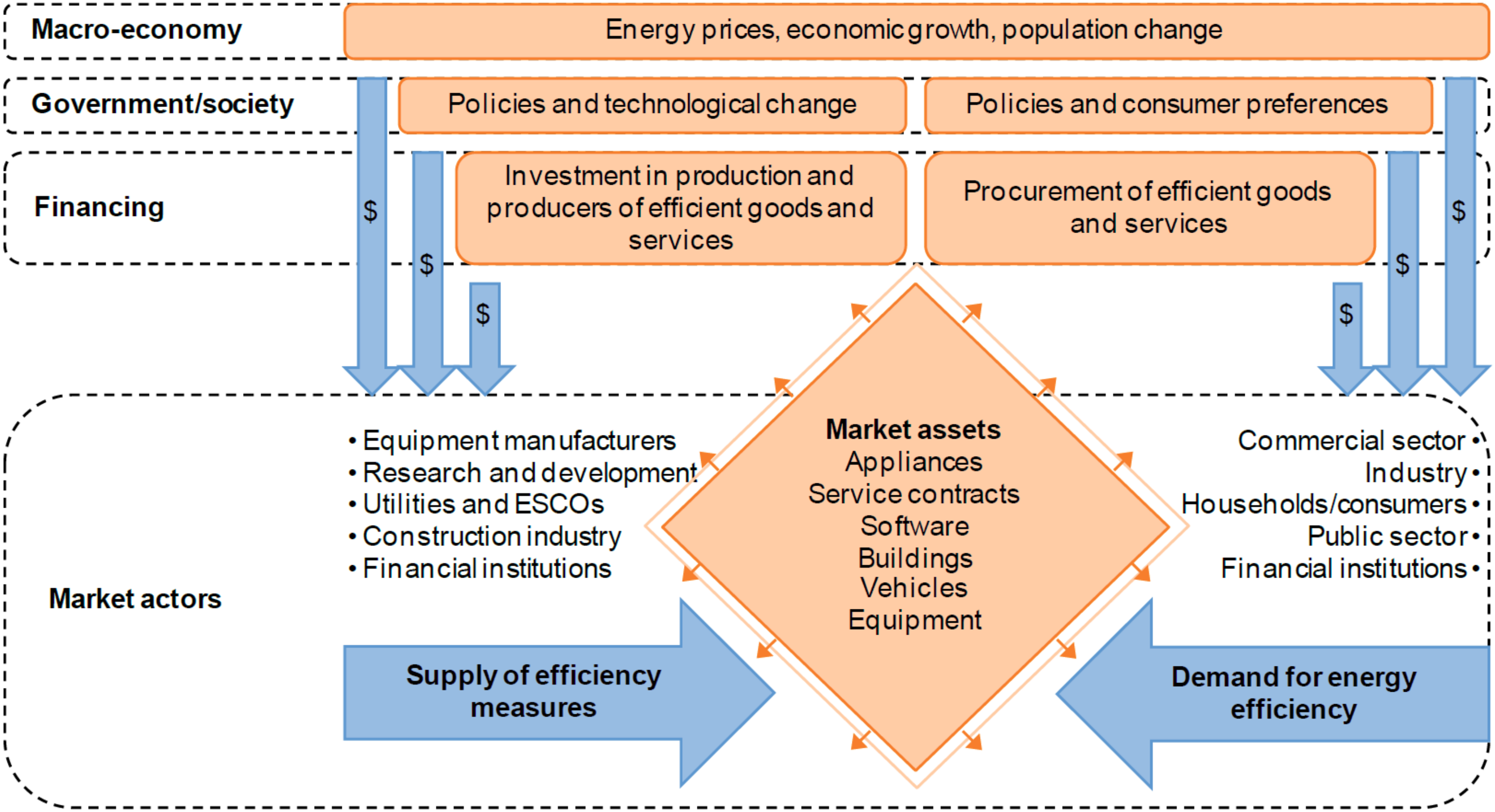
Multiple benefit approach



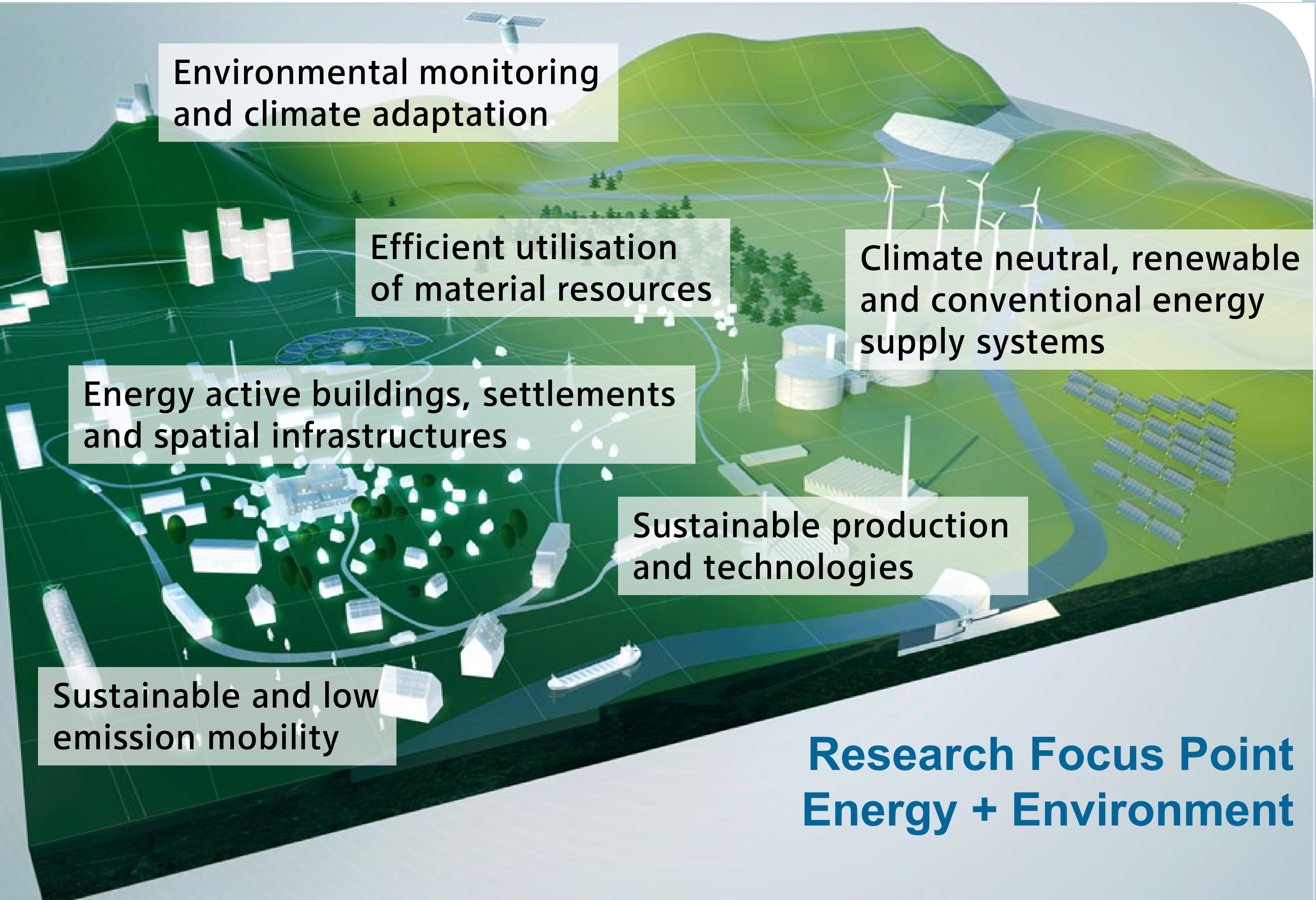
EU potential:

20% of a 1600 billion € energy market

The Market for Energy Efficiency



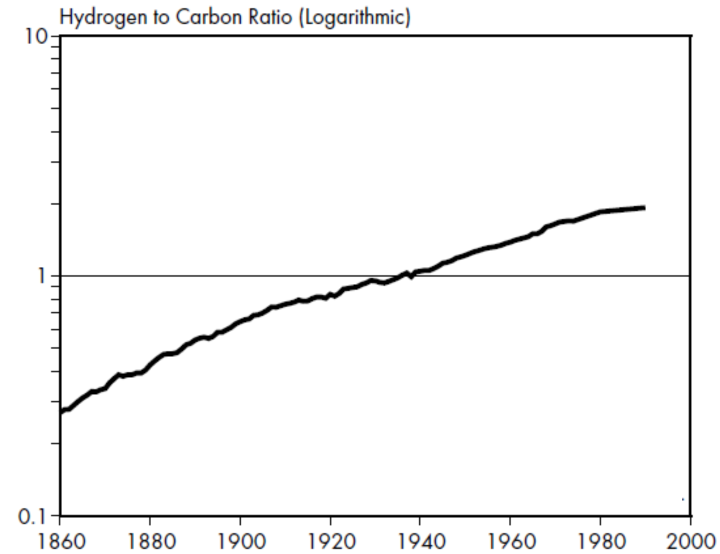
Related R&D @ Vienna University of Technology

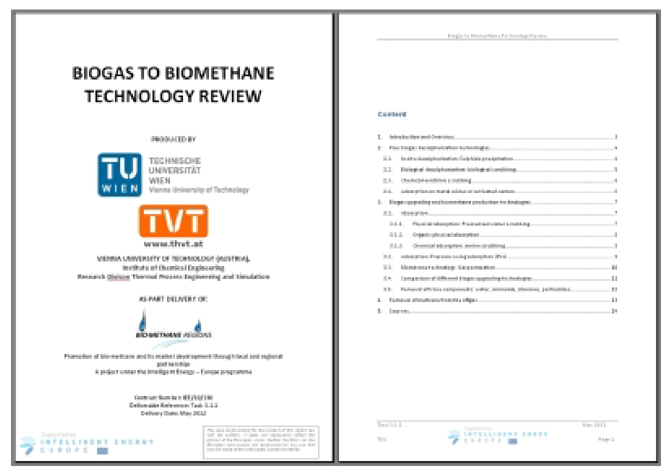


Lessons learned

- 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!

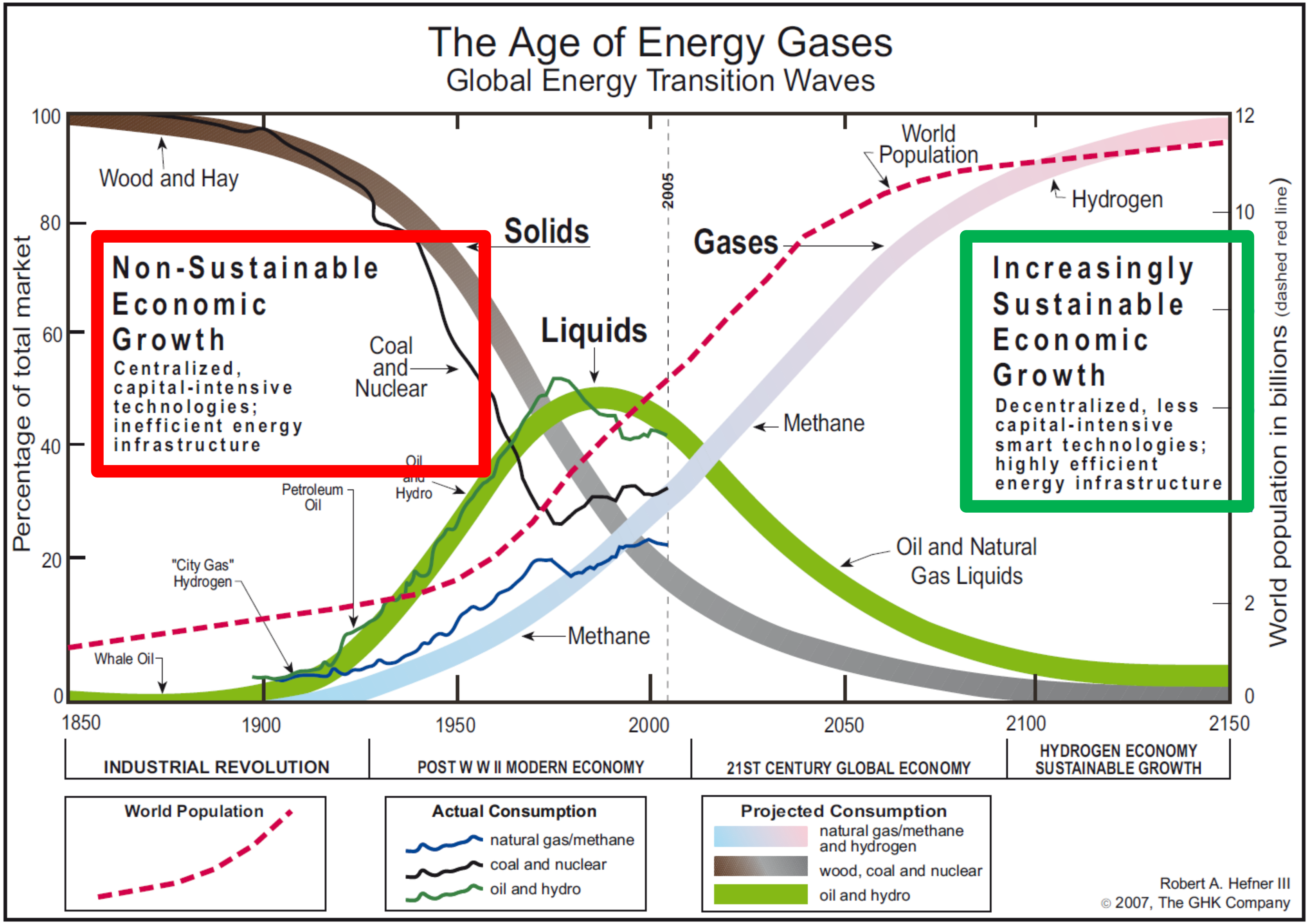
Hydrogen-Carbon Ratio, World Energy Mix, 1860–1990





Available upon request

What are the drivers ?



Thank you very much for your Interest!

Visit us:

- www.virtuellesbiogas.at
- bio.methan.at

Project websites:

- www.bio-methaneregions.eu
- www.bio-methaneregions.at

Co-funded by the Intelligent Energy Europe Programme of the European Union