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Biomass Utilization & Sustainability of Biofuels

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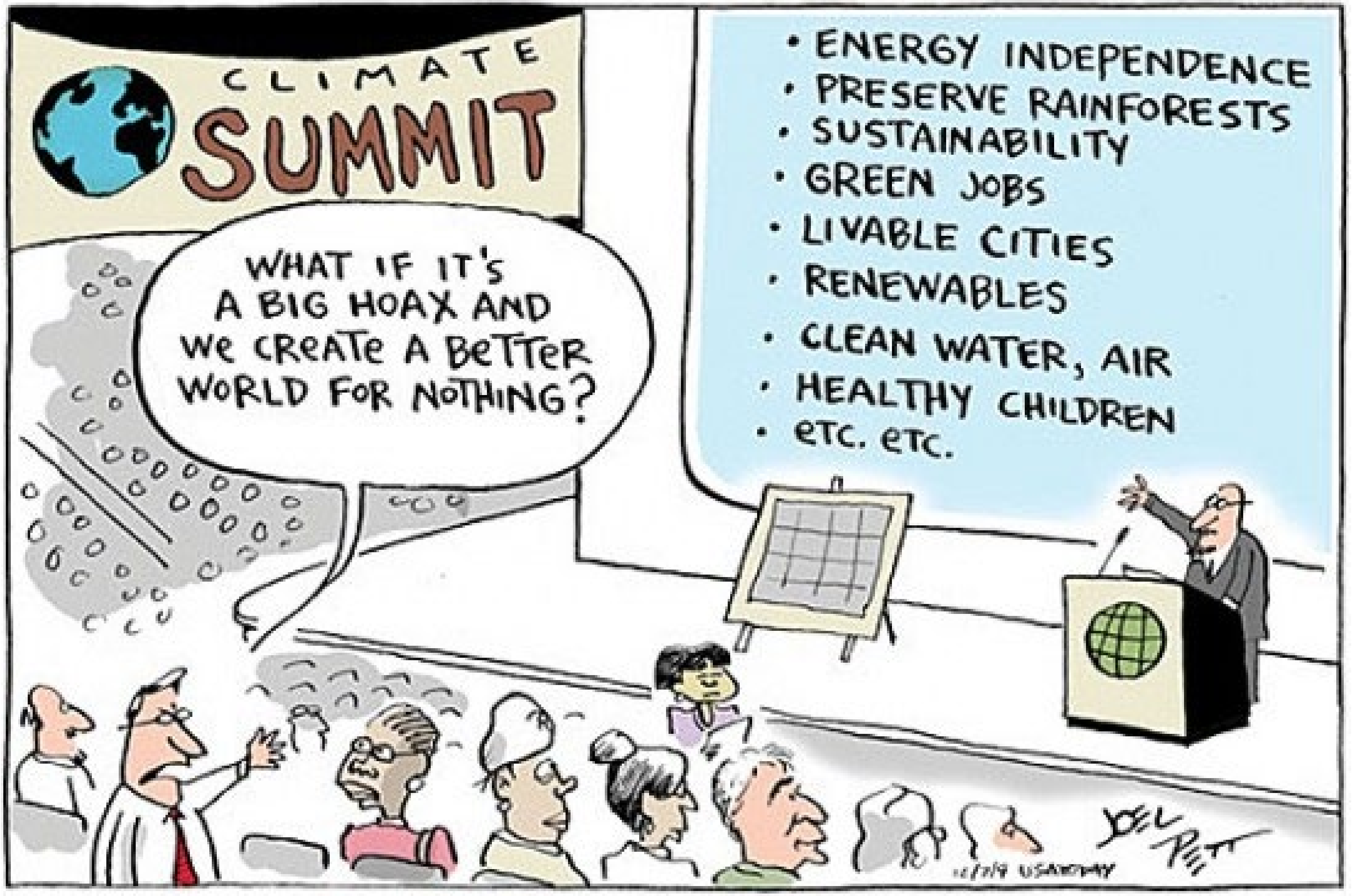
Interdisciplinary Summer School 2020 on "The Future of Energy Systems in Austria and the Czech Republic"

Outline

- Introduction
- Sustainability criteria – the European perspective
- Primary energy composition
- Global biomass related issues
- Biomass gasification
- Biogas digestion
- Biomethane for grid injection and as vehicle fuel
- Hydrogen & Power-To-Gas
- Conclusions

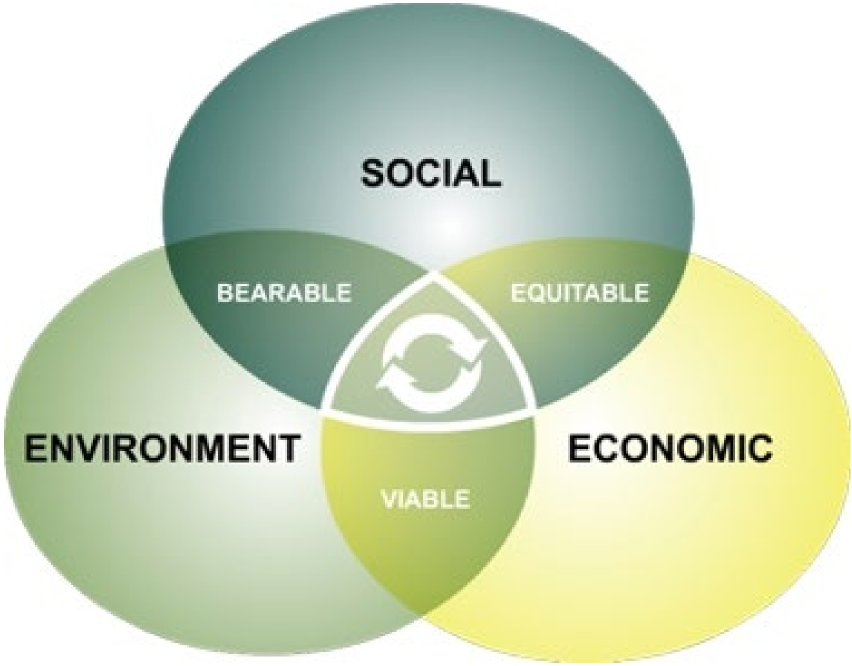
Why should we care about sustainability?

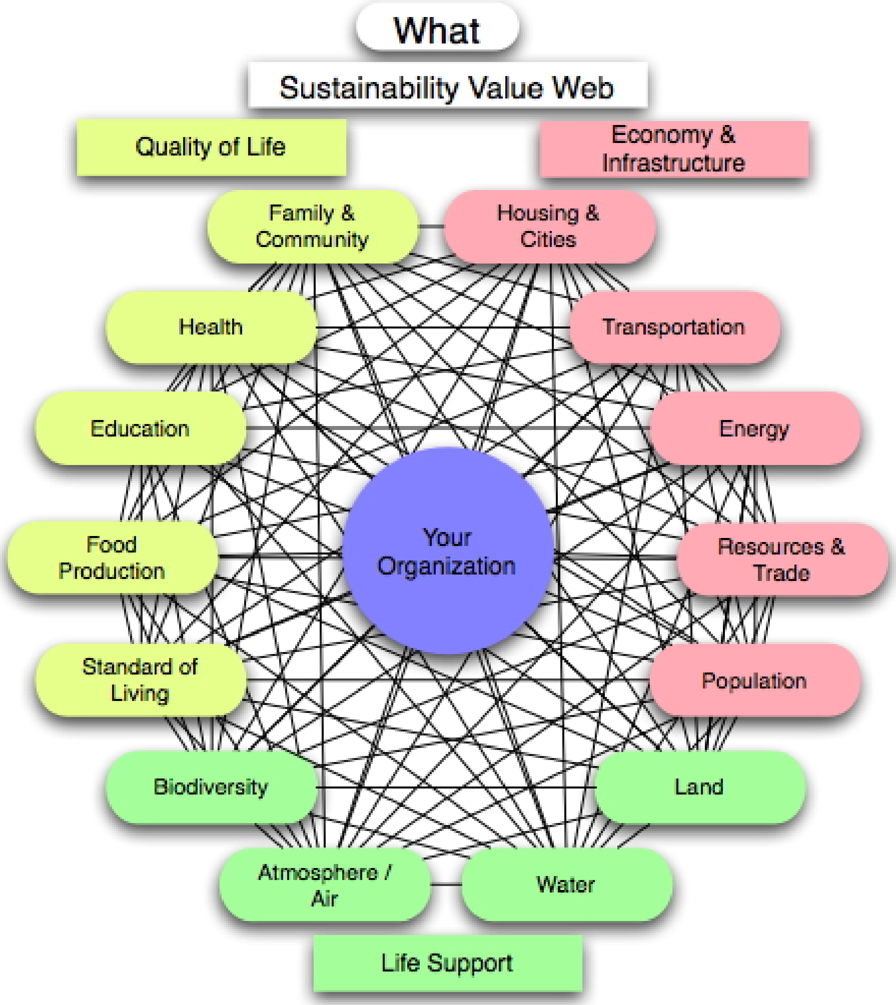


Sustainability Criteria of Biofuels

- The **Directive 2009/28/EC** sets out sustainability criteria for biofuels in its articles 17, 18 and 19. These criteria are related to greenhouse gas savings, land with high biodiversity value, land with high carbon stock and agro-environmental practices.
- The **criteria apply since December 2010**. The European Commission (EC) has adopted a number of Decisions and Communications to assist the implementation of the EU's sustainability criteria.

Sustainability…





- ✓ Sustainability involves all aspects of life

Are new Biofuels the Solution?

Source: IHT 11-04-2008

European Union‘s Definition of Sustainable Biofuels

- EU Directive 2009/28/EC (Renewable energy directive: RED) requires:
- Proof of sustainability of biomass:
  - no production from no-go areas (high biodiversity or high carbon stocks),
  - sustainability of production and operations
  - monitor social sustainability and food security
- Raw material should not be obtained from :
  - wetlands
  - continuously forested areas
  - from areas with 10-30% canopy cover
  - from peatlands
  - if the status of the land has changed compared to its status in January 2008
- GHG savings:
  - biofuels and bio-liquids must yield a GHG emission savings of at least 35%
  - (50% from 2017, 60% from production started after 2017)
- Traceability and mass balance must be assured

European
Commission

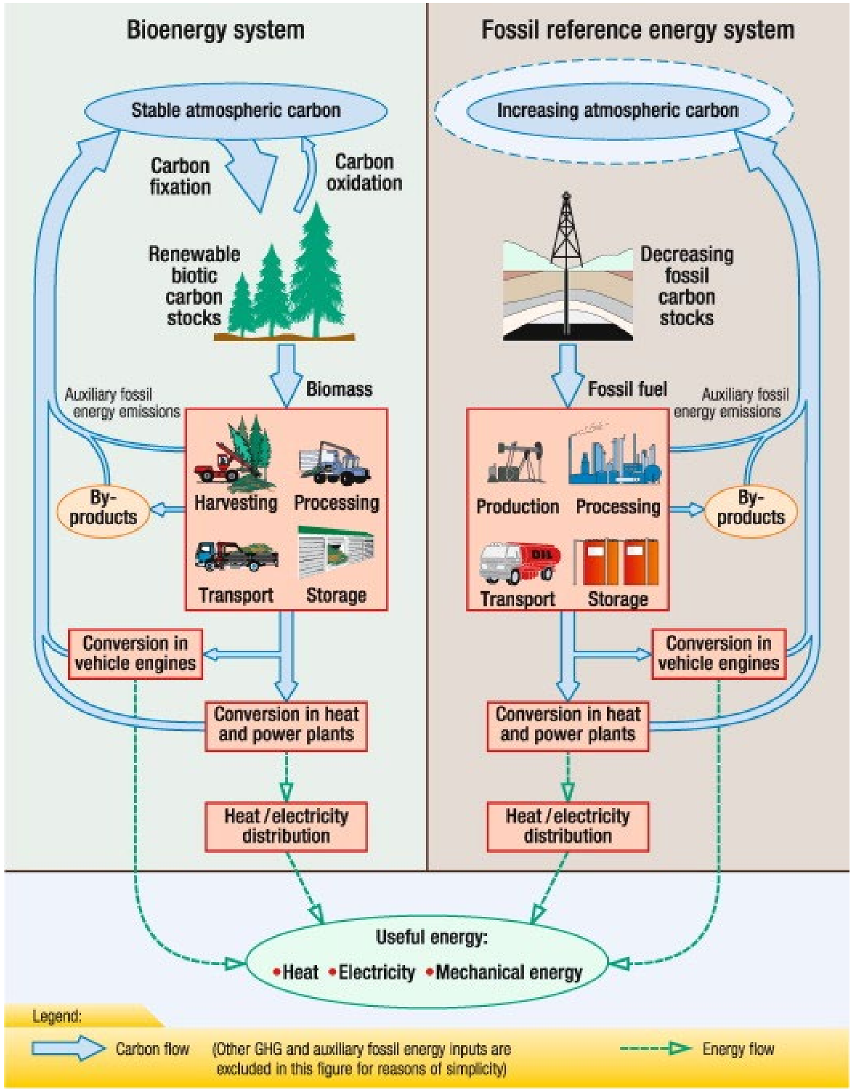
Rules for calculation of GHG savings – Methodology

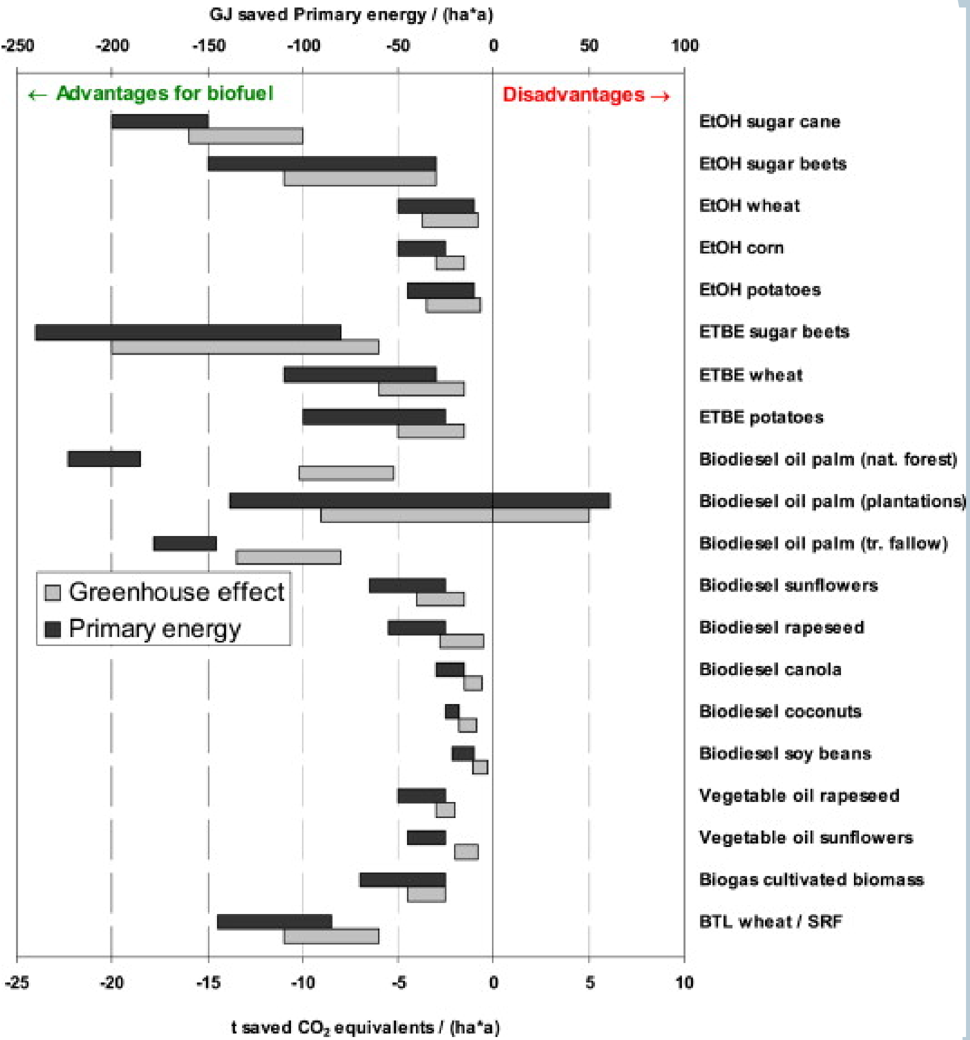
- Includes all process steps (life-cycle) (Annex VII.C)
- End-use efficiency may be taken into account
- Land use change has to be taken into account
- Carbon capture and storage/ replacement

- Co-products by energy allocation, except:
  - agricultural crop residues (not counted)
  - surplus electricity from CHP (special rule)

- Special rule for biofuels from wastes/ residues
- Comparison with EU average for petrol & diesel

Baselines: GHG Emissions of Fuels

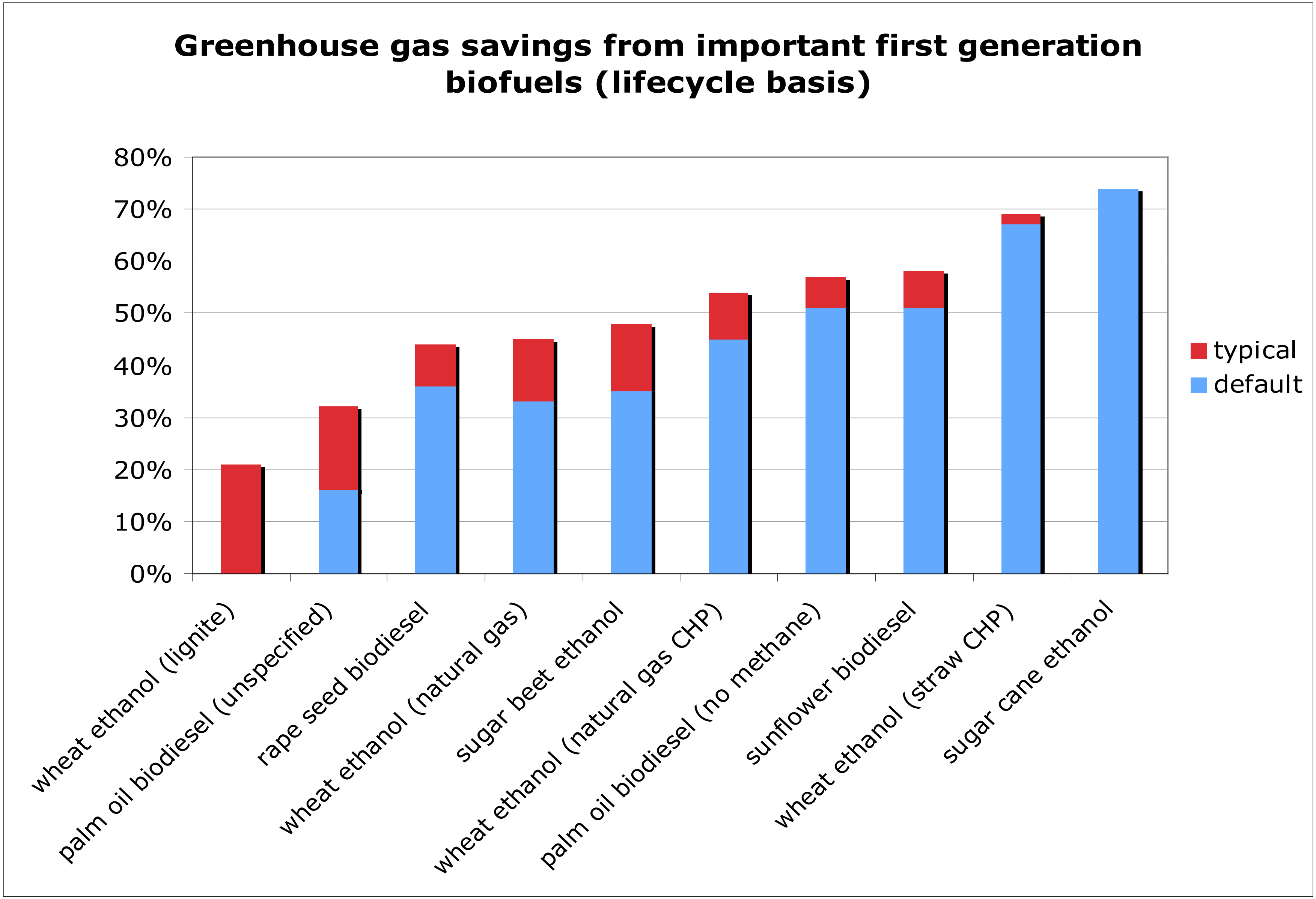




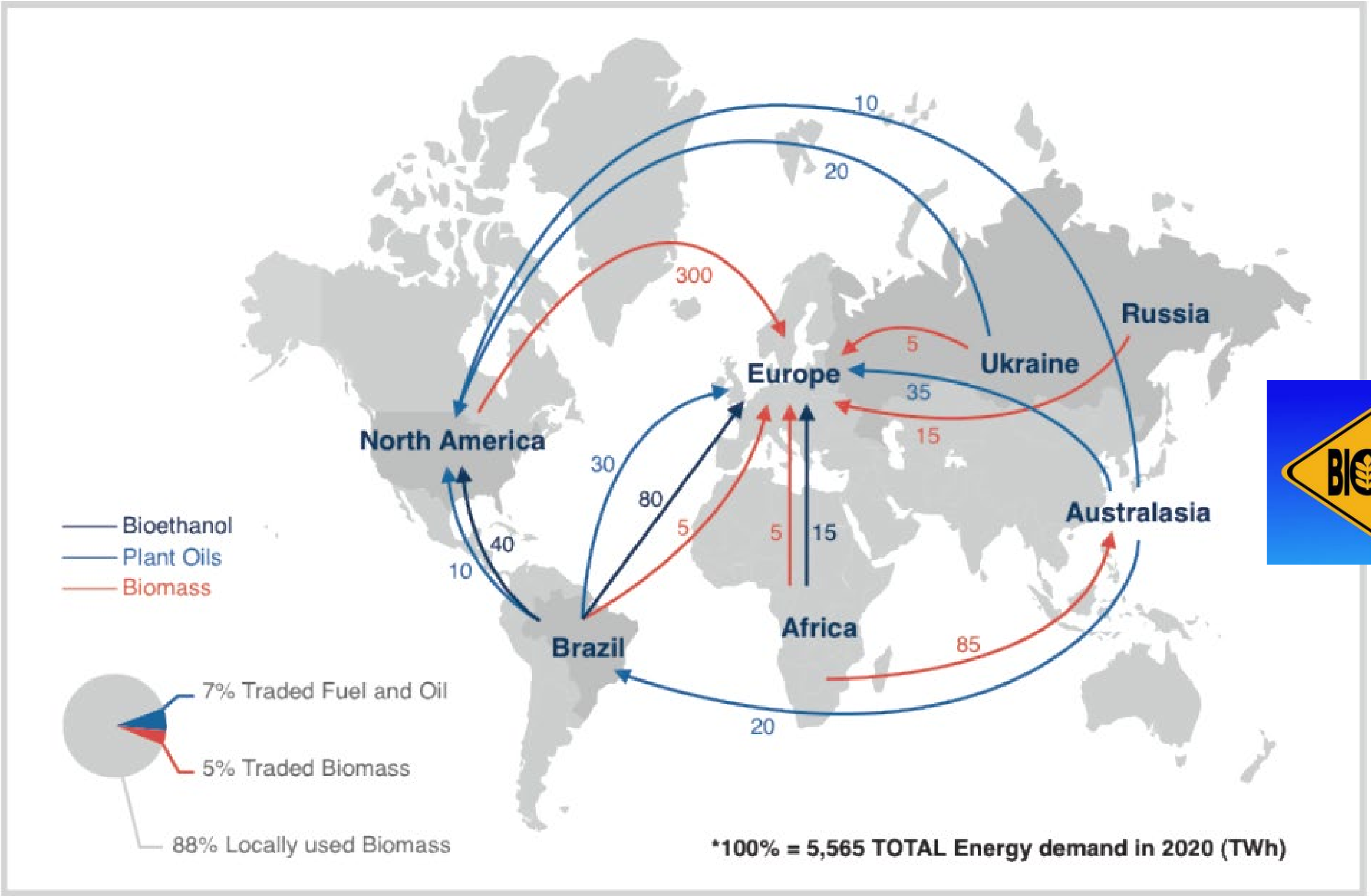
http://www.sciencedirect.com/science/article/pii/S0921344909000500

http://www.sciencedirect.com/science/article/pii/S0961953410004071

Greenhouse Gas Savings from Biofuels



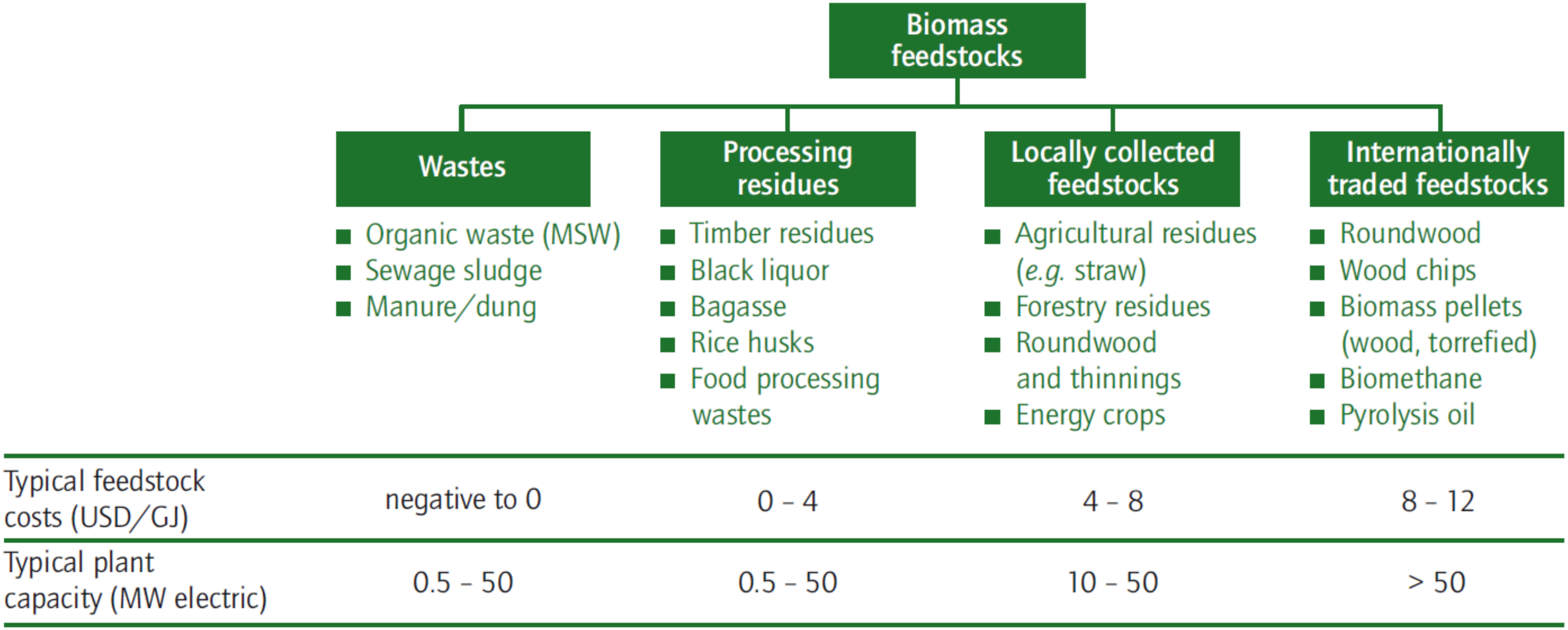
Trade… or will the fuel be used locally?



*100% = 5,565 TOTAL Energy demand in 2020 (TWh)

Figure 5: *Expected Biomass Trade Routes.* Values represent final energy demand in 2020.

Biomass Feedstocks



Biomass feedstocks

Wastes
- Organic waste (MSW)
- Sewage sludge
- Manure/dung

Processing residues
- Timber residues
- Black liquor
- Bagasse
- Rice husks
- Food processing wastes

Locally collected feedstocks
- Agricultural residues (*e.g.* straw)
- Forestry residues
- Roundwood and thinnings
- Energy crops

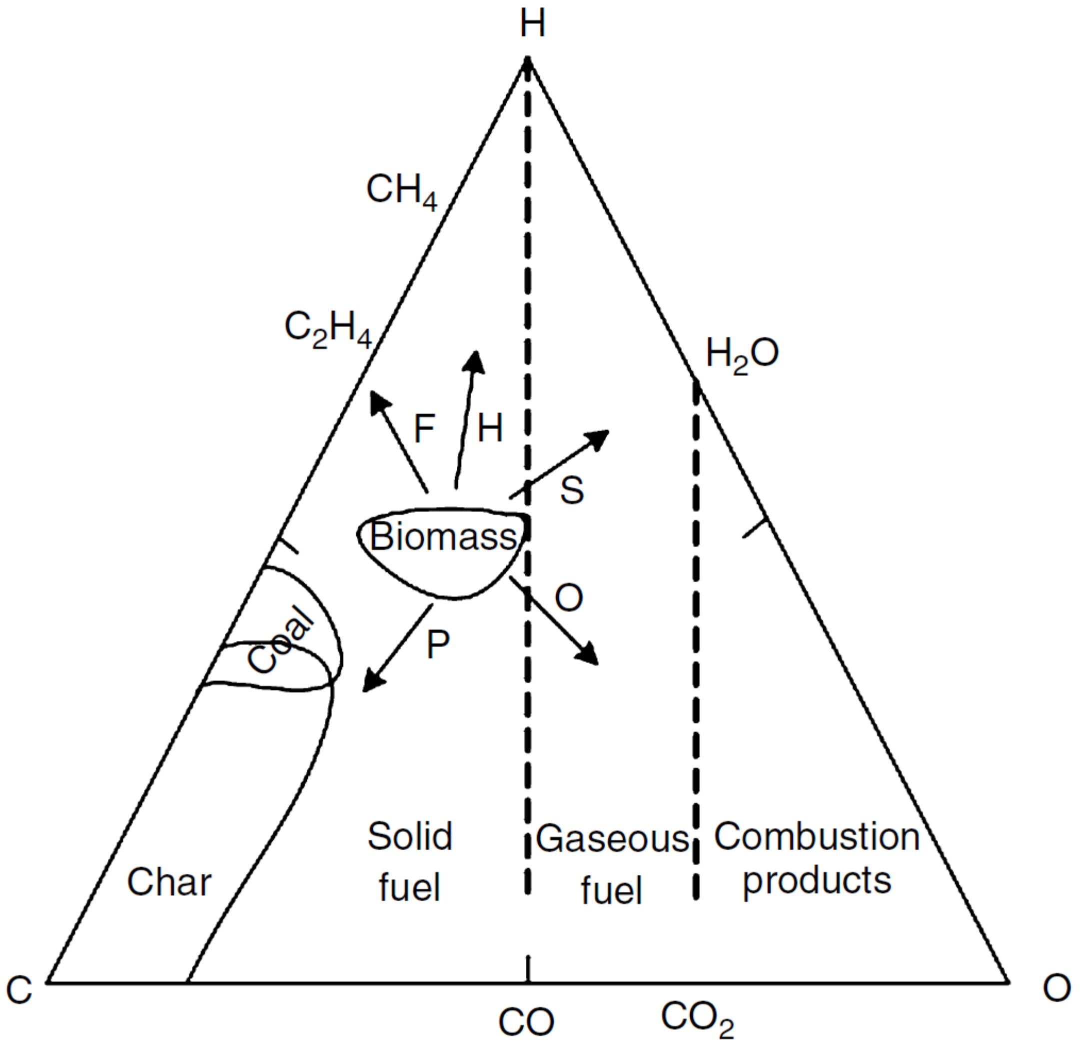
Internationally traded feedstocks
- Roundwood
- Wood chips
- Biomass pellets (wood, torrefied)
- Biomethane
- Pyrolysis oil

	Wastes	Processing residues	Locally collected feedstocks	Internationally traded feedstocks
Typical feedstock costs (USD/GJ)	negative to 0	0 – 4	4 – 8	8 – 12
Typical plant capacity (MW electric)	0.5 – 50	0.5 – 50	10 – 50	> 50

Examples of different biomass feedstocks, typical feedstock costs, and plant capacities

Source: IEA (2012)

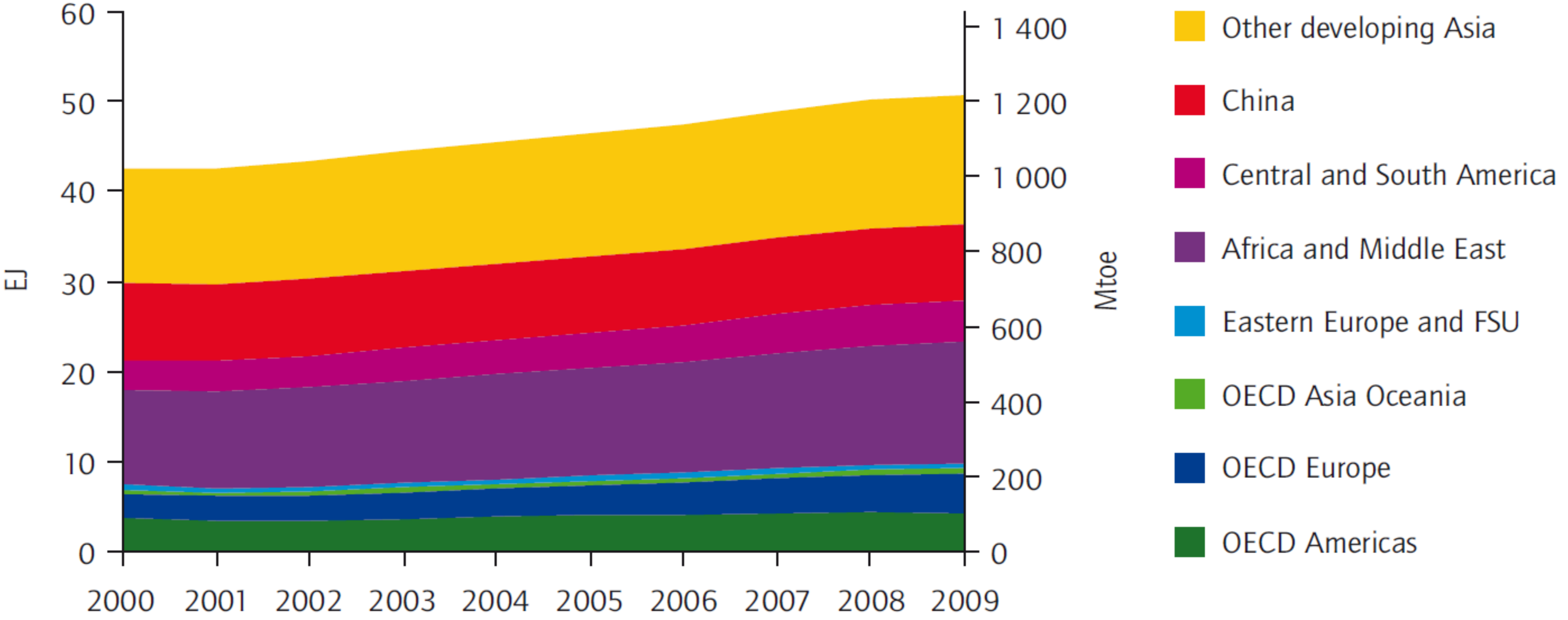
Biomass Composition and Utilization



H hydrogen S steam O oxygen P slow pyrolysis
F fast pyrolysis L lignin C cellulose/hemicellulose

Composition triangle C/H/O (mol/mol)

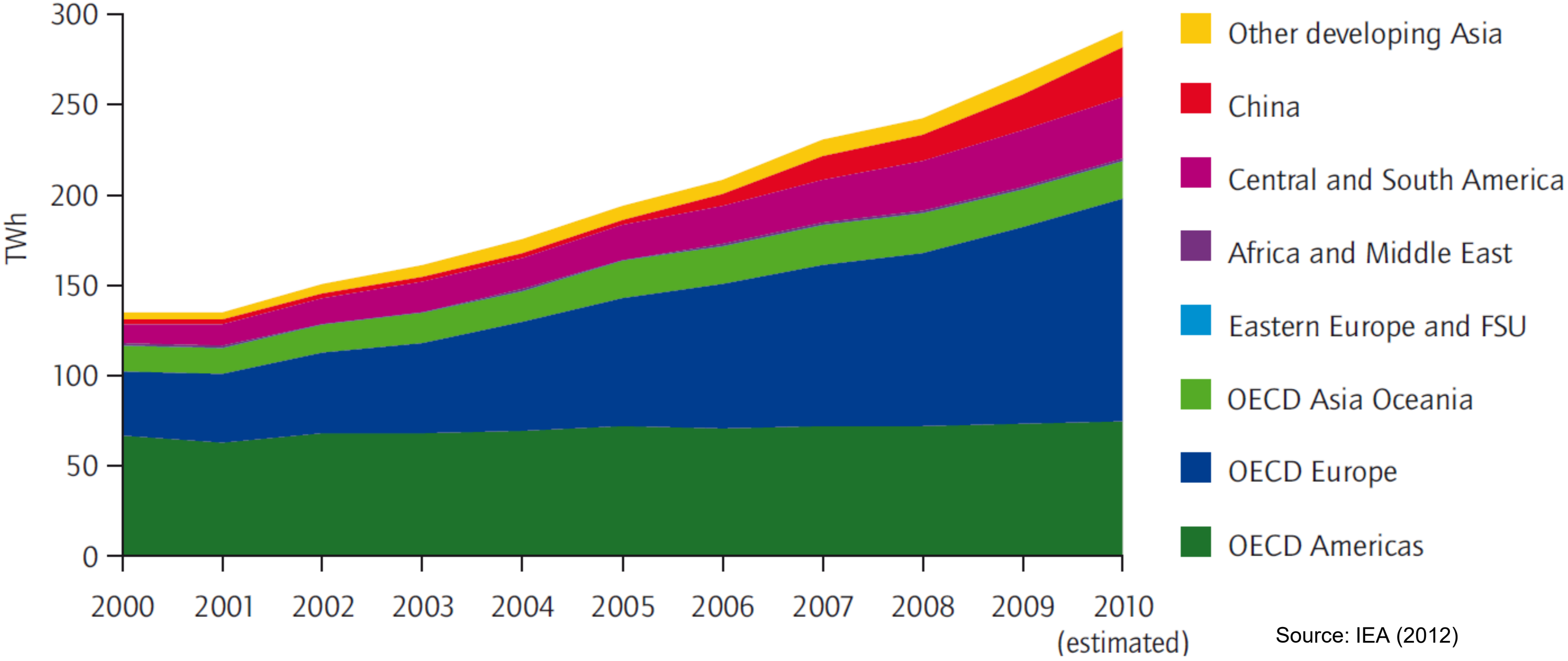
Global Primary Bioenergy Supply



Source: IEA (2012)

Global primary bioenergy supply 2000-2009

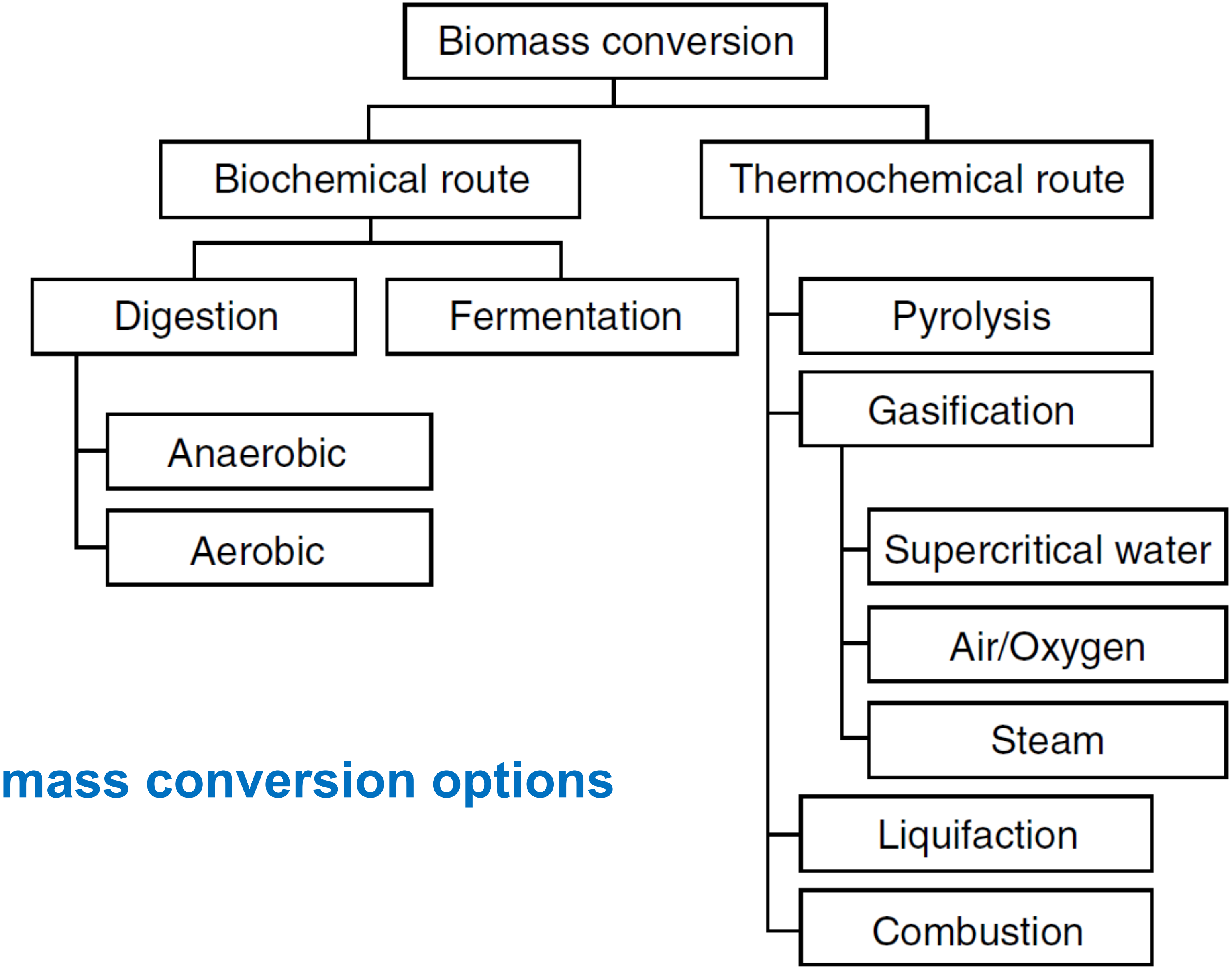
Electricity from Biomass – Global Perspective



Source: IEA (2012)

Global bioenergy electricity generation 2000-2010

Biomass Conversion



Biomass conversion

Biochemical route

Thermochemical route

Digestion

Fermentation

Anaerobic

Aerobic

Pyrolysis

Gasification

Supercritical water

Air/Oxygen

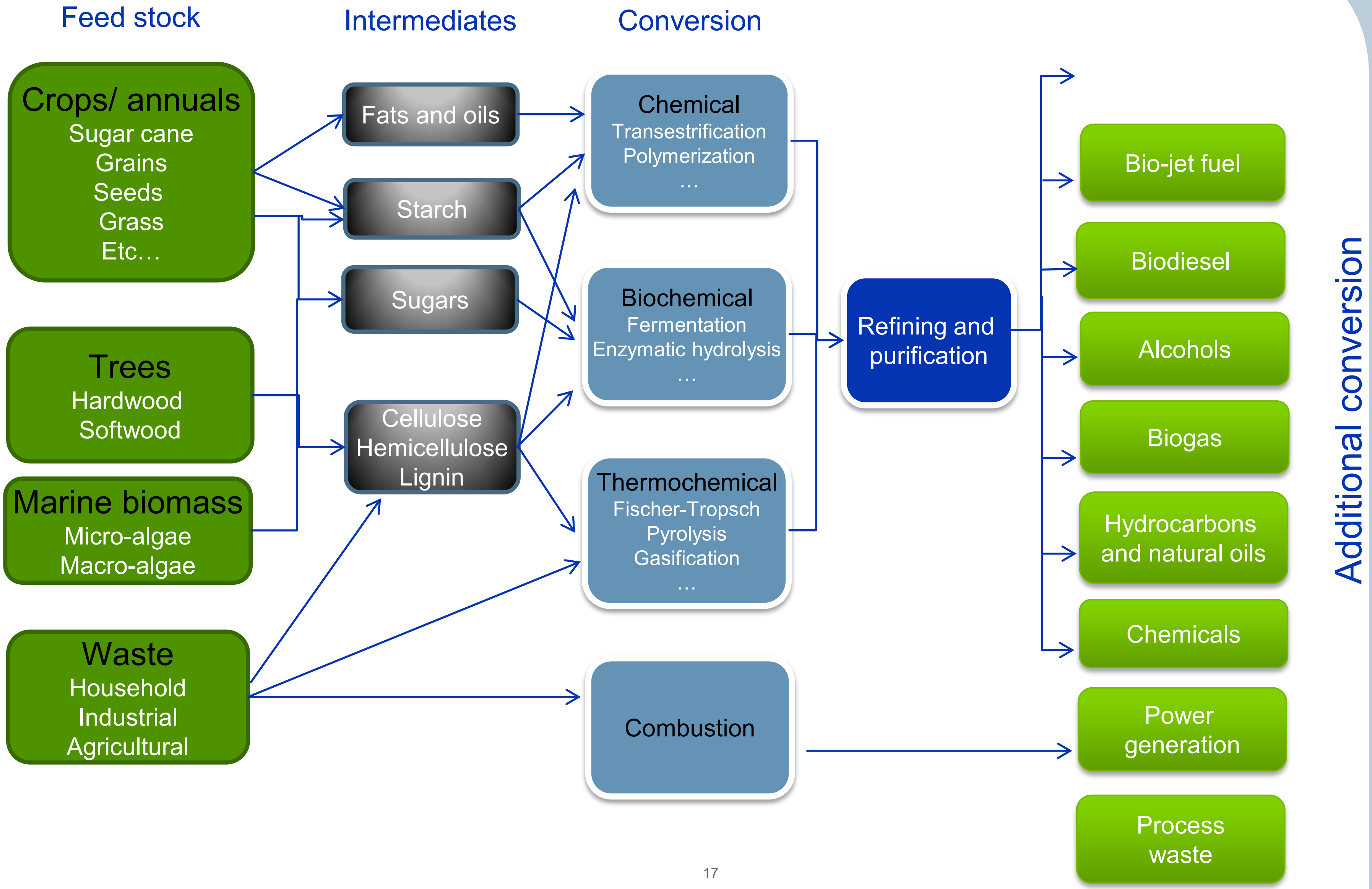
Steam

Liquifaction

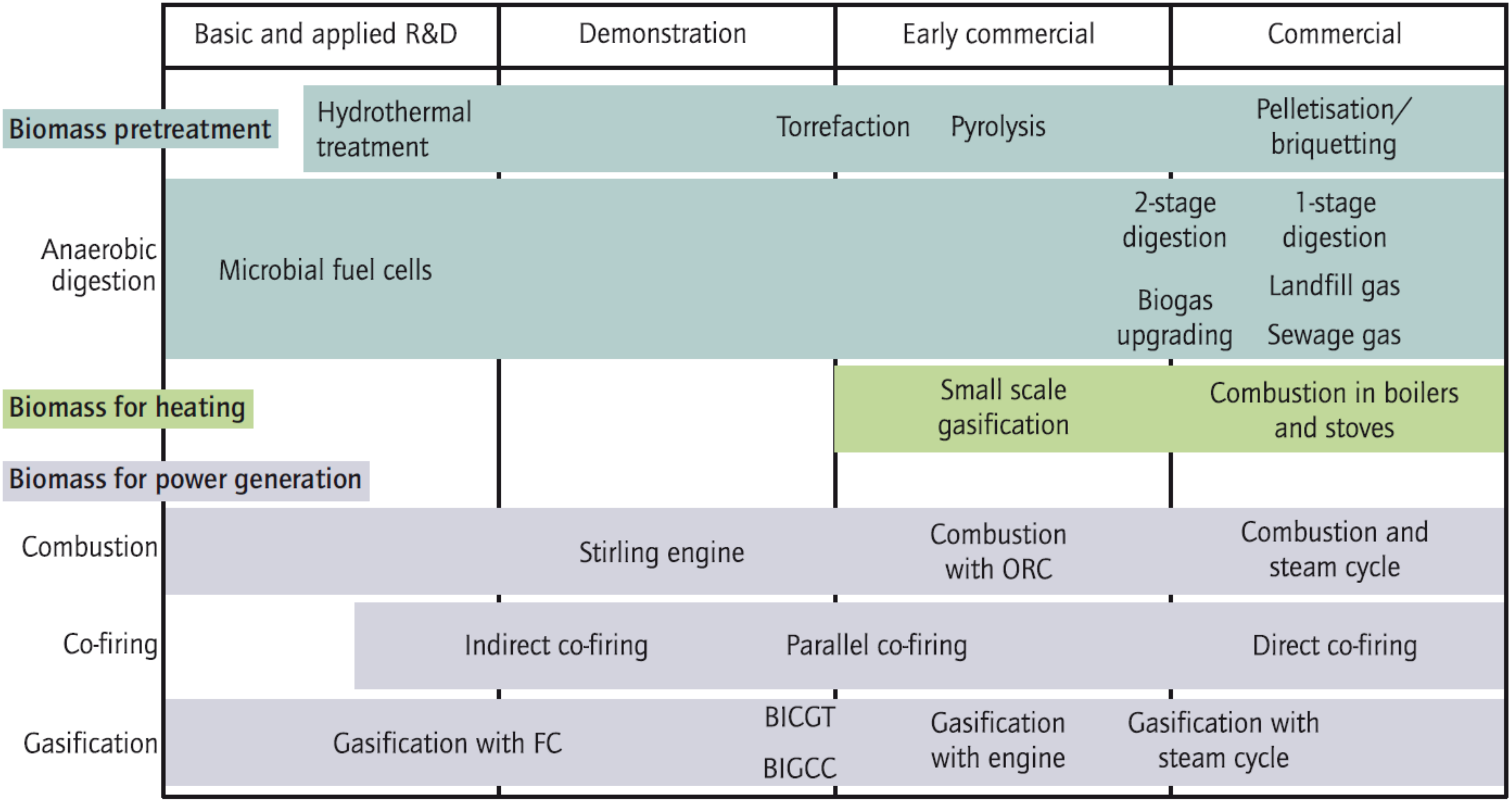
Combustion

Biomass conversion options

Biofuels…


Feed stock
Intermediates
Conversion
Crops/ annuals
Sugar cane
Grains
Seeds
Grass
Etc…
Trees
Hardwood
Softwood
Marine biomass
Micro-algae
Macro-algae
Waste
Household
Industrial
Agricultural
Fats and oils
Starch
Sugars
Cellulose
Hemicellulose
Lignin
Chemical
Transestrification
Polymerization
…
Biochemical
Fermentation
Enzymatic hydrolysis
…
Thermochemical
Fischer-Tropsch
Pyrolysis
Gasification
…
Combustion
Refining and purification
Bio-jet fuel
Biodiesel
Alcohols
Biogas
Hydrocarbons and natural oils
Chemicals
Power generation
Process waste
Additional conversion

Biomass Utilization Options



	Basic and applied R&D	Demonstration	Early commercial	Commercial
Biomass pretreatment	Hydrothermal treatment	Torrefaction	Pyrolysis	Pelletisation/ briquetting
Anaerobic digestion	Microbial fuel cells		2-stage digestion Biogas upgrading	1-stage digestion Landfill gas Sewage gas
Biomass for heating			Small scale gasification	Combustion in boilers and stoves
Biomass for power generation				
Combustion		Stirling engine	Combustion with ORC	Combustion and steam cycle
Co-firing		Indirect co-firing	Parallel co-firing	Direct co-firing
Gasification	Gasification with FC	BICGT BIGCC	Gasification with engine	Gasification with steam cycle

Note: ORC = Organic Rankine Cycle; FC = fuel cell; BICGT = biomass internal combustion gas turbine; BIGCC = biomass internal gasification combined cycle

Technology status of biomass utilization options

Source: Bauen et al. (2009), IEA (2012)

Biomass / Bioenergy Facts

Bioenergy

- Bioenergy represents over 10% of global primary energy supply
- Primary bioenergy demand > 50 EJ (end of 2011)

Biomass use:

- 86% for cooking, heating & cooling (only 25% modern bioenergy)
- **10,5% for power generation**
- 3,5% for transport fuels

Biomass electricity

- 70 GW of biomass power generation capacity end of 2011, over 65 GW in 2010
- Production in power-only and CHP plants by direct firing or co-firing
- (EU in 2010: 36 % power only , 64 % CHP)
- 88 % derived from solid biomass (US, EU, Brazil, China)

Source: Renewable Energy Policy Network for the 21st Century (2012)

Bioenergy Trends

Consequences of policies to reduce GHG and to diversify energy source

- Increasing demand for biomass fuels
- Local feedstock not sufficient to cover demand
- increasing international trade of biomass fuels
- creation of large feedstock plantations in tropical & sub-tropical regions (often corporate investments)

Increasing size of bioenergy power facilities over the last decade:

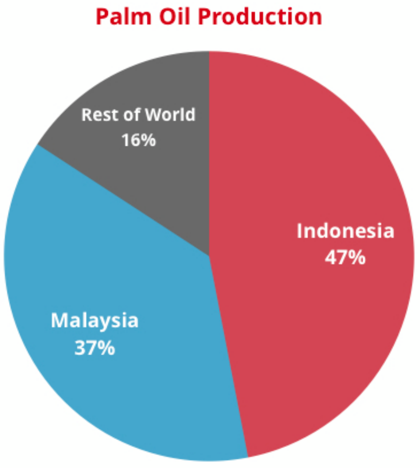
- 20 MW →750 MW in the UK (conversion of coal-fired power plant)
- Trend is enhanced because of co-firing developments

Locally used biomass versus internationally traded biomass

New challenges

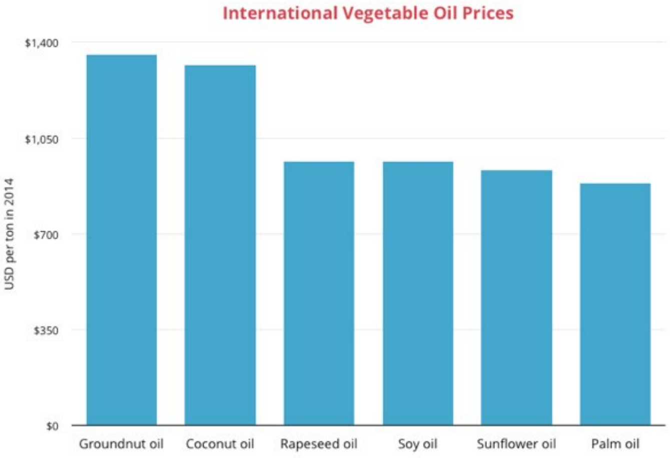
- Ensure sustainability of modern bioenergy
- Develop and report on local bioenergy

Palm Oil Production & Sustainability



Source: FAOstat

BREAKTHROUGH INSTITUTE



Source: FAO International Commodity Prices

BREAKTHROUGH INSTITUTE

Scale Influence on some Bioenergy Technologies

	Scale	Power range	Thermal efficiency	Electric efficiency
Heating (boiler)	Small	25 – 100 kW_{th}	80 – 85 %	
	Medium	100-500 kW_{th}	85 – 87 %	
	Large	500-5000 kW_{th}	87 – 93 %	
CHP (boiler + steam turbine)	Small	1-10 MW_e	63 – 70 %	13-21 %
	Medium	10-25 MW_e	59 – 63 %	21-26 %
	Large	25-50 MW_e	52 – 59 %	26-35 %
CHP (gas engine)	Small	0.1- 0.25 MW_e		31 – 33 %
	Medium	0.25 -1 MW_e		33 – 38 %
	Large	1 -2 MW_e		38 – 40 %
CHP (diesel engine)	Small	0.1 – 0.75 MW_e	46 – 50 %	37-42 %
	Medium	0.75 -1.5 MW_e	45 – 50 %	42-44 %
	Large	1.5 - 5 MW_e	44 – 45 %	44-45 %
Co-firing Coal power plants (boiler + steam turbine)	Only Large	500 - 750 MW_e	50 – 52 %	35-43 %

Source: Ecofys, EU-Project TREN/A2/143-2007 (2010)

Biomass Combustion

- Grate furnace and fluidized bed technology
- Steam turbines
- Combined heat and power
- Large scale facilities > 100 MW_{el}

Woody Biomass: Pulp + Electricity

Fray Bentos Pulp Mill produces 200 MW el. (10% of Uruguay’s domestic consumption) + 1 Mt/a eucalyptus pulp

Biomass Gasification

History of Gasification Technology

1659
Thomas Shirley: Discovered gas from coal mine

1739
Dean Clayton: Distilled coal in a closed vessel

1788
Robert Gardner: First gasification patent

1792
Murdoc: First use of coal-gas for interior lighting

1801
Fourcroy: Water-gas shift reaction

1861
Siemens gasifier: First successful unit

1920
Carl von Linde: Cryogenic separation of air, fully continuous gasification process

1926
Winkler fluidized-bed gasifier

1931
Lurgi: Pressurized moving-bed process

1945–1974
Post-war “oil glut”

1974
Arab oil embargo renewed gasification interest

1997
First commercial gasification plant in U.S.

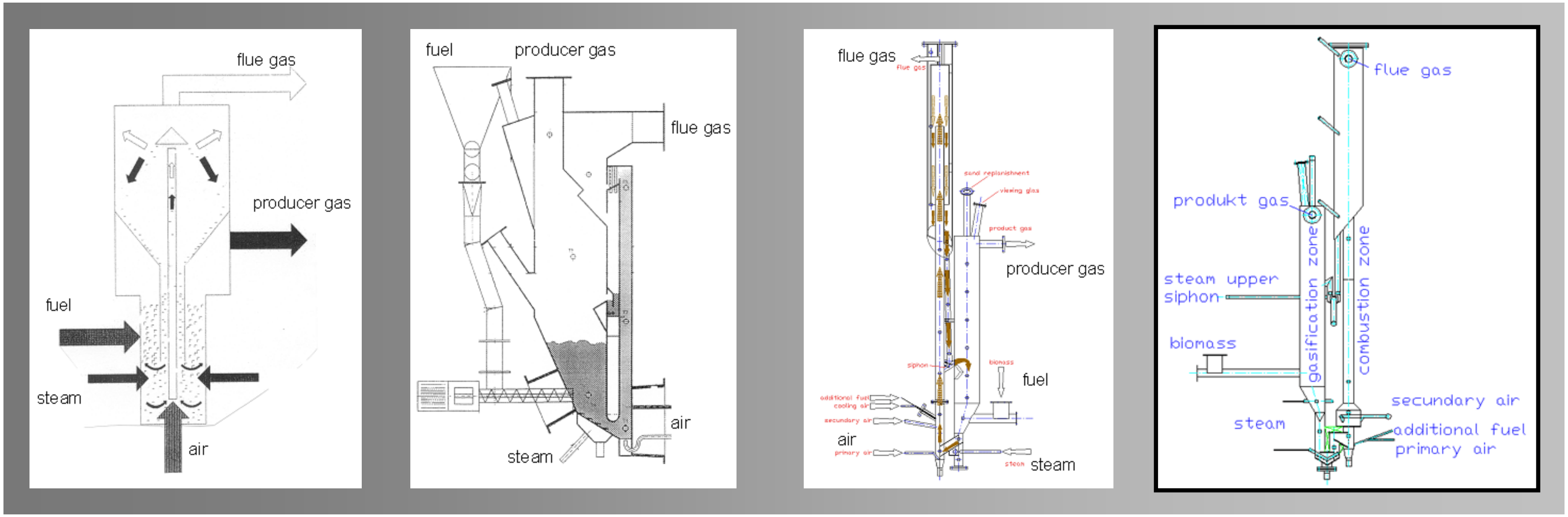
2001
Advanced gasification biomass renewable energy projects

Source: P.Basu, Academic Press (2010)

Fluidized Bed Steam Gasification - Historical Review

Development of fluidized bed steam biomass gasification

Research @ TU Wien – Institute of Chemical Engineering



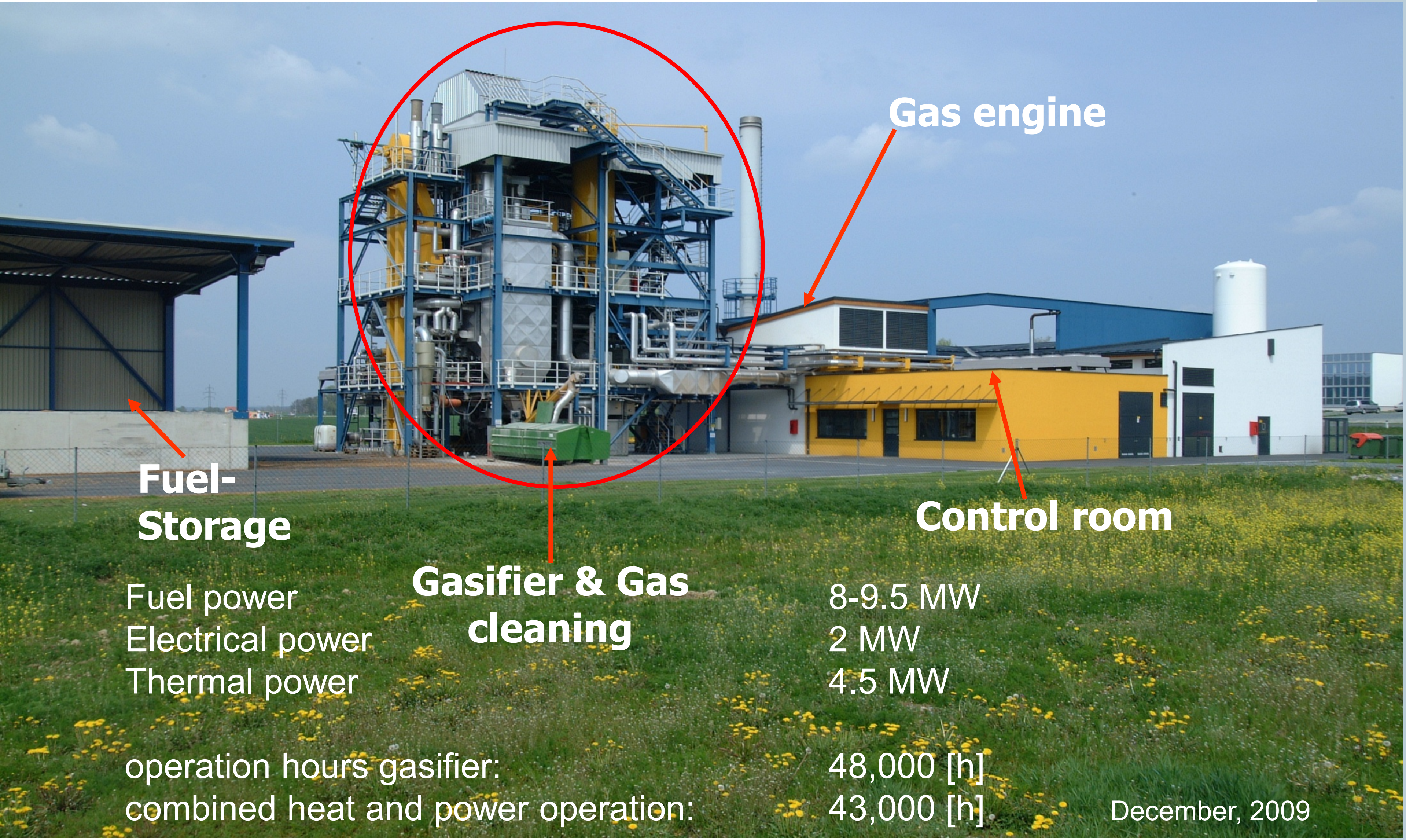
1993 - 1996
FICFB gasifier

1995 - 1999

1999 - 2003

2004 - now
DFB gasifier

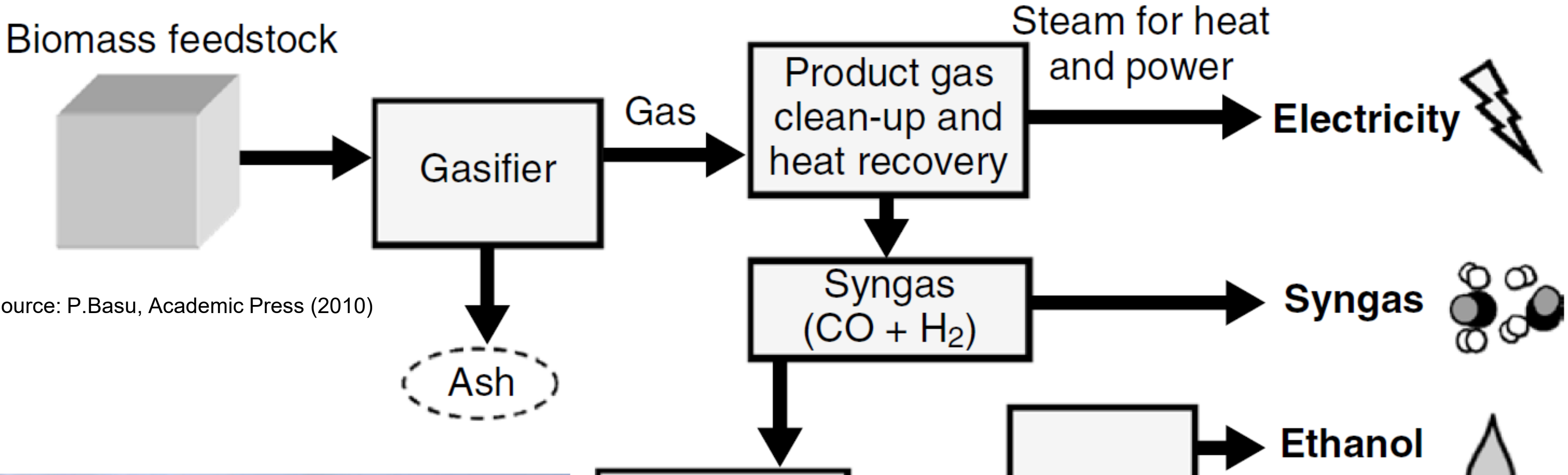
Biomass CHP Güssing



Fuel power	8-9.5 MW
Electrical power	2 MW
Thermal power	4.5 MW
operation hours gasifier:	48,000 [h]
combined heat and power operation:	43,000 [h]

December, 2009

Biomass Gasification



Source: P.Basu, Academic Press (2010)

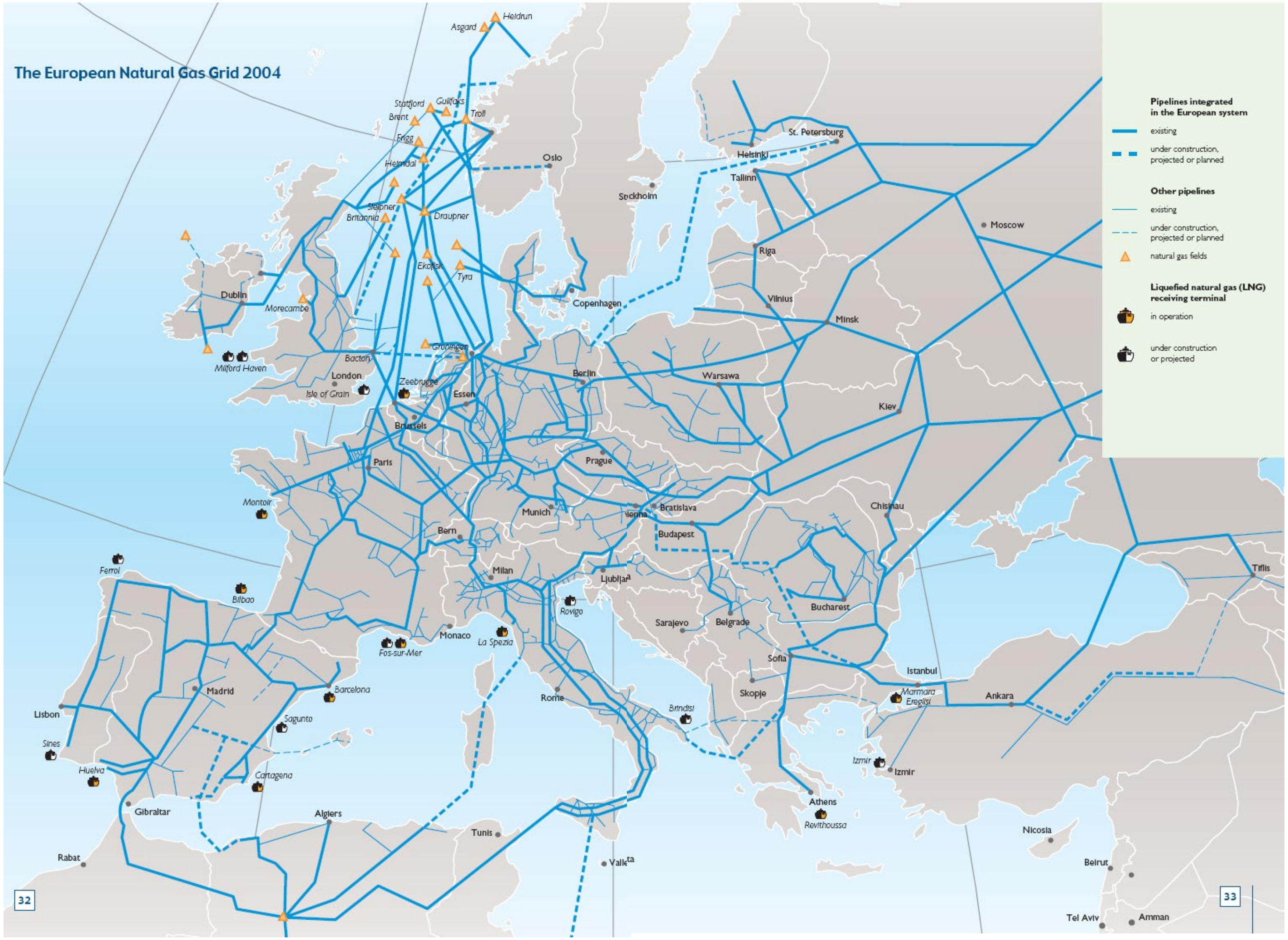
Additional options via gasification

Biomass Gasification

Agnion Heatpipe Reformer Technology for small scale application (e.g. 0,5 - 1 MW_{el})

Biogas Digestion and Grid Injection and Bio-CNG Use

Natural Gas Grid



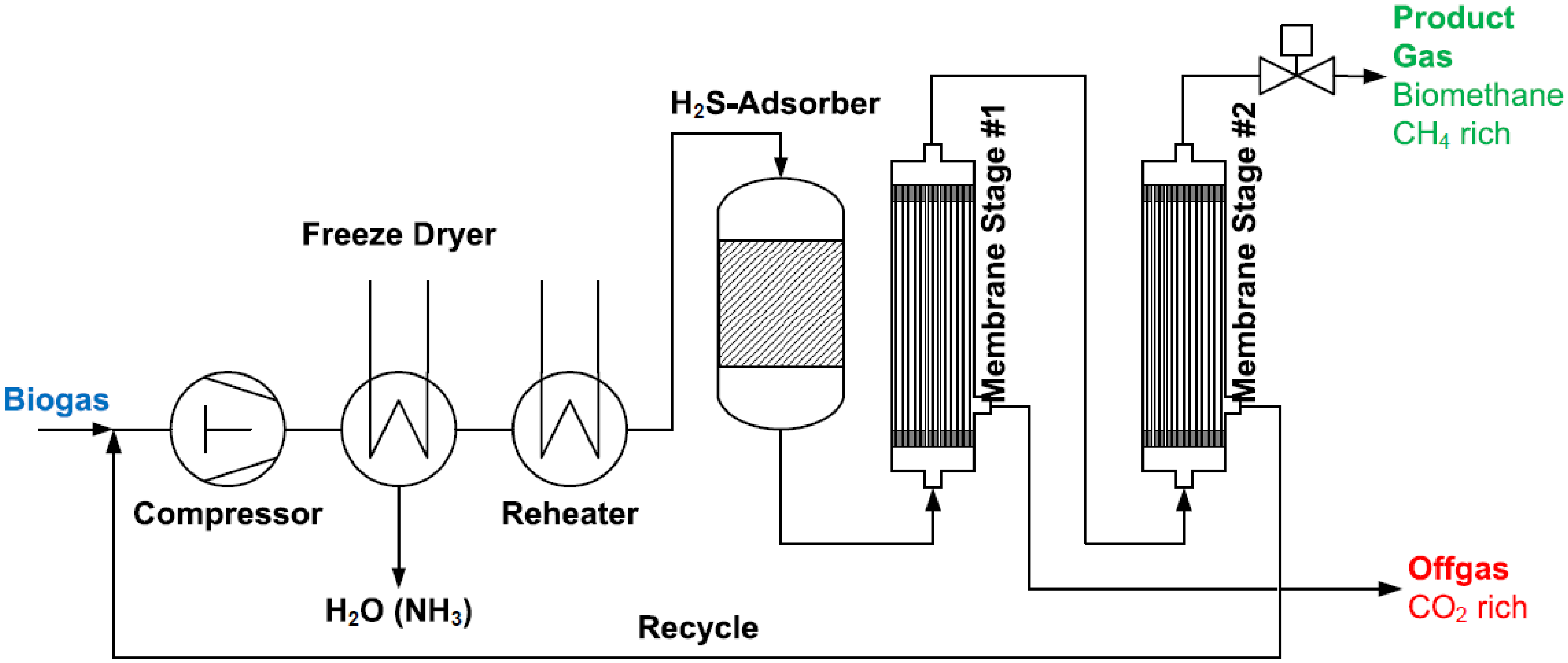
The European Natural Gas Grid

Source: Eurogas (2005)

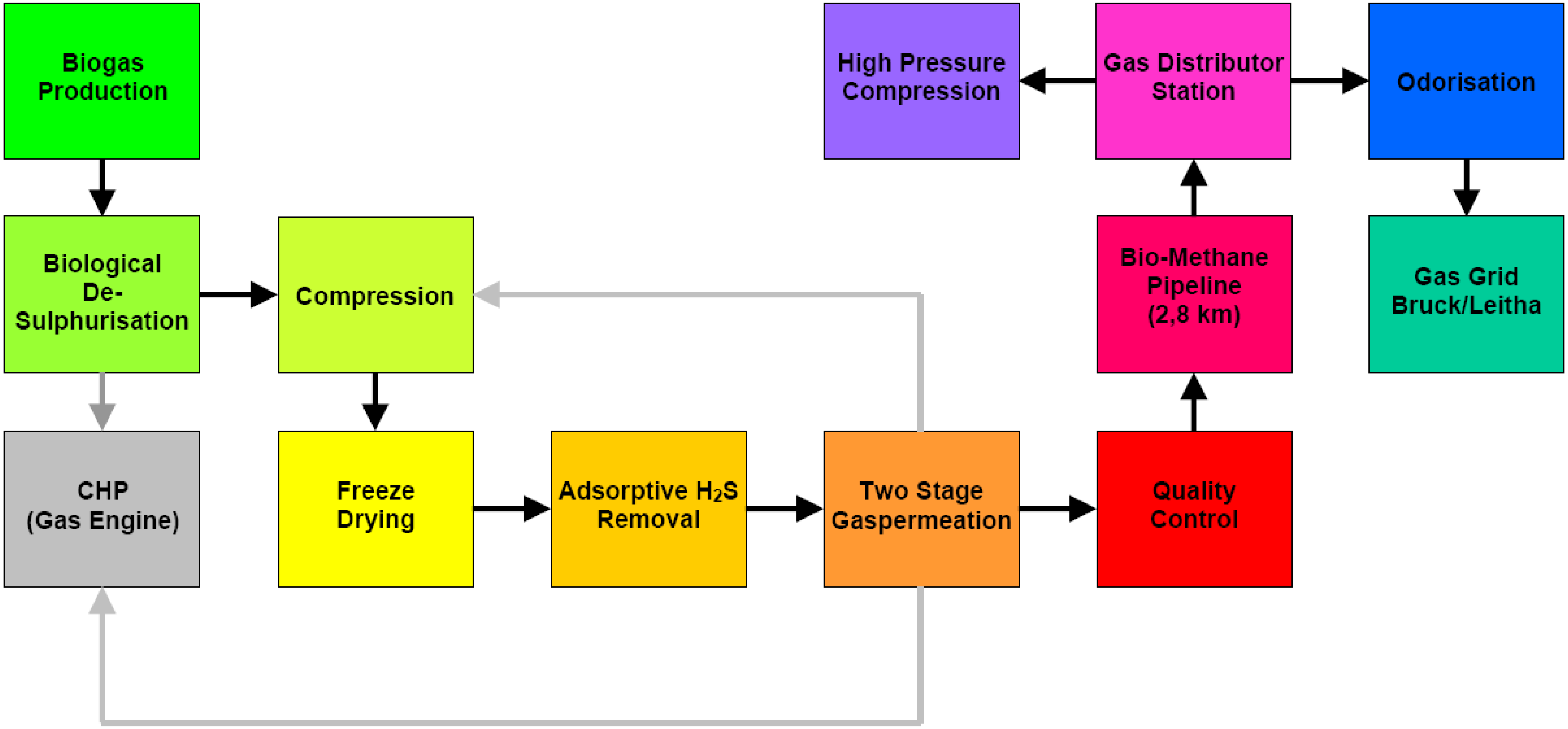
Biogas Upgrading in Bruck/Leitha

- Axiom – Membrane separation (180 m³/h biogas)

Process Scheme of a Two-stage Membrane System

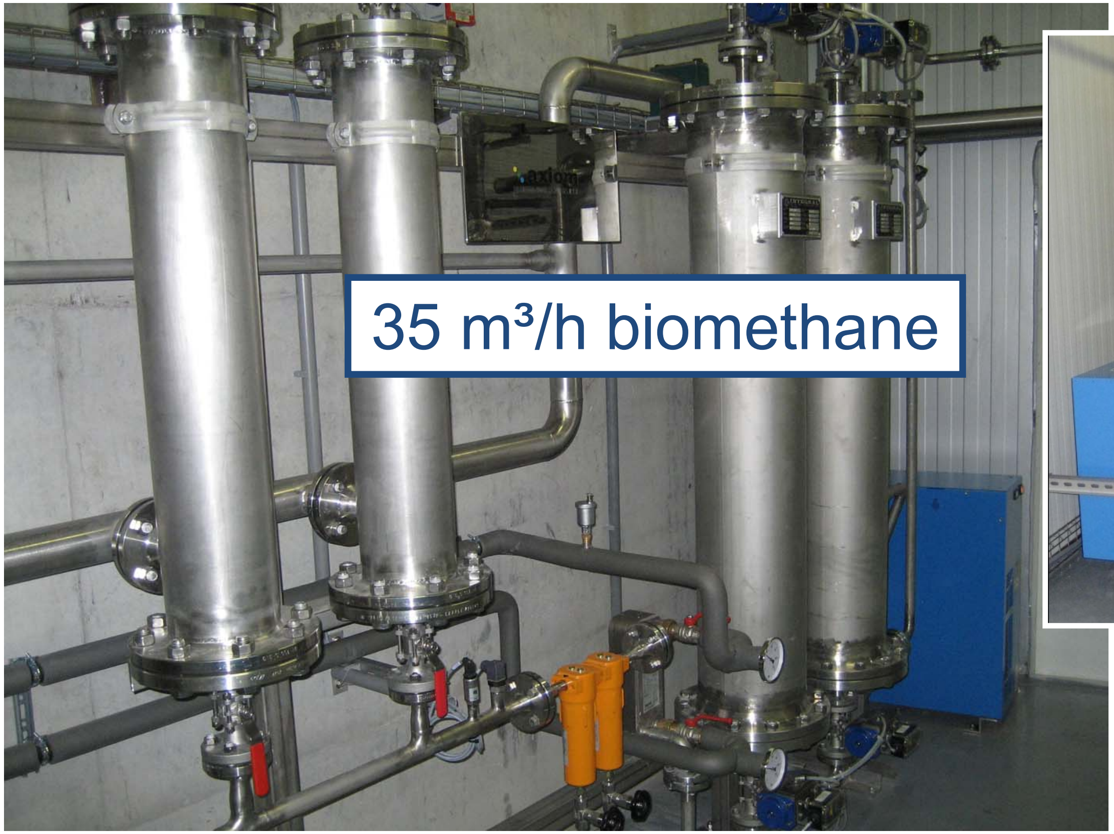


Process Integration (Two-stage design)



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

Biomethane Fuel Station using Membrane Technology



Permeate recycle to CHP plant

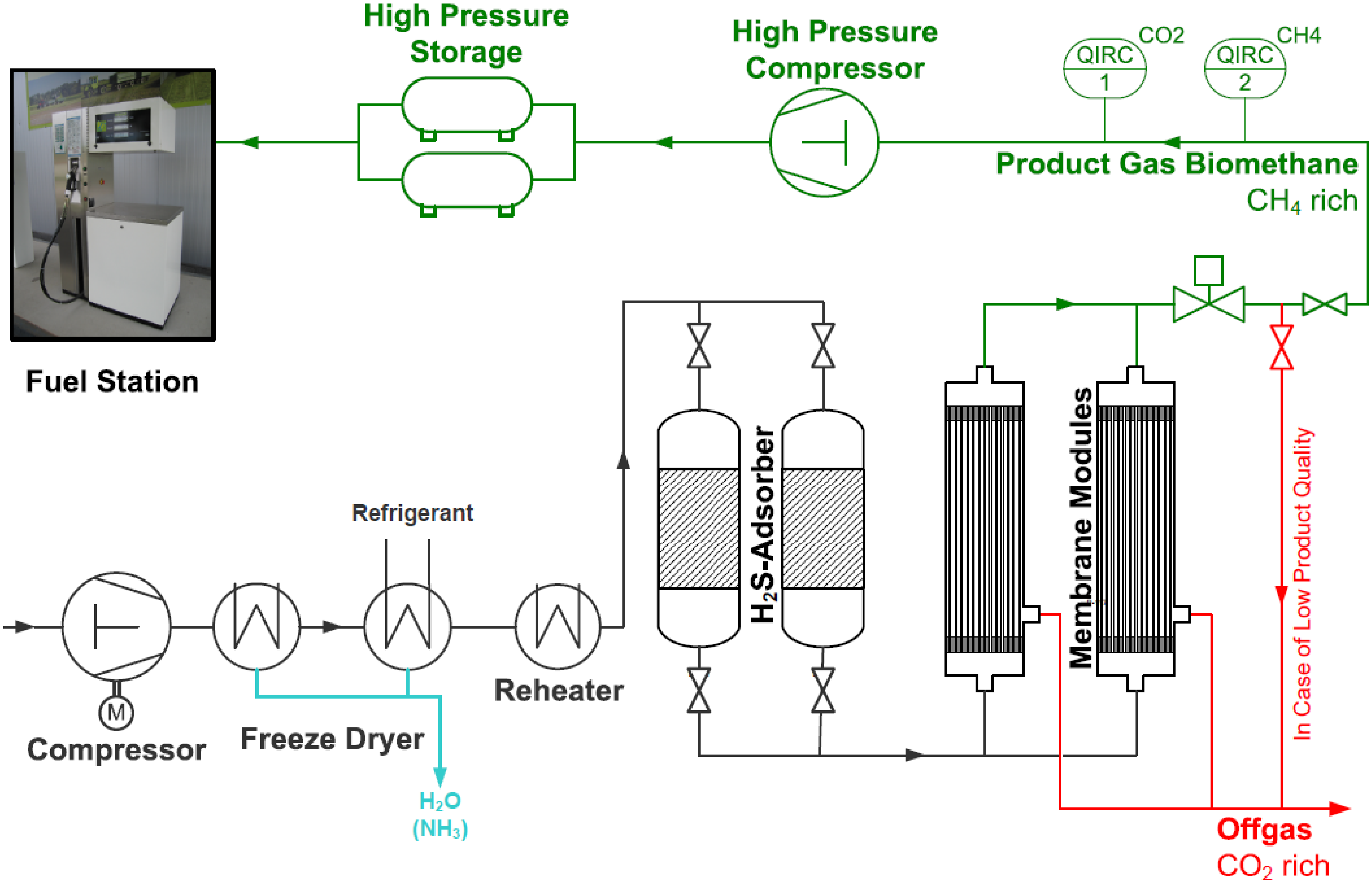
Further information: **www.methapur.com**

Biomethane fuel station Margarethen/Moos

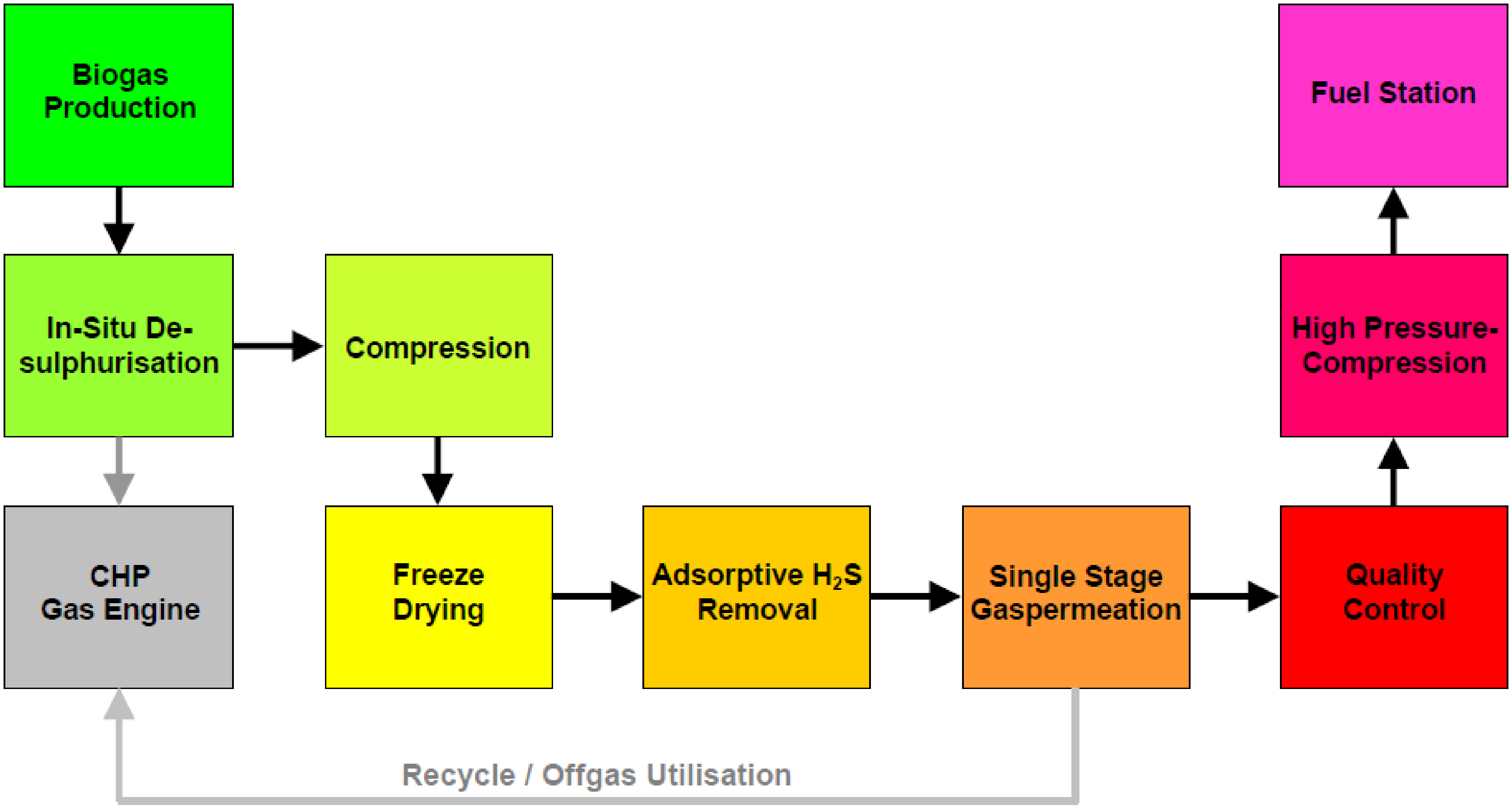
Bio-CNG with on-site fuel station

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

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**

Biogas Engerwitzdorf – Grid injection

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

Bio-methane Wiener Neustadt

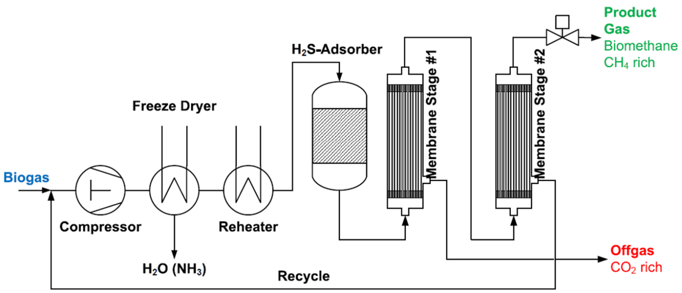
- Capacity: 220 (300) m³/h biogas
- Axiom – Membrane separation

Recent Start-up of First AXIOM Plant in Germany

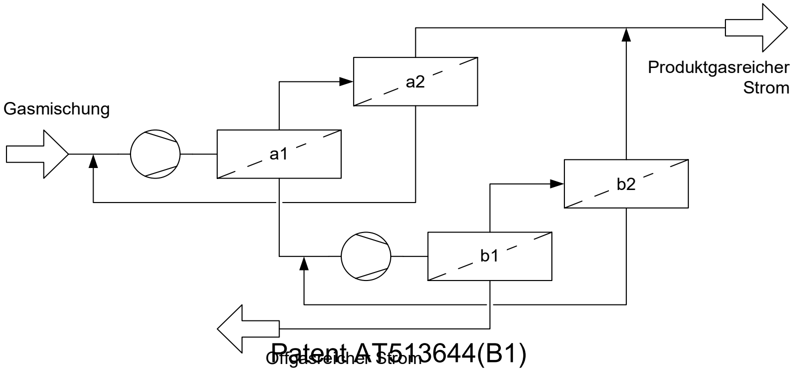
- Capacity 500 m³/h biogas, 300 m³/h biomethane, approx. 8 km pipeline for grid injection and high pressure compression to 60 bar

Membranes – intelligent staging and recycling

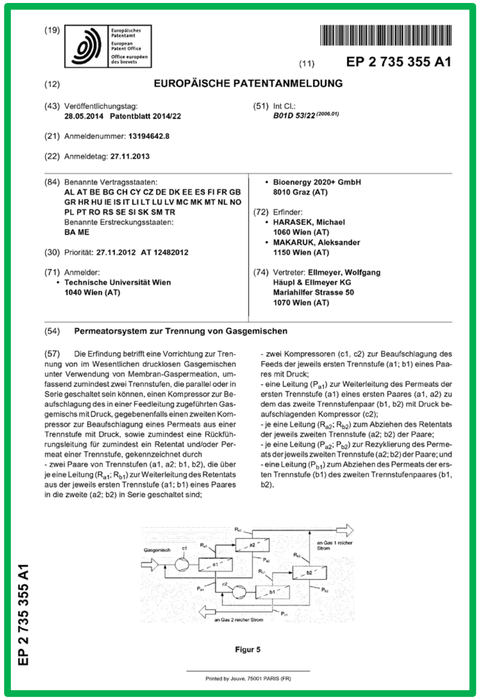
- ✓ Process design from 2006:



- ✓ New process design:



Patent AT513644(B1)



(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 735 355 A1

(12) **EUROPÄISCHE PATENTANMELDUNG**

(43) Veröffentlichungstag:
28.05.2014 Patentblatt 2014/22

(51) Int Cl.:
B01D 53/22 *(2006.01)*

(21) Anmeldenummer: **13194642.8**

(22) Anmeldetag: **27.11.2013**

(84) Benannte Vertragsstaaten:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Benannte Erstreckungsstaaten:
BA ME

(30) Priorität: **27.11.2012 AT 12482012**

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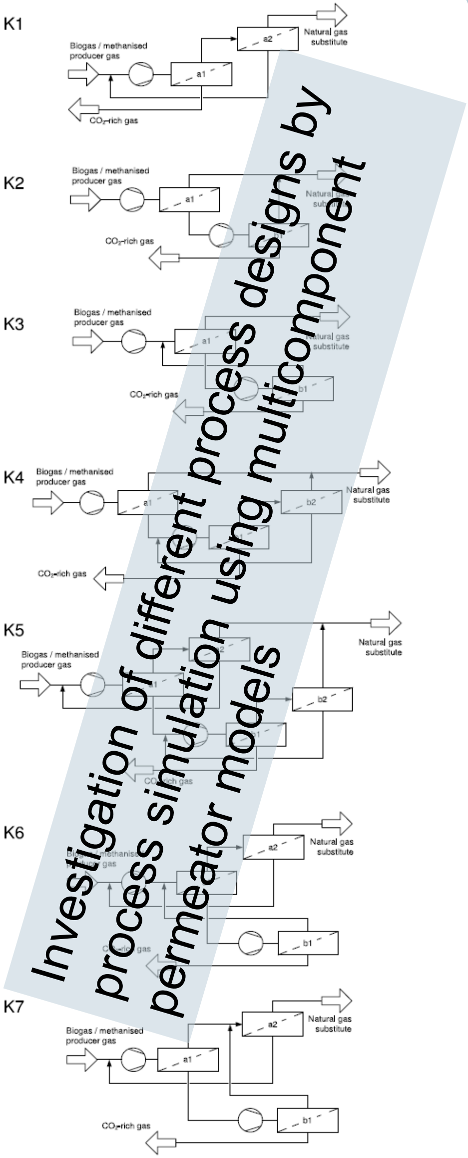
(54) **Permeatorsystem zur Trennung von Gasgemischen**

(57) Die Erfindung betrifft eine Vorrichtung zur Trennung von im Wesentlichen drucklosen Gasgemischen unter Verwendung von Membran-Gaspermeation, umfassend zumindest zwei Trennstufen, die parallel oder in Serie geschaltet sein können, einen Kompressor zur Beaufschlagung des in einer Feedleitung zugeführten Gasgemischs mit Druck, gegebenenfalls einen zweiten Kompressor zur Beaufschlagung eines Permeats aus einer Trennstufe mit Druck, sowie zumindest eine Rückführungsleitung für zumindest ein Retentat und/oder Permeat einer Trennstufe, gekennzeichnet durch
- zwei Paare von Trennstufen (a1, a2; b1, b2), die über je eine Leitung (R_{a1}; R_{b1}) zur Weiterleitung des Retentats aus der jeweils ersten Trennstufe (a1; b1) eines Paares in die zweite (a2; b2) in Serie geschaltet sind;
- zwei Kompressoren (c1, c2) zur Beaufschlagung des Feeds der jeweils ersten Trennstufe (a1; b1) eines Paares mit Druck;
- eine Leitung (P_{a1}) zur Weiterleitung des Permeats der ersten Trennstufe (a1) eines ersten Paares (a1, a2) zu dem das zweite Trennstufenpaar (b1, b2) mit Druck beaufschlagenden Kompressor (c2);
- je eine Leitung (R_{a2}; R_{b2}) zum Abziehen des Retentats der jeweils zweiten Trennstufe (a2; b2) der Paare;
- je eine Leitung (P_{a2}; P_{b2}) zur Rezyklierung des Permeats der jeweils zweiten Trennstufe (a2; b2) der Paare; und
- eine Leitung (P_{b1}) zum Abziehen des Permeats der ersten Trennstufe (b1) des zweiten Trennstufenpaares (b1, b2).

Figur 5

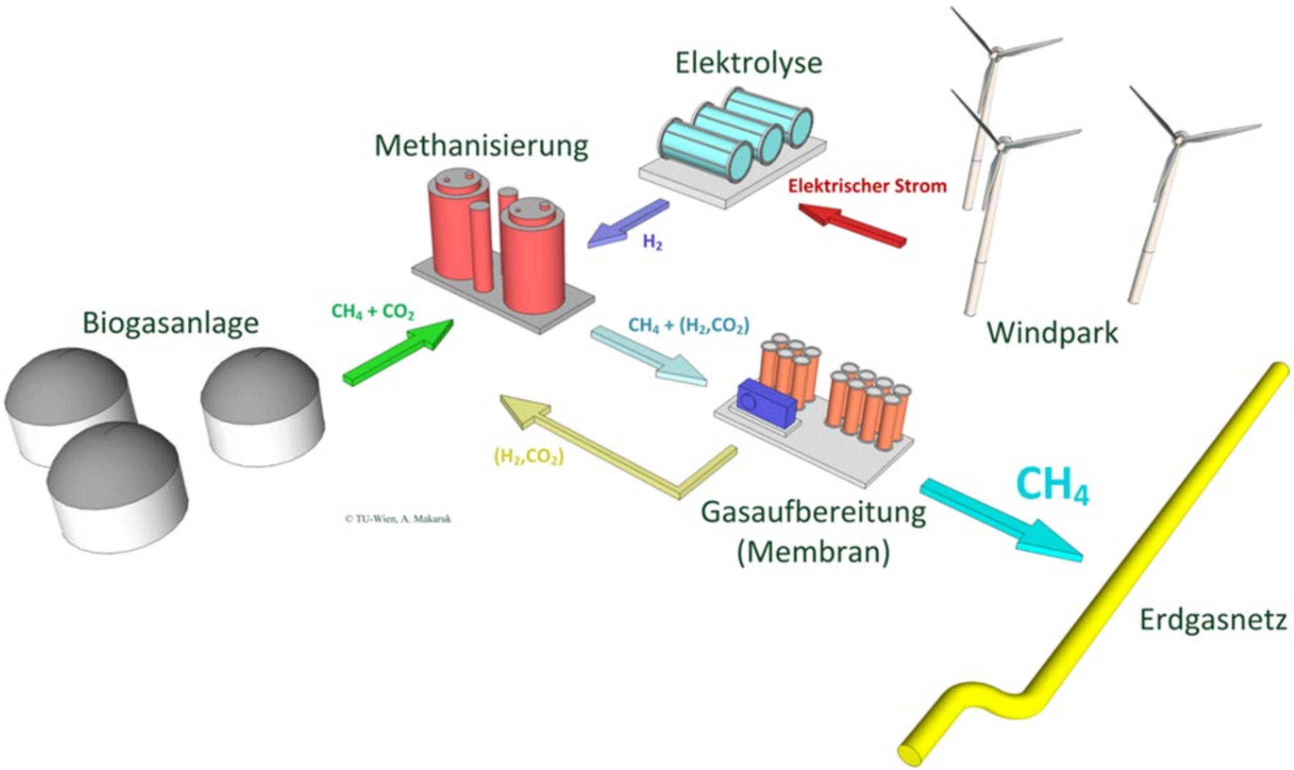
EP 2 735 355 A1

Printed by Jouve, 75001 PARIS (FR)



Investigation of different process designs by process simulation using multicomponent permeator models

P2G Integration with Biogas



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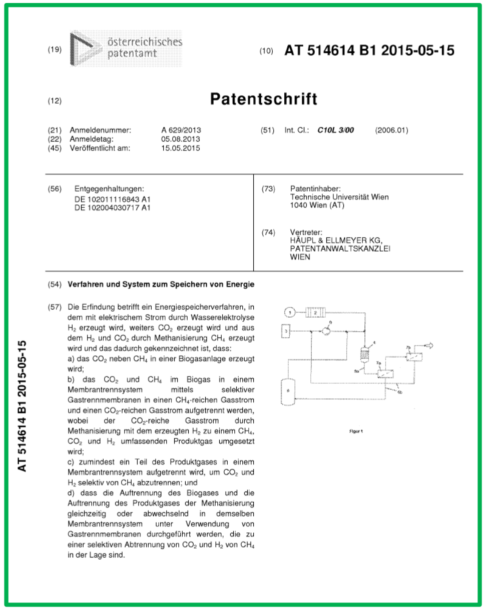

(19) österreichisches patentamt

(10) **AT 514614 B1 2015-05-15**

(12) **Patentschrift**

(21) Anmeldenummer: A 629/2013
(22) Anmeldetag: 05.08.2013
(45) Veröffentlicht am: 15.05.2015

(51) Int. Cl.: ***C10L 3/00*** (2006.01)

(56) Entgegenhaltungen:
DE 102011116843 A1
DE 102004030717 A1

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(74) Vertreter:
HÄUPL & ELLMEYER KG,
PATENTANWALTSKANZLEI
WIEN

(54) **Verfahren und System zum Speichern von Energie**

(57) Die Erfindung betrifft ein Energiespeicherverfahren, in dem mit elektrischem Strom durch Wasserelektrolyse H_2 erzeugt wird, weiters CO_2 erzeugt wird und aus dem H_2 und CO_2 durch Methanisierung CH_4 erzeugt wird und das dadurch gekennzeichnet ist, dass:

a) das CO_2 neben CH_4 in einer Biogasanlage erzeugt wird;

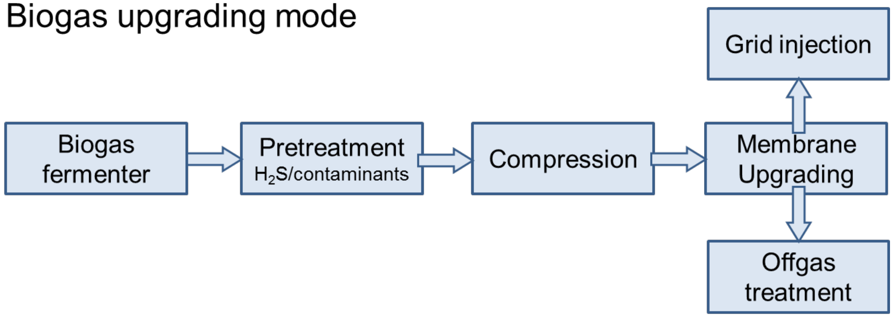
b) das CO_2 und CH_4 im Biogas in einem Membrantrennsystem mittels selektiver Gastrennmembranen in einen CH_4-reichen Gasstrom und einen CO_2-reichen Gasstrom aufgetrennt werden, wobei der CO_2-reiche Gasstrom durch Methanisierung mit dem erzeugten H_2 zu einem CH_4, CO_2 und H_2 umfassenden Produktgas umgesetzt wird;

c) zumindest ein Teil des Produktgases in einem Membrantrennsystem aufgetrennt wird, um CO_2 und H_2 selektiv von CH_4 abzutrennen; und

d) dass die Auftrennung des Biogases und die Auftrennung des Produktgases der Methanisierung gleichzeitig oder abwechselnd in demselben Membrantrennsystem unter Verwendung von Gastrennmembranen durchgeführt werden, die zu einer selektiven Abtrennung von CO_2 und H_2 von CH_4 in der Lage sind.

AT 514614 B1 2015-05-15

Biogas upgrading mode

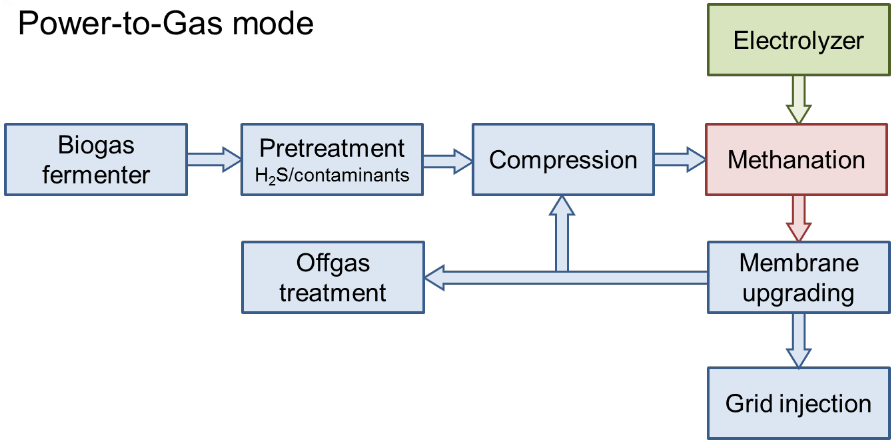


Grid injection

Biogas fermenter → Pretreatment H_2S/contaminants → Compression → Membrane Upgrading

Offgas treatment

Power-to-Gas mode



Electrolyzer

Biogas fermenter → Pretreatment H_2S/contaminants → Compression → Methanation

Offgas treatment

Membrane upgrading

Grid injection

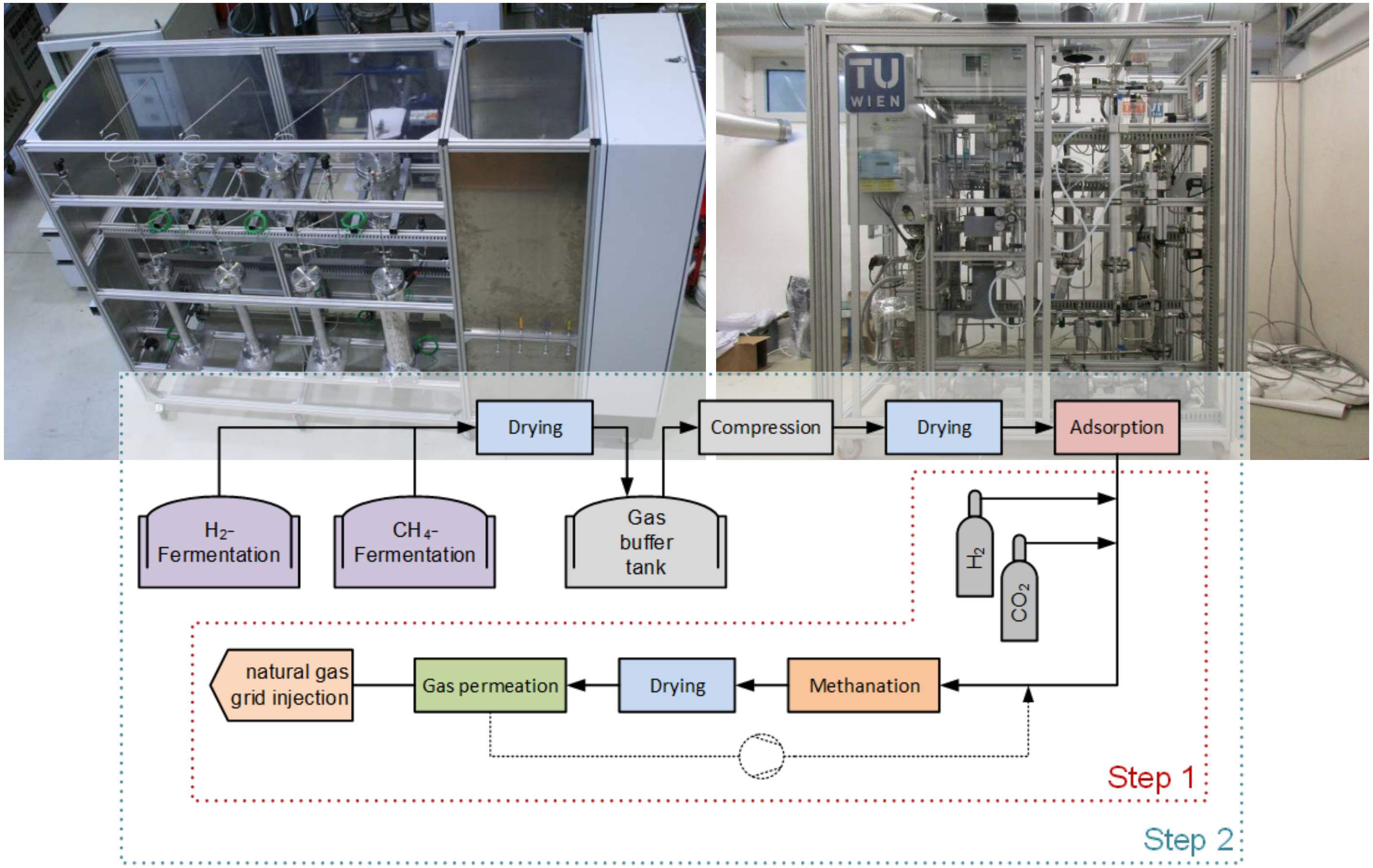
P2G pilot plant experiments – proof of concept

Research Studios Austria – “EE-Methane from CO_2” & “OptFuel”

Thermochemical methanation + Gas upgrading for grid injection

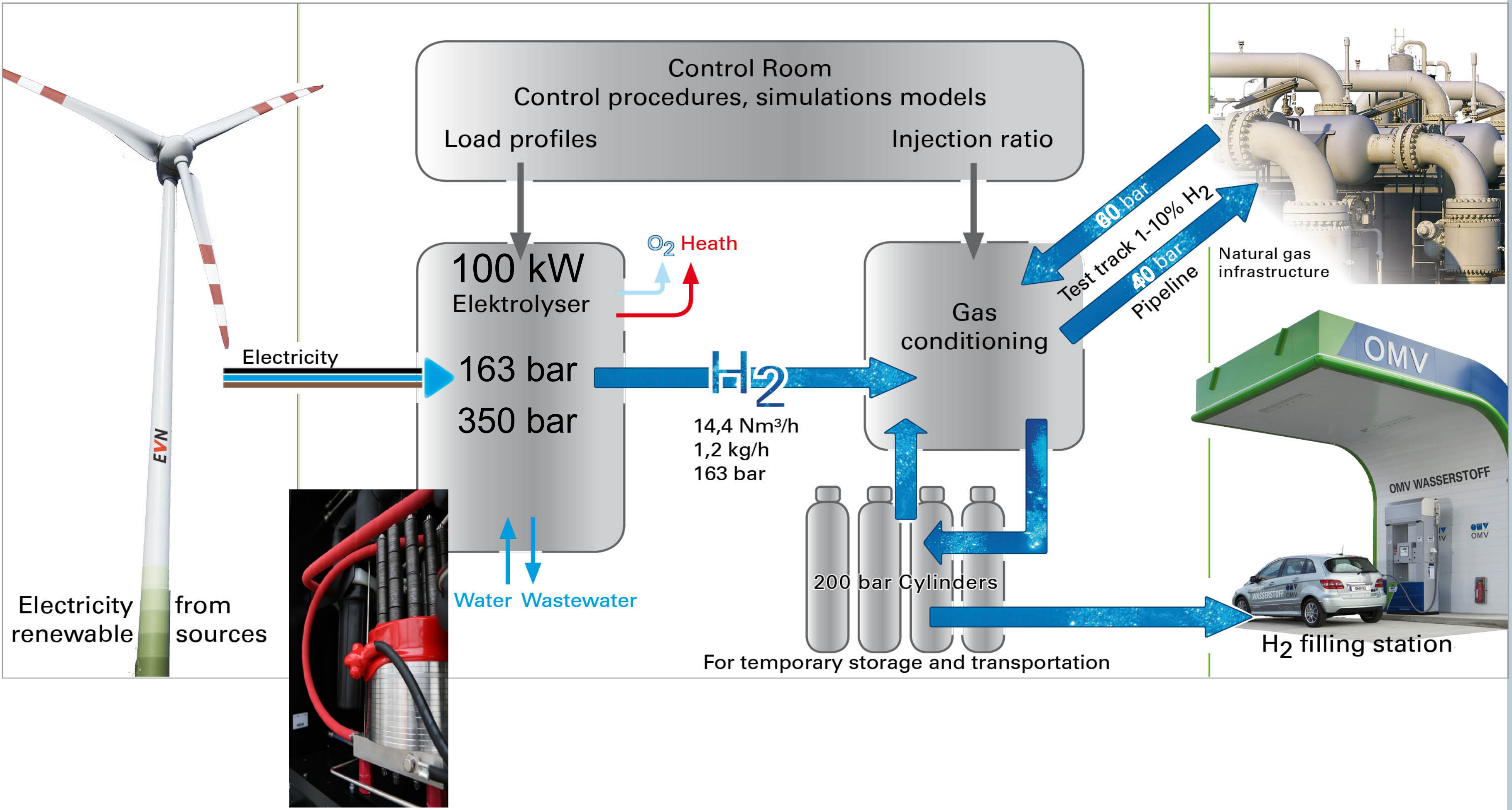
Recycling of unconverted H_2 + CO_2 (membrane permeate)

Key goals: new catalyst, minimize CO in product, maximize conversion, simplify process, pilot tests of process chain, process model for scale-up



Projects: wind2hydrogen / HylyPure®

Hydrogen for H_2-fuel station and for injection into the natural gas grid – Production of gas mixtures for HylyPure



Control Room
Control procedures, simulations models
Load profiles
Injection ratio

Electricity

100 kW
Elektrolyser
163 bar
350 bar

O_2 Heath

Water Wastewater

H_2
14,4 Nm³/h
1,2 kg/h
163 bar

Gas conditioning

60 bar
Test track 1-10% H_2
40 bar
Pipeline

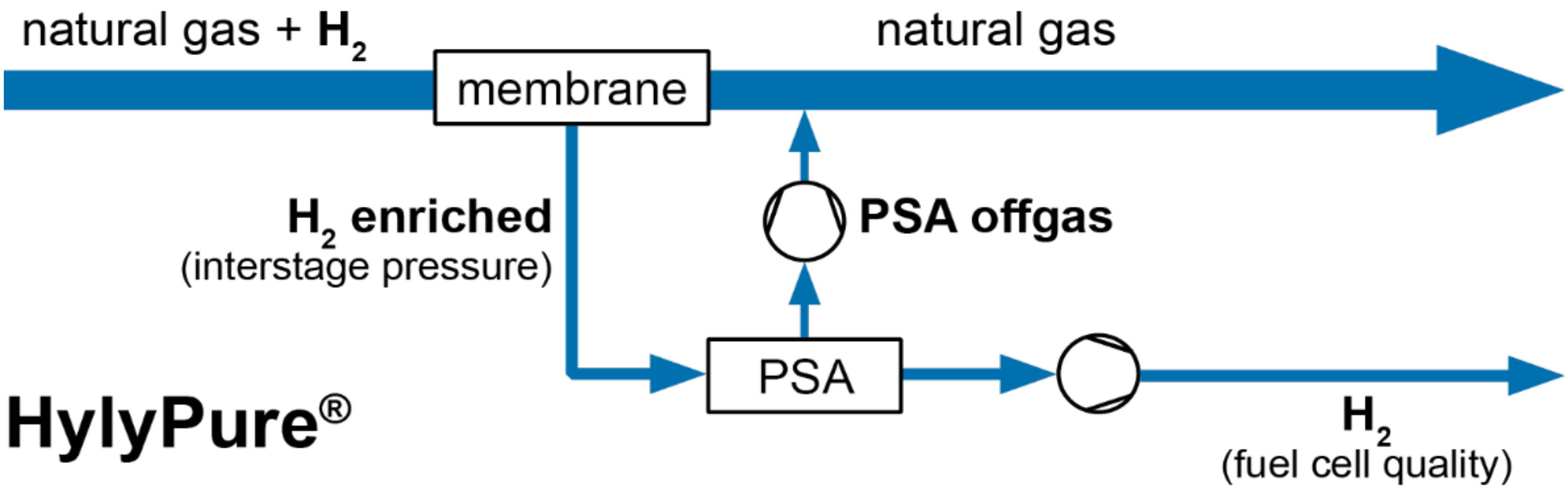
Natural gas infrastructure

200 bar Cylinders
For temporary storage and transportation

H_2 filling station

Electricity from renewable sources

Process concept



- Combination of several process steps
  - Membrane gas permeation using H_2-selective membranes
  - Pressure swing adsorption (PSA)
  - Final cleaning stage by adsorption

Feed

- Natural gas
  - CH_4, CO_2, H_2
  - C_xH_y, N_2, H_2O, H_2S, etc.
- Maximum H_2
  - 4 % (v/v) in Austria
  - 2%/10 % (v/v) in Germany
- Pressure levels
  - 70-120 bar (Level 1)
  - 6-70 bar (Level 2)
  - < 6 bar (Level 3)

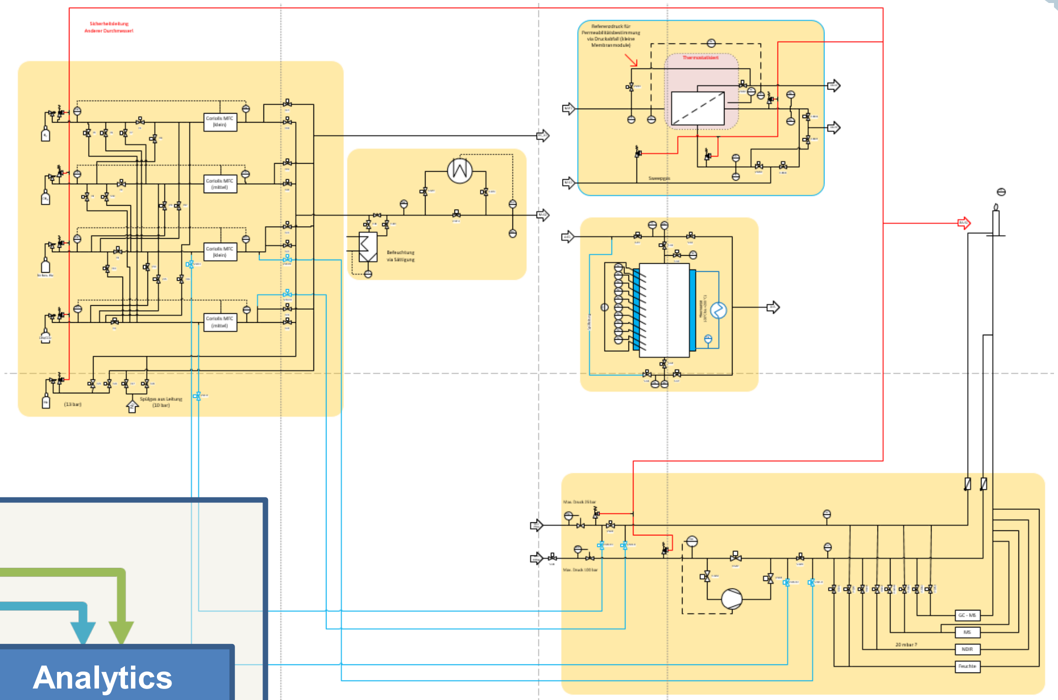
Product

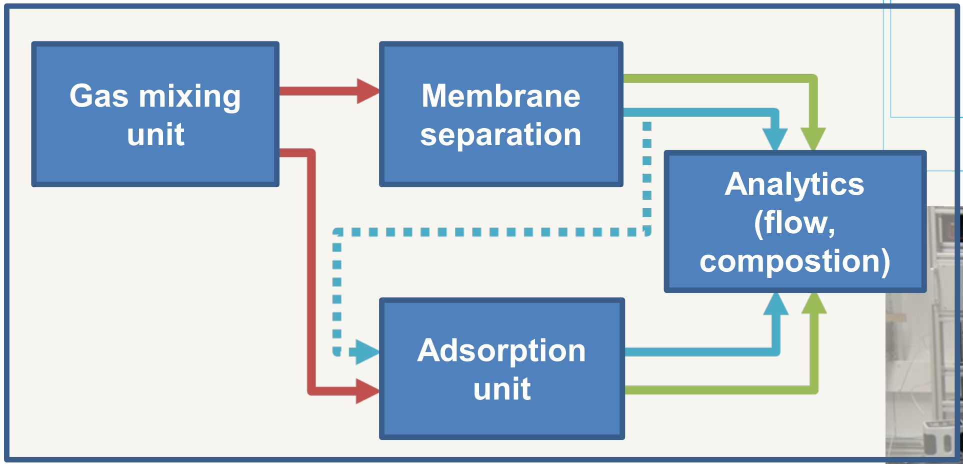
- Fuel cell quality
  - ISO 14687-2:2012
  - min. 99.97 % H_2
  - Higher hydrocarbons (as CH_4): 2 ppm
  - CO_2 : 2 ppm
- Pressure: up to 700 bar

HylyPure® is a project of TU Wien and OMV AG.
HylyPure® is supported by the Austrian Climate and Energy Fund.

Experimental setup / schematic

- Proof-of-concept @ lab-scale



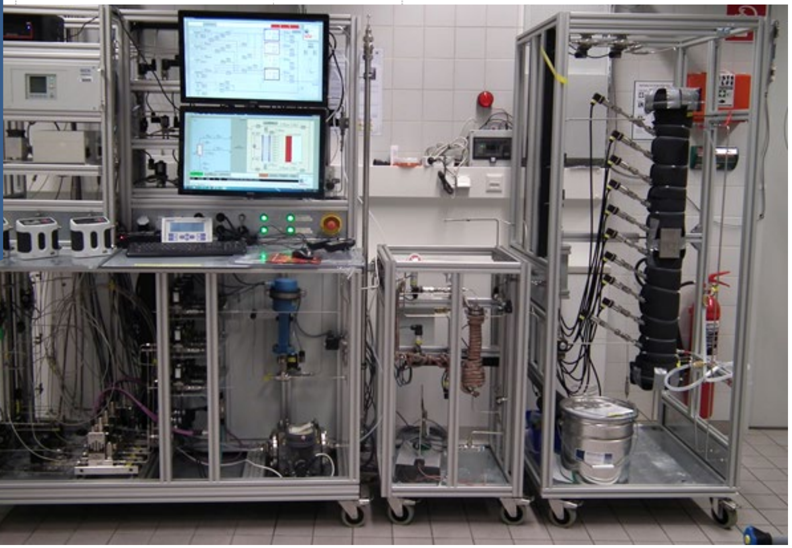


Gas mixing unit

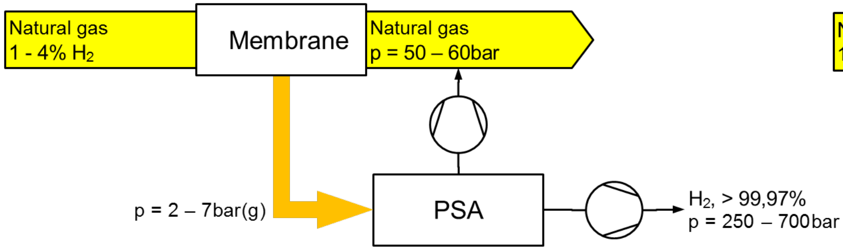
Membrane separation

Analytics (flow, compostion)

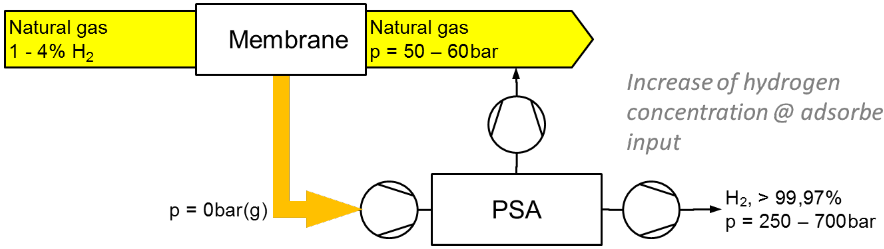
Adsorption unit



HylyPure® – Process options

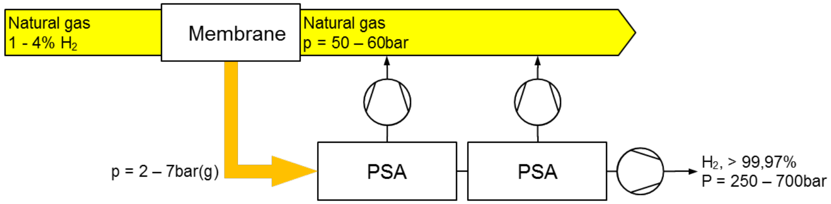


Natural gas
1 - 4% H_2
Membrane
Natural gas
p = 50 – 60bar
p = 2 – 7bar(g)
PSA
H_2, > 99,97%
p = 250 – 700bar



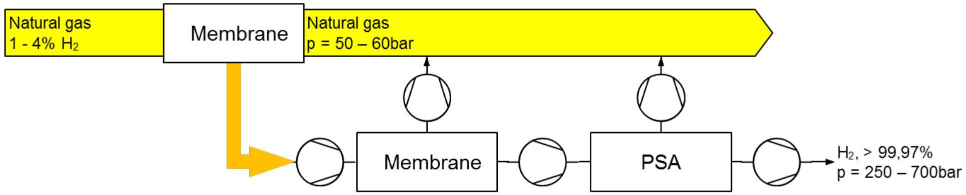
Natural gas
1 - 4% H_2
Membrane
Natural gas
p = 50 – 60bar
p = 0bar(g)
PSA
H_2, > 99,97%
p = 250 – 700bar

Increase of hydrogen concentration @ adsorber input



Natural gas
1 - 4% H_2
Membrane
Natural gas
p = 50 – 60bar
p = 2 – 7bar(g)
PSA
PSA
H_2, > 99,97%
P = 250 – 700bar

Increase of hydrogen recovery



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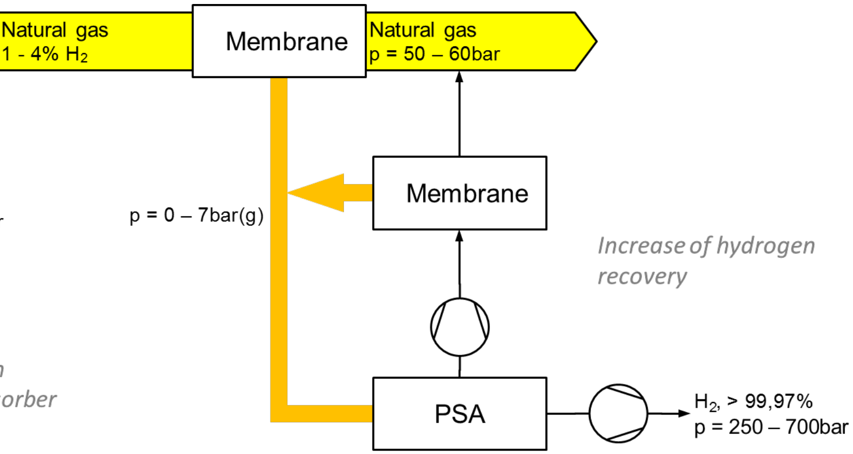
Increase of hydrogen concentration @ adsorber input

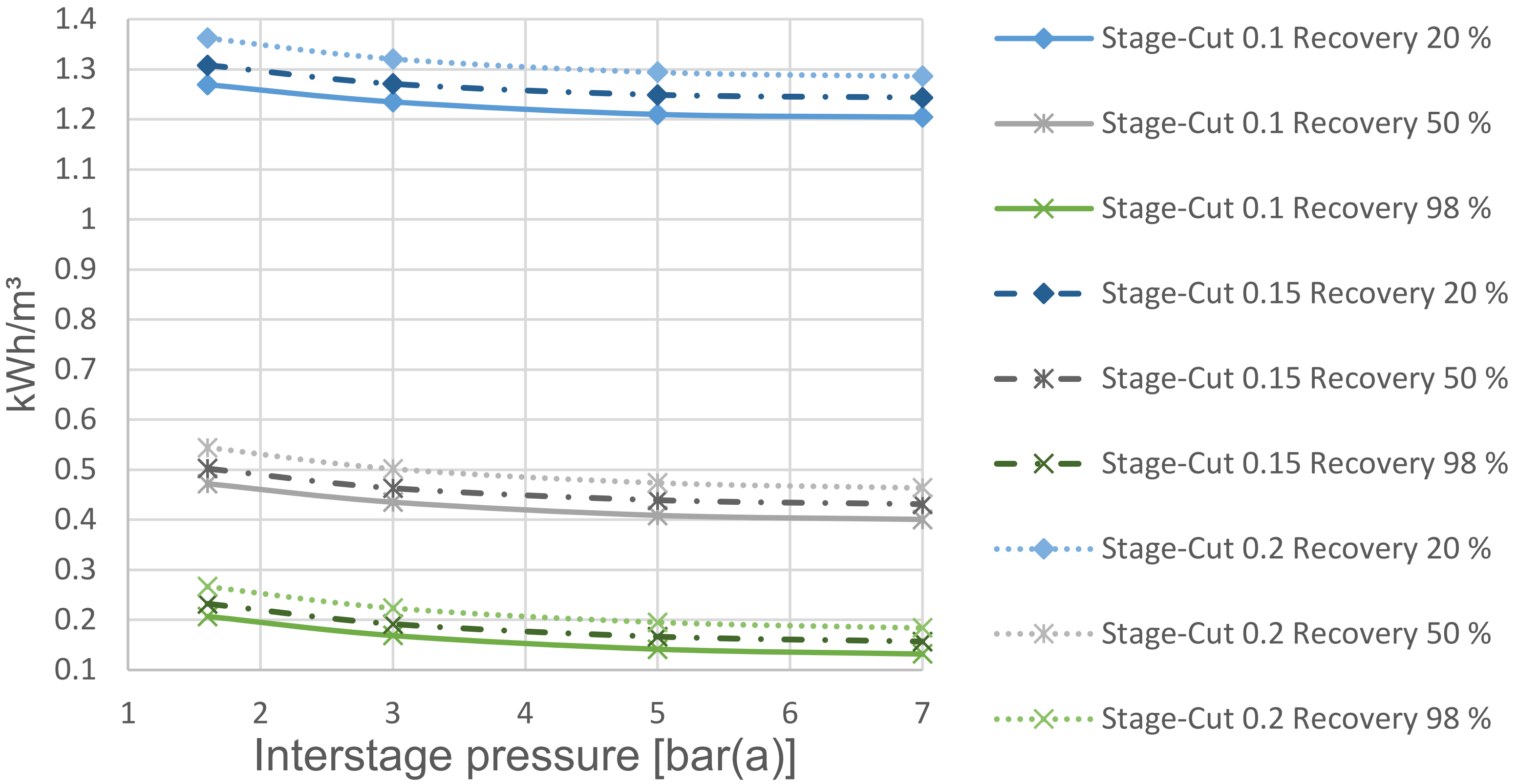


Natural gas
1 - 4% H_2
Membrane
Natural gas
p = 50 – 60bar
Membrane
p = 0 – 7bar(g)
PSA
H_2, > 99,97%
p = 250 – 700bar

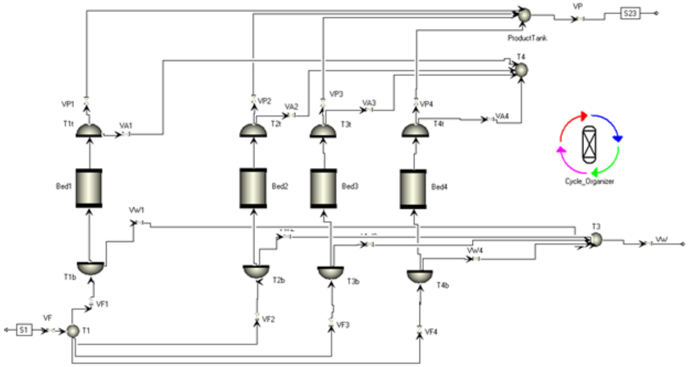
Increase of hydrogen recovery

Further options possible…

Energy consumption of HylyPure® process



Reference process: Decentral hydrogen production by water electrolysis
Energy consumption: 4.2-4.8 kWh/m³; Delivery pressure: 25.81 bar(a)
(Ivy, 2014 – Summary of electrolytic hydrogen production. Milestone completion report, Golden, Colorado)

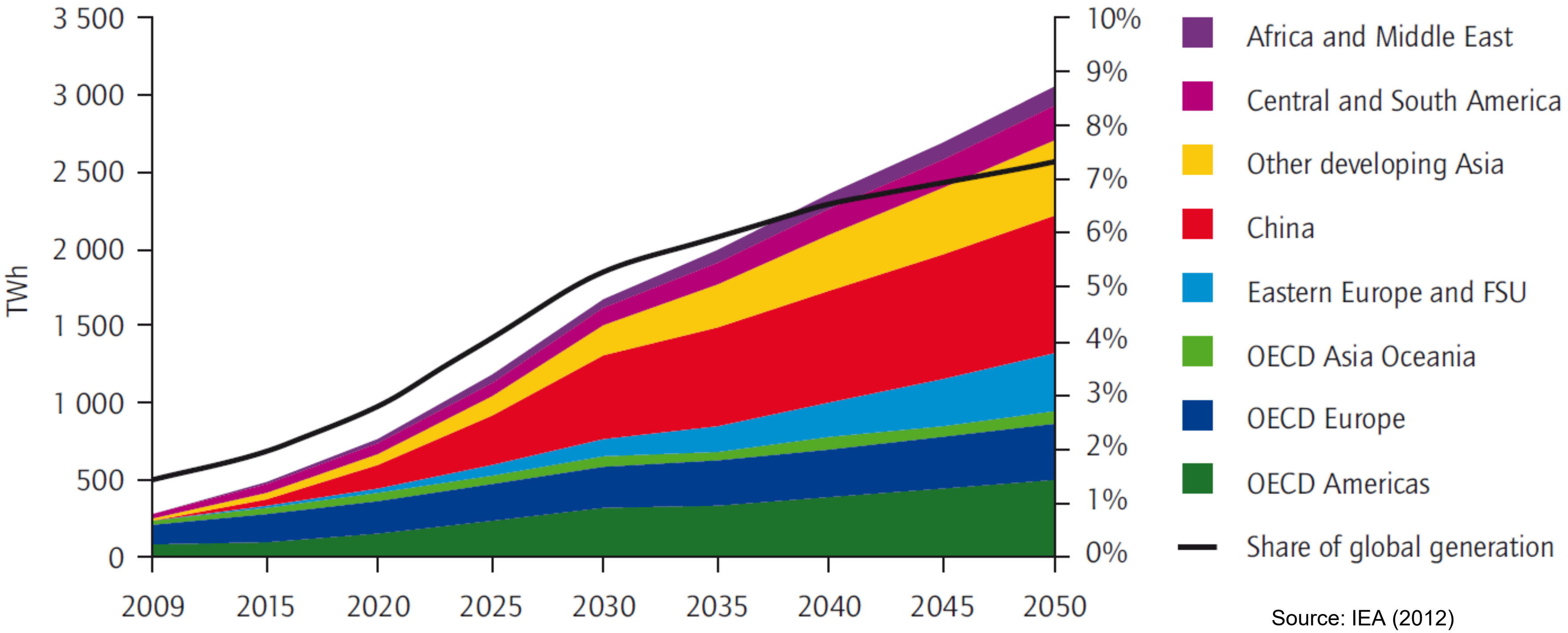


What about Scale-up?

Rightsizing …

Bigger and BIGGER…

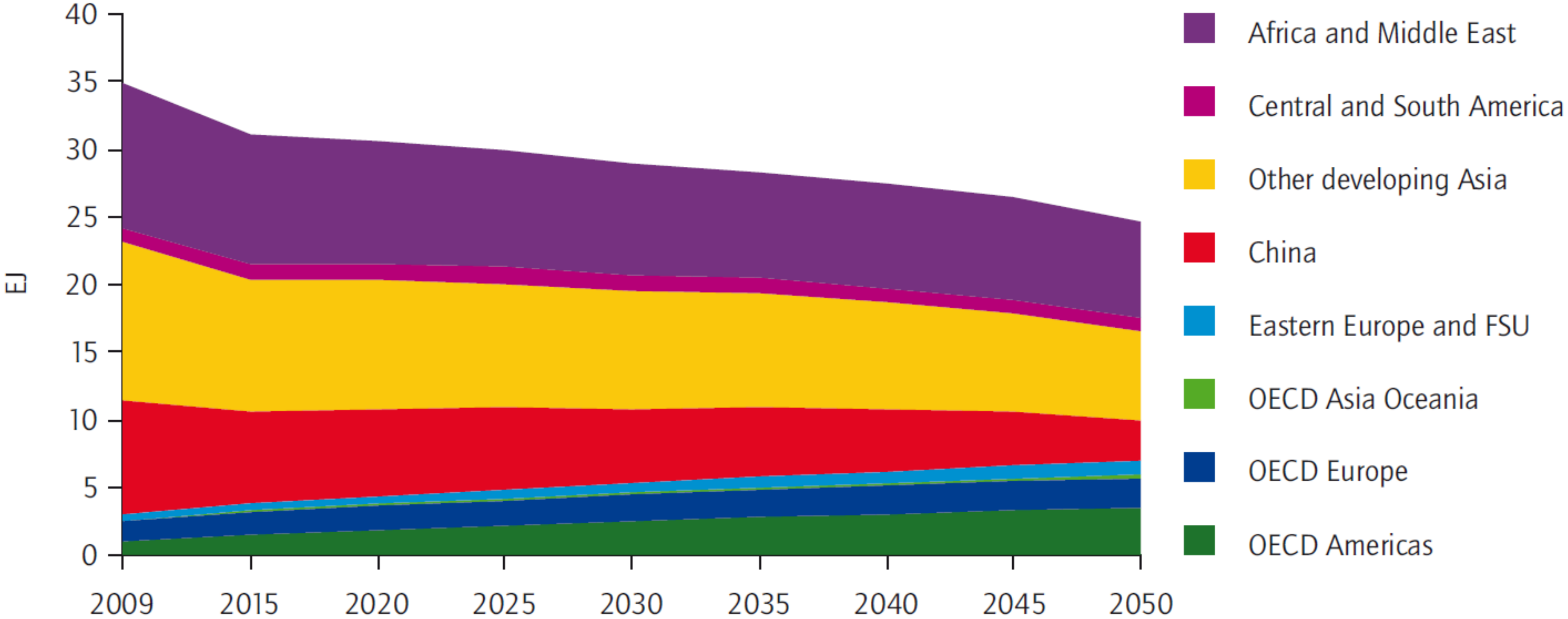
Electricity from Biomass – IEA Future Scenario



Source: IEA (2012)

In 2050, IEA estimates 2 460 TWh of electricity will be produced from biomass and waste, a fivefold increase on 2010

Bioenergy for Heating – IEA Future Scenario



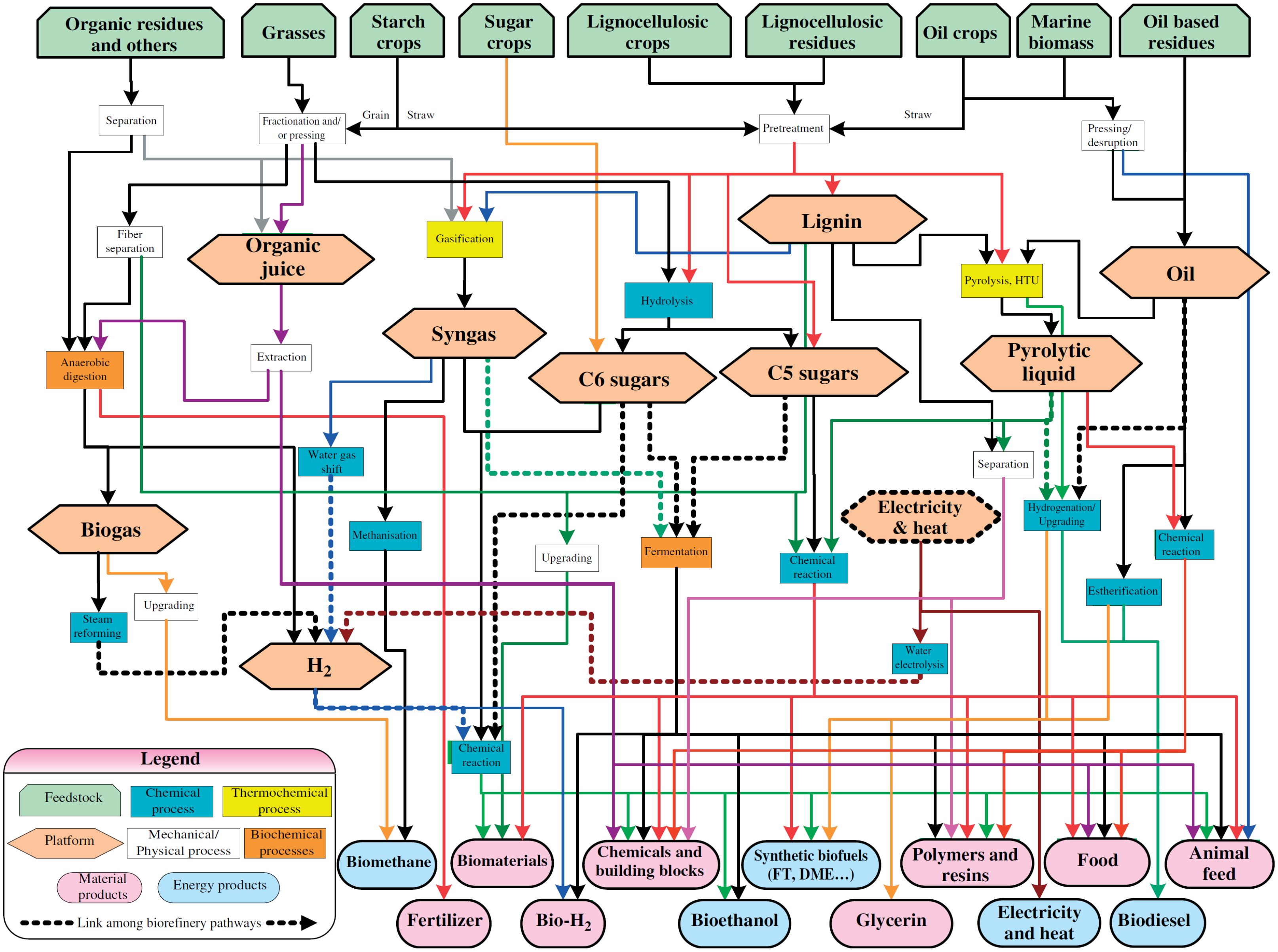
Source: IEA (2012)

Final bioenergy consumption in the buildings sector in different world regions

And the Future?

And the Future?

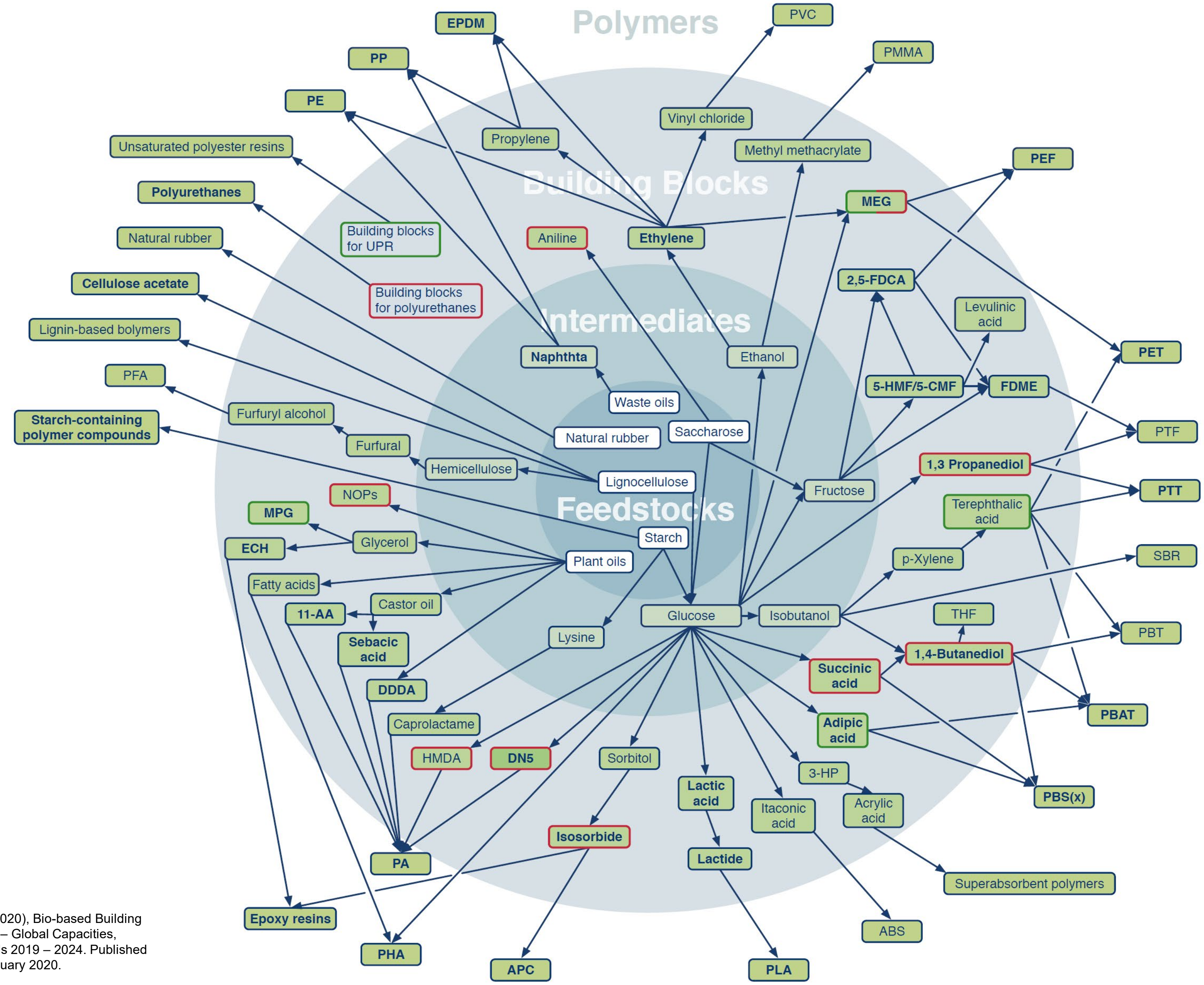
…Utilizing biomass rather than going for energy & fuels



Biorefinery systems network – IEA Task 42

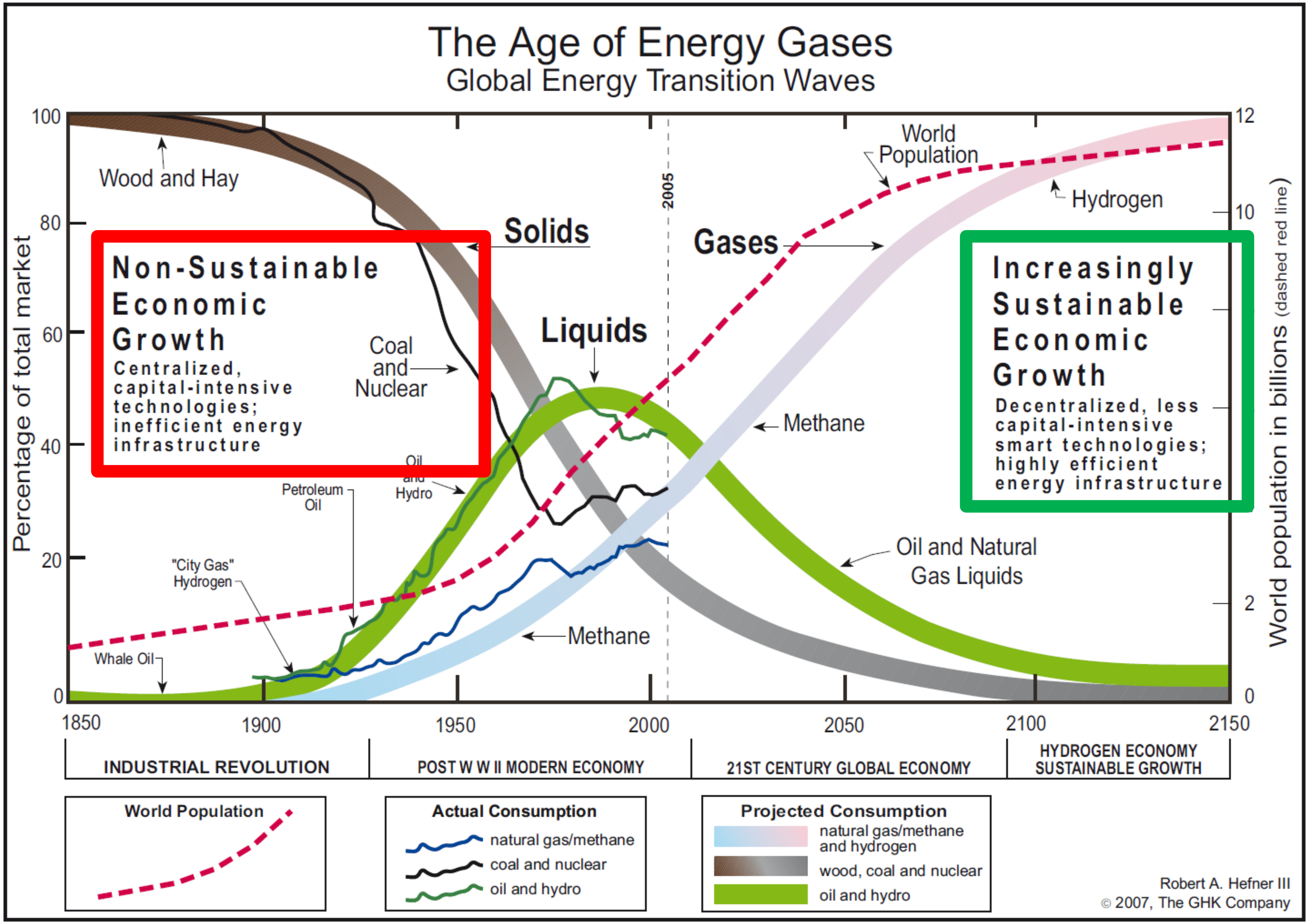
Biorefineries: bio-based building blocks and polymers

Biorefineries and beyond…



Koczinski, P., et al. (2020), Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2019 – 2024. Published by Nova Institute, January 2020.

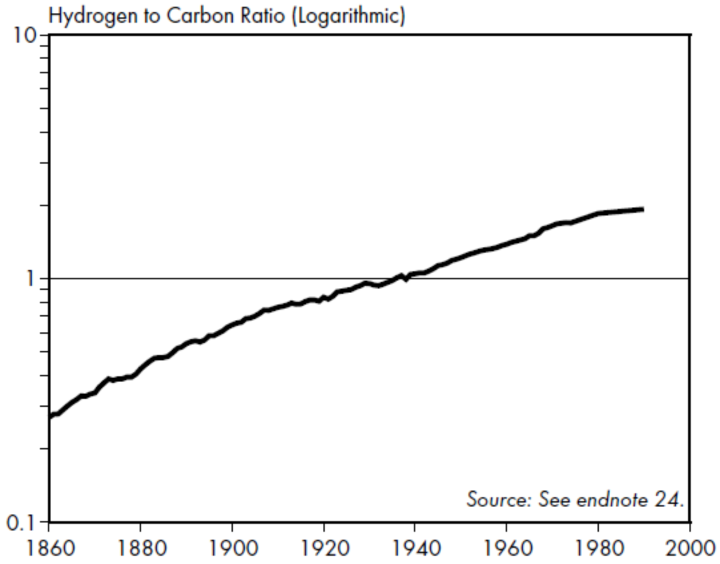
The Age of Energy Gases?



Lessons Learned

- Biomass to grid is more than power!
- Polygeneration technology options available
- Thermochemical and biochemical routes dependent on biomass composition
- These routes will also contribute to the production of sustainable biofuels
- Electricity from biomass share on global energy production to rise in the next decades

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



Source: See endnote 24.

Thank you for your attention!

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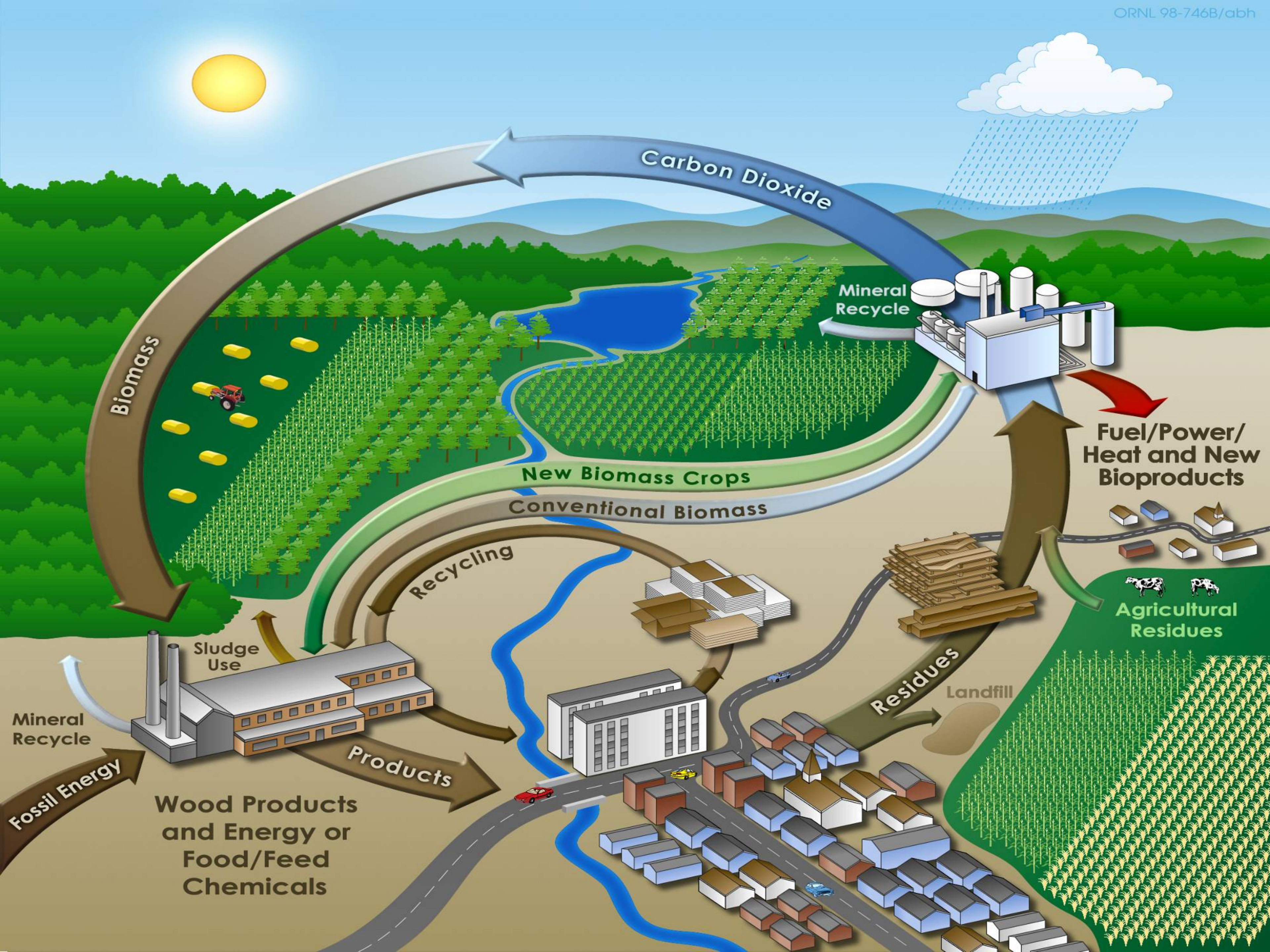
ORNL 98-746B/abh
Carbon Dioxide
Biomass
Mineral Recycle
Fuel/Power/ Heat and New Bioproducts
New Biomass Crops
Conventional Biomass
Recycling
Agricultural Residues
Sludge Use
Mineral Recycle
Landfill
Residues
Products
Fossil Energy
Wood Products and Energy or Food/Feed Chemicals