Rapport SGC 213

International Seminar on Gasification 2009

-Biomass Gasification, Gas Clean-up and Gas Treatment

Editor: Jörgen Held
Swedish Gas Centre

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SGC Svenskt Gastekniskt Center AB

28 October 2009

PREFACE

This report is a compilation of the presentations given at the international seminar on gasification held 22-23 October 2009 in Stockholm, Sweden.

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SGC coordinates the technological development within the field of energy gases and promotes a widespread and efficient usage of energy gases, with the least possible environmental impact.

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SWEDISH GAS CENTRE

Jörgen Held
Managing Director

SUMMARY

22-23 October, 2009 Swedish Gas Centre (SGC) arranged its annual international seminar on gasification, in Stockholm, Sweden. In total 17 international and national experts were invited to give presentations. The seminar was chaired by Staffan Karlsson, SGC.
The seminar was divided into three parts

- Biomass Gasification
- Gas Cleaning and Gas Treatment
- Strategy, Policy and Vision

BACKGROUND
In the light of the strong fossil fuel dependency, especially within the transportation sector, and the need to move on to a sustainable energy system the production of non-fossil high quality fuels is of major interest. In this context gasification of biomass is expected to play a central part.

Political ambitions, environmental concern, green house gas reduction targets and security of supply issues have sparked a rapid development related to production of vehicle fuels through gasification of biomass.

Several biomass routes aiming at different end products are under development or on the verge of becoming commercial.

STATUS – HIGH QUALITY FUEL PRODUCTION
Gasification of biomass and subsequent gas cleaning and treatment has been successfully demonstrated in different projects during the years and several activities are on-going. Below are some examples of R&D activities, demonstrations and industrial plans to commercialize different biomass gasification concepts described.

Biomethane or Bio-SNG (Substitute Natural Gas)
Recent development and successful demonstration of the indirect gasification concept together with high conversion efficiency make bio-SNG an attractive biofuel route.

The R&D activities at the semi-industrial plant in Güssing (8 MW_{th}), Austria and the MILENA pilot plant at the Energy Research Centre of the Netherlands including the development of the OLGA tar removal process have resulted in a strong industrial interest and plans to build commercial plants for bio-SNG production.

The GoBiGas-project, a collaboration between Gothenburg Energy and E.ON, will probably result in the first industrial scale (20 MW) biomethane plant. The project has received public funding (approx. 22 Meuro) from the Swedish Energy Agency and the plant is planned to be in operation in 2012.

HVC in the Netherlands plans to build a 50 MW plant and E.ON plans to build several plants in the size of 200 MW or more.

Methanol/DME through black liquor gasification

In chemical pulp mills the black liquor can be gasified in entrained flow gasifiers producing a syngas with a low methane content. To compensate for the energy removed out of the process additional biomass is combusted in a conventional boiler in order to provide necessary process heat and steam for the pulp mill. From an energy balance perspective black liquor utilization is a low-hanging fruit since the black liquor contains more energy than needed for the process heat and steam generation. In addition the black liquor is pumpable and well suited for injection at elevated pressure in entrained flow gasifiers.

Chemrec AB has successfully demonstrated black liquor gasification in a 3 MW entrained flow gasifier in Piteå, Sweden. Within the BioDME project the whole chain from black liquor to production and utilization of DME as vehicle fuel will be demonstrated. The BioDME project has received funding, 8.2 Meuro, from the European Union. The consortium behind the project consists of Chemrec AB, AB Volvo, Haldor Topsøe A/S, Delphi, Preem, Total and ETC Piteå.

Chemrec AB has in addition been granted approx. 50 Meuro from the Swedish Energy Agency to build a 75 MW plant in Örnsköldsvik. The plant is planned to be in operation in 2013.

FT-diesel

Fischer-Tropsch is a process to convert syngas to higher hydrocarbons. The FT-diesel is free of aromatic and polyaromatic hydrocarbons (PAH) and sulphur. The clean fuel results in a good combustion quality with significantly reduced particle emissions. FT-diesel fits any diesel engine and can substitute fossil diesel The relatively low conversion efficiency, from feedstock to end product, is a drawback.

Choren with its three stage gasifier (Carbo-V®) is in the process of starting up a 45 MW industrial scale plant. The first runs with the gasifier are expected to take place in November 2009 and the downstream process is planned to be in operation in 2010. The next step is to build a 640 MW plant (4x160 MW).

In the Bioliq®-process, a joint development between Forschungszentrum Karlsruhe and Lurgi GmbH, biomass undergoes fast pyrolysis in decentralized bio syncrude production plants. The fast pyrolysis can be seen as a pretreatment in order to increase the energy density and produce a storable and transportable product. The syncrude will be transported to a centralized synfuel production plant and gasified in an entrained flow gasifier. The plan is to have a complete bioliq plant in operation around 2012.

Methanol and Ethanol

Enerkem in Canada has been operating its pilot plant in Sherbrooke since 2003. The plant produces syngas, methanol and second-generation ethanol. Different feedstocks, including municipal solid waste, forest residues, demolition wood and wheat straw have been used to test and validate the technology. This has resulted in the construction of a commercial demonstration plant in Westbury which is expected to produce methanol and ethanol by mid 2010.

During the seminar international and national experts gave presentations concerning biomass gasification, gas cleaning and gas treatment as well as strategy and policy issues.

The presentations give an excellent overview of the current status and what to be expected in terms of development, industrial interest and commercialization of different biomass gasification routes.

NOMENCLATURE

DME	Di Methyl Ether
FT-fuel	Fischer-Tropsch fuel
MW	Megawatt
R&D	Research and Development
SNG	Substitute Natural Gas

Malmö, 28 October 2009

Jörgen Held
Managing Director Swedish Gas Centre

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WELCOME

to…

Jörgen Held
Managing director, Swedish Gas Centre

SGC Svenskt Gastekniskt Center AB

International Seminar on Gasification

- Gas Clean-up and Gas Treatment

22-23 October 2009

Clarion Hotel Sign, Stockholm

Organized by

SGC Svenskt Gastekniskt Center AB

Swedish Gas Centre

Supported by

Energimyndigheten, e-on, Göteborg Energi, Stockholm Gas, Lunds Energi Koncernen, Elforsk, Öresundskraft, Vattenfall

Swedish Gas Centre

Nr of employees: 6
Office: Malmö, Sweden
Annual turnover: approx 2.5 million euro
Website: http://www.sgc.se

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Swedish Gas Centre

SGC co-ordinates the technological development within the field of gas technology with a clear focus on renewable and sustainable energy gases.

SGC promotes a widespread and efficient use of energy gases through compilation and dissemination of results, knowledge and experiences.

SGC Svenskt Gastekniskt Center AB

Swedish Gas Centre

SGC administrates and operates a national R&DD programme within the field of energy gas technology

Period: 1 April 2009 – 31 March 2013
Budget: Approx. 8 million euro. (3.2 million euro public funding)

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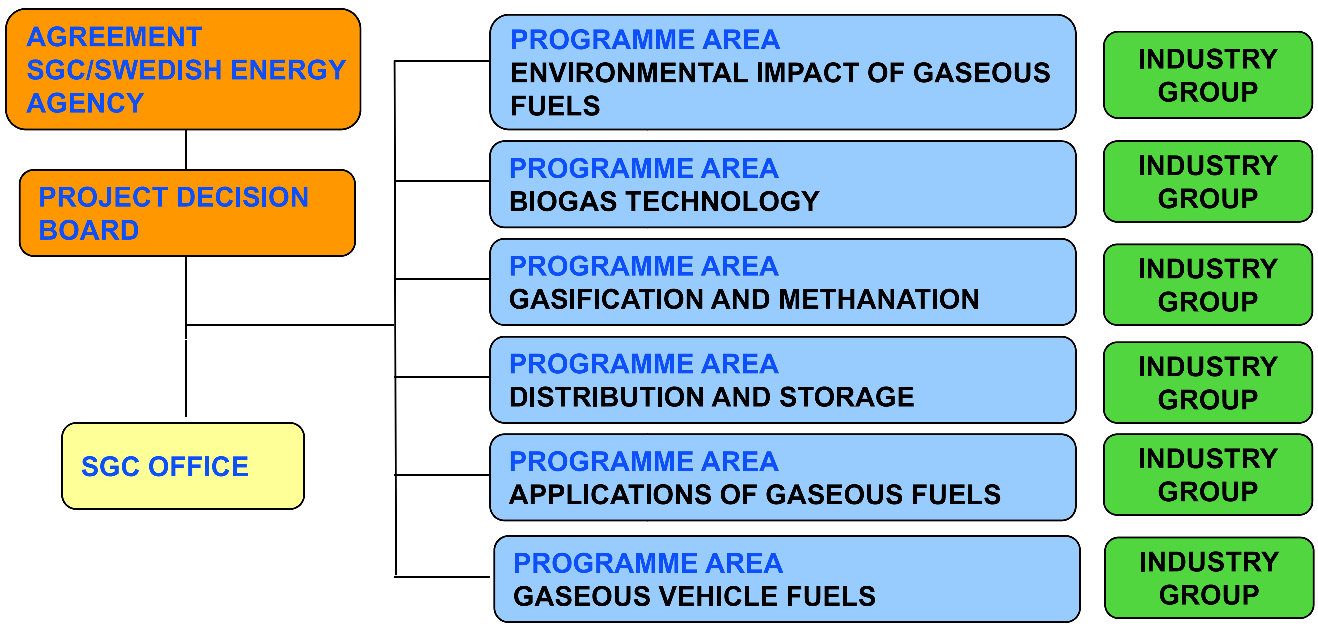

Swedish Gas Centre

This seminar is part of the technology surveillance SGC performes within the field of gasification and methanation.

The ambition of SGC is to offer a platform for exchange of results, information, experiences and networking on an international level.

Once again
WELCOME!

Black Liquor Gasification
-
The tool to convert Pulp Mills to Bio-refineries

GASIFICATION 2009

Stockholm, October 22-23, 2009

Ingvar Landälv
CTO
Chemrec AB, www.chemrec.se

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Concept Background
-
What is Black Liquor?

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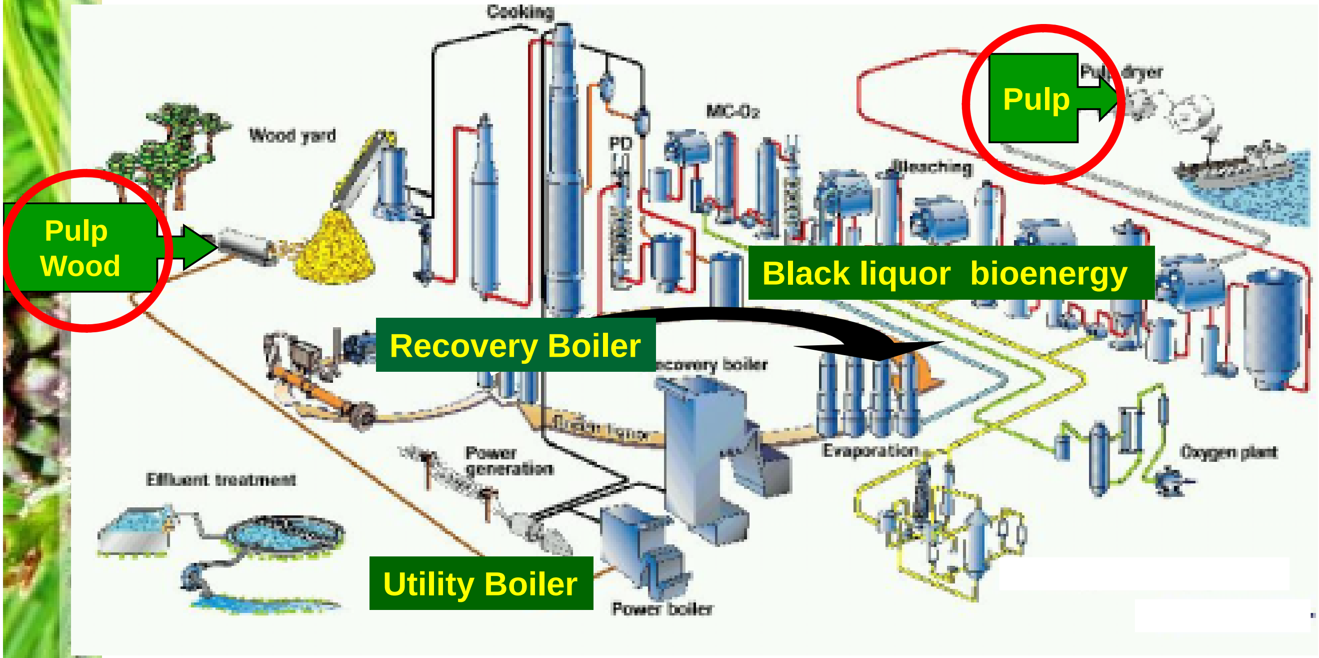
A typical Pulp Mill of Today
- One Feedstock and One Product -



Transform

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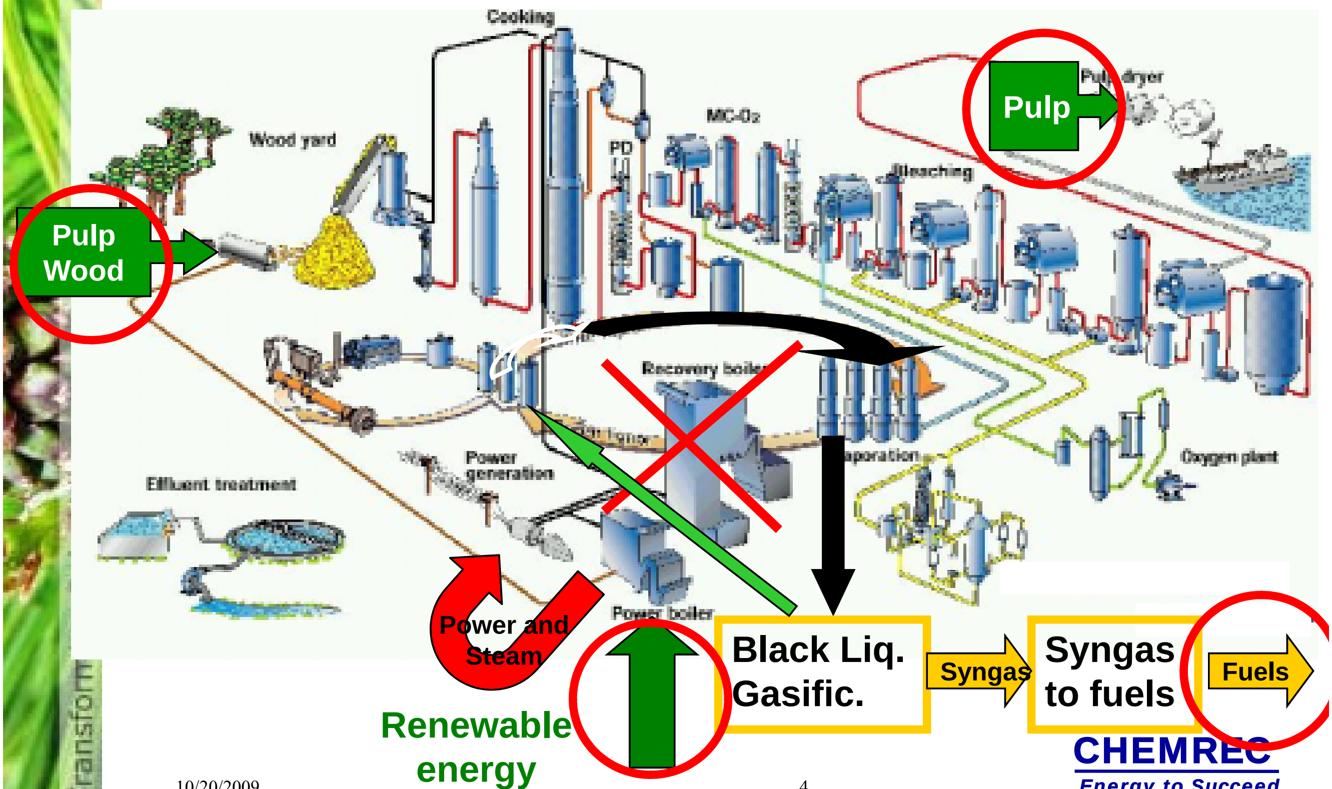
The Pulp Mill turned to a Biorefinery
- two Feedstocks and two Products -



Transform

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Black Liquor at room temperature

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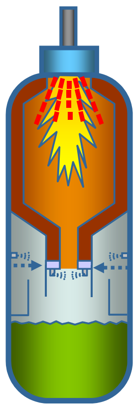
Transforming Pulp Mills to Biorefineries

Black liquor uniquely suitable for gasification

- **Liquid**
  - *Easy to feed to a pressurized gasifier*
  - *Can be atomized to fine droplets*
  - *Rapid gasification rates*
  - *Stable properties over time*
- **Efficient gasification**
  - *Full carbon conversion at ~1000 deg C*
  - *No tar formation*
  - *Low methane formation*
- **Available in large quantities**
  - *World BL capacity about 660 TWh*
  - *Corresponds to ~ 10 billion gal gasoline equivalents per year*
  - *Typically 250-300 MW of BL per pulp mill*



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Key Drivers

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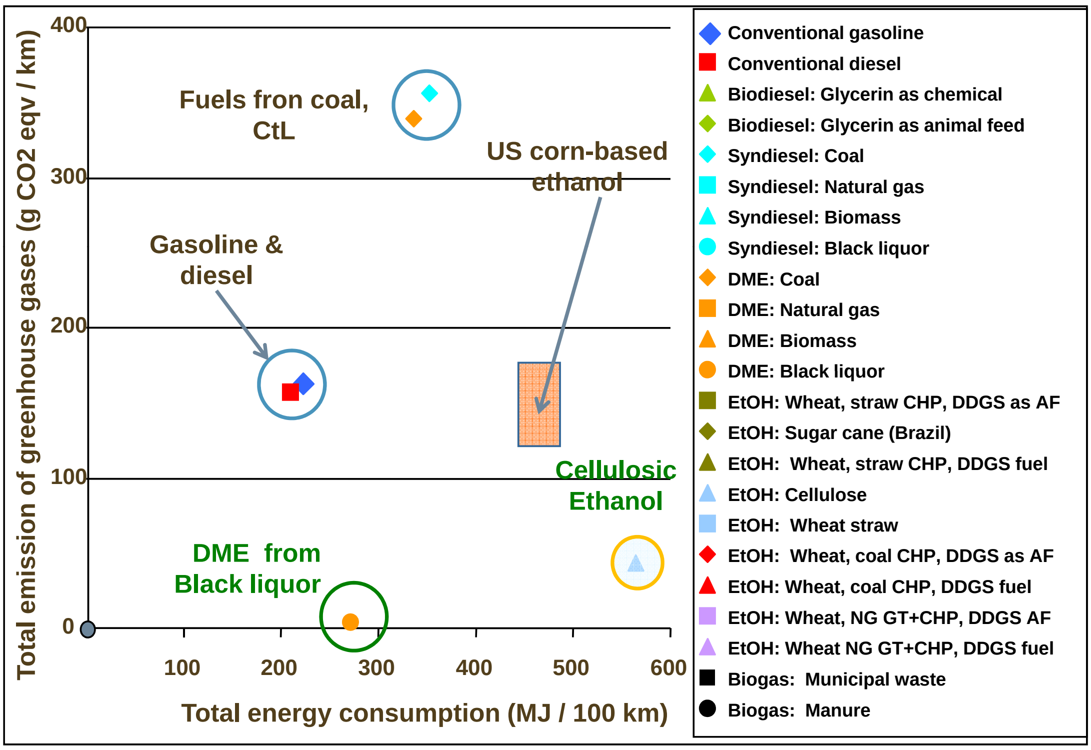
Well to Wheel CO2 emissions and total energy consumption for some different path ways



Source: EUCAR/CONCAWE/JRC

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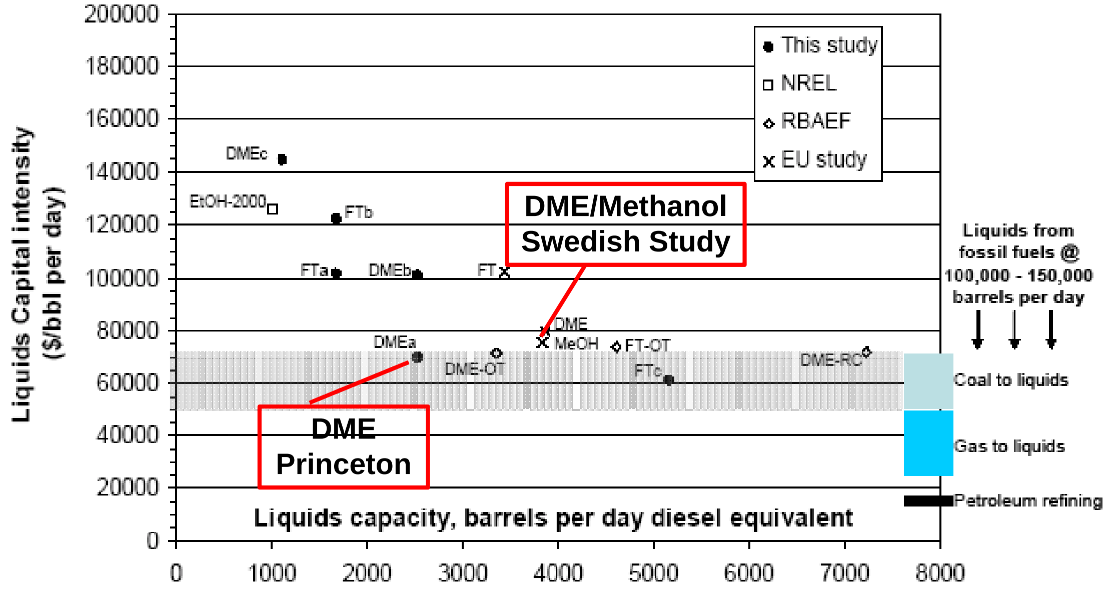
Effective Capital Investment Intensity

\$/(bbl per day) vs bbl per day diesel eqiv.
4Q, 2005 investment level



Source: Princeton, 2006

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Plant Operations

Focus:
Pressurized & O_2-blown

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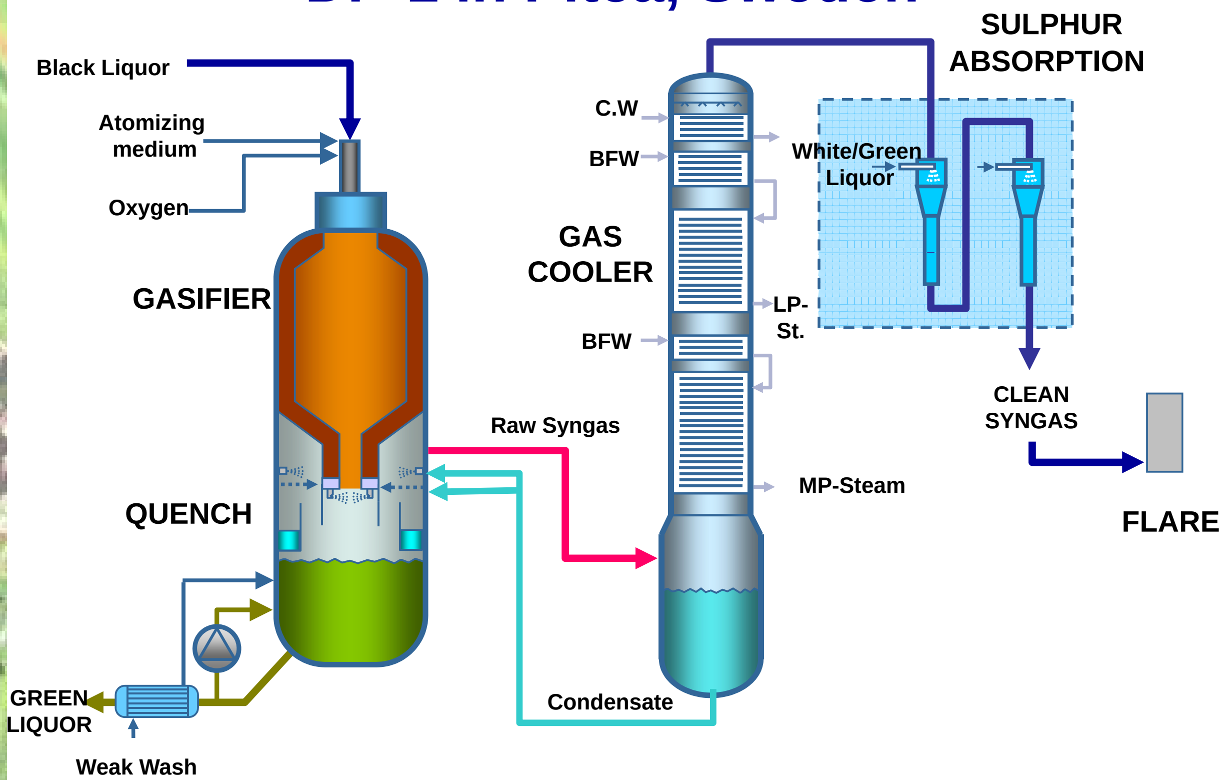
Development Plant for Oxygen-blown high pressure BL gasification

- Located at the SmurfitKappa mill in Pitea, Sweden
- Oxygen-blown and operated at 30 bar(g)
- Capacity 20 metric tons per day of black liquor solids (3 MW(th))
- Used for technical development and design verification
- Started up 2005 –Now in operation more than 11000 hours.
- Operations: 10 operators in 5 shifts

Chemrec Gasification Process DP-1 in Piteå, Sweden



Purpose of DP-1

- Provides detailed performance data as basis for scale-up activities and specification of downstream systems
- Used as test facility for process and equipment improvements
- Functions as facility for test runs with client liquors
- Used as syngas generator for the BioDME plant from July 2010 to end of 2012.

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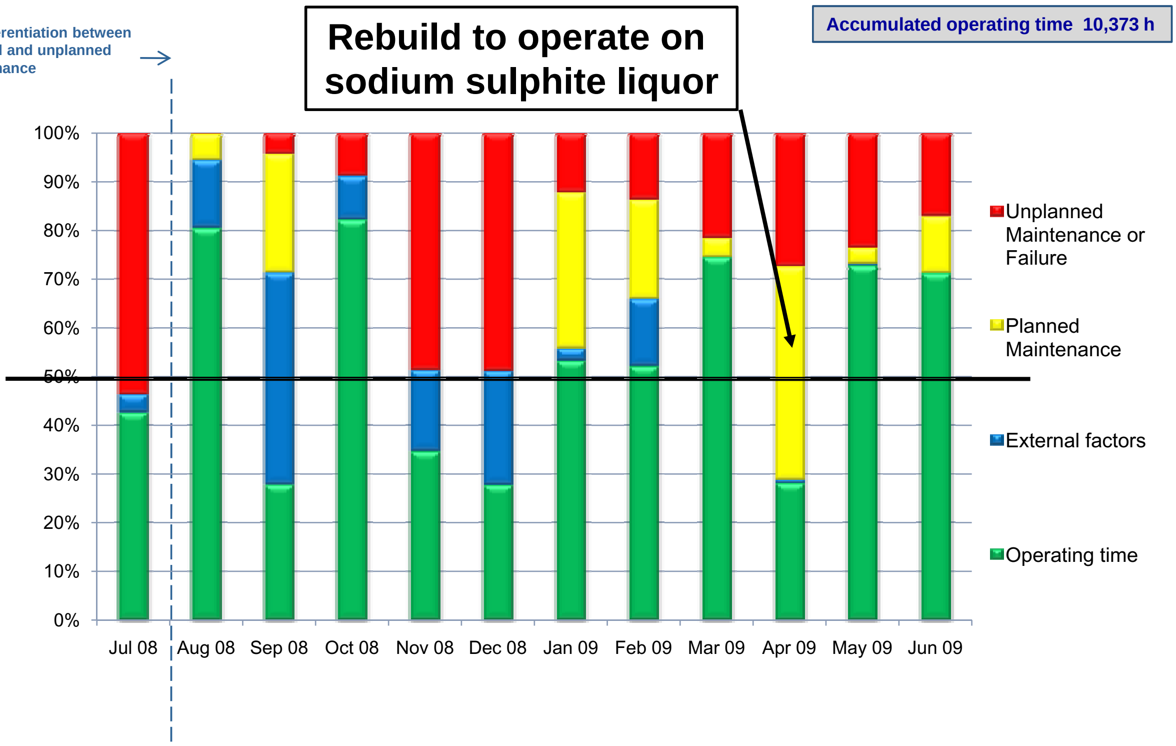
Distribution of calendar time



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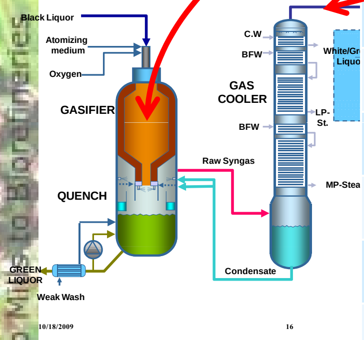
Gas composition for a typical case (p = 27 bar, λ = 0.3, T = 1050 ºC)



	Inside reactor (%)	Cooled syngas (%)
CO_2	33.9 ±0.3	33.6 ±0.2
H_2S	1.65 ±0.04	1.71 ±0.02
CH_4	1.36 ±0.07	1.44 ±0.07
CO	28.7 ±0.2	28.5 ±0.2
H_2	34.3 ±0.2	34.8 ±0.1
COS	468 ±22 ppm	122 ±5 ppm
H_2/CO	1.19 ±0.01	1.22 ±0.01
H_2/CO_2	1.01 ±0.01	1.04 ±0.01
CO/CO_2	0.85 ±0.01	0.85 ±0.01

*** Average of ten samples per sample point**

Data by the BLG Program,
R. Gebart et al, TCBiomass 2009

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Trace elements in cooled syngas

Element	*Average Gas Concentration (ppb by weight)*
Fe	<1.8
K	<1.8
Li	<0.02
Na	<17.4
Ni	<0.05
NH4-N	89.5
Cl	1297
Br	<1.0
I	<4.6
CN total	<0.5
F	<2.6

* Data by the BLG Program,
R. Gebart et al, TCBiomass 2009

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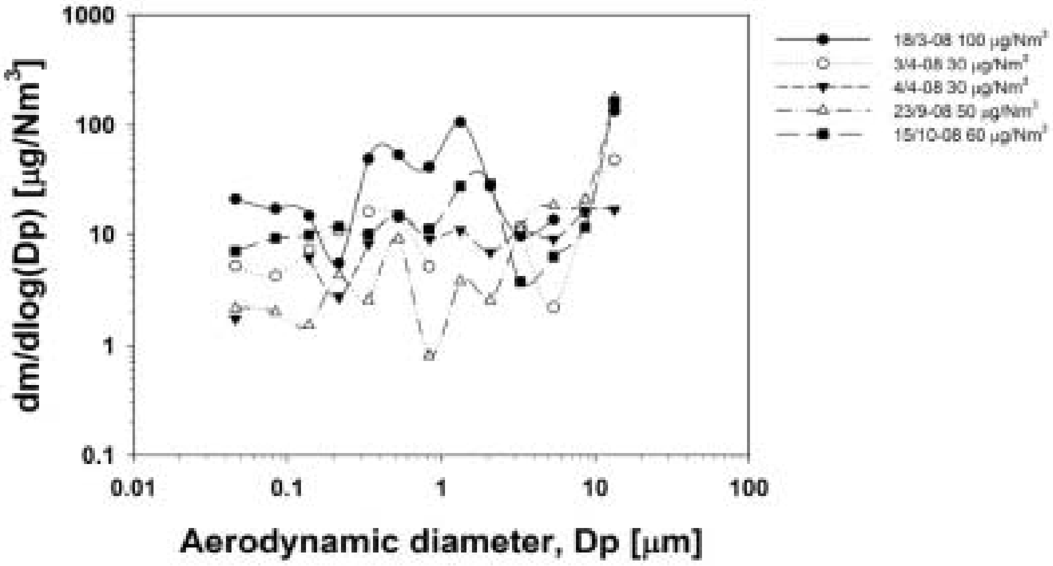
Particle mass size distribution in cooled syngas



Extremely low particle concentration, typically <0.1 mg/Nm3 total

* Data by the BLG Program,
R. Gebart et al, TCBiomass 2009

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Summary of DP-1 Operations

- Consistent gas quality
- Very low particulate levels in cooled syngas, typically < 0.1 mg/ Nm3.
- Low methane content without reforming
- Very low tar content in cooled gas
  - 50-70 ppm benzene
  - < 5 ppm naphthalene
  - higher tars: << ppm levels
- Very low fouling in gas coolers and condensate systems
- Normally 99%+ smelt reduction efficiency

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Project Plans

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THE BIODME PROJECT

Supported by:

Energimyndigheten *)

SEVENTH FRAMEWORK PROGRAMME

***) The Swedish Energency**

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BioDME Consortium

CHEMREC
- Plant engineering, construction and operation
- Plant owner

DELPHI
- DME injection system development

HALDOR TOPSØE — CATALYSING YOUR BUSINESS
- DME production technology provider

ETC
- Laboratory support to plant operation

preem
- DME distribution

TOTAL
- DME fuel specification
- Fuel Additive development

VOLVO

BioDME Project Coordinator
- Engine development
- Vehicle manufacturing
- Field test responsible

BioDME

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BioDME Overall Scope and Objective

Demonstration of an environmentally optimized future bio-fuel for road transport covering the full chain from production of fuel from biomass to the utilization in vehicles

Starting date:	1 September 2008
Total budget:	28.4 M€ / ~ 40 MMUSD
Duration:	48 months
EU funding:	8.2 M€ / ~ 12 MMUSD
Coordinator:	AB Volvo

BioDME

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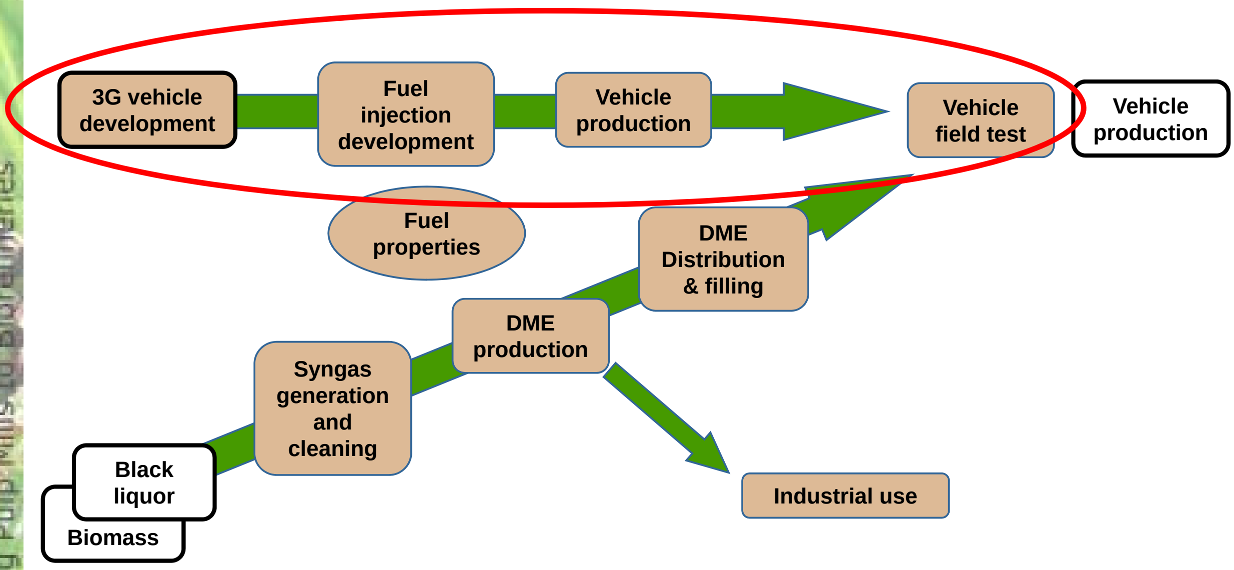
Transforming Pulp Mills to Biorefineries

Overall Scope Illustration



BioDME

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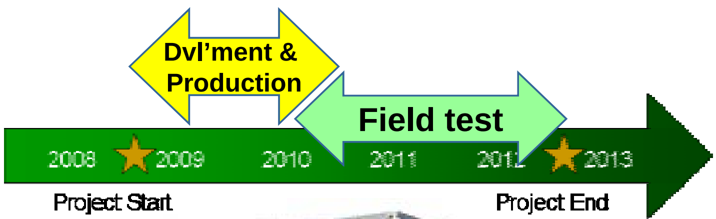
Transforming Pulp Mills to Biorefineries

DME engine & vehicle development and production followed by Field Test

- Development and production of 14 Volvo DME trucks
- 14 Volvo DME trucks in customer operation
- Demonstrate and verify DME technology in real applications
- Planned yearly distance 100 000 km per truck (average)



BioDME

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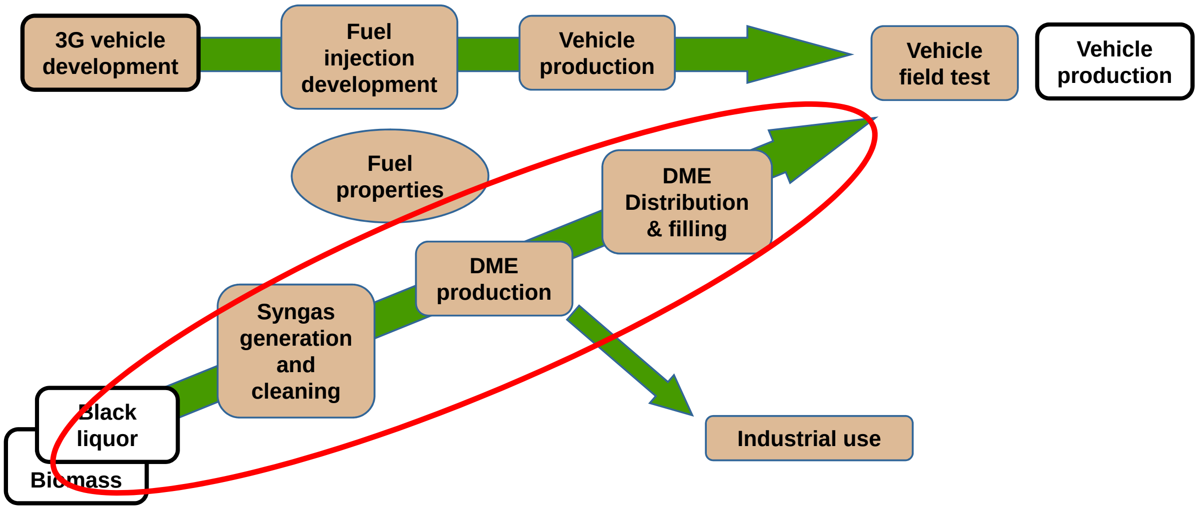
Overall Scope Illustration



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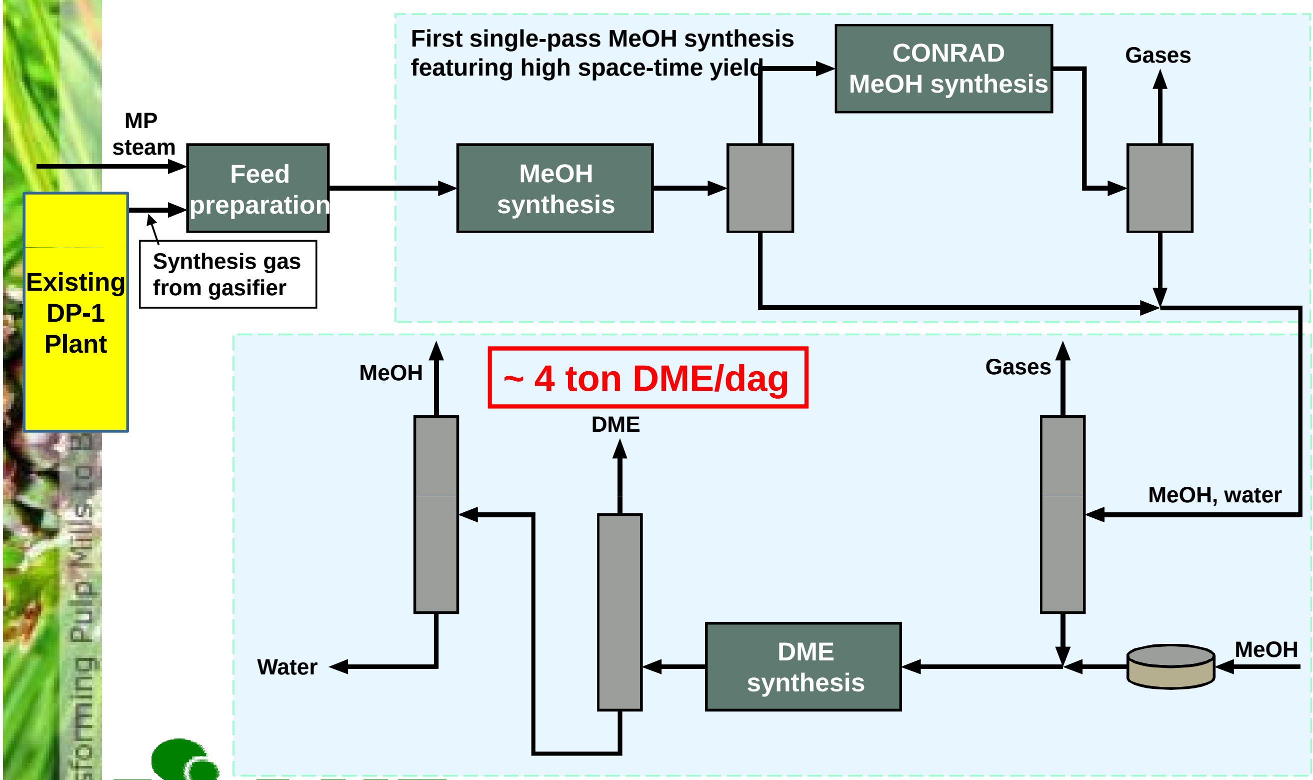
3ed generationens DME process

Source: HaldorTopsoe



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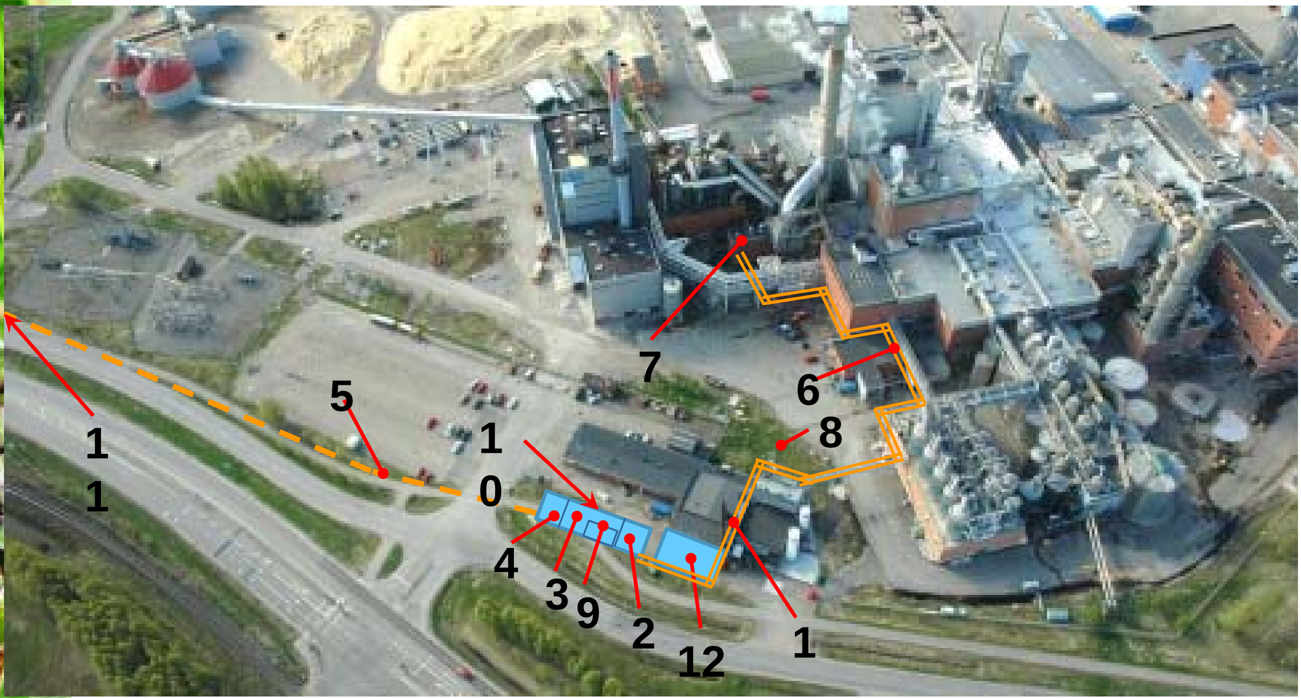
Project area overview

Transforming



1. Two altenatives for pipe bridge between DP1
2. & BioDME.
3. Area for gas treating.
4. DME –unit.
4. D[illegible]nk for DME and MeOH.
5. Pipeline to storage location of DME.
6. Pipe from AGR to incinerator at pulp mill.
7. Incinerator at SmurfitKappa.
8. Location of transformer for power supply.
9. Power room at BioDME.
10. Civil structure for BioDME.
11. Storage location for DME.
12. Occupied area for other purpose.

BioDME

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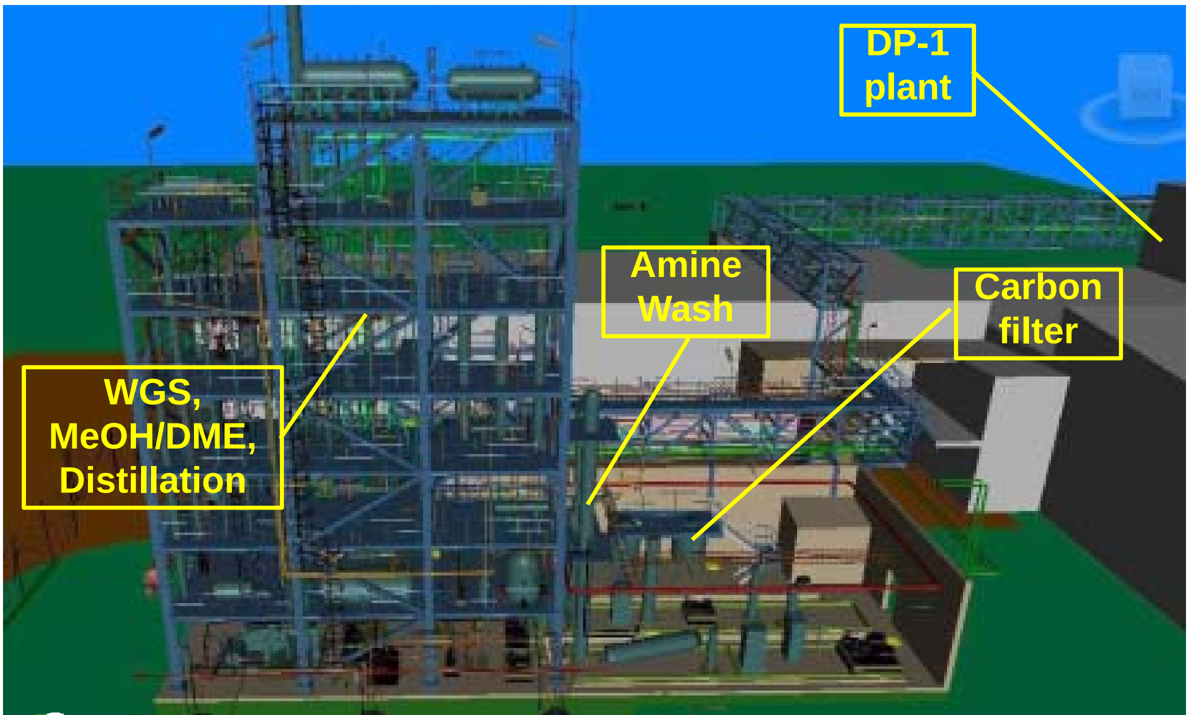
New BioDME Pilot CAD Illustration

Transforming Pulp Mills to Biorefineries



BioDME

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Transforming Pulp Mills to Biorefineries

Illustration of the BioDME pilot

BioDME

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Transforming Pulp Mills to Biorefineries

Key Developments for Large Scale Plants

1. Scale up of Gasification Unit
2. Technology for Gas Clean-up

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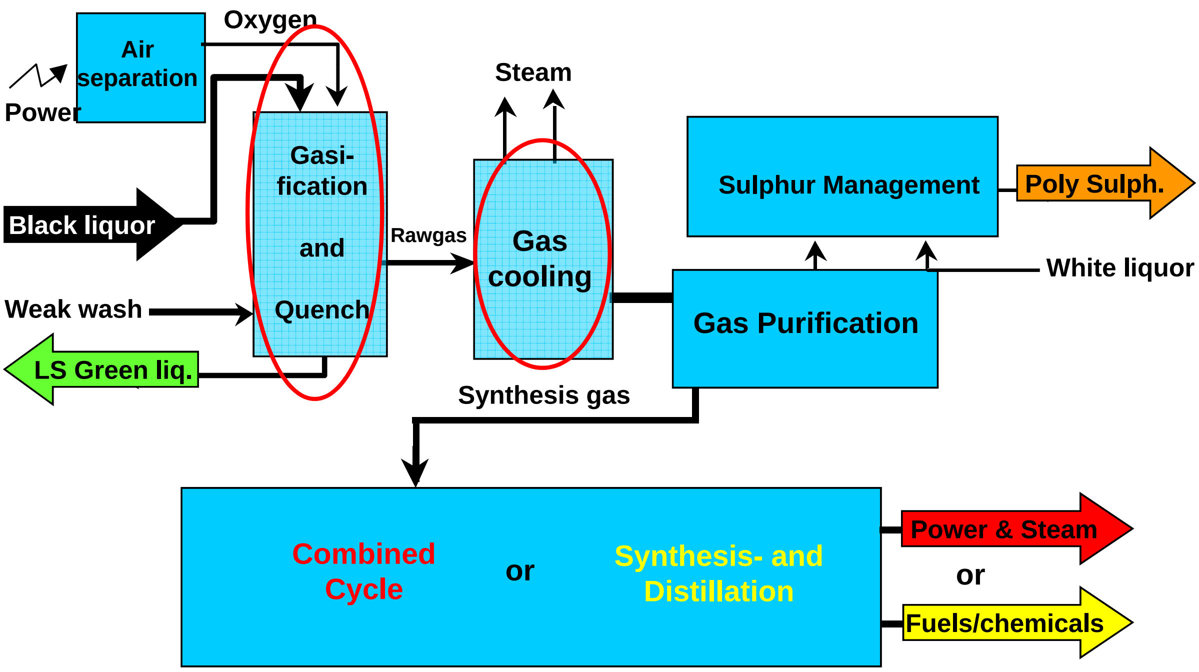
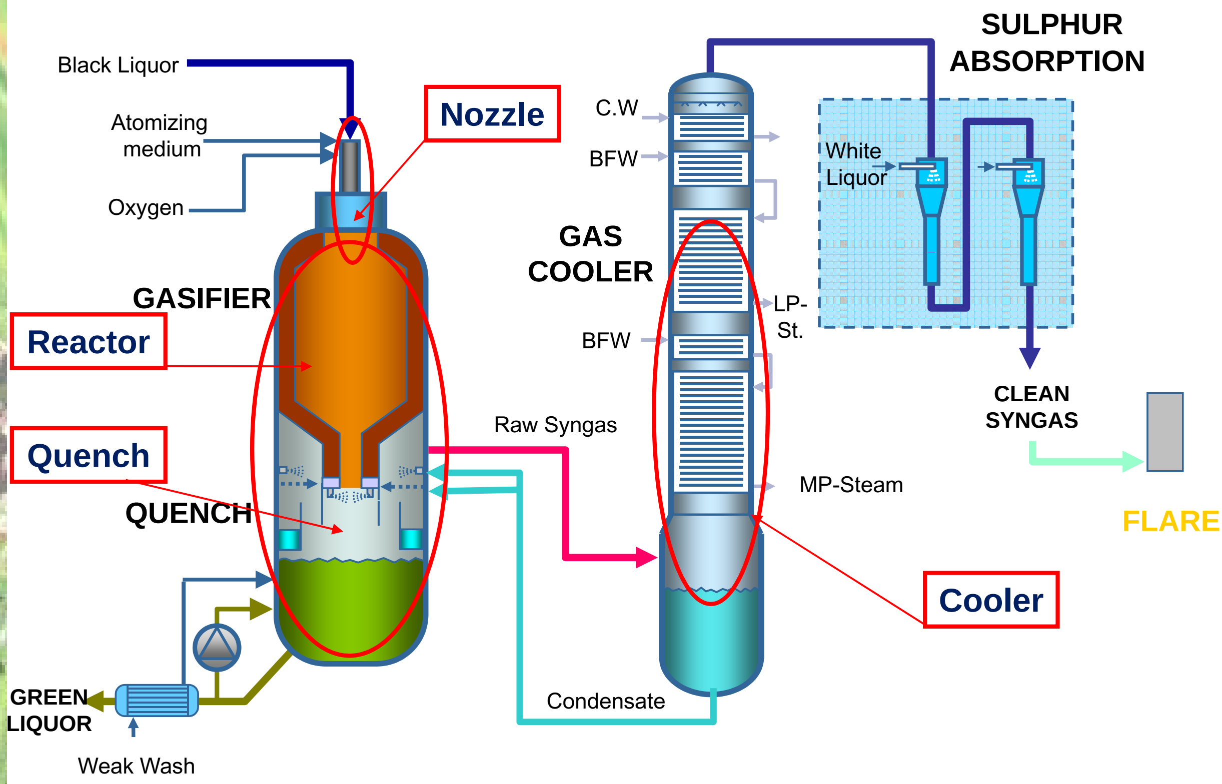
General BLG Scheme with Key Scale up Areas



Transforming Pulp Mills to Biorefineries

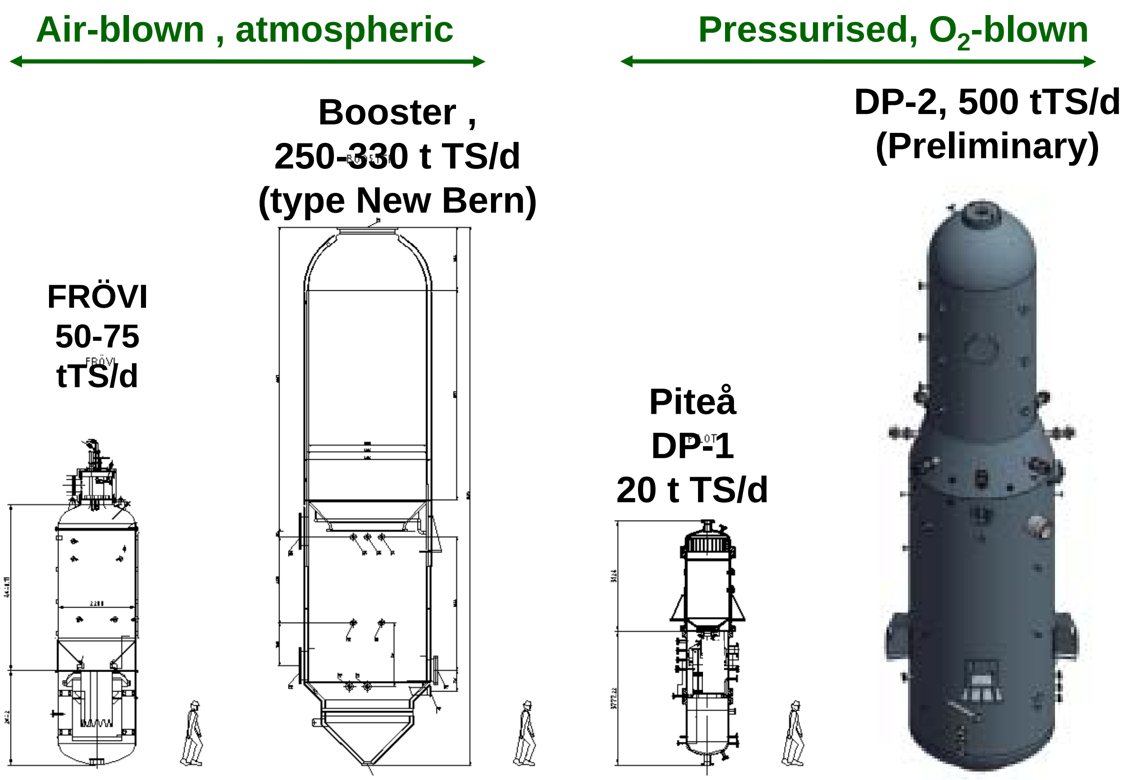
Key scale up activities



Transforming Pulp Mills to Biorefineries

Transforming Pulp Mills to Biorefineries

Chemrec's Gasifiers – a comparison



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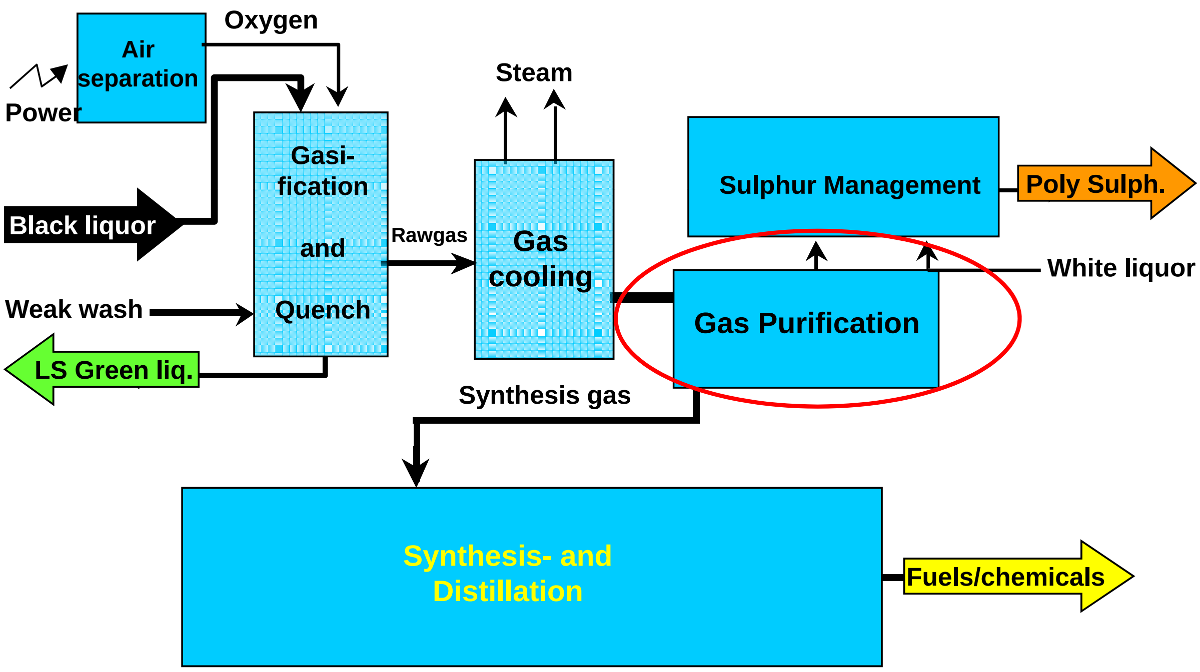
Transforming Pulp Mills to Biorefineries

Gas Purification – a key Tecnology



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The Domsjö Project

Location:

Örnsköldsvik, Sweden

Products:

DME and methanol

Capacity:

95 000 t DME or 132 000 t methanol / year

Project cost:

Approx. SEK 3 billion / € 300 million

Planned production start:

H1 2013

SEK 500 million / €50 investment grant approved by Swedish Energy Agency September 2009

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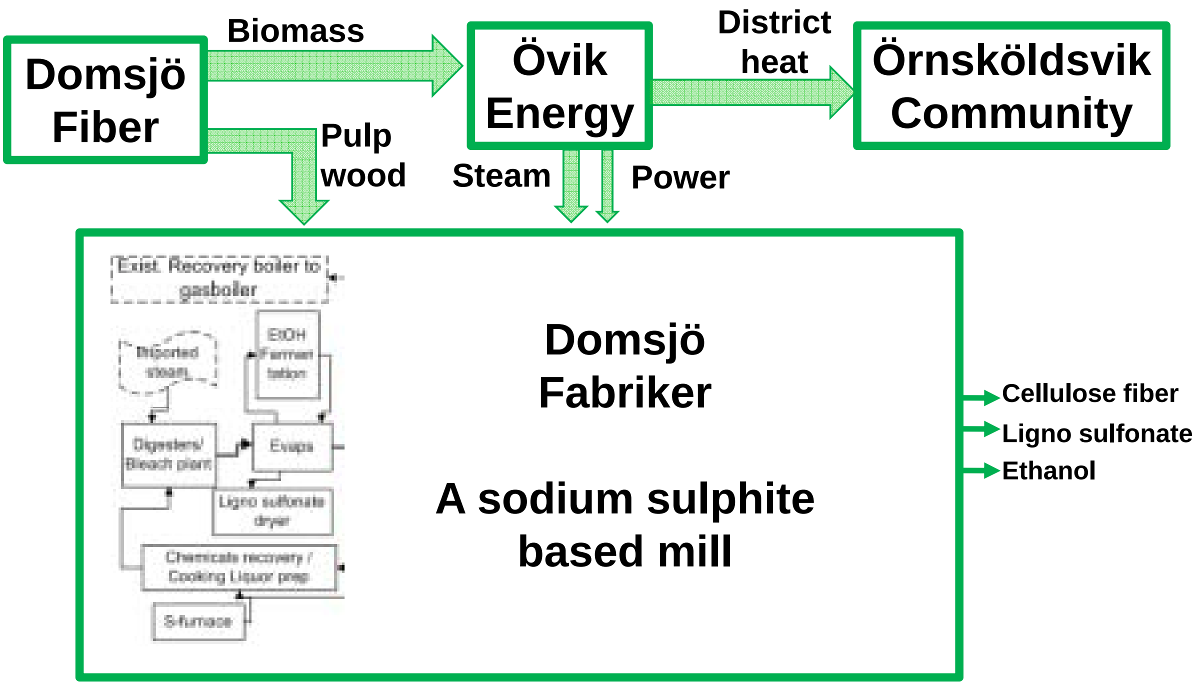
The Energy Combine of Örnsköldsvik
Domsjö Mill ė Övik Energy ė Övik Community
- TODAY -



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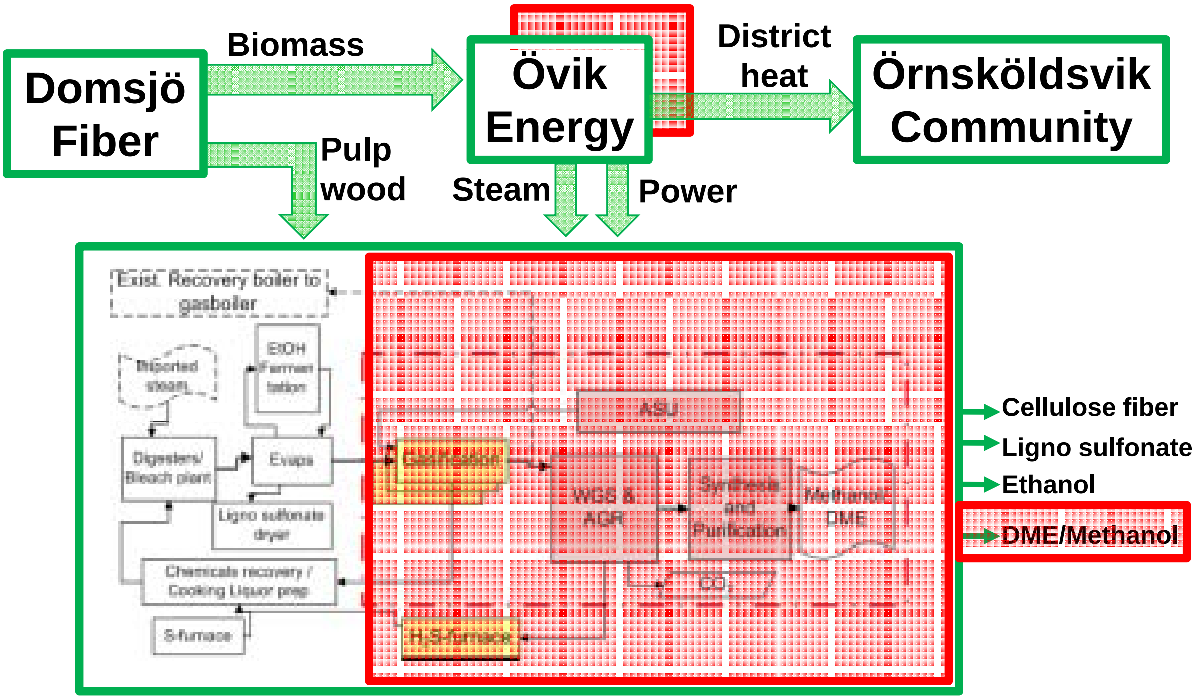
The Energy Combine of Örnsköldsvik Domsjö Mill ė Övik Energy ė Övik Communit
- TOMORROW -



Transforming Pulp Mills to Biorefineries

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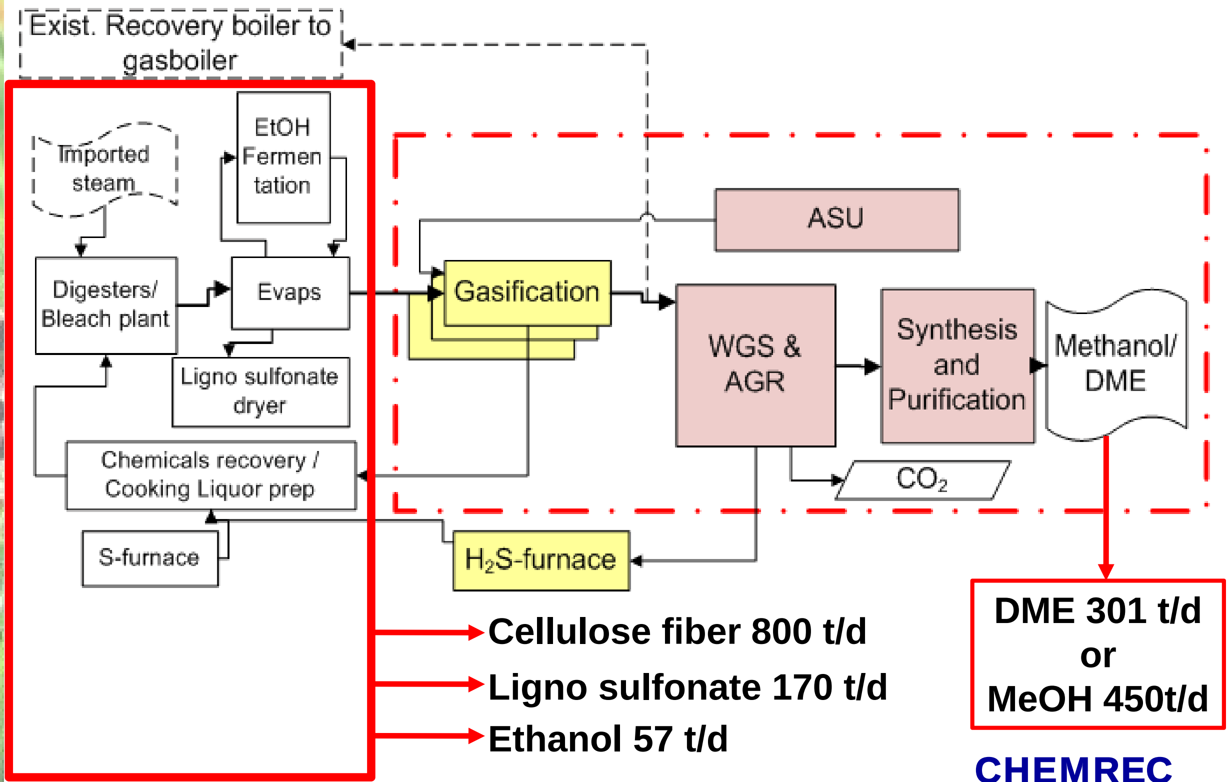
Complete Domsjö Mill including Fuel Production



Transforming Pulp Mills to Biorefineries

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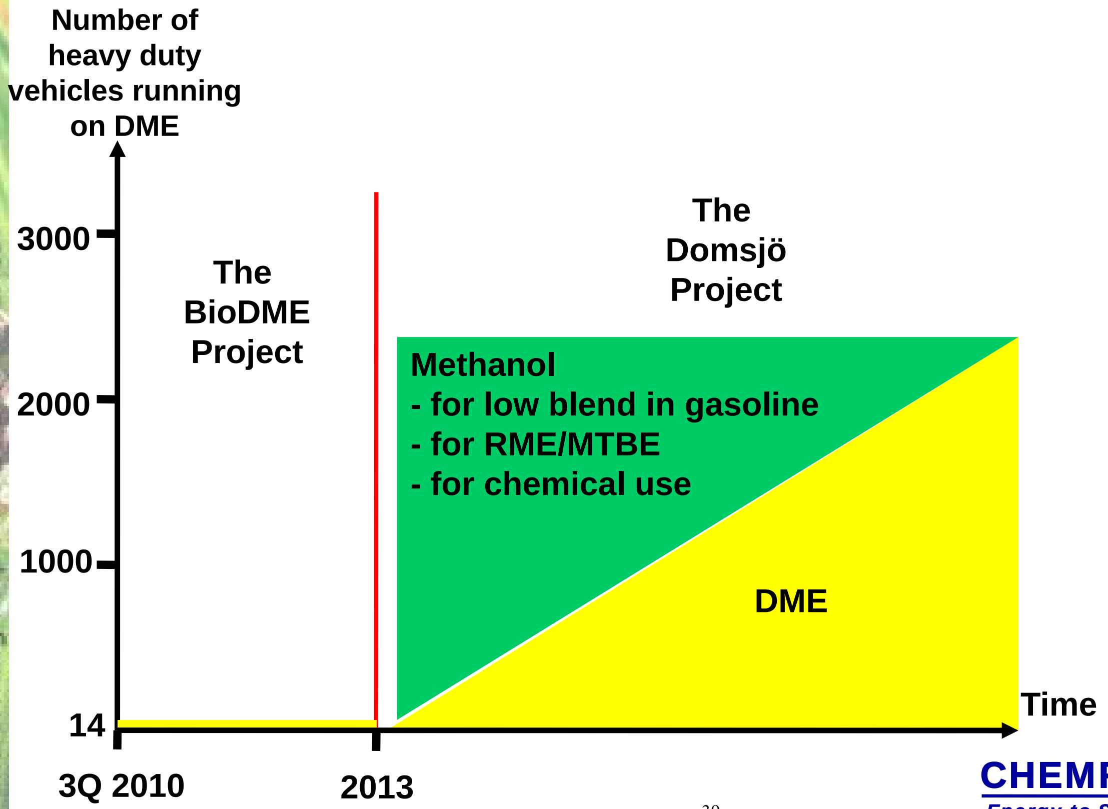
Concept for development of the DME market for heavy duty vehicles



Transforming Pulp Mills to Biorefineries

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Current project status of Domsjö project

Domsjö

&

CHEMREC

in collaboration

- Pre-feasibility study completed
- Domsjö mill liquor gasified successfully tested in DP-1
- Investment grant approved by Swedish Energy Agency
- Feasibility study under way
- Front-end Engineering Design (FEED) scheduled for Q1-Q3 2010 for project procurement in Q3-Q4 2010
- Planned production start H1 2013

Transforming Pulp Mills to Biorefineries

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Transforming Pulp Mills to Biorefineries

Summary and Conclusions

- Adding fuel generation to a pulp mill increases cash flow with 30-35% (without green credits).
- Fuel generation at pulp mills has in various studies shown to have highest efficiency and lowest production cost compared to renewable fuels alternatives
- No quality demand on added renewable biomass. It is fed to a hug fuel boiler.
- Gasification opens up for new pulping cycles in the mill which potential of increased pulp yield.
- Brown field construction simplifies permitting procedures.
- Pulp mills are ideally located for large scale handling of renewable material as the logistics and systems are already in place.
- In most cases pulp mills are located where huge amounts of biomass materials are available in the proximate vicinity.

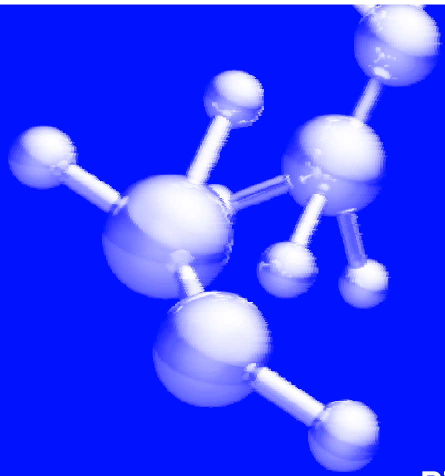
CHEMREC
Energy to Succeed

Transforming Pulp Mills to Biorefineries

With support from and in collaboration with…

www.chemrec.se

CHEMREC
Energy to Succeed

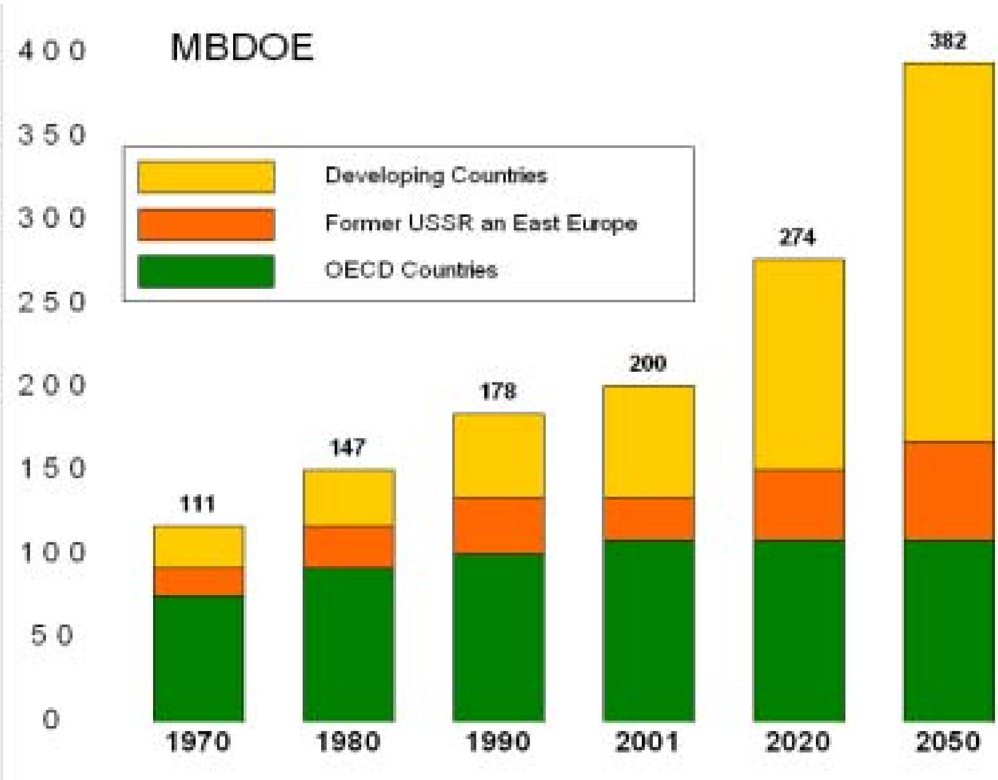


Biomass Gasification
22-23 of October, Stockholm, Sweden
Swedish Gas Centre (SGC)

BTL - Biomass to Liquid Technology and Renewable Products

Lars Otter, Dr. Armin Günther, Lurgi GmbH

World Energy Consumption / Regions



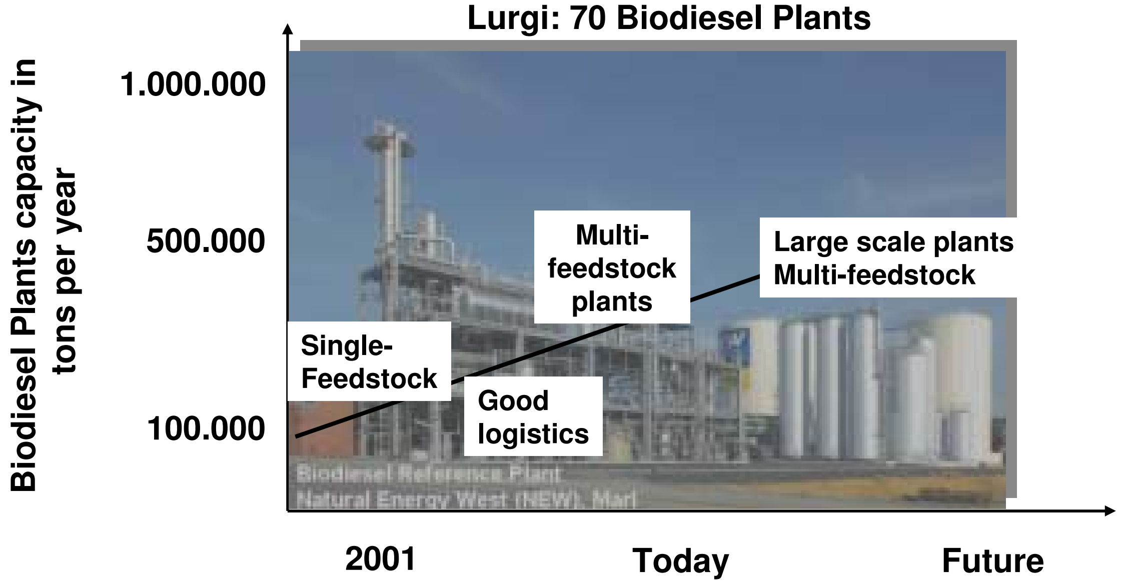
Source: BP

1st Generation Biofuels
Biodiesel Plants

Lurgi

AIR LIQUIDE

Lurgi: 70 Biodiesel Plants



Multifeedstock, trends integration of oil pressing and extraction.
Utilisation of by-products: glycerin

"Challenging times for biodiesel"

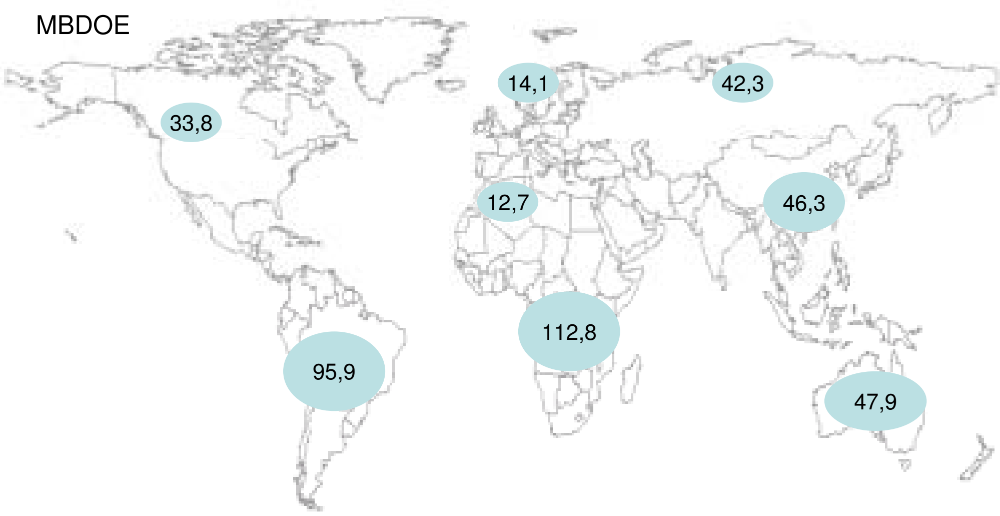
Other treatment path -> 1.5 Generation: hydrotreating of oils and fats for the production of "green diesel"
Product with high cetane number, low CFPP. Low grade feedstock is possible.

Potential for Biofuels from Biomass

Lurgi

AIR LIQUIDE

- Energy from renewable resources can be increased from ~10% today to ~30% by 2050



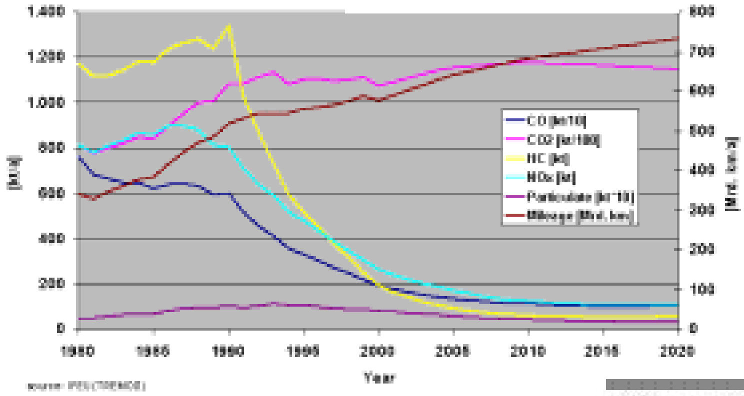
World energy consumption 2005 ~ 240.MBDOE - Biomass ~ 10%
World energy consumption 2050 ~ 380.MBDOE - Biomass utilized realistically ~ 30%

Source for Biomass potential: Utrecht University Faaji 2006

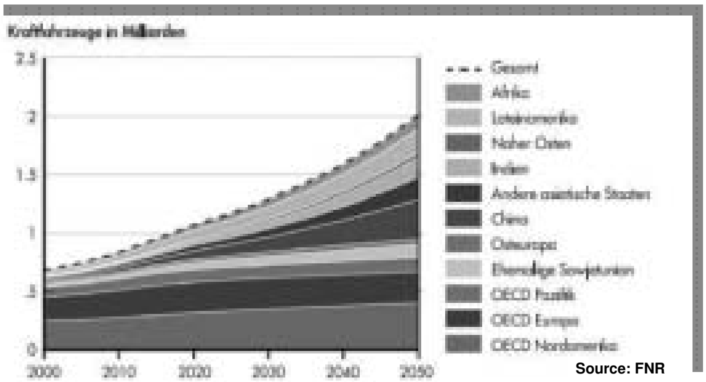
Trends in Passenger Car Emissions
How to Reduce CO2-Emissions ?

Lurgi

Example Germany



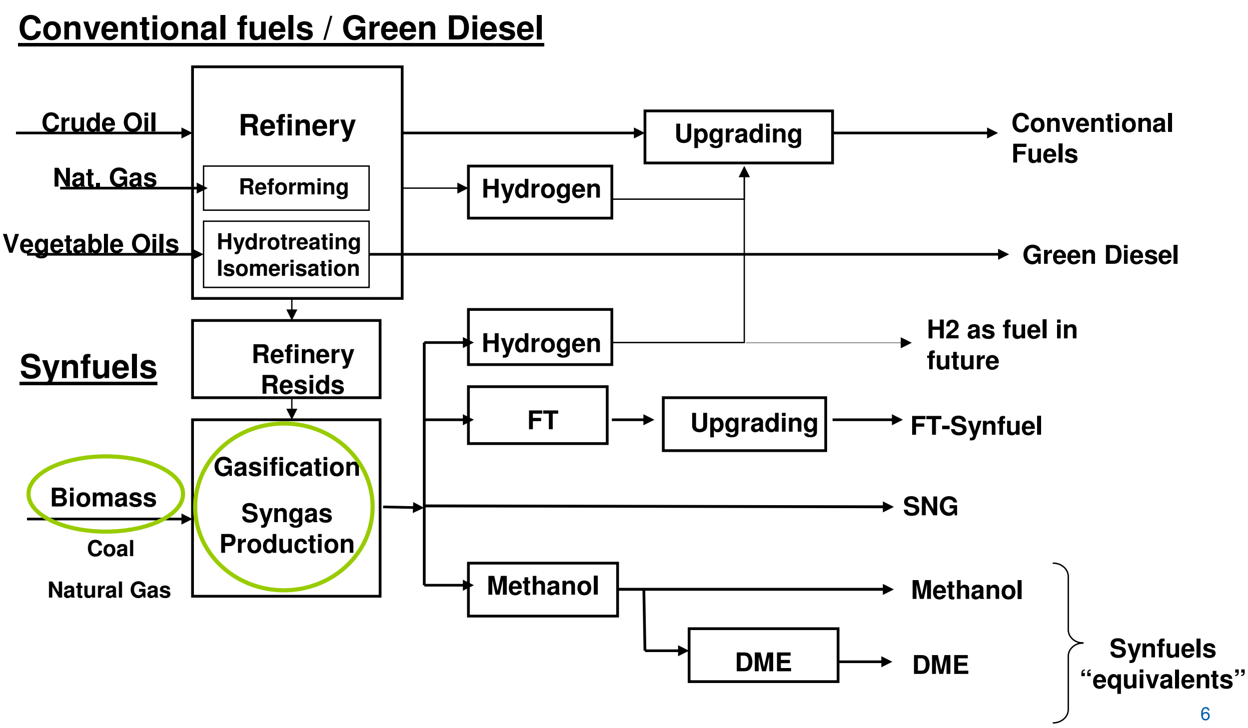
Source: Volkswagen AG



Source: FNR

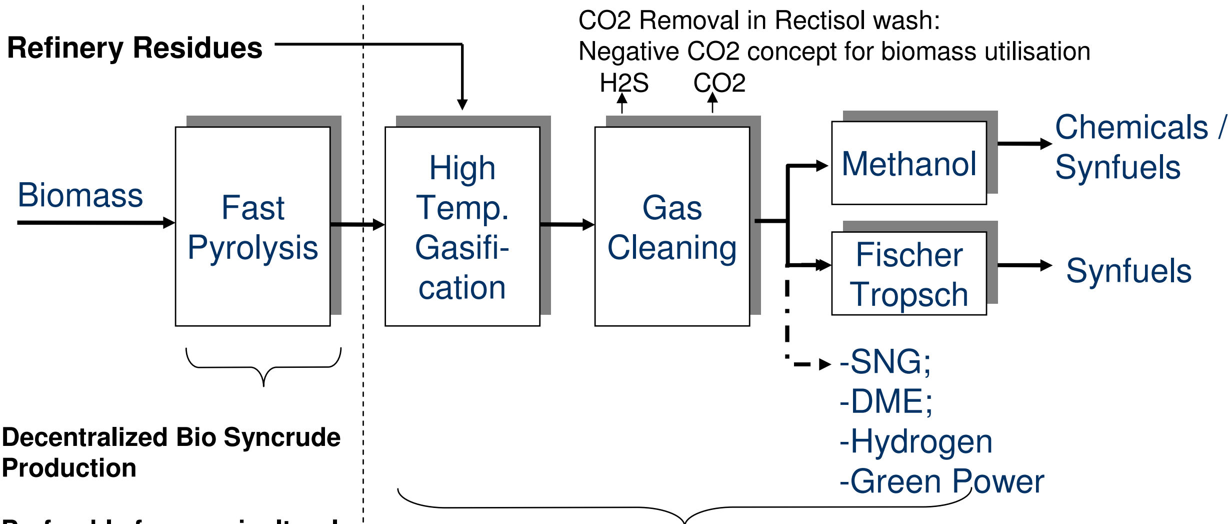
Fuel Production Technologies

Lurgi



2. Generation Biofuels:
Bioliq: „The thermo / chemical route“

Bioliq®-Process: Joint Development by FZK *) / Lurgi and sponsored by FNR*)



Preferably from agricultural by products / energy plants

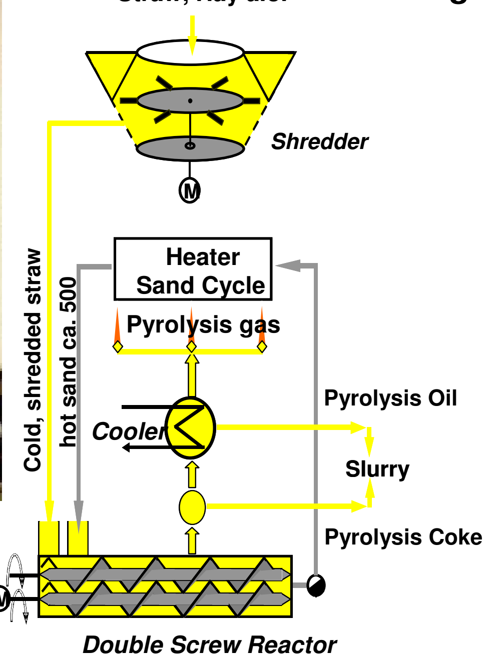
Storage & Transport **Preferred location in existing Refineries**

*) FZK: Forschungszentrum Karlsruhe
**) FNR: Fachagentur für Nachwachsende Rohstoffe

Pyrolysis Process of Lurgi / FZK

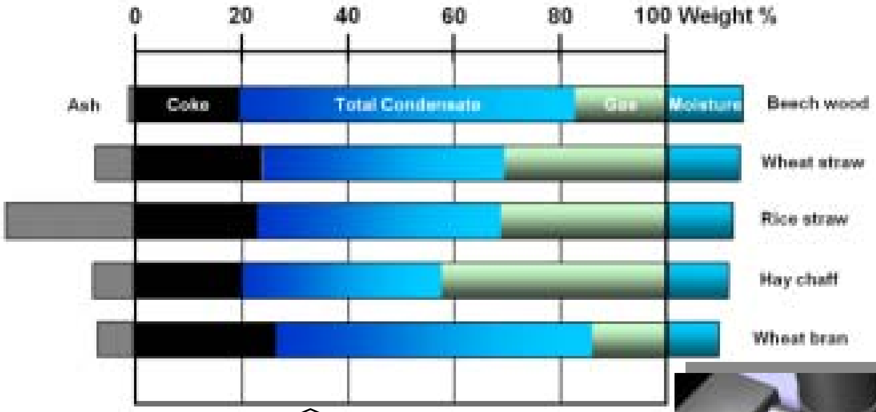
Development together with Forschungszentrum Karlsruhe

The Lurgi flash-coker

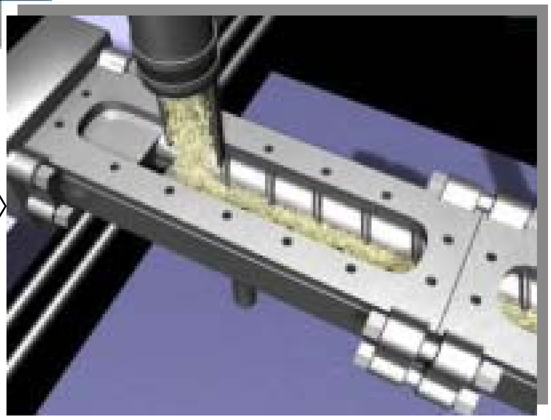


Source: FZK

Results Fast Pyrolysis Process of Lurgi / FZK-Plant

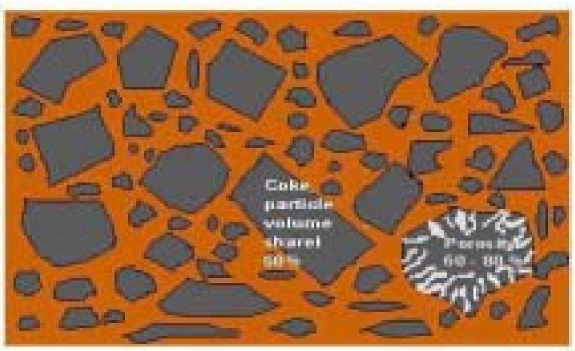


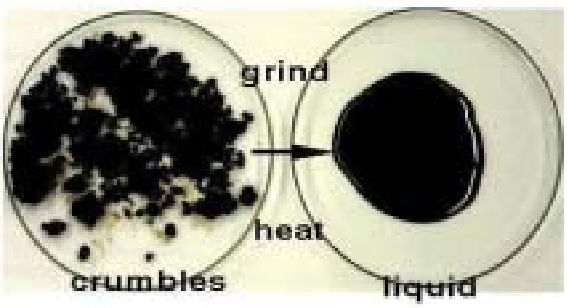
Converting different types of waste Biomass to "Bio Syncrude"



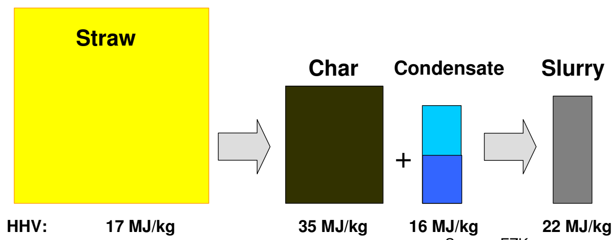
Source: FZK

Slurry mixed with Pyrolysis coke





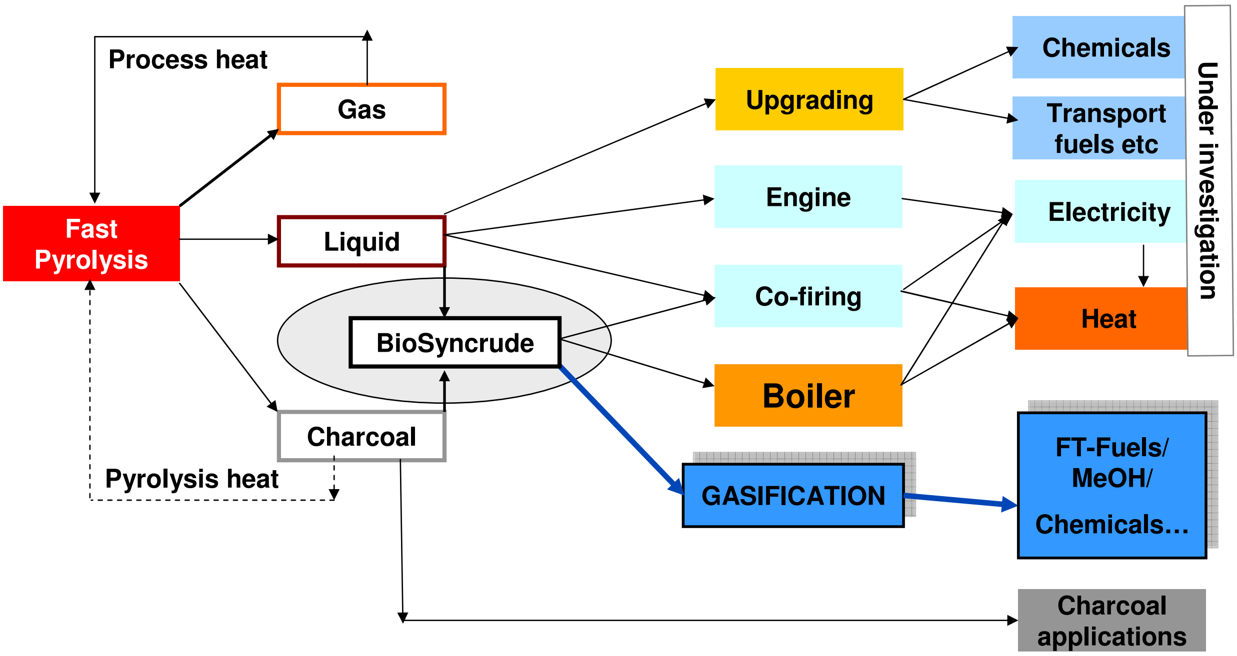
- Joint grinding of pyrolysis oil and coke give pump able/ storable slurry
- Energy concentration from biomass to slurry by factor 13
- ca. 80% of the energy content of the biomass is contained in the slurry



Source: FZK

Bio-Oil / BioSyncrude a valuable intermediate

Applications of BioSyncrude



Sources: IEA Bioenergy: T34:2007:01
& Lurgi

Synthetic Fuels from Biomass Pyrolysis Plant

- Bioliq Technology under Development with FZ-Karlsruhe

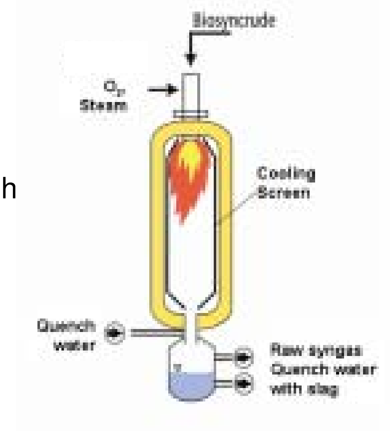
Entrained Flow Gasification

MPG Multi Purpose Gasifier with cooling screen

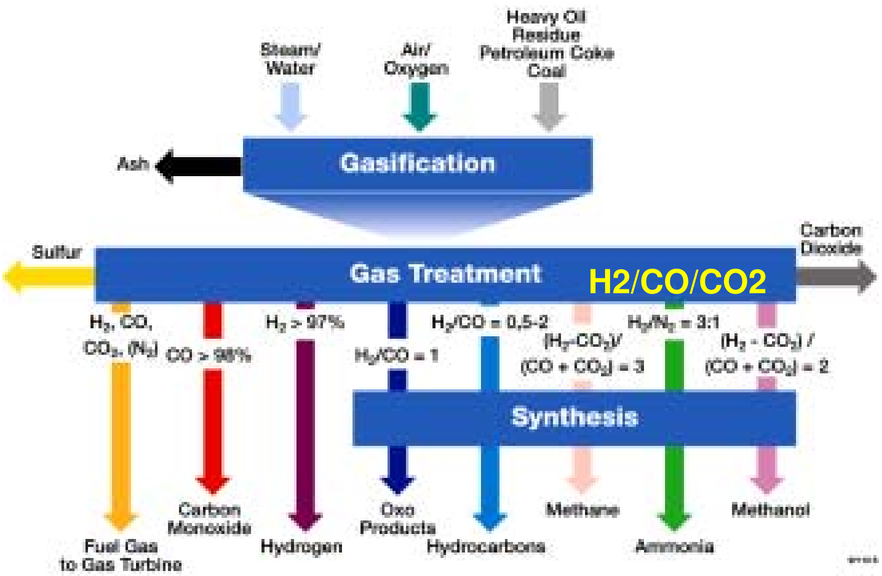
- Commercially proven technology for refinery residues
- Further development: Integration with LR Coker for gasification of BioSyncrude
- Gasification with O2, suitable for high ash feedstock's, 1200 °C & high pressure, tar free Syngas.

Feedstock Flexibility

-No limitations on Flash Point of Feedstock
-Allow high Viscosity
-Particles up to 1 mm



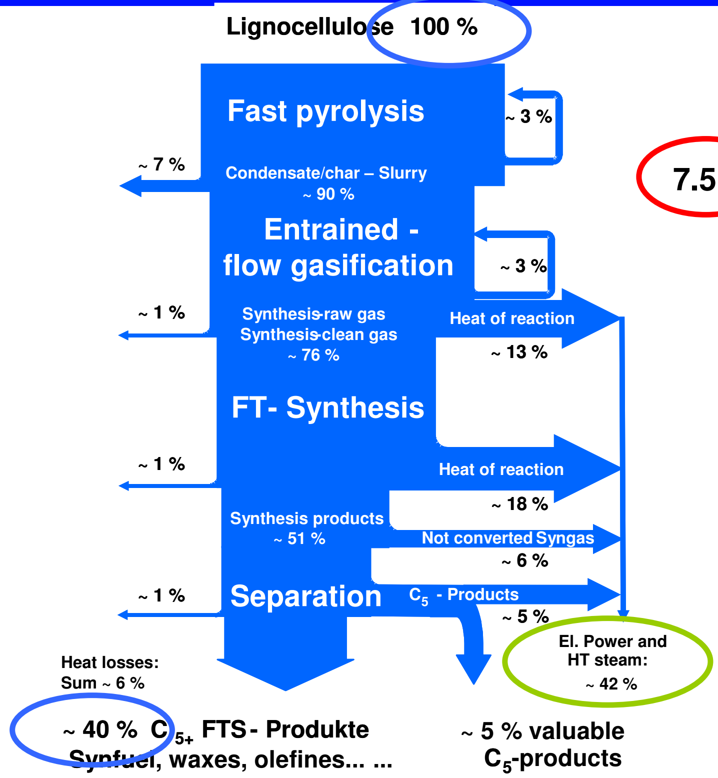
Multi Purpose Gasification – Syngas production
Downstream Synthesis



IGCC Petrochemicals

Refinery Synfuels Fertilizer SNG

Energy and mass balance



7.5 t Wood or Straw with 15 wt.% H_2O

5.4 t Condensate/char - slurry plus ~ 1,8 t O_2

1.2 t FTS-raw products

1 t Synthetic fuel

Co-production of: chemicals, steam, electricity

Source: FZK

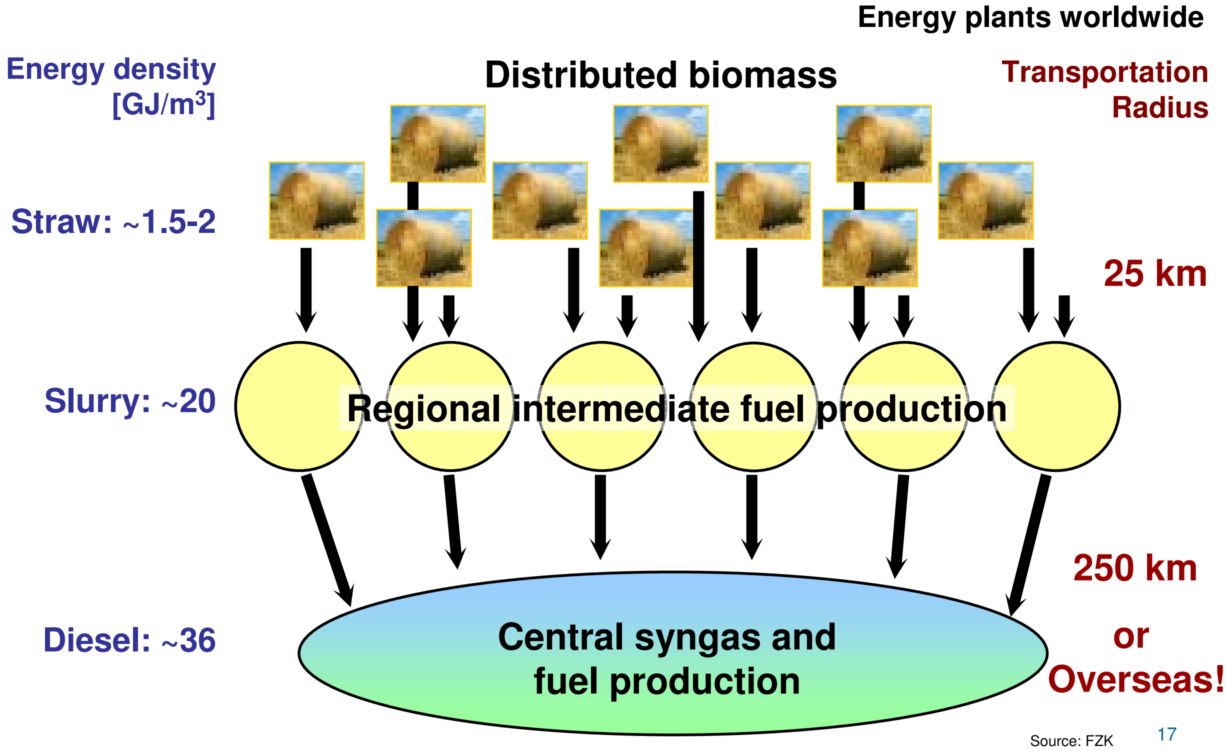
Synthetic Fuels from Biomass

- A Major Issue – Energy Density

Model shows the volume of different materials which is equivalent to 1 ltr of petrochemical oil

How to design the logistics of Large-scale plants ?

The Slurry Gasification Concept

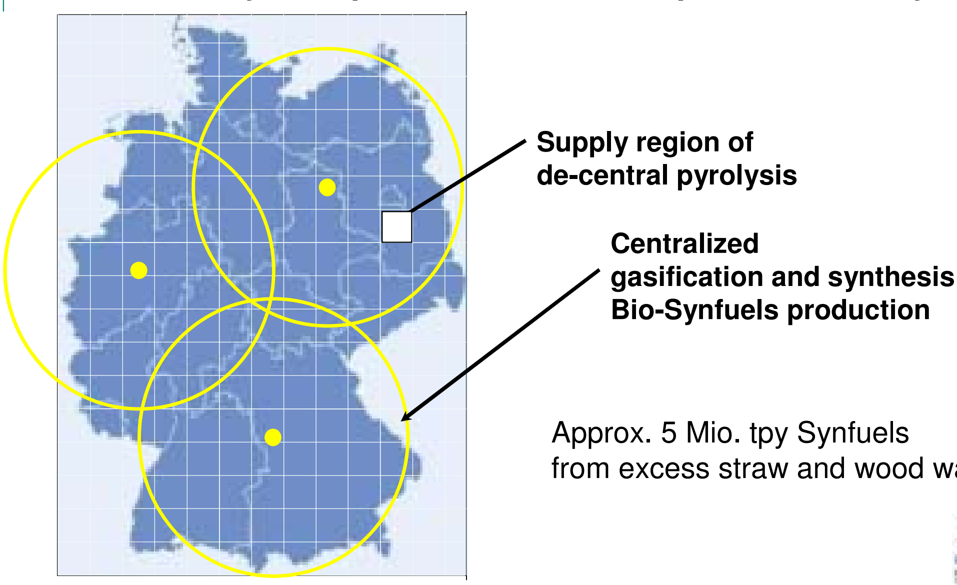


Source: FZK

Zentralized / dezentralized Biofuels concept

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Synfuel potential as an example for Germany



Approx. 5 Mio. tpy Synfuels
from excess straw and wood waste

Source KIT/FZK 2009

Current state of bioliq pilot plant

Construction stage

2008

~2012

Fast pyrolysis	bioliq I
BioSyncrude gasification	bioliq II
Synthesis gas cleaning and conditioning & MeOH	bioliq III
Transportation fuel	bioliq IV

Operation of complete bioliq plant

Key factors for BTL-success

Biomass to Liquid - Critical Success Factor:

Secured long-term framework for BTL

May be a combination of:

1. Tax exemption for biofuels

- Retailers are exempted from CO_2 fee and mineral oil fee in accordance with blending ratio

2. Direct investment support

3. Retailers' obligation / certificates

- Retailers are obliged to blend x% biofuels in conventional diesel
- Penalty fee if obligation not met

4. Obtain credit for higher CO_2 avoidance for BTL

Need for internationally harmonisation of:
Tax regulations
Import and export conditions
Sustainable production regulations

Summary

Lurgi AIR LIQUIDE

In future BTL will be the sustainable alternative for oil, gas and coal to reduce CO_2 in transport sector

Feedstock availability, energy efficiency and land use are the drivers towards Biomass-to-Liquid Technologies

BTL Technology will be based on widely proven process steps

BTL can become mainstream if several parameters meet simultaneously. Need to be:

- Cleaner – clear life cycle benefits
- Tangible – soon i.e., by 2015
- Independent – should not be in competition and independent to e.g. food production, electricity production via biomass

BTL will complete the overall fuel mix together with 1st Generation Biofuels in future

Lurgi AIR LIQUIDE

Thank

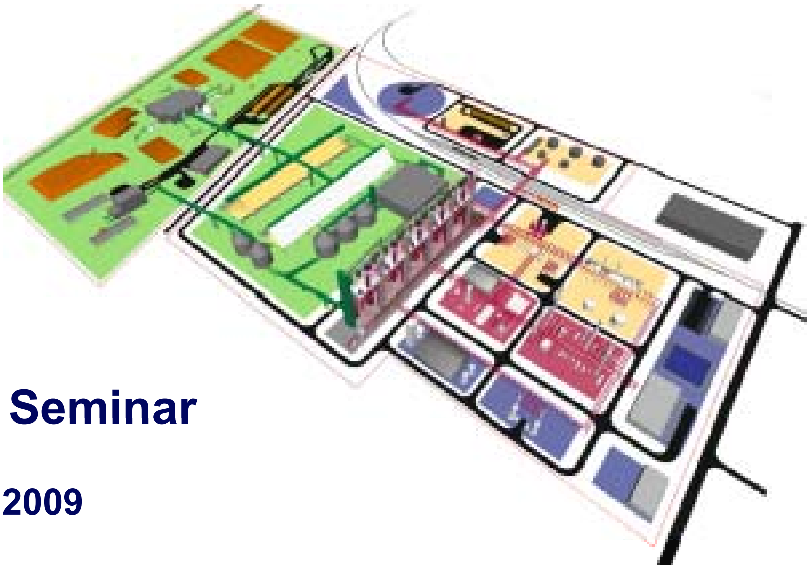
You!

!

!

!

Commercial scale BTL production on the verge of becoming reality



Biomass Gasification Seminar

Stockholm, 22.-23. October, 2009

CHOREN Industries GmbH
Frauensteiner Strasse 59 • 09599 Freiberg • Germany
kathrin.bienert@choren.com • www.choren.com

Outline

- CHOREN at a glance
- CHOREN's gasification technology
- Industrial application of syngas
- Current development status and outlook

CHOREN at a glance

C = Carbon
H = Hydrogen
O = Oxygen
REN = Renewable

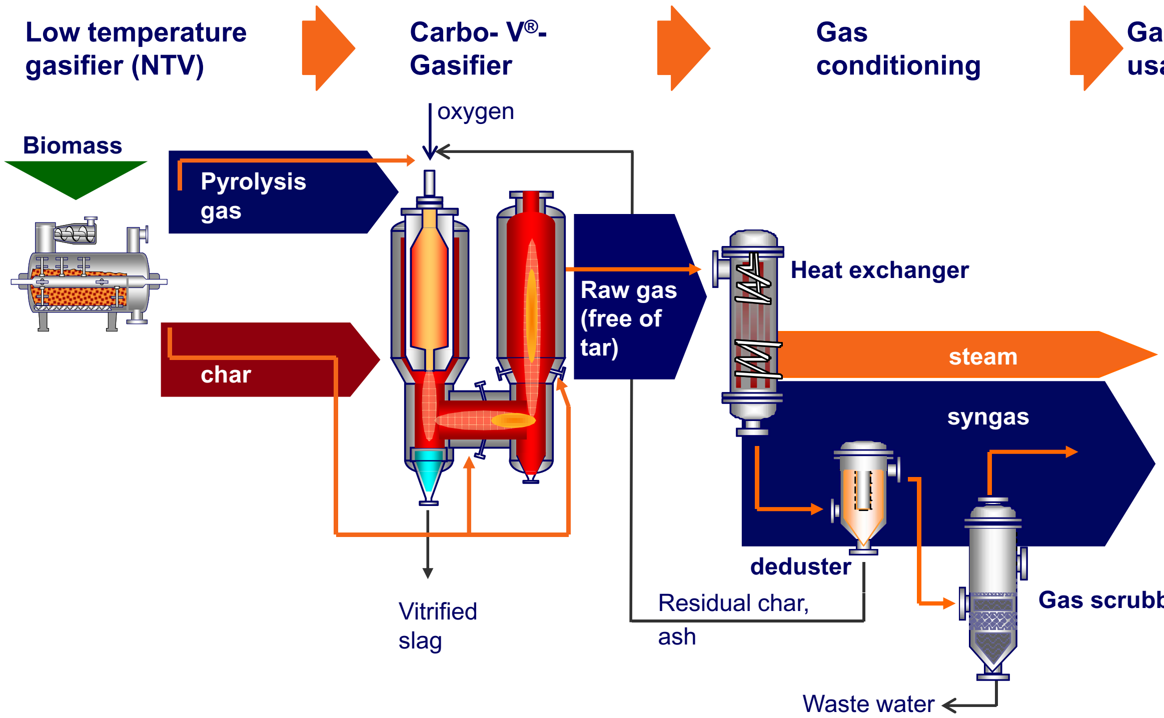
- German gasification technology company, founded in 1990
- Patented Carbo-V® process
- Branches in China and USA
- First mover in BTL technology via FT
- Private company; Partnership with VW, Daimler and Shell
- Capital employed > 180 m Euro
- ~ 280 employees
- World's first commercial BTL facility in operation (early 2010)

- **Strategic goal: global market leader for medium and large-scale gasification technology**

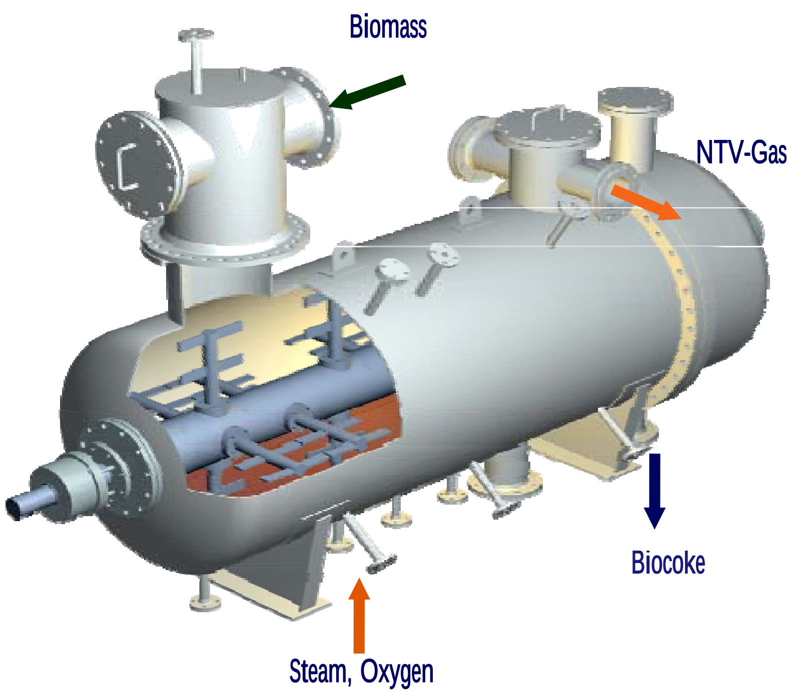
Key-Features of Carbo-V®

- 3-step gasification process:
  1. Low temperature gasification (400 - 500°C)
  2. High temperature gasification (1300 -1550°C)
  3. Chemical quenching of hot gas down to 900°C
- Entrained flow gasification for step 2. and 3.
- Cooling screen integrated in high temperature reactor
- Oxygen-blown
- Pressurized gasification (6 bar a)
- Slagging gasifier
- Vitrified slag
- Product gas containing ~75% of ($CO+H_2$); balance for CO_2 and H_2O
- Tar-free product gas

The Carbo-V® Process



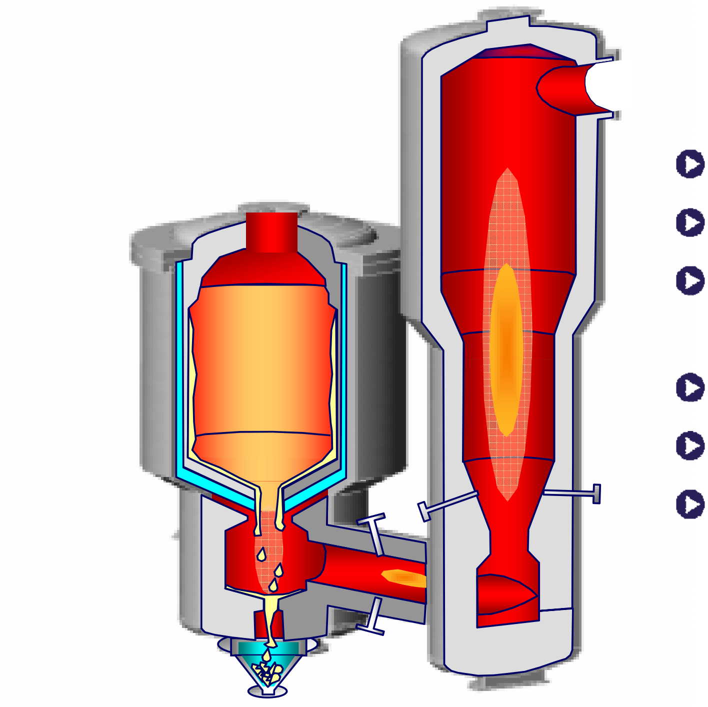
NTV ~ Low Temperature Gasifier



- rotating equipment
- pressurized at 5 bar g
- Heat resistant steel

HTV ~ HT Gasifier with Chemical Quench

CHOREN



- stationary equipment
- Pressurized at 5 bar g
- design expertise from coal gasification
- Cooling screen
- slag protected refractory
- tar free syngas

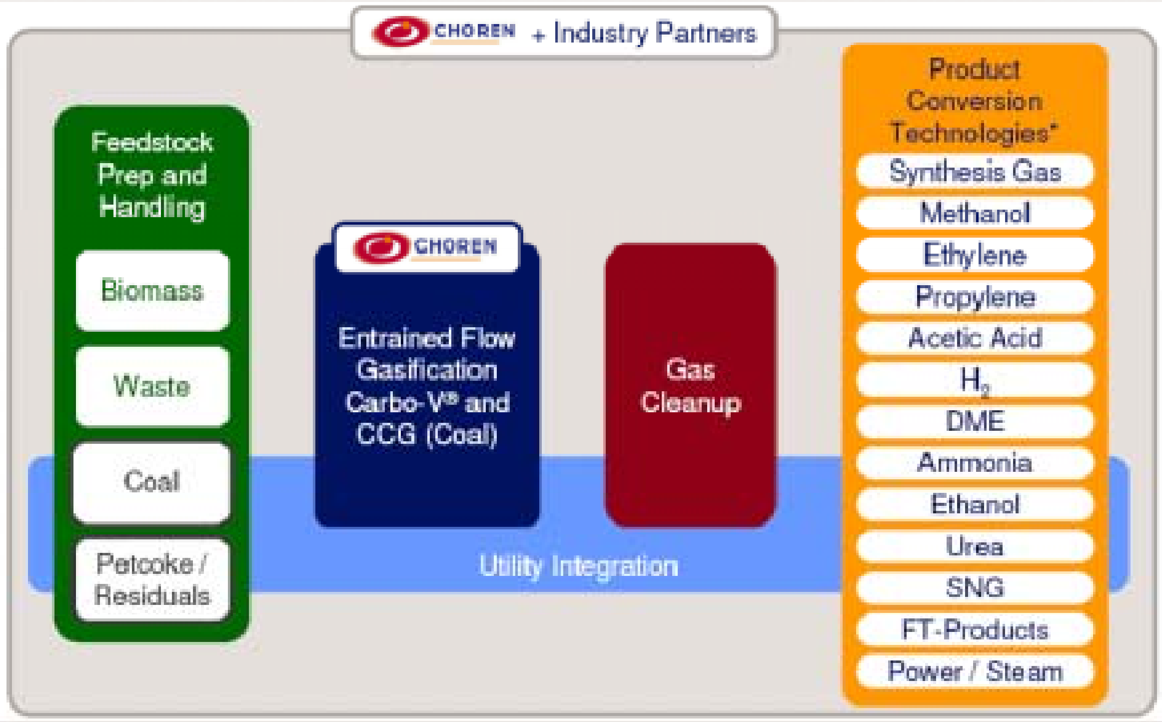
Carbo-V®– gas composition

CHOREN

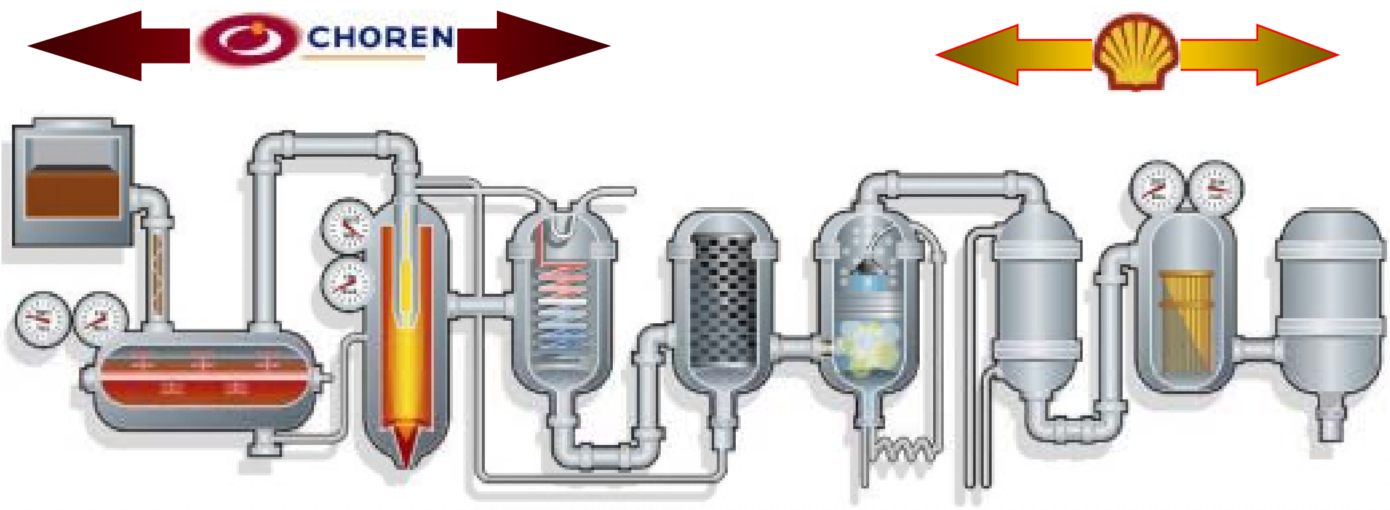
Gasification of wood, gas composition after gas scrubber

	Carbo-V 160/5 O2 (99,5%) mol % in dry gas
CO	41,2
CO_2	24,0
H_2	33,7
CH_4	< 0,1
N_2	1,1
H_2S	< 0,02

Application of Syngas



The BTL Process-line



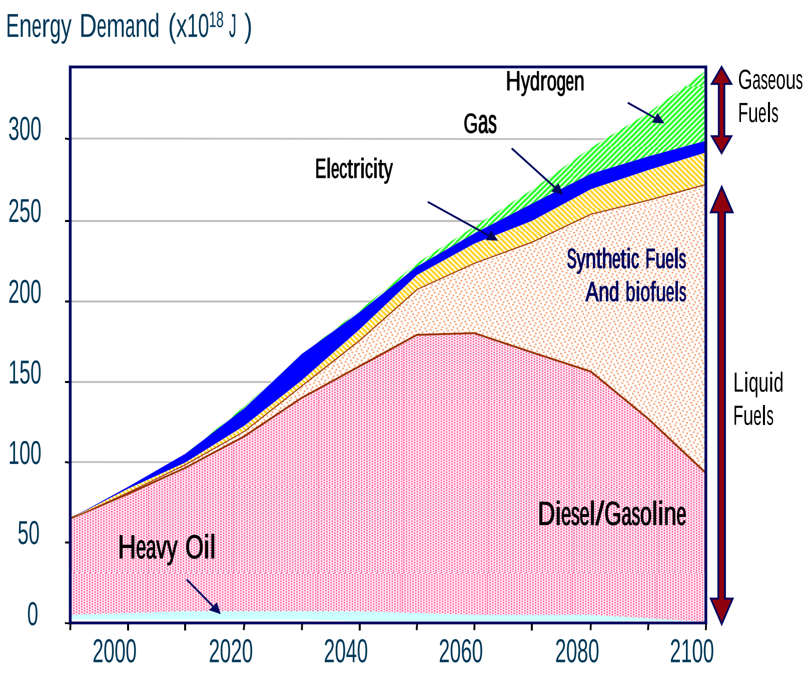
Three Phase Gasification

Gas Treatment

Fischer-Tropsch & Hydrocracking

Predicted Automotive Fuel Demand

New fuels for the future – but fossil fuels still dominate

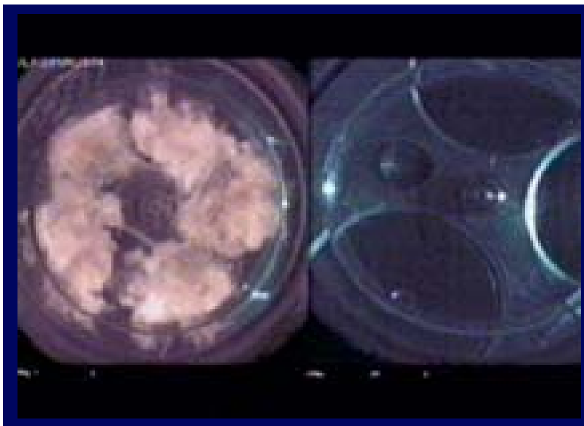


Source: WEC & Shell

- Improved energy efficiency will be of prime importance
- Key selection criterion for alternative fuels ought to be cost effectiveness
- Bio Fuels are the only short term viable non-fossil fuel option
- Wealth of potential vehicle-fuel solutions
- Fossil fuels will dominate the market for the next decades
- Existing logistics for liquid fuels will benefit non-gaseous fuels

SunDiesel® – *made by CHOREN*

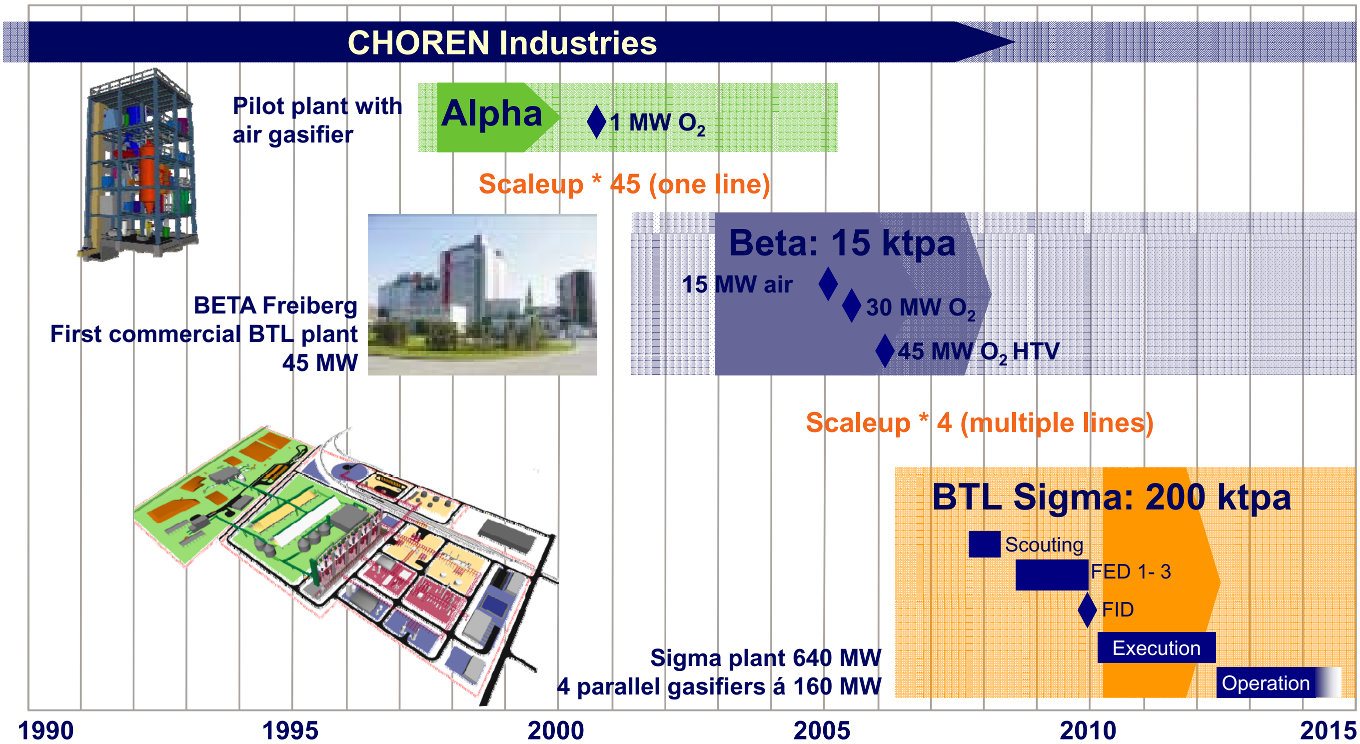
- Fits any diesel engine / fits current infrastructure system
- Sustainable / renewable and almost CO_2 neutral
- Clean fuel – NOx & SOx, significantly reduced particle emissions
- Higher yield/ha
- High energy density (~40 MJ per litre)
- Very stable – storage & transport not an issue
- Produced domestically – creates jobs
- Contributes towards energy security



Fossil Diesel SunDiesel®

Development stages at CHOREN

CHOREN



Alpha-Plant in Freiberg

CHOREN

2001: First BTL from bio-syngas in laboratory scale

April 2003: First liquids (methanol) produced from wood

May 2003: After the production of 11,000 litres, the R&D program for methanol was finished

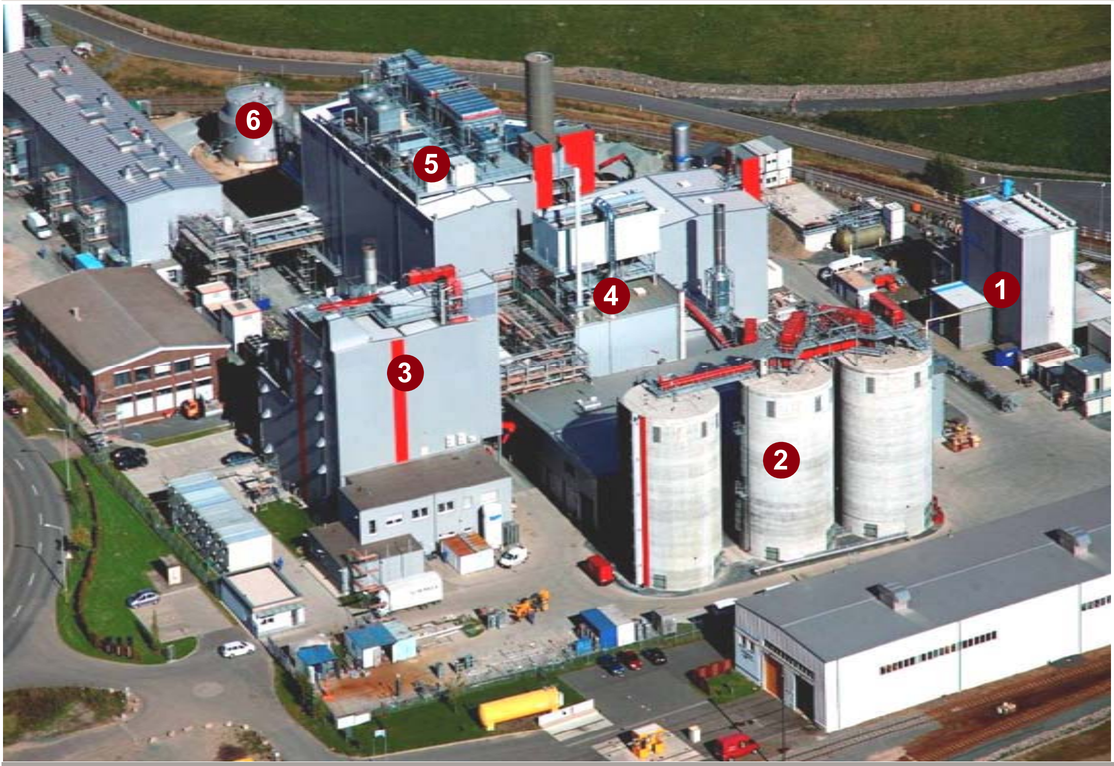
June 2003: First production of FT-liquids from wood

2004: Process and product optimization in the EU 6th frame program (RENEW)

2005: long duration (3,000 h) test of BTL production

Beta-Plant

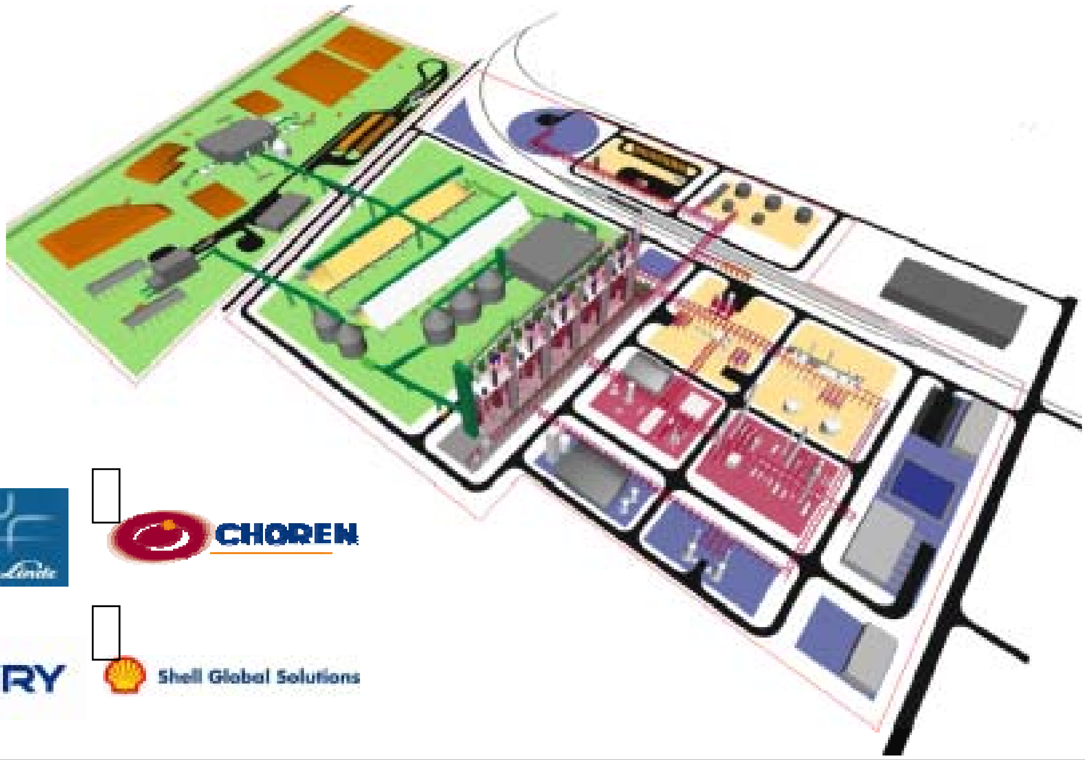
45 MW thermal **68,000 t/a feedstock** **18.0 mio. l *SunFuel***



1 Alpha-Plant
2 Biomass storage (wood chips)
3 Carbo-V® Gasifier
Power station
4 Fischer-Tropsch-synthesis
5 Tank farm
6

Sigma 1 plant layout

Schwedt site – end of scouting phase



CHOREN
PÖYRY
Shell Global Solutions

Key data of Sigma 1

Fuel production BTL	**200,000 t/a equals 5,000 BOPD equals 260 million litres**
Gasification capacity MW$_{th}$	**4 x 160 MW$_{th}$ parallel operation = 640**
Biomass demand	**approx. 1 million t$_{dry}$/a**
Area required for the facility	**30 ha**
• Production plant	up to 10 ha
• Biomass store	up to 15 ha
• Tank farm and peripheric systems:	up to 5 ha
Employment (primary)	**850**
• Biomass supply	600 up to 700
• Production	200
Investment	**> 800 million €**
Reduction of greenhouse gas emissions	**650.000 t CO_2 / a**

C = Carbon

H = Hydrogen

O = Oxygen

REN = Renewable

Disclaimer: The document is incomplete without reference to, and should be viewed solely in conjunction with the oral briefing provided by CHOREN. Certain statements that are included in this presentation are forward-looking in nature. There are associated risks and uncertainties inherent in such statements and actual results may differ materially from those expressed or implied by the forward-looking statements. CHOREN doesn't assume any liability for those statements. There is no requirement or obligation for CHOREN to update these forward looking statements.

B&W vølund

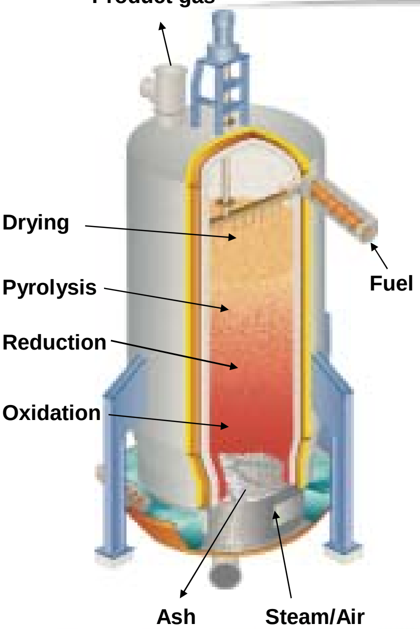
Update on the Harboøre Updraft Gasification Technology

Stockholm, October 2009

Kasper Lundtorp
Manager, Research & Development

Facts at a glance

- Main business areas:
  - *Waste-to-energy systems*
  - *Biomass energy systems*
  - *Gasification*
- Headquartered in Denmark
- Founded in 1898
- 100% owned by Babcock & Wilcox Company Power Generation Group Ltd., Ohio, USA
- 360 employees worldwide



Up-draft gasification

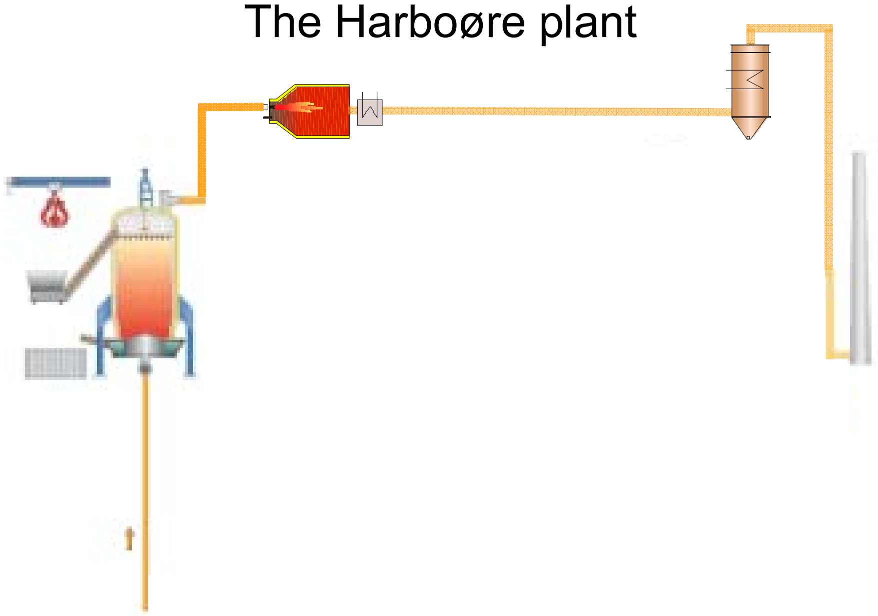
- A new technology based on an old concept
- Based on a concept from Keramische Industrie Bedarfs, Berlin (Dr. Horst Gatzke).
- A B&W Vølund research area since 1988

The Harboøre CHP plant

- First of a kind – focus on having the overall concept working
- Fuel: Woodchips. Moisture content: 35-55 %
- 3.7 MW_{th} / 1 MW_e
- Commissioned in 1996
- CHP capability added in 2000
- Originally designed for district heating

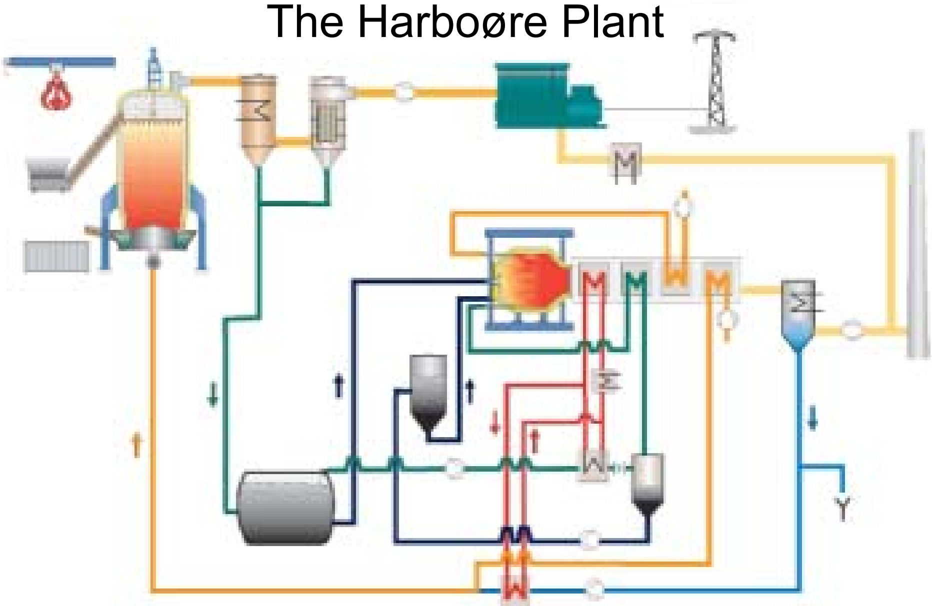
Babcock & Wilcox Vølund

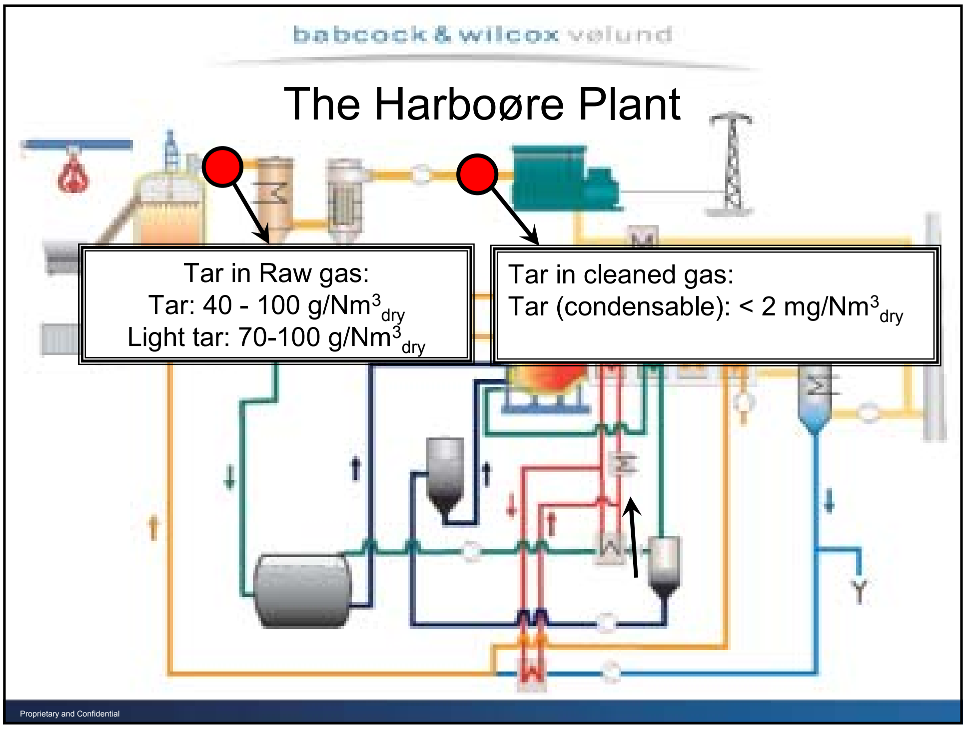
The Harboøre plant

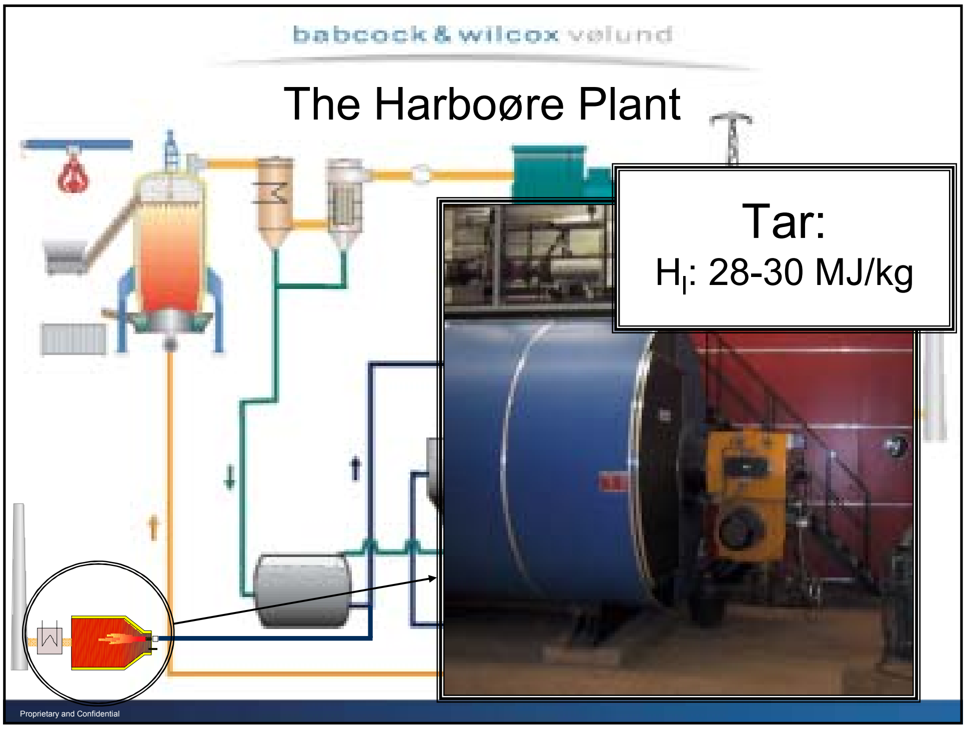


babcock & wilcox vølund

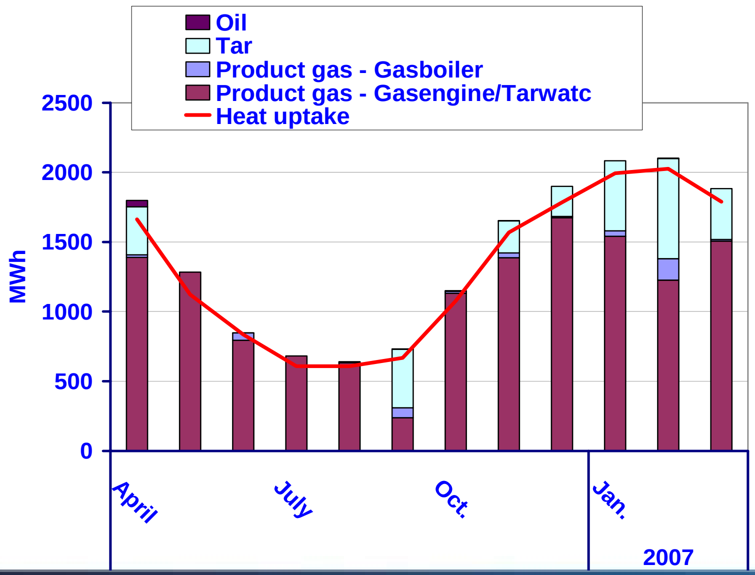
The Harboøre Plant




babcock & wilcox vølund
The Harboøre Plant
Tar in Raw gas:
Tar: 40 - 100 g/Nm3dry
Light tar: 70-100 g/Nm3dry
Tar in cleaned gas:
Tar (condensable): < 2 mg/Nm3dry
Proprietary and Confidential

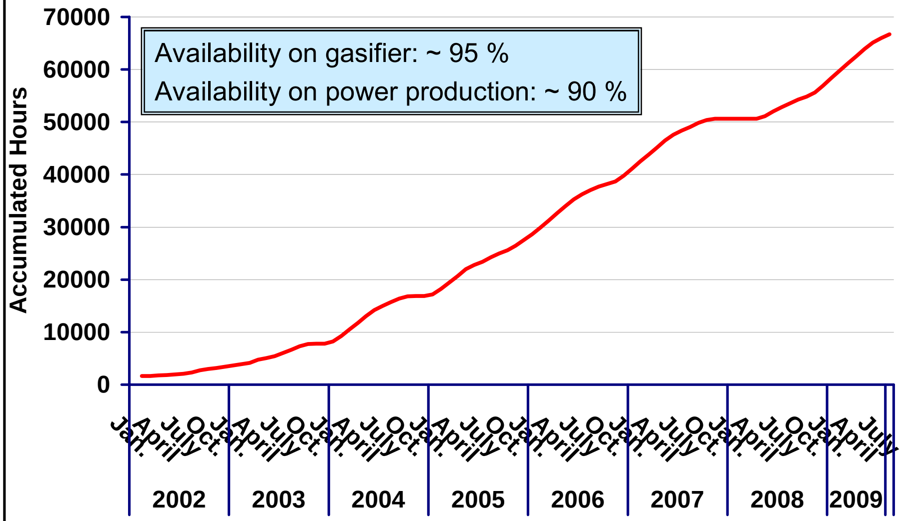

babcock & wilcox vølund
The Harboøre Plant
Tar:
Hl: 28-30 MJ/kg
Proprietary and Confidential

Production of heat at The Harboøre Plant

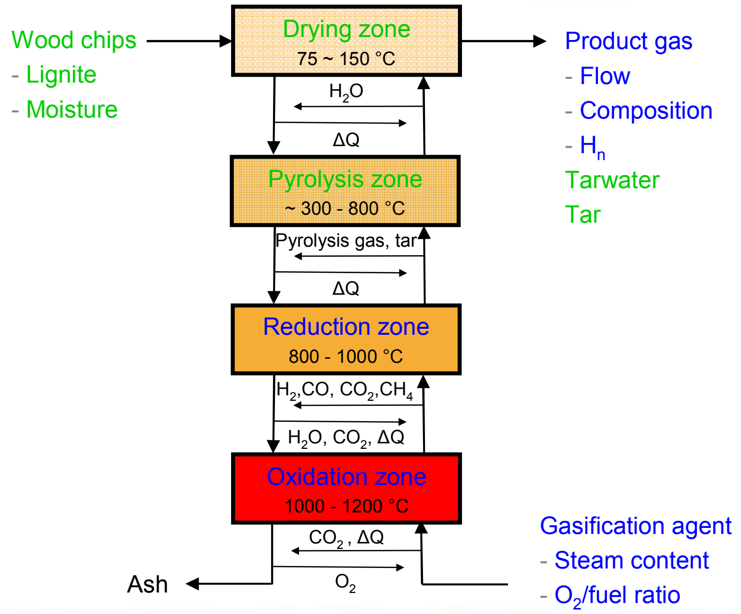


babcock & wilcox vølund

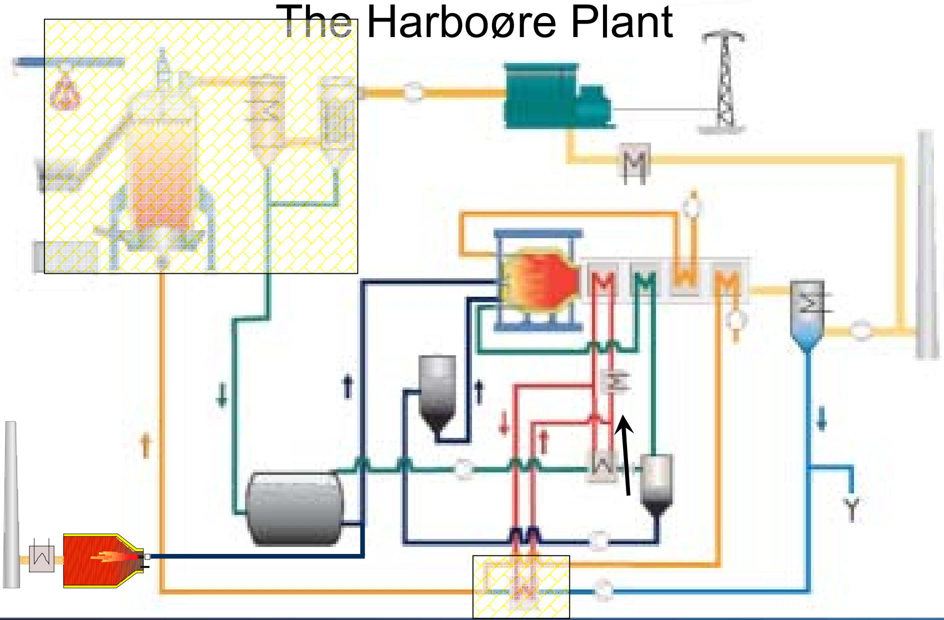
Harboøre CHP – Gasengine operation



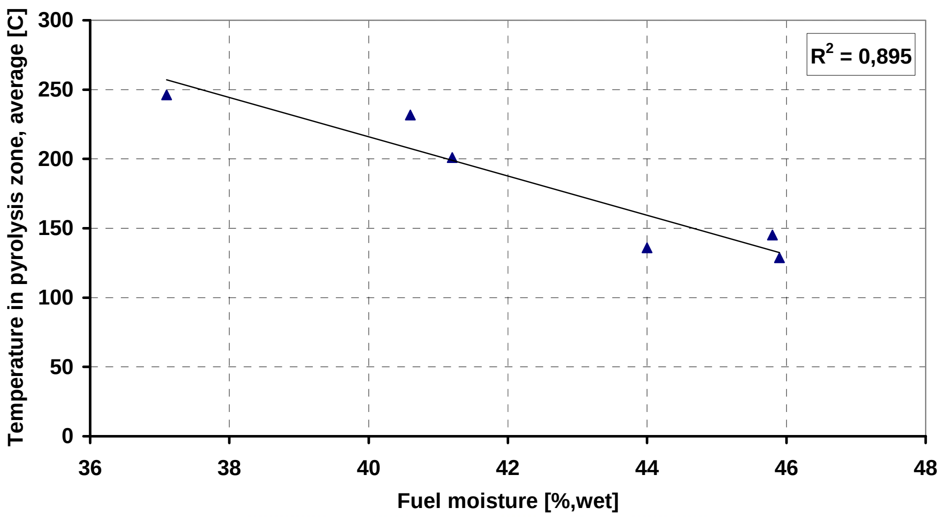
Proprietary and Confidential



The Harboøre Plant



Pyrolysis dependency of fuel moist



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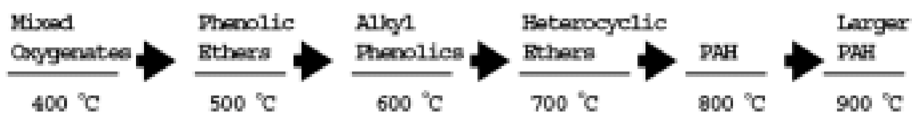
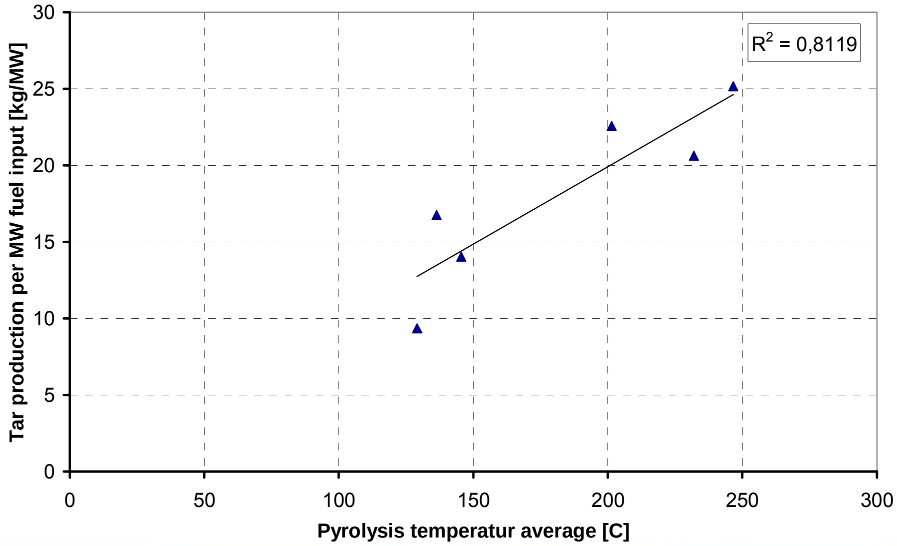
Tar composition



Egsgaard and Larsen, 1999

Proprietary and Confidential

Tar production dependency of pyr. temp.

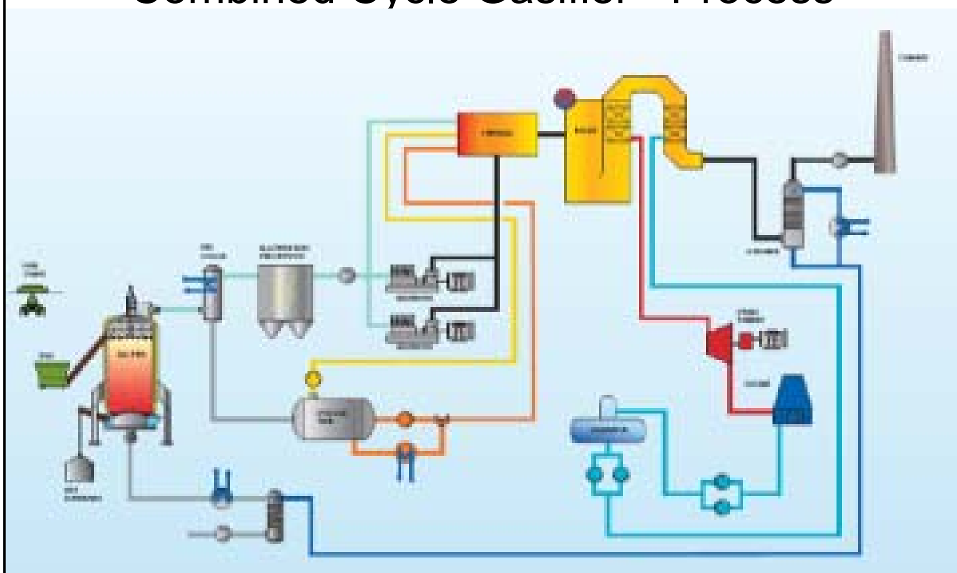


Commercialising the technology: Concepts

- Combined heat and power stations
- Burnable gas generator
- Wasteboost – external superheater for Waste fired power plants
- Combined cycle gasifier based power station

Autumn 2007 at Yamagata (2 MWe)

Combined Cycle Gasifier - Process



Combined Cycle Gasifier - Benefits

- Higher electrical output (approx. 38%)
- CO is burned out – expected less than100 mg/Nm^3 at 6% O_2
- NO_x staging – expected 200 mg/Nm^3 at 6% O_2
- Water neutral (no consumption – no waste water) may produce water if required.
- District heating is optional
- Good turn-down (1:10)
- Tar may be stored for start-up / back-up fuel

Babcock & Wilcox Vølund

Generating Powerful Solutions™

www.vølund.dk

Enerkem

Gasification of heterogeneous biomass residues and catalytic synthesis of alcohols

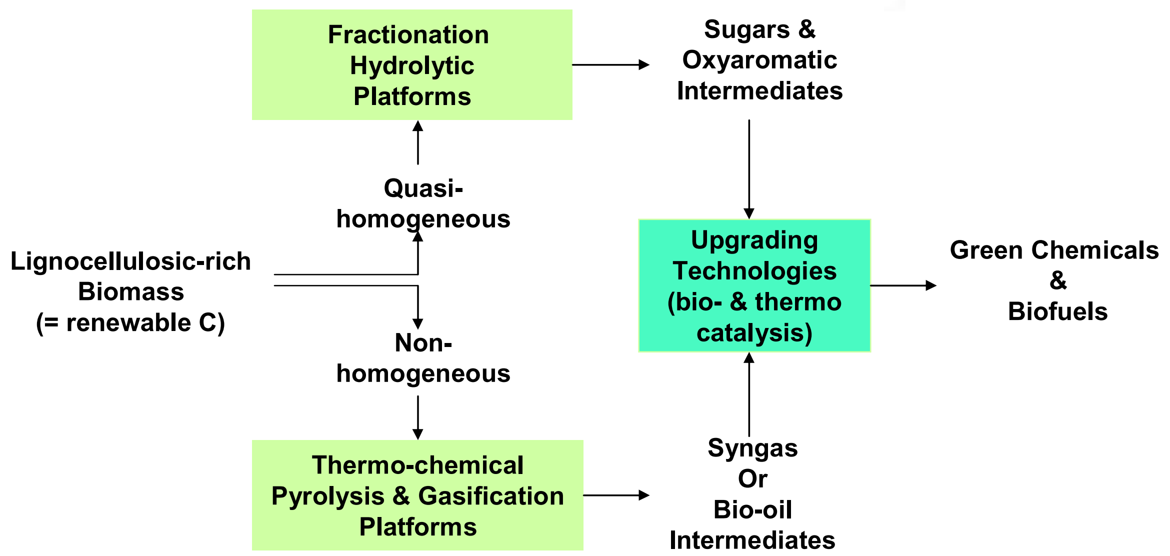
Esteban Chornet
CTO

Enerkem

Outline

- Context and Platforms
- Feedstocks
- Intermediates
- Integration of Platforms
- Gasification route to liquids
- Gas conditioning
- Commercialization efforts

Context



Note: *Heat & Power produced from the biomass itself, from intermediates or from process residues, will make the entire conversion strategies energy self-sufficient.*

Leading developer and producer of advanced fuels and green chemicals from waste

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Lignocellulosic Biomass as feedstock: categories & costs

- **Homogeneous biomass:**
  - **- Debarked wood chips ($US > 80 / tonne)**
- **Quasi-homogeneous biomass:**
  - **- Plantations (woody or herbaceous) ($US 60-80 / tonne)**
  - **- Residues: forest and agriculture ($US 30-60 / tonne)**
  - **- Residues from process industries ($US 0-30 / tonne)**

Residues need to be from species that are structurally and chemically alike

- **Non-homogeneous biomass (low grade):**
  - **- Residues mixed species ($US 30 - 60 / tonne)**
  - **- Urban biomass ($US (-50)-0 / tonne) -**
    - **• RDF from MSW from ICI (typically > 50 wt% biomass)**
    - **• Construction / Demolition wood**

Note: 1 tonne (dry basis) : ~ 18 GJ

Availability of Feedstocks

Even if abundant, when financing a project, the first question is : how much biomass is secured contractually ?

- Unused residual biomass is available in quantities > 200,000 t/y (anhydrous basis) in areas dedicated to large forest and agricultural operations.

  Contracts negotiated with Governments and/or large corporations

- Unused residual biomass is available in quantities comprised up to 200,000 t/y and readily available in the 25 000 - 100 000 t/y (anhydrous basis)

  Contracts negotiated with municipalities or private suppliers

- Urban biomass [MSW+ICI] 2.0 kg per person and day

  Contracts negotiated with municipalities or waste management companies

Strategies for quasi-homogeneous biomass

Quasi-homogeneous biomass -> biofuels + co-products

Biological approach:

Pretreatment; saccharification, fermentation, distillation

Fractionation approach:

Extractives, hemicellulosic sugars, cellulosic fibers, lignin are obtained as separate fractions (more homogeneous that the initial biomass) and subsequently upgraded individually on site or off site (to reach economies of scale)

In both approaches two ad-hoc operations are important:

Waste water treatment and recycling

Heat and/or power production from process residues

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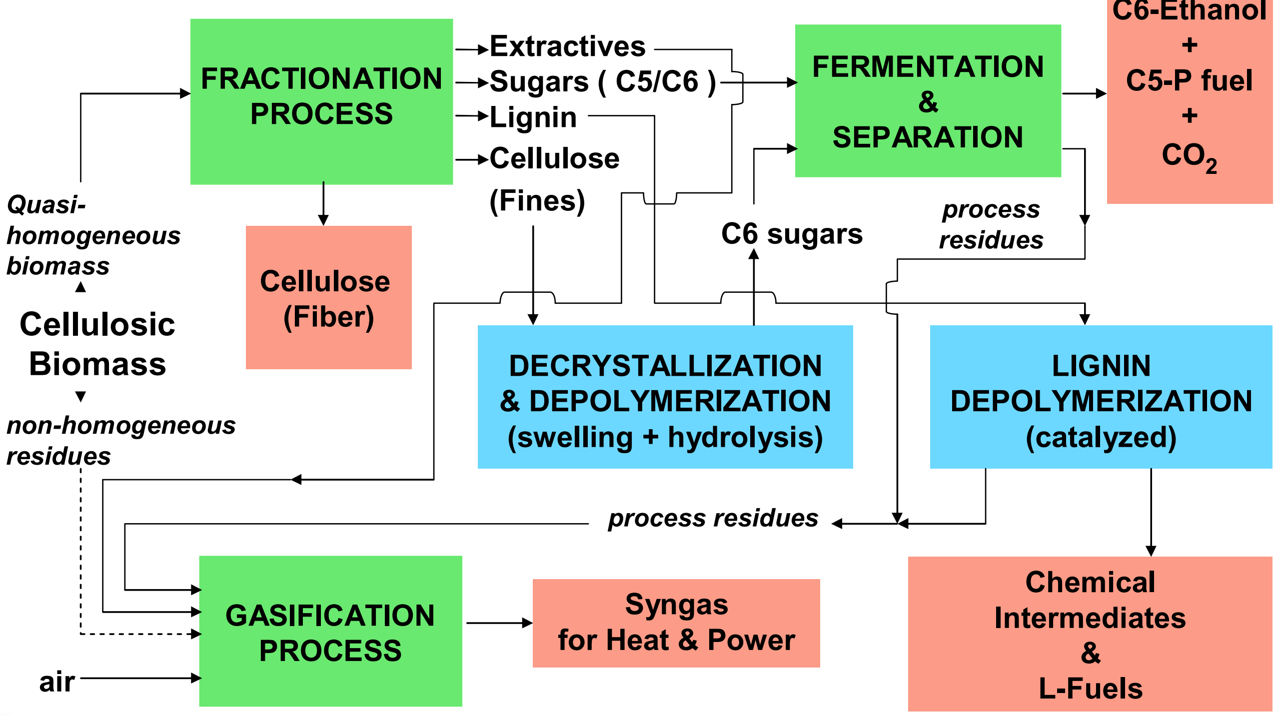
An energy self-suficient biorefinery



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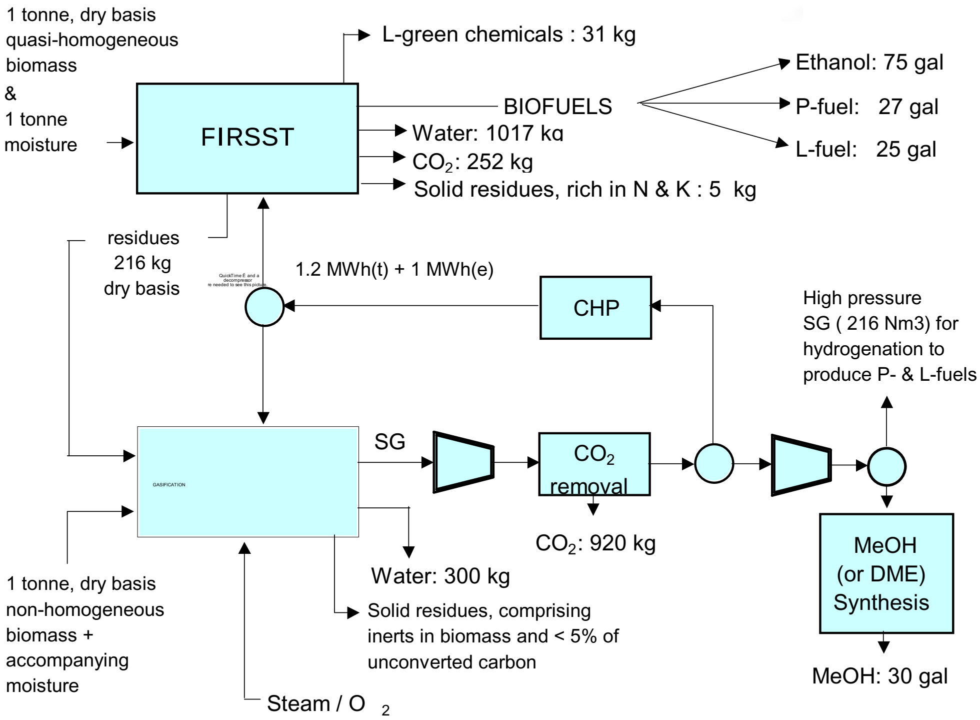
Energy Self-sufficient BioRefinery Integrating Quasi-homogeneous and Non-Homogeneous Biomass



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Gasification of non-homogeneous residual biomass

Leading developer and producer of advanced fuels and green chemicals from waste

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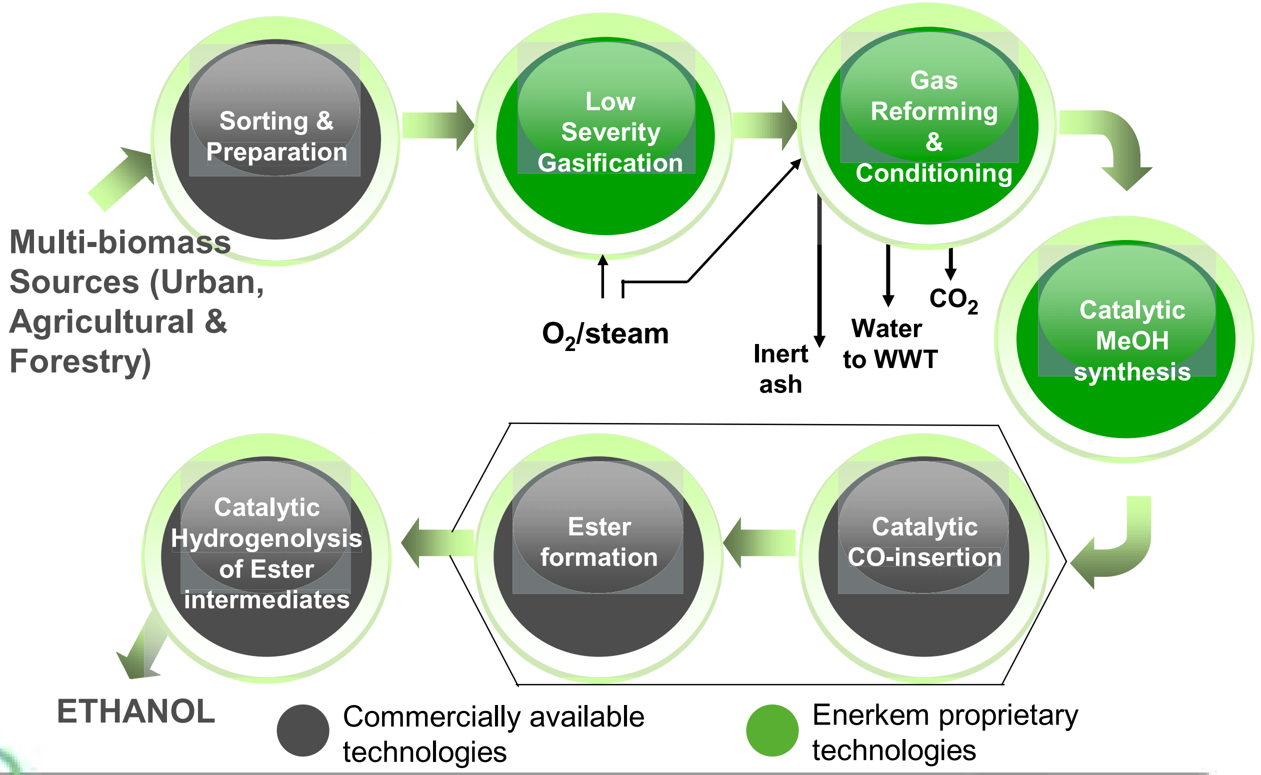
ENERKEM's Thermo-Chemical Platform



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Enerkem's Gasification & Synthesis Approach

- Enerkem's low severity fluid bed gasification: < 750 ºC; < 3 atm which includes proprietary fluff feeding system and O2+steam or O2-enriched air + steam
- Water (as moisture, as tar + water emulsion and as steam) acts as a moderator of the fluid bed temperature via control of the partial oxidation reactions.
- Cl and S control via formation of stable compounds
- Gasification solids removal from bed and from cyclones. Solids recovered meet specifications for landfill sites and they can also be used as construction materials
- Secondary reactor for higher temperature conversion of char and steam reforming, either thermal or catalytic, for enhanced H2 and CO production.
- Heat recovery and scrubbing
- Compression and Synthesis to MeOH in 3-Phase reactor. MeOH is the building block for DME, Higher Alcohols, or HCs.
- Unconverted syngas used for cogeneration if electricity is required to be produced internally. If not, a recycling loop for additional conversion of the residual syngas can be considered
- Wastewater treatment plant is part of the overall process

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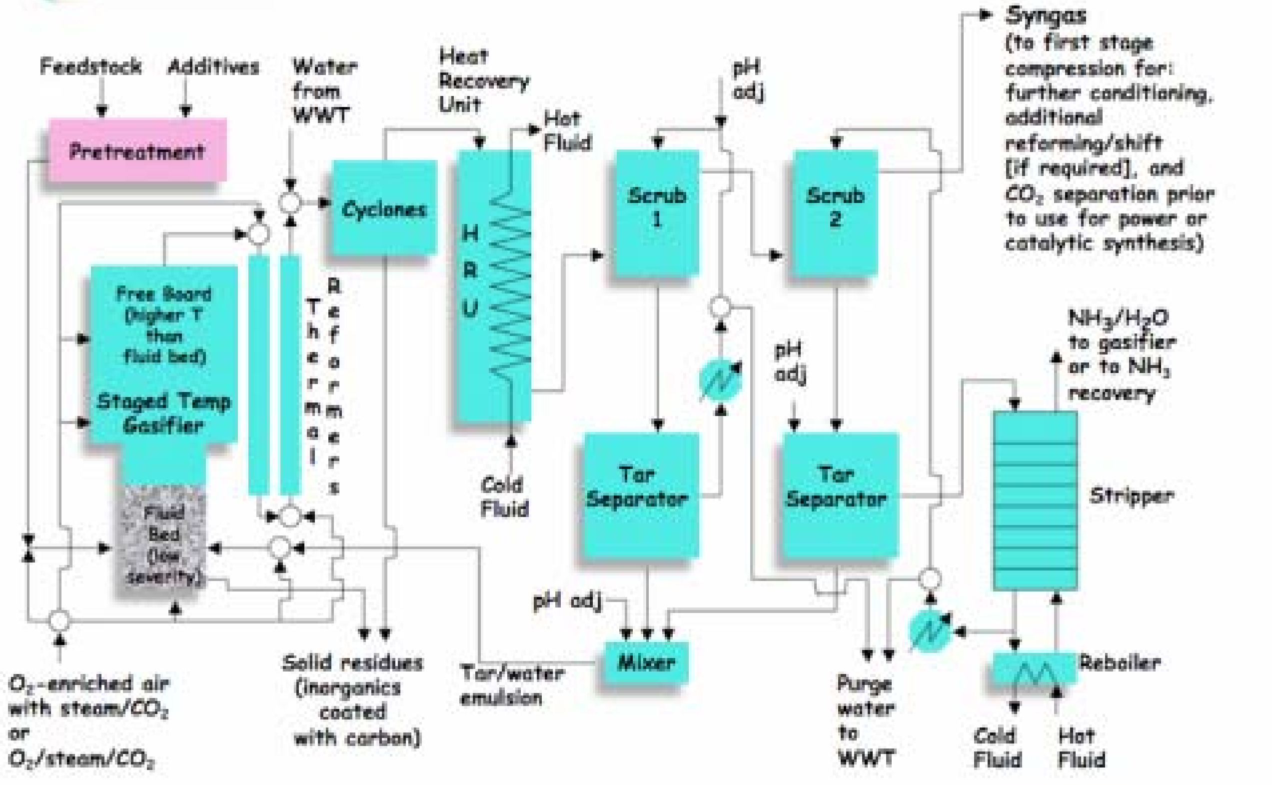
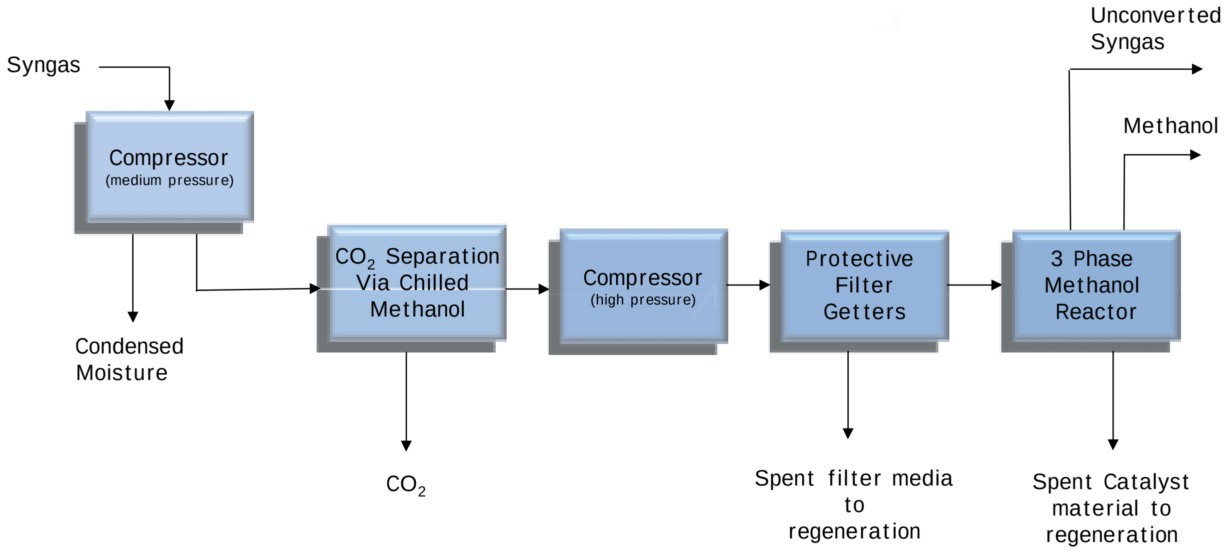
Managing the bulk inorganics in "urban biomass"

- The inorganics in the feedstock are metal salts. A fraction (1/3) of the inorganics will stay in the bed and is withdrawn through appropriate ports. A larger fraction (2/3) is recovered as fine particulates in the cyclones.
- As the reaction temperature reaches the individual salt melting points, the melted salt material can act as flux for aggregation of solid particles present in the reactor (fluidized or not). If melting is allowed, due to the vapor pressure of the melted salts, a fraction of the latter will vaporize. To avoid such situation, Enerkem has developed the following operational strategy:
  - to operate the biomass gasifiers at lower temperatures than the melting point of the salts . However carbon conversion is affected and, in order to reach carbon conversions to syngas > 95%, a higher temperature zone must be added following the fluid bed.
  - to inject additives that will prevent aggregation and agglomeration in the bed, which is induced if the inorganic salts are allowed to melt.

Enerkem



Syngas production from non-homogeneous biomass residues and wastes



Methanol Synthesis PFD

Leading developer and producer of advanced fuels and green chemicals from waste
Enerkem

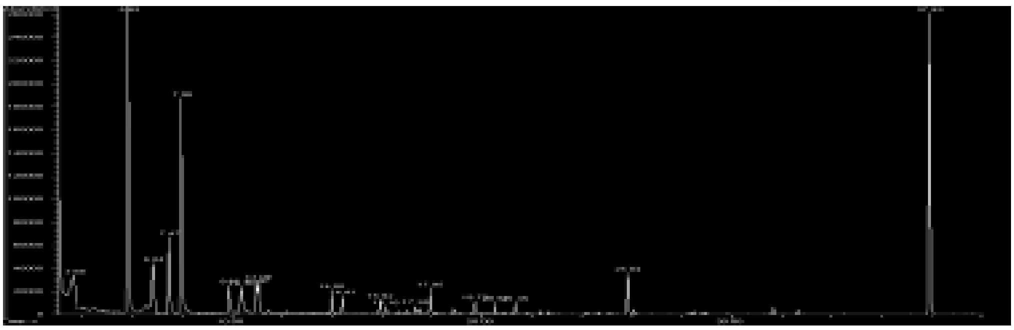
Typical dry syngas composition (mol%)

	O2/steam gasification	O2/steam gasification, + steam reforming (molar ratio steam/dry syngas : 1.6) + CO2 removal
N_2	< 5	< 5
A	< 1	< 1
H_2	20 - 24	50 - 60
CO	20 - 24	25 - 30
CO_2	30 - 35	< 5
CH_4	8 - 12	< 4
C_2H_4	4 - 8	< 1
C_xH_y (C_2-C_5)	4 - 8	< 1
C_xH_y (C_6 and higher)	2 - 4	traces

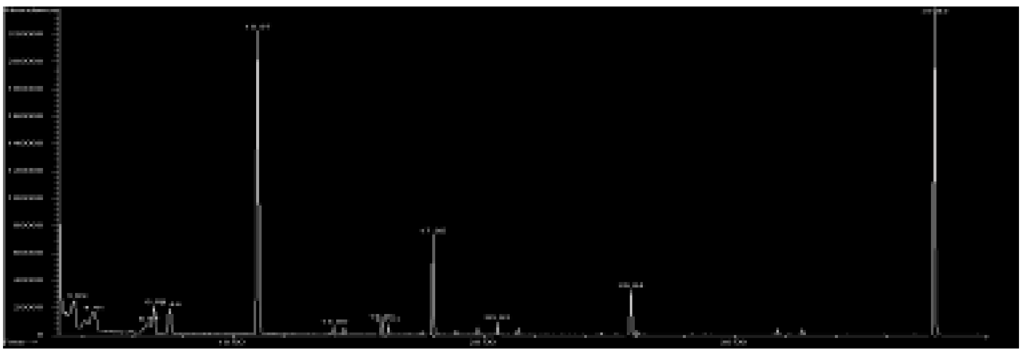
Tar and Particulate concentrations before scrubbers

SG	Tar (g/Nm3)	Particulates (g/Nm3)
After low severity fluid bed zone	15 - 20 (phenolic)	10 - 16 (mainly 1 - 25 µm range)
After cracking/reforming zone	2 - 7 (very low phenolic content)	C in particulates is converted mainly with steam and overall particulate mass level is reduced by 20-30 wt%

Chromatograms of the tar (trapped in isopropyl alcohol): primary gas produced < 750 C and thermally cracked/reformed gas at > 900 C



< 750 C



> 900 C

Managing the trace contaminants

- Cl, always present in biomass, yields HCl. It can easily be neutralized by forming stable chlorides of which CaCl2 is the prototype, albeit with a low melting point that requires appropriate choices of operating temperatures.
- S forms H2S and COS. Removing S requires either a dry process forming a stable sulfide that can be isolated or a wet process that absorbs the S-species and permits to recover them. Enerkem is able to use either approach.
- N forms NH3. Scrubbing the NH3 can be accomplished at levels that will be compatible with emissions regulations.
- Sensitive metals:
  - Mercury- the approach is the use of getters that stabilize the gaseous Hg (normally as a sulfide)
  - Arsenic - volatile species will be scrubbed and the solubilized As-containing ions are oxidized and precipitated out as stable compounds.

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SG Composition after water scrubbing loops 1 & 2

Tar	< 10 mg/Nm3
Particulates	< 10 mg/Nm3
S (as H2S + COS)	< 20 mg/Nm3
Cl (as HCl)	< 5 mg/Nm3

This SG , is compressed at medium pressures, scrubbed by chilled methanol and flown through getters to remove contaminants (including carbonyls) down to trace levels prior to high pressure compression (50 - 60 bar) for the MeOH synthesis.

Enerkem

Comparison of emissions from combustion of NG and SG (after water scrubbing)

Component	Combustion of NG[a,i] (ppmv @ 11% O_2)	Combustion of Syngas (from MSW[c]) (ppmv @ 11% O_2)	Combustion of NG[a,i] (mg/Am^3 @ 11% O_2)	Combustion of Syngas (from MSW[c]) (mg/Am^3 @ 11% O_2)	Ontario Limits
PM			4,4	4,8	17 mg/Am^3
SO_2	0,13[h]	< or = 18[f]	0,3[h]	< or = 20[f]	56 mg/Am^3
NO_x	31-86[b]	50	58-162[b]	94	110 ppmv
CO	42,4	0,3	48,6	0,4	n.a.
CH_4	2,0	n.a.	1,3	n.a.	n.a.
THC	n.a.	6,3[g]	6,4[d]	5,5[d] (incl. CH_4)	100 ppmv
TEQ	n.a.	n.a.	n.a.	0,000006	0,00014 mg/Am^3
Cl in gas	n.a.	6,2[e]	n.a.	9,2[e]	27 mg/Am^3

[a] From Emission Factors of Environmental Protection Agency (EPA), 07/98

[b] For Large Wall-Fired Boilers > 100 MMBTU/h, range covering controlled to uncontrolled

[c] Gasification of Sherbrooke and Edmonton Municipal Solid Wastes: measured values

[d] THC. Total Hydrocarbons. Equivalent CH

[e] HCl only

n.a. not available

[f] "0" reading on analyser with 10 ppm accuracy (Bacharach Model 300)

[g] TOC only

[h] SOx

[i] Calculated from emission factors of (EPA) [a] assuming 45% excess air

Am^3 = @25 °C and 1 atm

Note: Improved control systems being under development now, particularly for Sox and Nox should still lower the overall emissions of MSW-derived syngas. As well all the other indexes will also be lowered with improvements in low BTU burners

Status of the GoBiGas Project

SGC Gasification seminar October 2009
Ingemar Gunnarsson

Göteborg Energi

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Our vision….

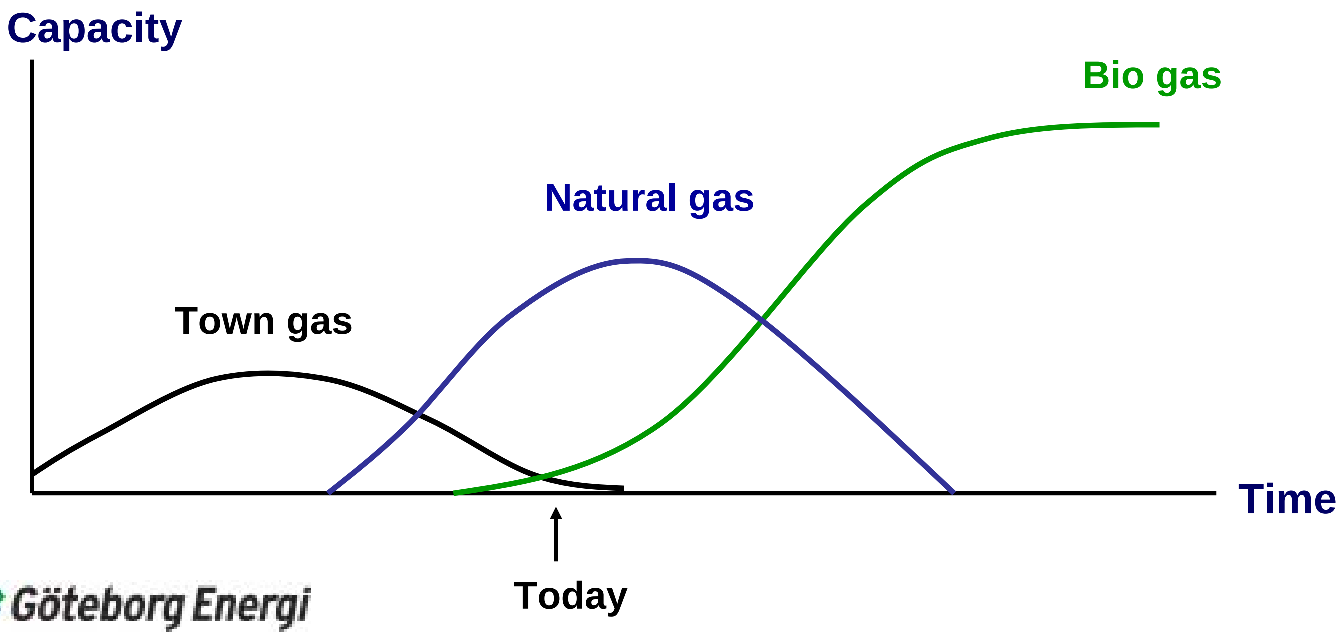
Göteborg Energi shall actively contribute to the development of a sustainable society in Göteborg

Göteborg Energi

Only renewable gas in the future

Short term target 2020 > 1 TWh of Bio – SNG

Long term target 2050 – only renewable energy sources



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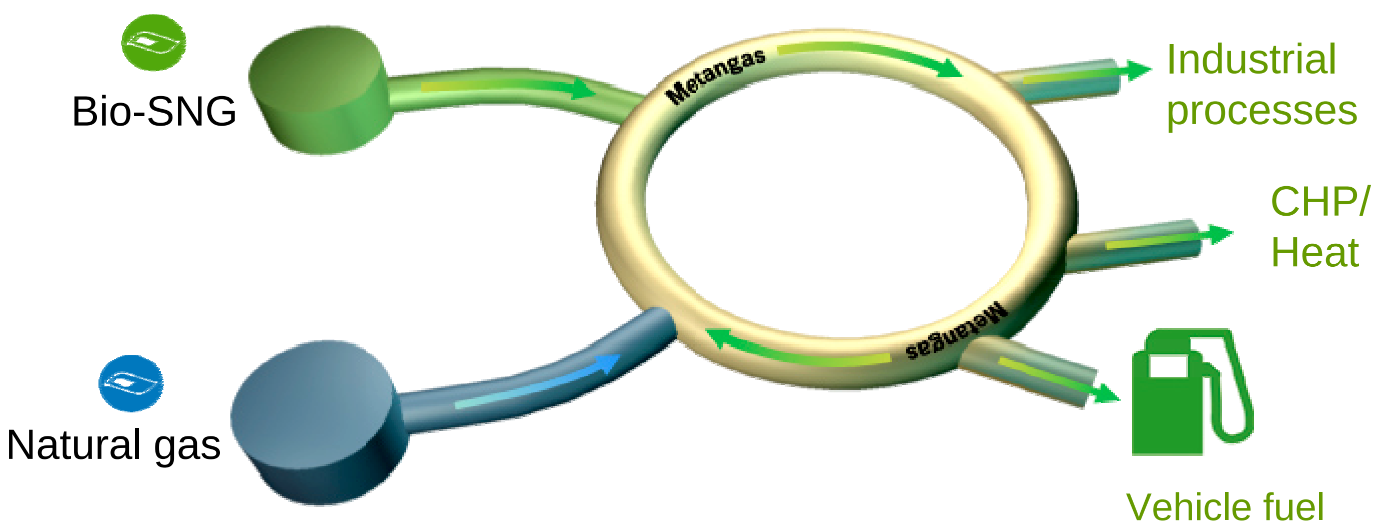
"Green gas concept"

- A huge market potential is opened for biogas
- The reliability of the biogas supply improves



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GoBiGas – Gothenburg Biomass Gasification Project

- **Commercial scale**
  - 100 MW Bio-SNG
  - Operating period 8000 hr/yr
  - ė 80 MNm^3/yr or 800 GWh/yr,

- **Gasification** of forest residues
- Production of **high-calorific gas** (SNG) by methanation for distribution in the existing gas grid. Plant situated **in the harbor of Gothenburg,** fuel transport by ship or by train
- **Joint project** Göteborg Energi and E.ON

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GoBiGas – step by step

- **Performance goals:**
  - Biomass to gas – 65 - 70%
  - Energy efficiency - >90%
- **Phase 1:**
  - 20 MW generating 160 GWh/yr in operation 2012
  - Allothermal gasification
  - 2000 Nm^3/hr or 16 MNm^3/yr (equal to 15 000 vehicles/yr)
- **Phase 2:**
  - 80 MW generating 640 GWh/yr in operation 2015/2016
  - Technology not yet chosen
  - 8000 Nm^3/hr or 64 MNm^3/yr (equal to 75 000 vehicles/yr)

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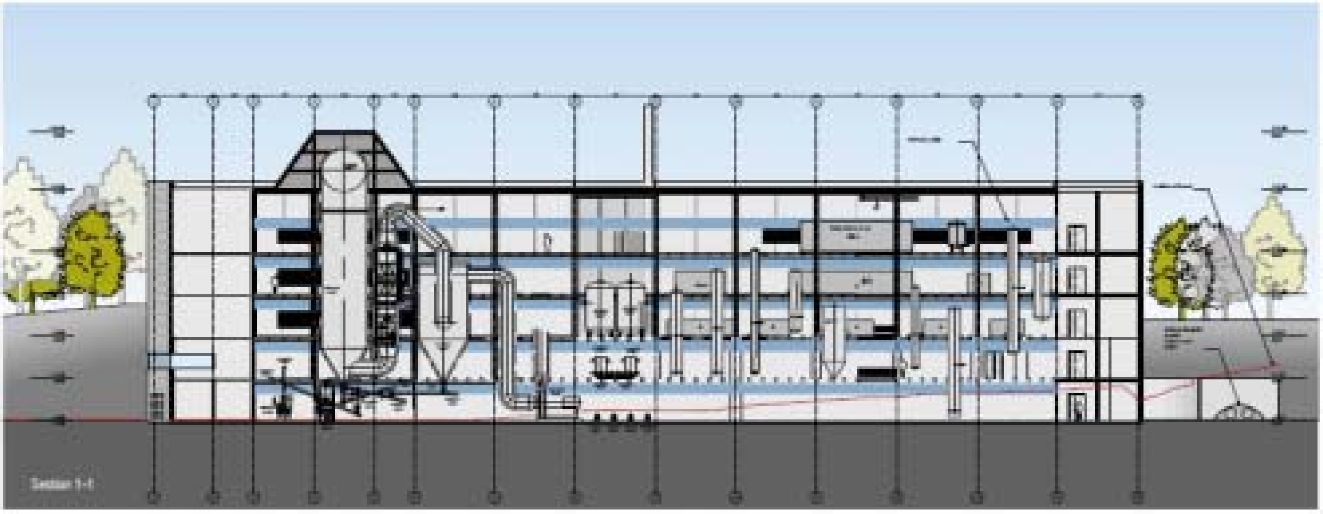
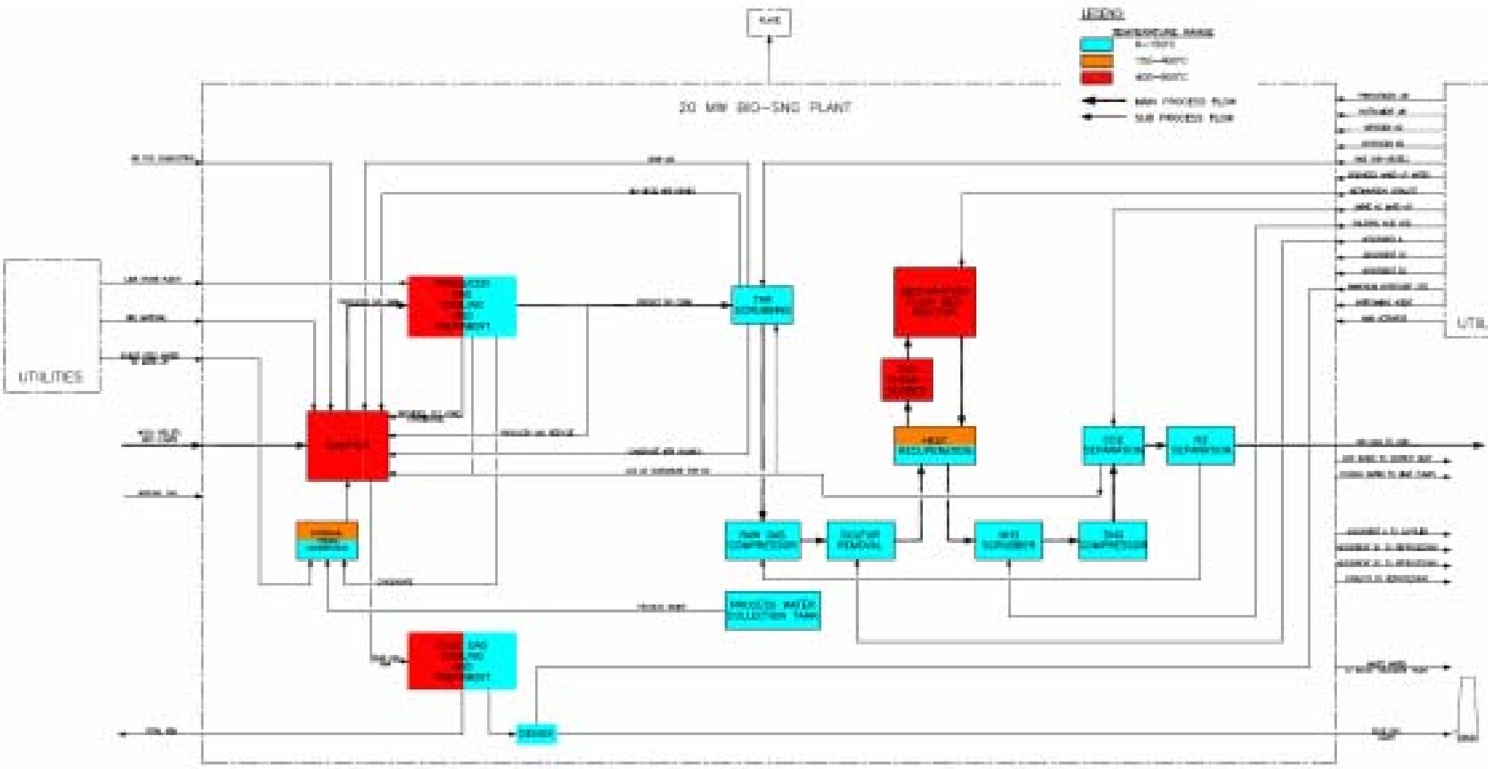
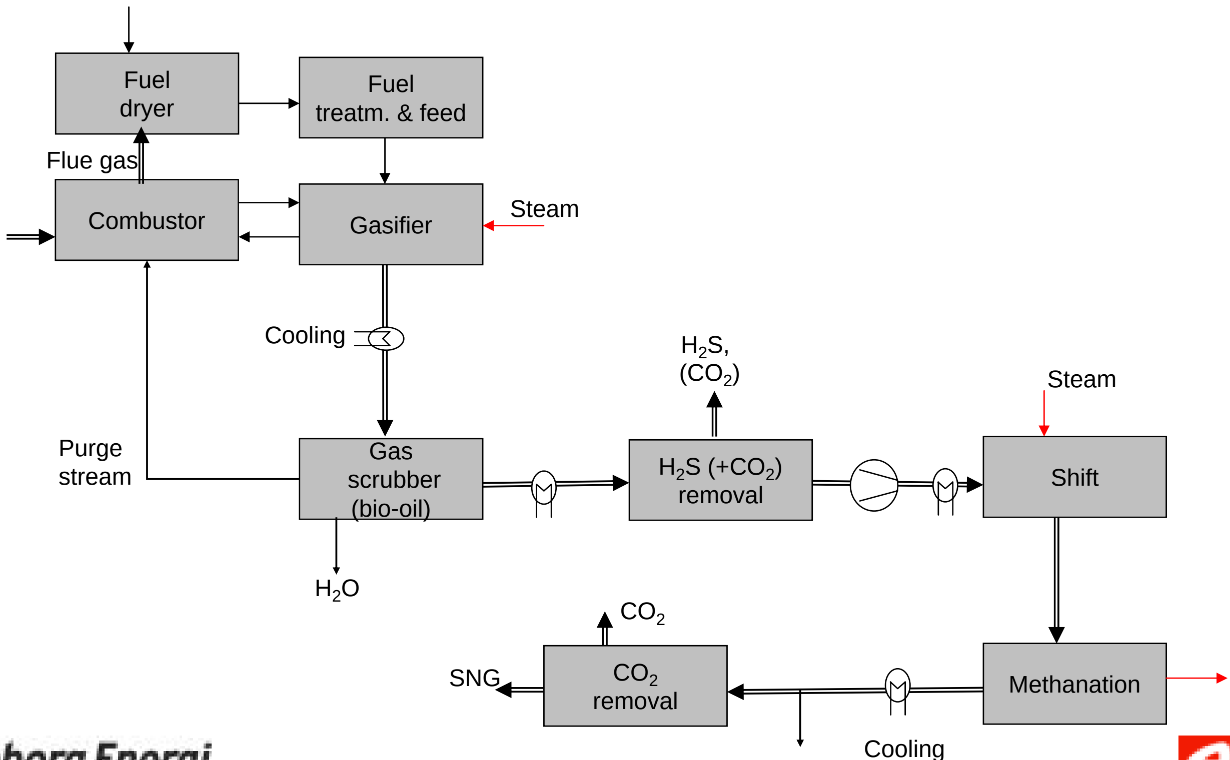
GoBiGas – phase 1

Production:		Consumption:	
Bio-SNG	20 MW	Fuel (pellets)	32 MW
District heating	4 MW	Electricity	2,5 MW
Heat to heat pumps	8 MW	RME (bio-oil)	0,5 MW





Allothermal (in-direct) gasification



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Reference plant: Gasification and Methanation in Güssing, Austria

- Gasification in fluidized bed with separate combustion zone (in-direct, allothermal gasification)
  - 8 MW biofuel
  - Gas engine 2 MWe and 4,5 MWth to local district heating system
  - Operating time Aug 2009 > 45 000 hours
- Methanation and gas cleaning plant 1MW
  - Up-scaling from 10 kW
  - Start-up December 2008
  - Inaugeration and gas delivery to fuelling station in June 2009
  - Continued operation in cooperation with GoBiGas Oct 2009 – Jan 2010, with operators from Göteborg Energi and E.ON

Göteborg Energi

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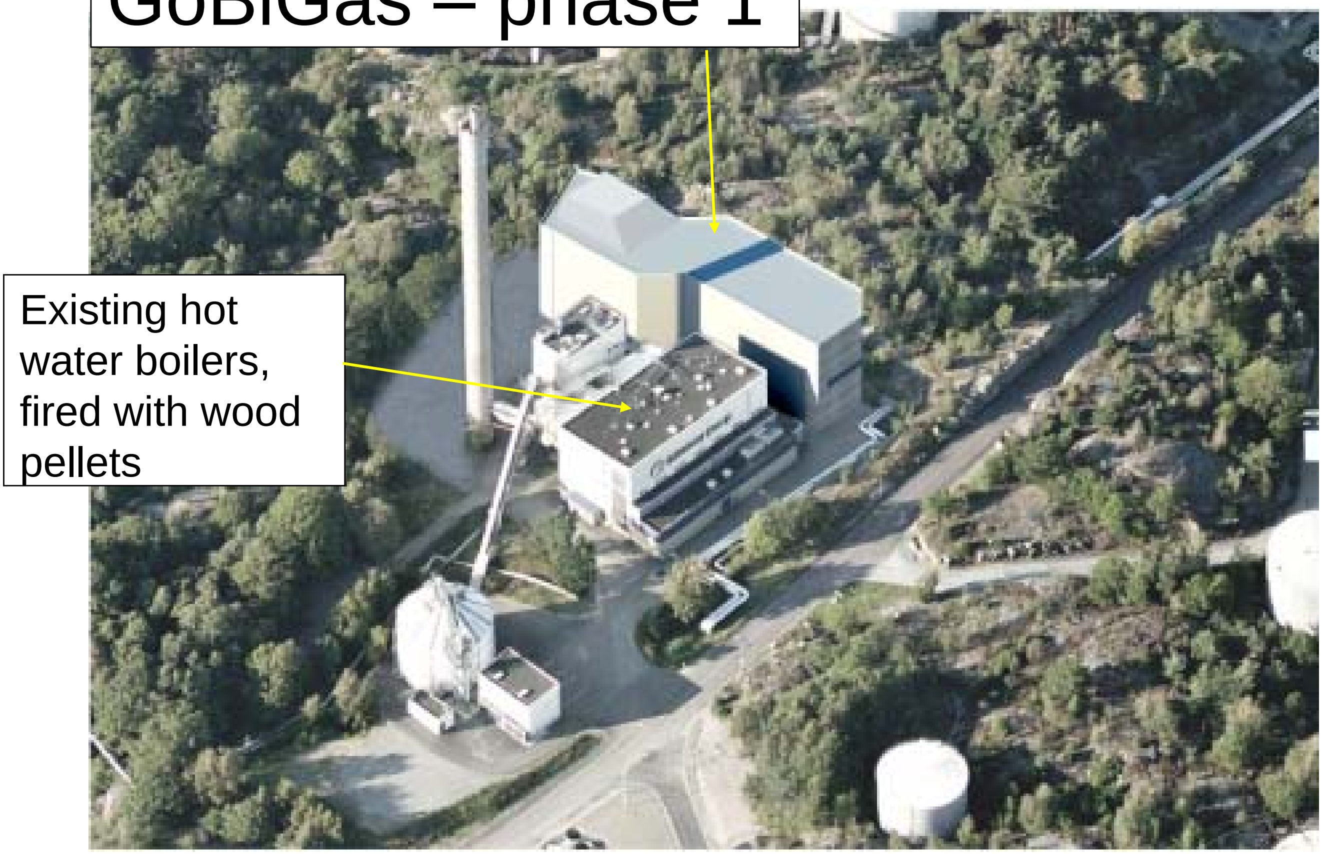
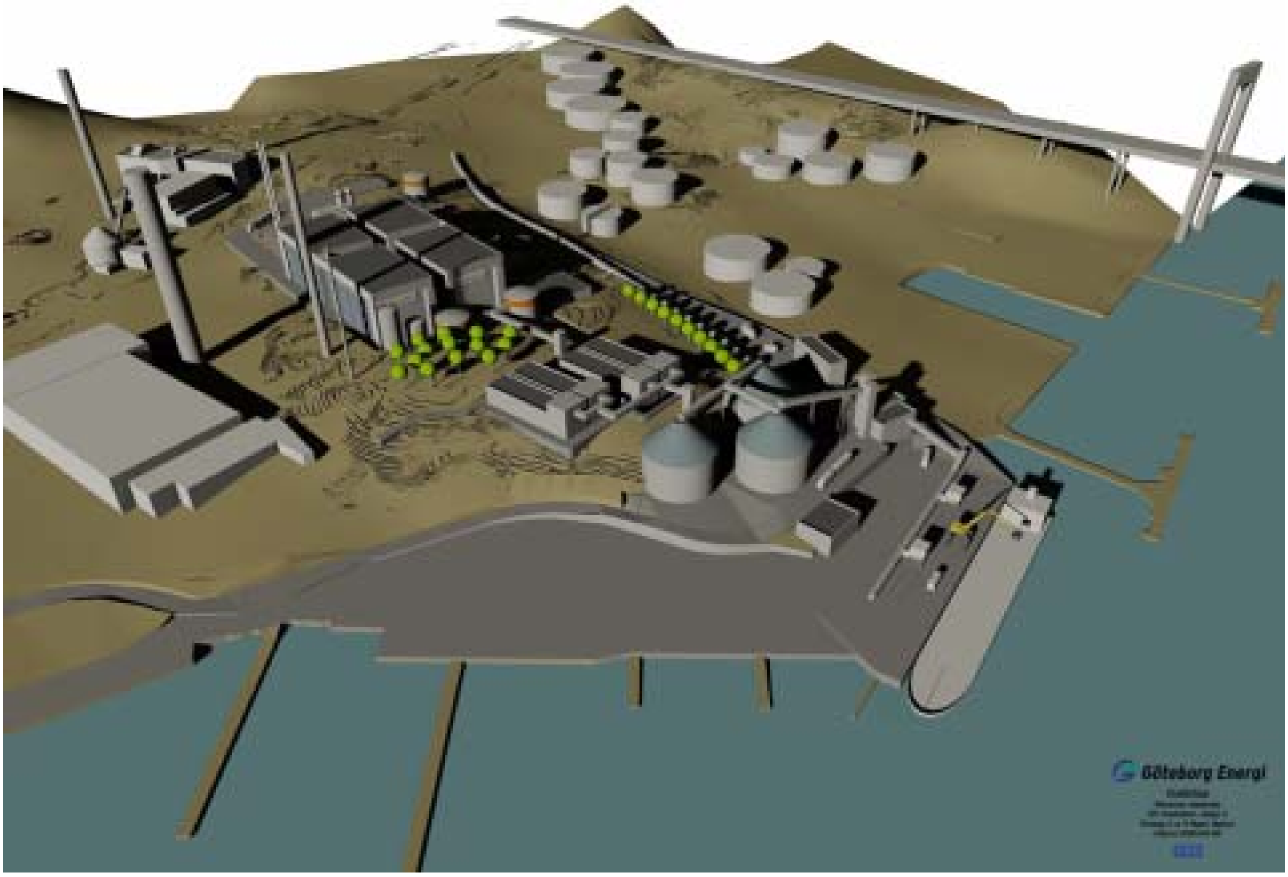
GoBiGas – phase 1





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Project status - October 2009

- **State funding**
  - **222 MSEK** granted from the Swedish Energy Agency!!! But provided that EU approves the funding.
- **Gasification**
  - Cooperation between Metso Power and Repotec, Basic Engineering being carried out
- **Methanation**
  - Operation of 1 MW pilot plant in Güssing based on CTU technology
  - Evaluation of technology => Basic Engineering
- **Ground work and civil engineering**
  - Engineering and preparation for start of work at site June 1, 2010
- **Permits**
  - Applications for environmental permits and building permits for Phase 1 and Phase 2
- **Procurement**
  - Developing strategies: Scopes of supply for the different parts (no turn-key delivery)

=> Investment decision in May 2010!

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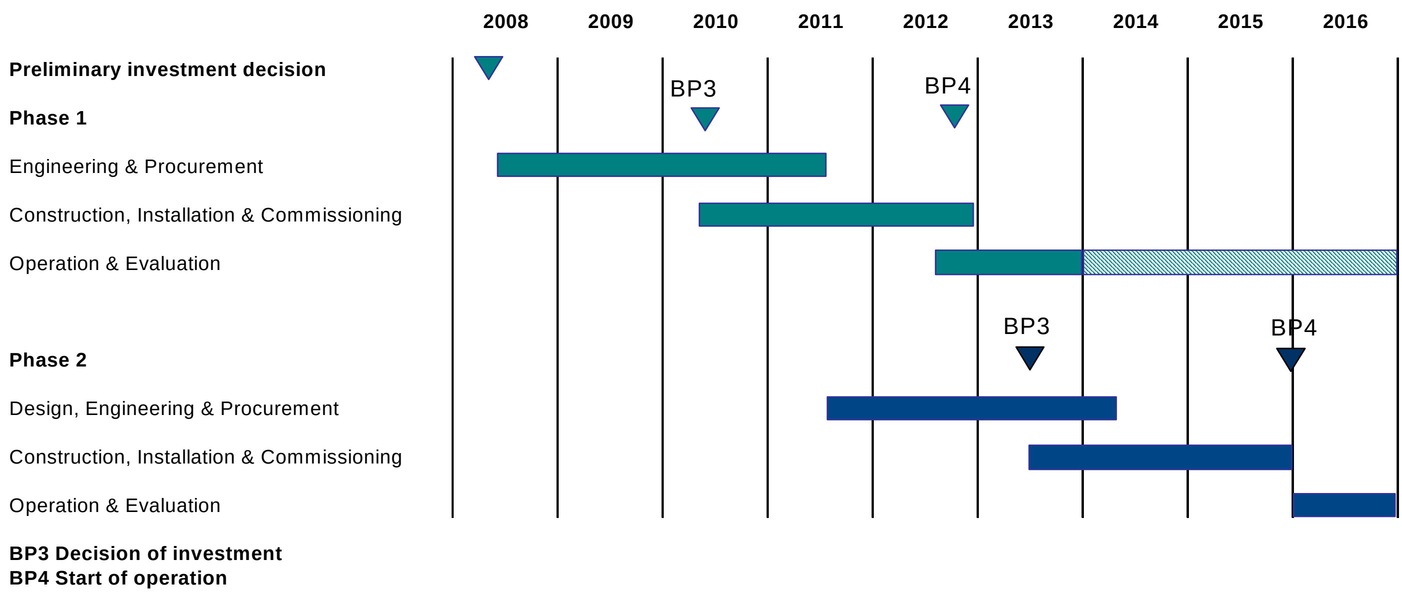
GoBiGas – Main time schedule



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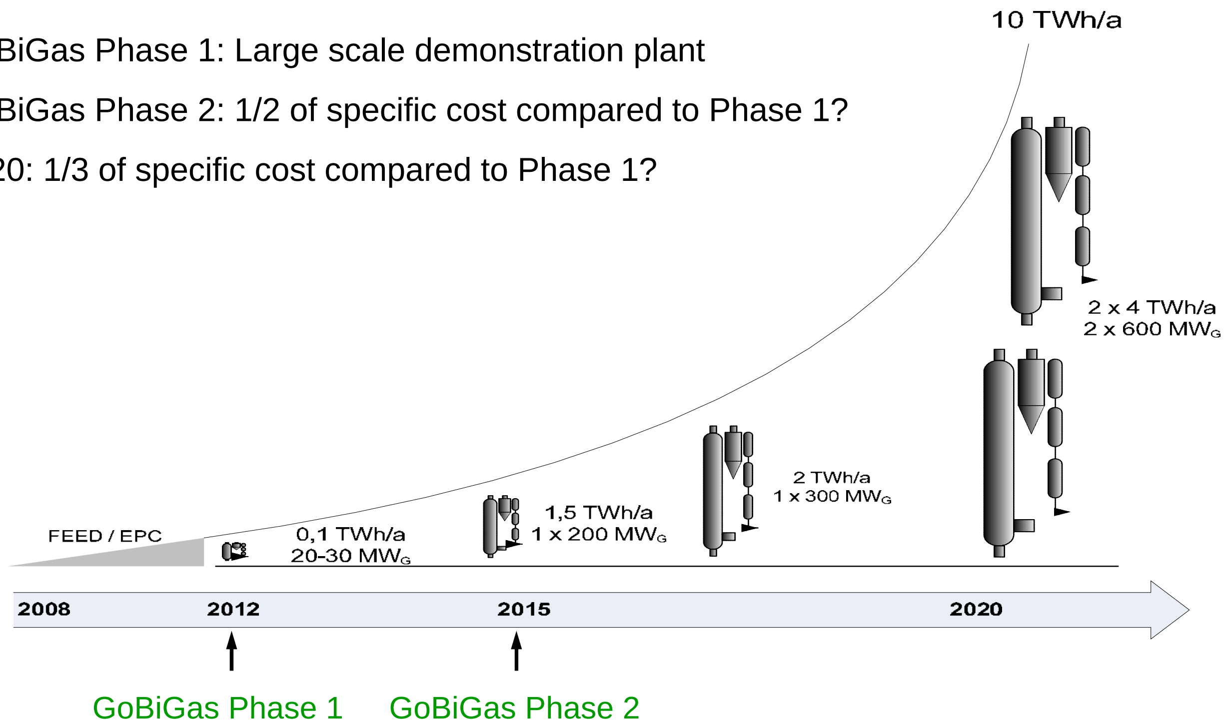
Commercial development of gasification technology in Sweden

GoBiGas Phase 1: Large scale demonstration plant

GoBiGas Phase 2: 1/2 of specific cost compared to Phase 1?

2020: 1/3 of specific cost compared to Phase 1?



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Vision for the future –GoBiGas!

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Thank you for listening!

Göteborg Energi

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Gasification 2009

- Gas Clean-up and Gas Treatment

On-going Gasification Activities in Spain

Cesar Dopazo, Antonio Gomez, Norberto Fueyo

University of Zaragoza, Spain

Swedish Gas Centre (SGC)
Stockholm, October 22-23, 2009

Content

- Energy data
- Biomass in Spain: Present, Potential and Generation Costs
- Spanish “Renewable Energy Plan” (PER) 2005-2010. Biomass
- Biomass Plant Location
- Biomass Gasification Small Plants: ENAMORA, GUASCOR, TAIM
- Gasification Research: Universities, CIEMAT, **LITEC**
- References
- Prospects

Primary Energy. Spain: 2008

	ktoe	% /Total
Oil	67629	47.6
Natural Gas	34525	24.3
Nuclear	15202	10.7
Coal	13924	9.8
Renewables	**10798** 10254 (2007)	**7.6** 6.9 (2007)
TOTAL	**142078** 146929 (2007)	100

Electricity Generation (brut). Spain: 2008

	TWh	%/Total
Natural Gas	122.8	38.8
Renewables	**64.7**	**20.5**
Nuclear	59.0	18.7
Coal	49.5	15.7
Oil	20.0	6.3
TOTAL	**316**	**100**

Renewable Electricity. Spain: 2008

	TWh	%
Wind	31.3	48.5
Hydroelec (small)	4.5	7.0
Hydroelec (large)	21.5	33.1
Urban Solid Waste	1.8	2.8
Solar PV	2.5	3.8
Biomass	**2.5**	**3.8**
Biogas	**0.6**	**1.0**
TOTAL	**64.7**	**100**

BIOMASS ENERGY –SPAIN 2007

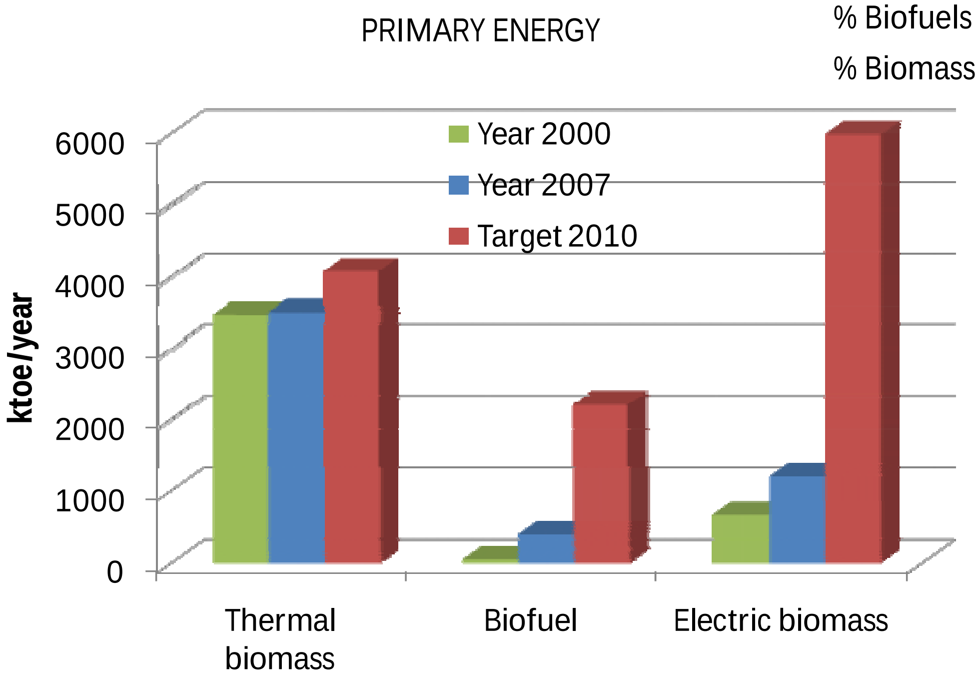
Primary Energy: 5074 ktoe/yr

% Biomass of total primary energy: **3.45%**

% Biomass of total final energy: **3.91%**

% Biofuels in transport sector: **0.92%**

% Biomass in electricity generation: **1.44 %**

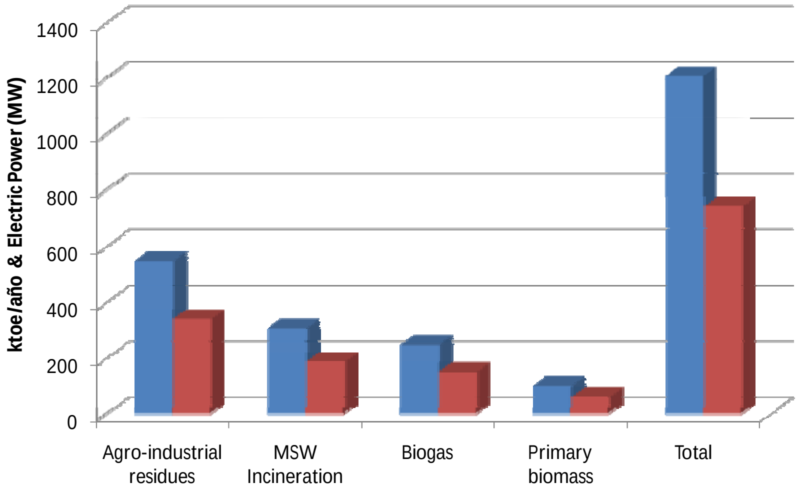


Biomass sector stalled: R.D. 661/2007 (May 25, 2007)

Biomass: traditional uses for heat generation

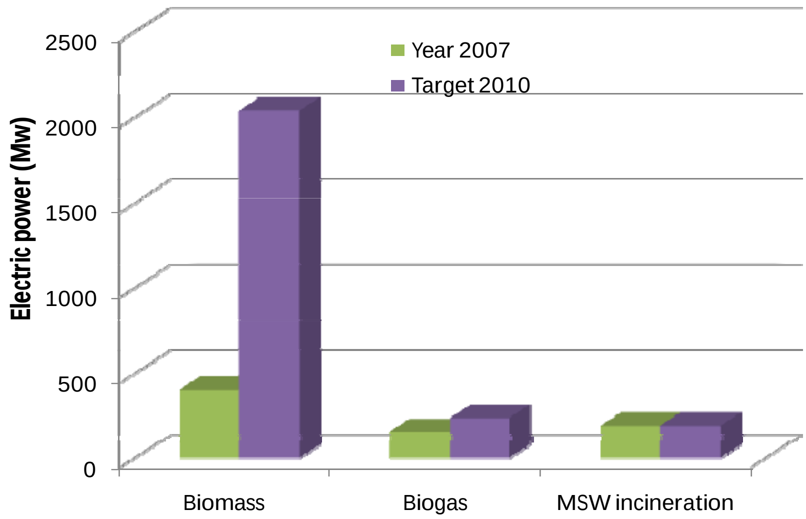
Biofuels: far from **2200 ktoe** required by **2010**

Biomass for Electricity : slow increase, mainly from **agro-industry residues**



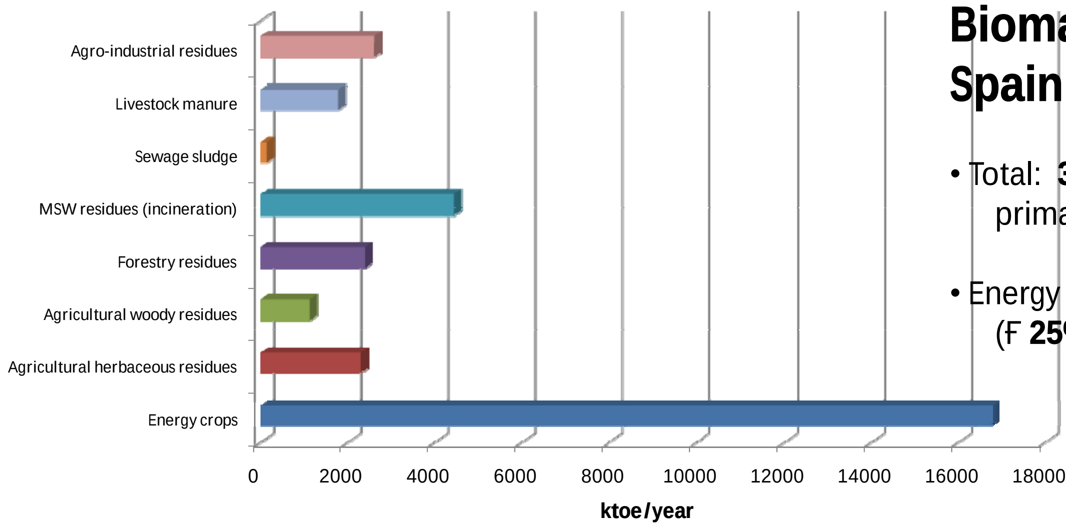
Biomass for Electricity:

Á Generation mainly from residues : agro-industrial, MSW incineration and landfill gas
Á Small generation from energy crops, agricultural residues and forestry residues
Á No coal co-combustion installations



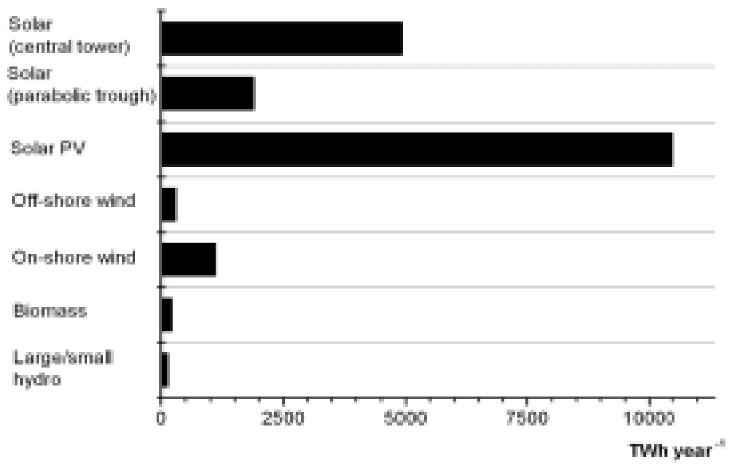
Biomass for Electricity:

Á Generation from primary biomass far from 2010 targets of Spanish Renewable Energy Plan



Biomass energy potential in Spain:

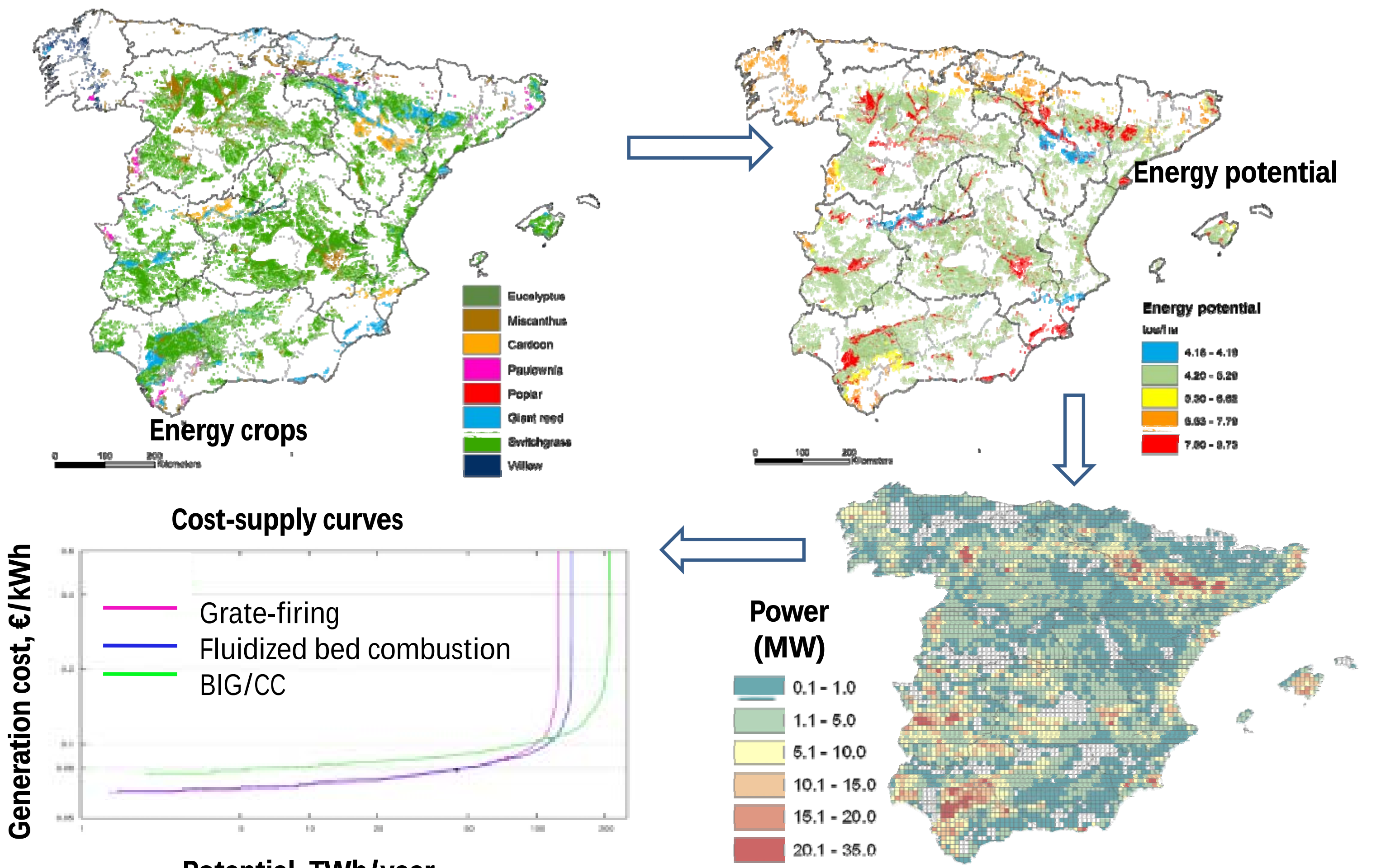
- Total: **31602 ktoe/yr** (21.5 % of primary energy consumption in 2007)
- Energy crops: required land 28500 km^2 (Ғ **25% arable land**)



•Biomass potential is low compared with other renewable resources.

- **Source: Dopazo C, Fueyo N et al. "The potential of renewable energies in Spain", Fluid Mechanics Group, University of Zaragoza, 2008**

Potential of enegy crops and electricity generation costs with different technologies. METHODOLOGY



Source: Dopazo C, Fueyo N et al, "The potential of renewable energies in Spain"

Spanish "Renewable Energy Plan" PER 2005-2010 AUGUST 2005

- **Targets (2010):**
  - % RES /Primary Energy Consumption: **12.1%**
  - % RES /Electricity (brut) Production: **30.3%**
  - % Biofuels in Transport Sector: **5.8%**
- Estimated Investment (2005-2010): **23598 M €**
- Public Incentives (2005-2010): 8491 M €
  - Feed-in Tariffs (Primas) (Electricity): 4956 M €
  - Fiscal Incentives (Biofuels): 2855 M €
  - Subsidies (Biomass: thermal and solar): 680 M €
- Sectoral estrategies to reach new targets
- Fundamental role of biomass and wind

Target achievements by 2008. “PER” 2005-2010

ELECTRICITY	2008 Increment (MW)	2005-08 Increm (MW)	PER Target 2005-10 (MW)	Achieved 2008 /Target 2005-10
Hydro (<50MW)	76	291	810	36 %
Biomass	29	115	973	12 %
Co-Combustion	0	0	722	0 %
Wind	1726	8229	12000	69 %
Solar PV	2536	3233	363	891 %
Biogas	3	28	94	30 %
Solar Thermoelec	50	61	500	77 %
TOTAL ELECTRICIT				

THERMAL	2008 Increment (ktoe)	2005-08 Increm (ktoe)	PER Target 2005-10 (ktoe)	Achieved 2008 /Target 2005-10
Biomass	62	132	583	23 %
Low Temp Solar	36	76	325	23 %
TOTAL THERM	98	207	908	23 %

BIOFUELS (ktoe)	669	1479	1972	75 %

Overall Biomass Plant Location. Spain

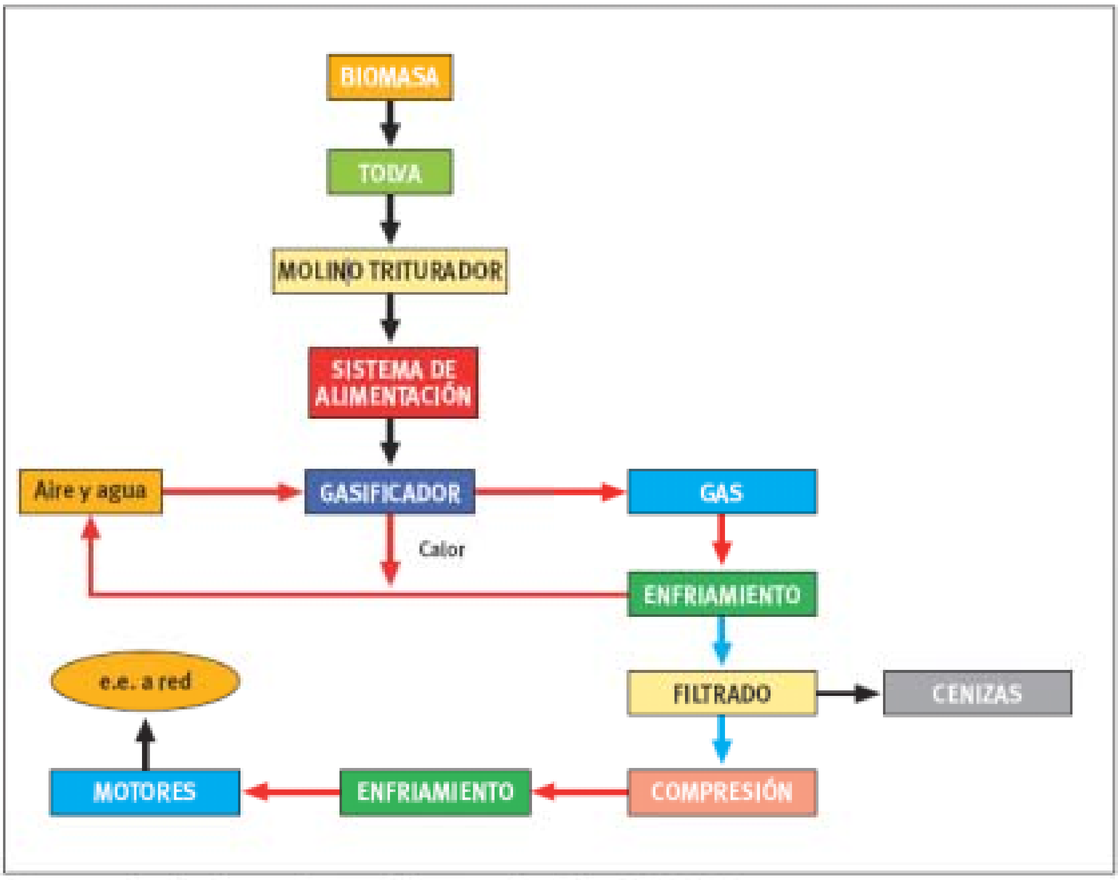
(Source: IDAE, 2008)

Biomass Gasification Small Plants

Gasifier and Syngas Treatment System. Mora de Ebro

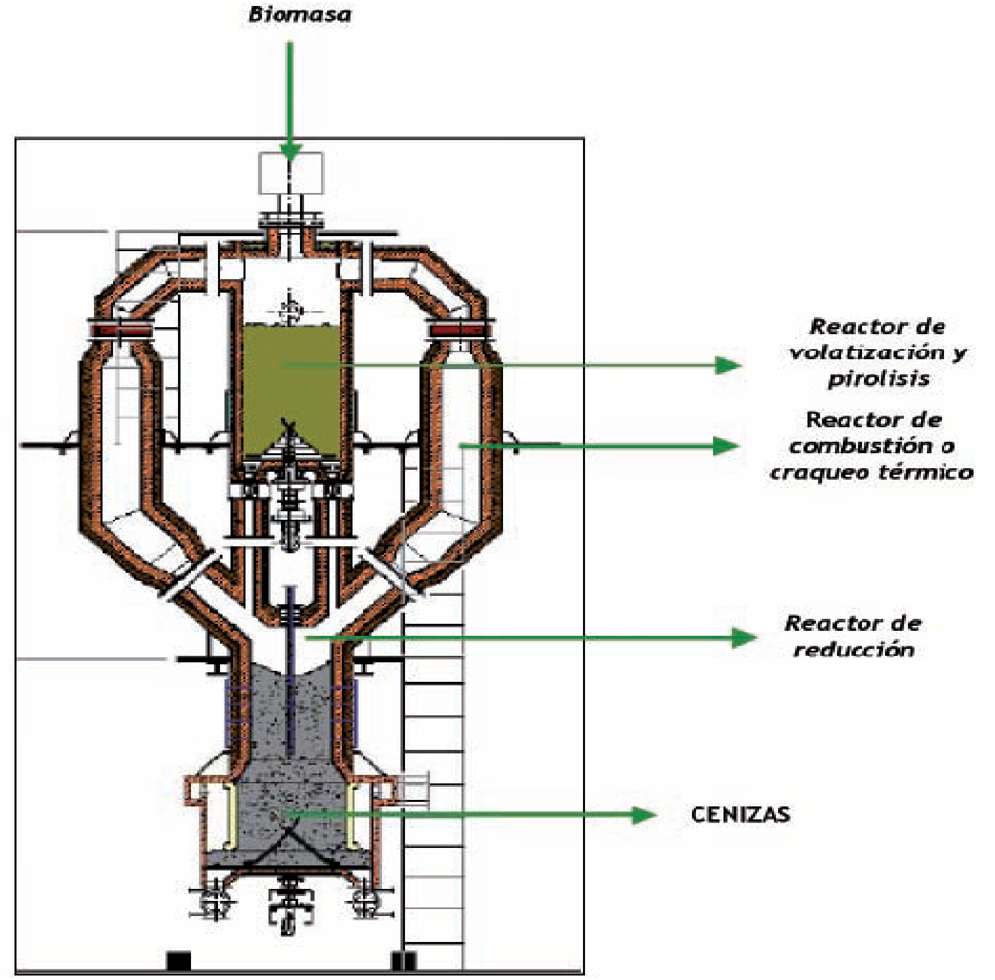
(Source: ENAMORA Ą GUASCOR)

Operating sketch. ENAMORA Technology



Multi-step Gasifier. GUASCOR

Multi-step Gasifier Sketch. GUASCOR



Gasifier and syngas treatment characteristics. GUASCOR

TECHNICAL CHARACTERISTICS	
Biomass: pine chips < 10 cm (t/yr)	550
Hours/year of operation	1700
Rated thermal power (kWth)	1711
Maximum thermal power (kWth)	3500
Gasifier mass flow rate (kg/hr)	400-800
Self-consumption (kWe)	85

Gasifier characteristics. TAIM

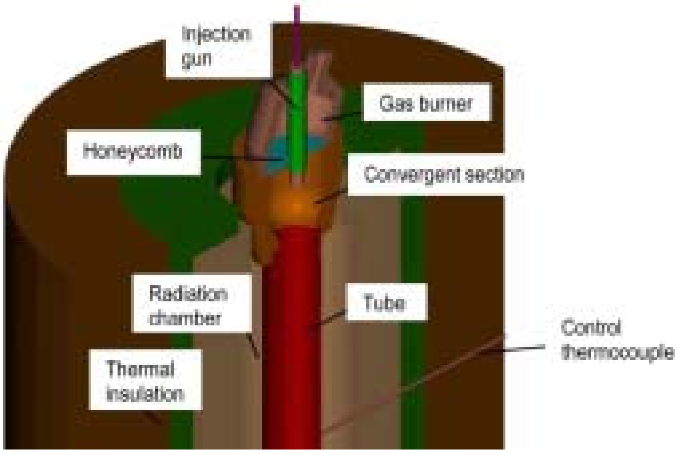
Gasifier	Downdraft
Syngas flow rate (Nm3/hr)	1380-1490
Syngas composition	N2: 50-55%, H2: 12-15%, CO: 15-20%, CO2: 8-15%, CH4: 2-5%; C2H6: 1%
Syngas LHV (kWh/Nm3)	1.52-1.61
Thermal Power (MWth)	2.1-2.4
Gas	Air
Operating Temperature (º C)	1200
Biomass	Forest and wood residues
Mass Flow rate (kg/hr)	650-700
Biomass humidity (%)	20-30
Thermal Efficiency (%)	75-85
Water flow rate (m3/hr)	0.50
Ash (kg/hr)	35

Research activities

- Small laboratory facilities at several **Universities** (Alicante, Valladolid, Complutense-Madrid, Malaga, Oviedo, Santiago, Sevilla; Zaragoza)
- **CIEMAT**: Circulating Fluidized Bed Gasifier (80 kg/hr)
- **LITEC**: Laminar Flow Reactor: Reactivity of several solid fuels and biomass

Entrained Flow Reactor (EFR). LITEC

- Realistic conditions:
  - Temperature up to 1500 º C
  - dT/dt ~ 10^4-10^5 º K/s
  - Residence time up to 3 s.
  - Adjustable co-flow composition (inert, variable O_2, oxy-firing, SO_2 addition, NO...)
- Strict control of particle combustion

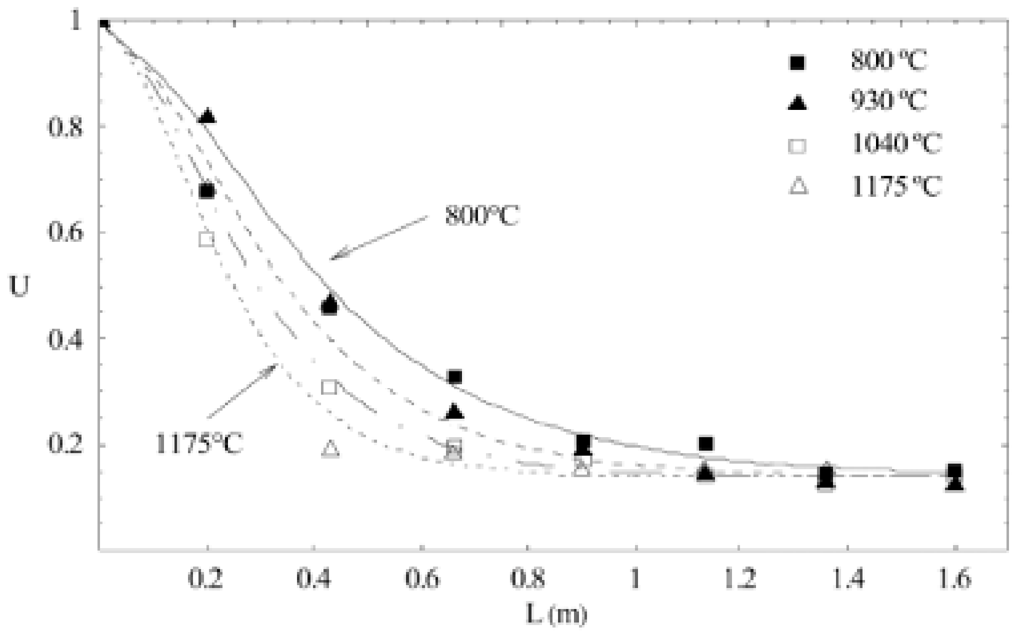


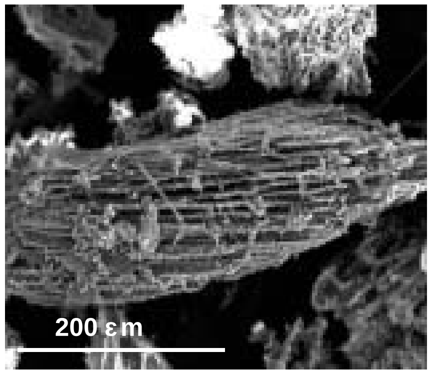
Reactivity studies. LITEC

- **Experimental:**
  - Particle sampling at different heights (residence times)
  - Test matrix for different values of relevant parameters
  - Two types of tests:
    - Devolatilisation:
      - N_2 coflow
      - Several Temperatures
    - Char oxidation:
      - Several O_2 concentrations
      - Several temperatures

- **Modelling:**
  - Simulation of particle history for a matrix of kinetic parameters (frequency factor, activation energy, reaction order)
  - Kinetic parameters characterising a particular fuel: those yielding the best fit to experimental observations

Devolatilisation studies (cardoon). LITEC





Partially devolatilised cardoon particle

Evaluation of practical applications. LITEC

- **Kinetic parameters:**
  - Valid for a wide range of particle sizes and (realistic) combustion conditions
  - Applied to predict biomass behaviour in full scale plants
  - Different studies, including co-firing and 100%-biomass

- **Example:** 2 plants of 16 MWe each, 100% olive residues (*orujillo*), pf burners (in operation, good agreement with predictions)

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Thanks for your attention !!!

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Prof. Dr. Ing. F. Fantozzi

University of Perugia - Italy
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Francesco Fantozzi
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Stockholm, October 2009

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OUTLINE

- Why biomass (and waste) gasification?
- Green Certificates in Italy
- Gasification R&D in Italy
- IPRP technology
- Focus on selected activities at CRB

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Biomass and Waste Vs Solar & Wind

MAIN PROS

- programmable energy source;
- storable energy source;
- high energy density;
- agriculture (SRF & dedicated crops);
- waste reduction (residual biomass and waste);

MAIN CONS

- scale effect;
- transportation costs;
- local impact;
- poor social acceptability;

MAIN CONS ARE SCALE RELATED Č SMALL SCALE

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Small scale Biomass and Waste conversion

SMALL SCALE REQUIRES
INTERNAL COMBUSTION ENGINES

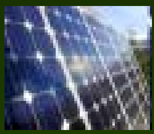
Reciprocating Engines

Gas turbines

INTERNAL COMBUSTION ENGINES
REQUIRE LIQUID OR GASEOUS FUELS

GASIFICATION
PYROLYSIS
ANAEROBIC DIGESTION

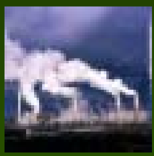
Green Certificates Mechanism in Italy



Renewable plant

gets — sells — releases — GSE

GREEN CERTIFICATES equivalent
2% + 0.35% per year since 2004
of net output production



Fossil plant

buys — pays — requires

Green Certificates (CV)	2007	2008
weighted average price (€/MWh)	96.83	103.47
no. of Green Certificates traded	586203	690412
value of Green Certificates traded (MWh)	1	1
value (million €)	56.76	71.44

- ALL-INCLUSIVE TARIFF FOR SMALL SCALE PLANTS (< 1 MW el)
  22 €cent/kWh for **15** years
- BONUS TARIFF FOR AGROFORESTRY BIOMASS FROM SHORT SUPPLY CHAIN (origin < 100 km)
  30 €cent/kWh for **15** years.

Source GME - May 2009

Gasification Research Expertise in Italy

University of Genova

University of Firenze

University of Sassari

University of Napoli

University of Perugia

University of L'Aquila

ENEA Trisaia (MT)

Main engineering companies ENEL – ANSALDO – MARCEGAGLIA

SOURCE - Quaderni dell'Accademia dei Georgofili – 2007-I Firenze Italy – In Italian

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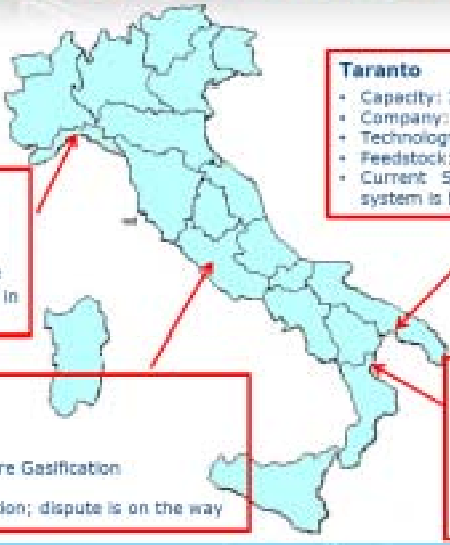
ENEA
Italian National Agency for New Technologies, Energy and the Environment

Department of Energy Technologies, Renewable Energy Sources and Energy Saving
Trisaia Research Centre

Implementations: Commercial Systems



Genova
- Capacity: 3 MW
- Company: Ansaldo Energia
- Technology: Updraft Gasifier
- Feedstock: Coal, Biomass, RDF
- Current Status: testing is in progress

Taranto
- Capacity: 3 MW
- Company: Marcegaglia Group
- Technology: Updraft Gasifier
- Feedstock: Biomass
- Current Status: testing was concluded; system is being shut down

Malagrotta (RM)
- Capacity: 100 MW
- Company: 7-Hills/JFE
- Technology: High Temperature Gasification
- Feedstock: RDF
- Current Status: not in operation; dispute is on the way

Rossano (CS)
- Capacity: 20 MW
- Company: Rossano Energia /Prime Energy
- Technology: Updraft Gasifier
- Feedstock: Olive Waste
- Current Status: no evidence about its continuous running

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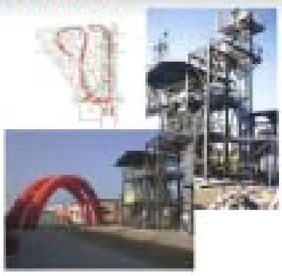
Downdraft Gasifiers

CURRENT RESEARCH ACTIVITY

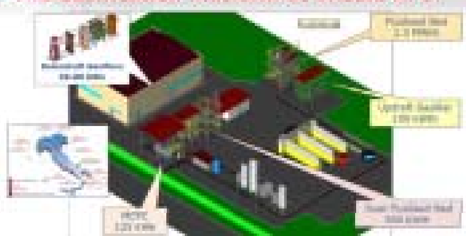
a) Demonstration
b) Use of different feedstocks
b) Gas engines testing
c) Oxygen-enriched air gasification

Former Fluidised Bed Gasifier

a) Fluidised bed gasifier with internal circulation of bed material
b) Technology patented by ENEA/University of L'Aquila
c) First prototype: 1 MWth air-blown gasifier to be fuelled with rice husks
d) It was designed, erected and tested in Trisaia and then transported and installed in China



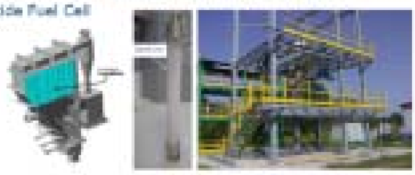
The Gasification Platform at Trisaia R. C.



Novel Fluidised Bed Gasifier

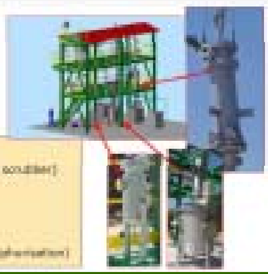
CURRENT ACTIVITY

a) 1.3 MWth gasifier is under construction
b) Oxygen/steam as gasification agents
b) Catalytic ceramic candles inside the gasifier (UNIQUE Project)
c) 100 W Solid Oxide Fuel Cell



Updraft Gasifier

- Technology is the same as Genova gasifier by Ansaldo Energia
- 150 kWth gasifier is currently under construction



SCHEDULED RESEARCH ACTIVITY
- Cleaning systems (coalescent filters, bio-diesel scrubber)
- Gasification agent (air, air/steam)
- Feedstocks (biomass, RDF)
- Gas application (methanol synthesis)
- Cleaning applications (CO, sequestration, desulphurisation)

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CRB – Centro Ricerche Biomasse
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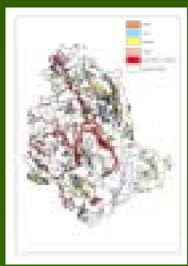

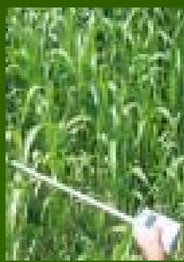

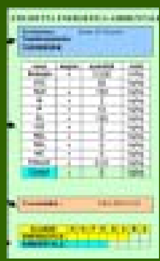

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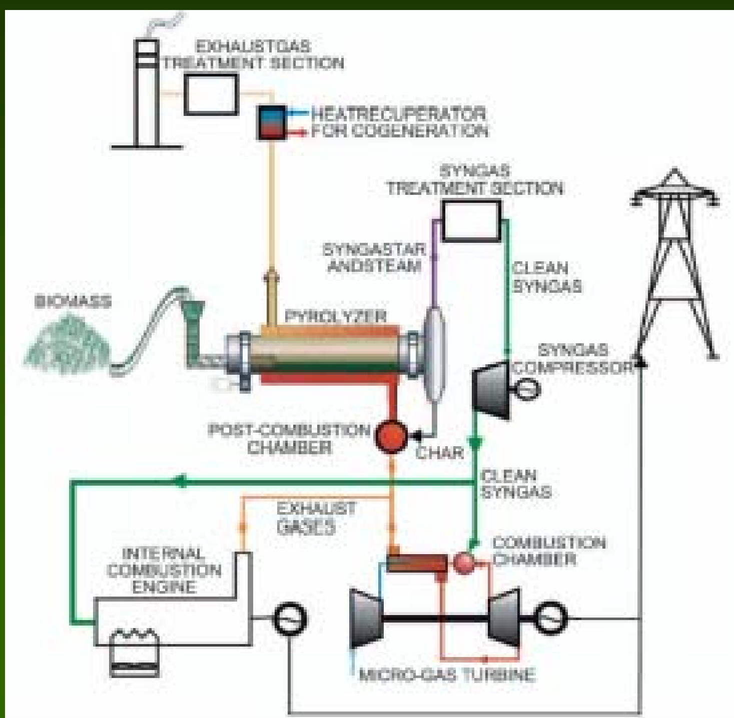
IPRP TECHNOLOGY

Integrated Pyrolysis Regenerated Plant



THERMODYNAMIC OPTIMISATION

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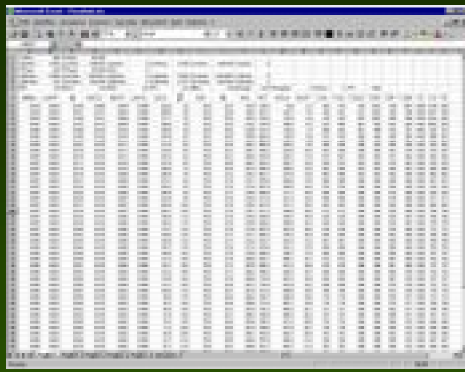

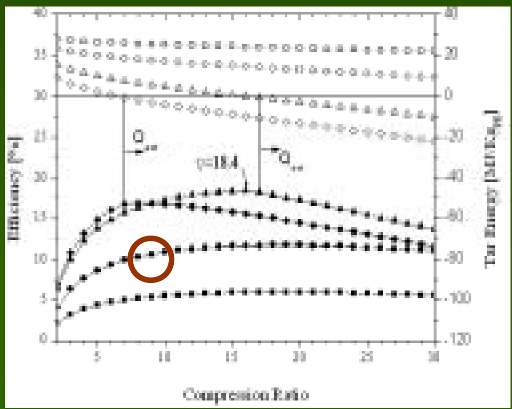

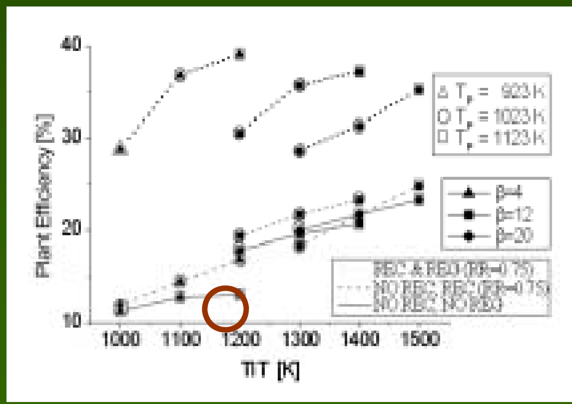

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ECONOMIC FEASIBILITY

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LABORATORY SCALE UNIT

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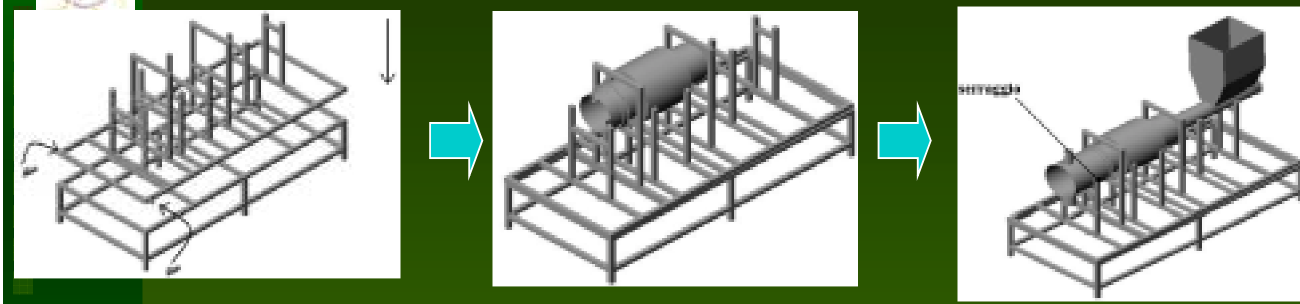

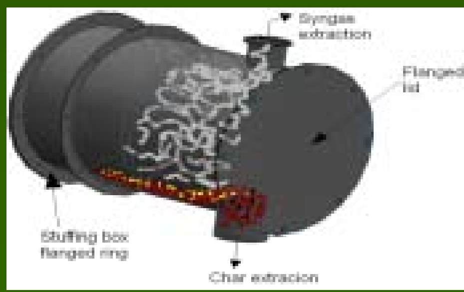

LAYOUT

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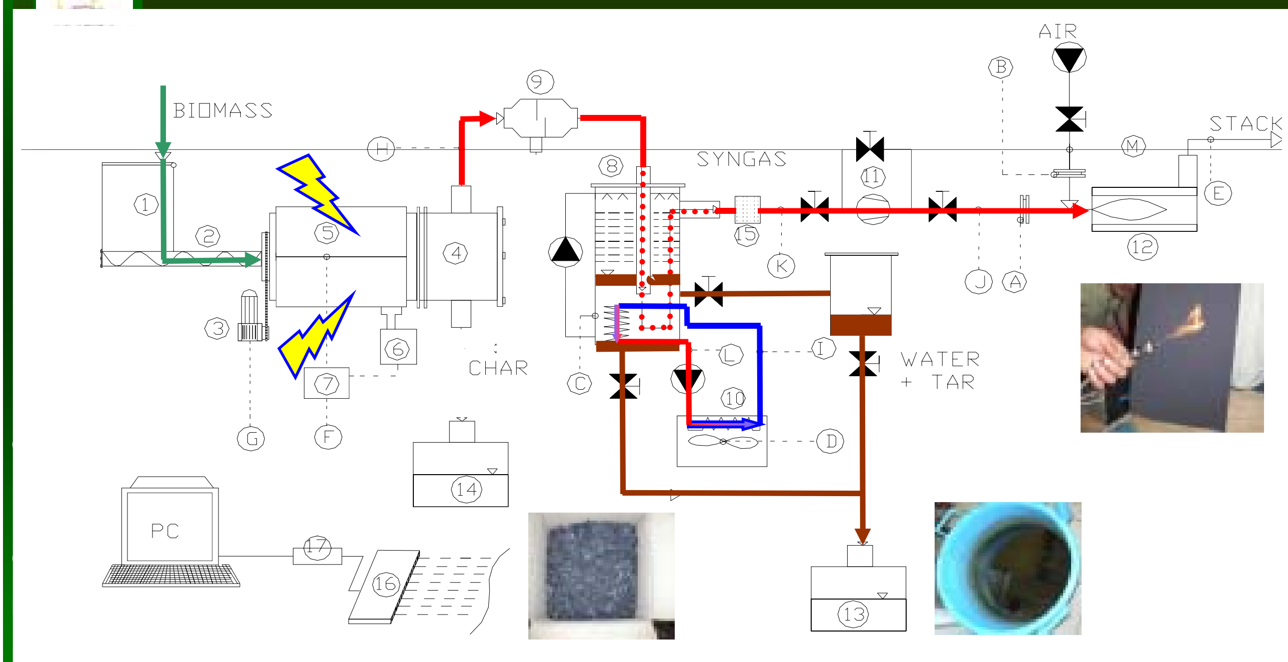

F. Fantozzi

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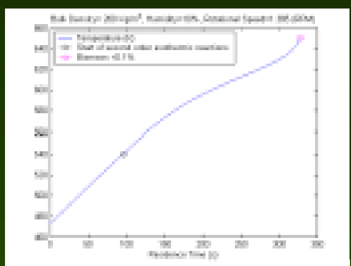
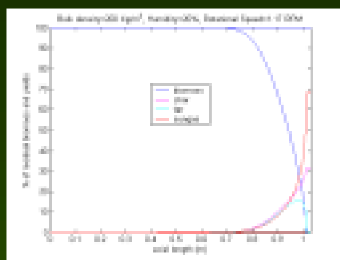
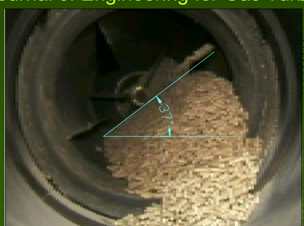
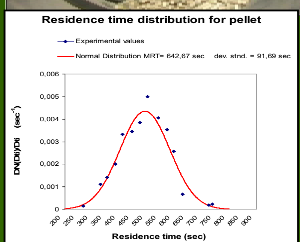
NUMERICAL SIMULATION

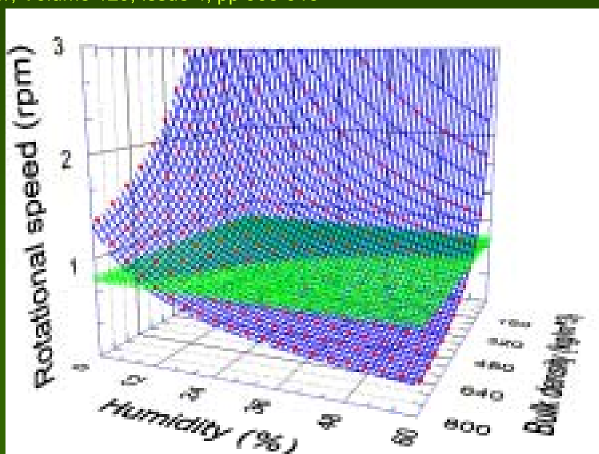




F. Fantozzi, P. Bartocci, S. Colantoni and U. Desideri, 2006, Rotary Kiln Slow Pyrolysis For Syngas And Char Production From Biomass And Waste - Part 2 Introducing Product Yields In The Energy Balance, TRANSACTION OF THE ASME, Journal of Engineering for Gas Turbines & Power, Volume 129, Issue 4, pp 908-913







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IPRP DEMONSTRATIVE UNIT

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NET POWER OUTPUT	80 kW
ELECTRIC EFFICIENCY	16%
COFINANCING	UMBRIA REGION
LOCALISATION	TERNI, ITALY
STATE OF PROJECT	START UP
COMMERCIALISATION	BIO-NET SRL*

* Spin Off company of the University of Perugia

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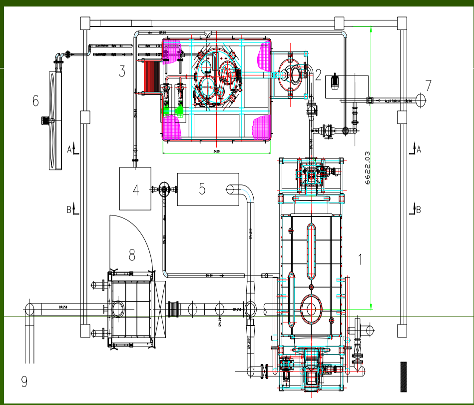

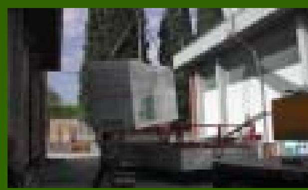

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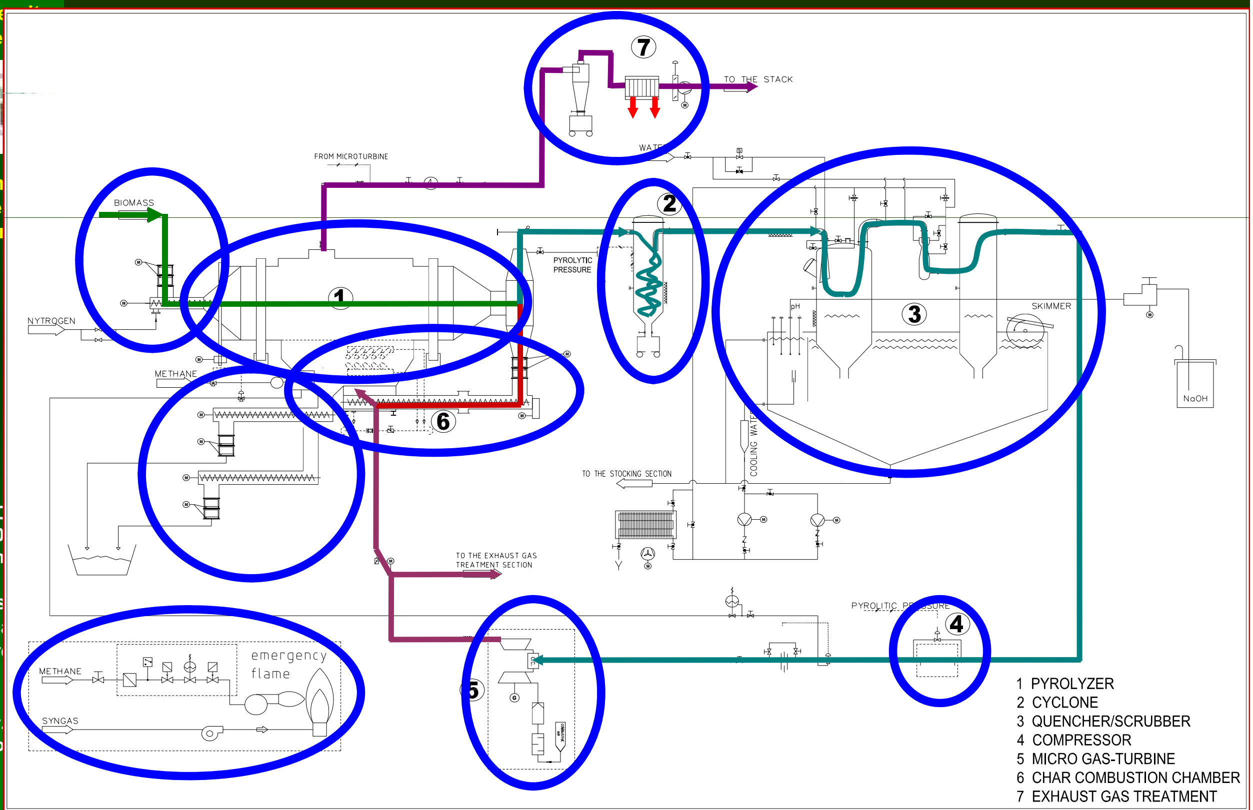

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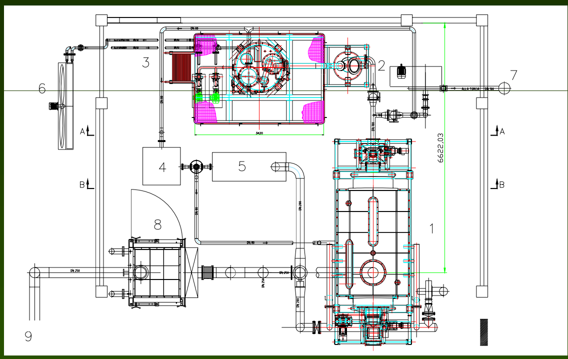
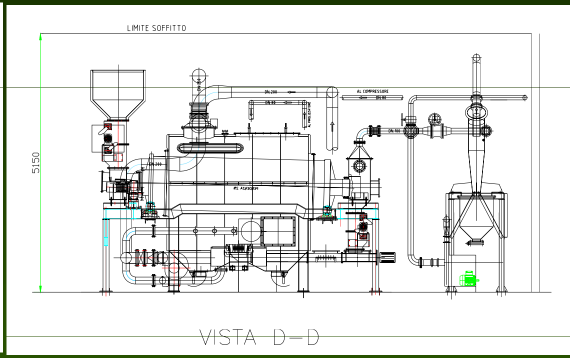
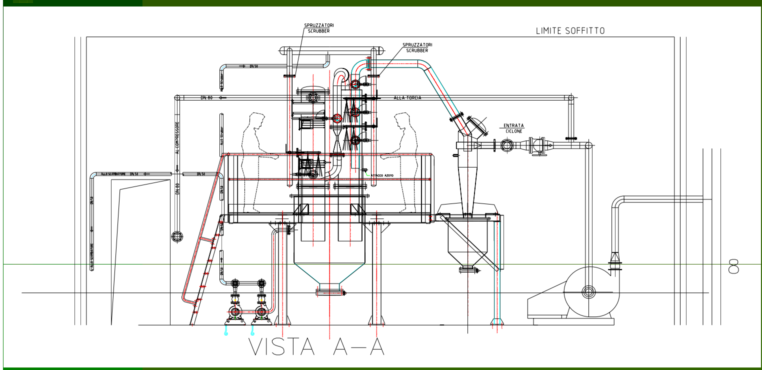
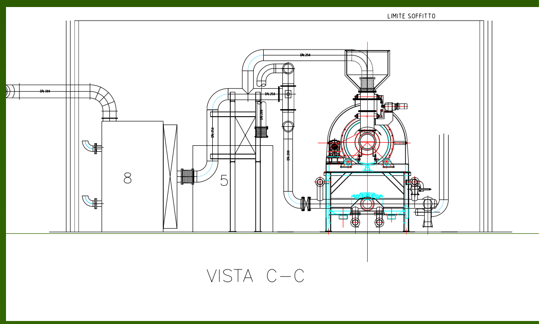
• design









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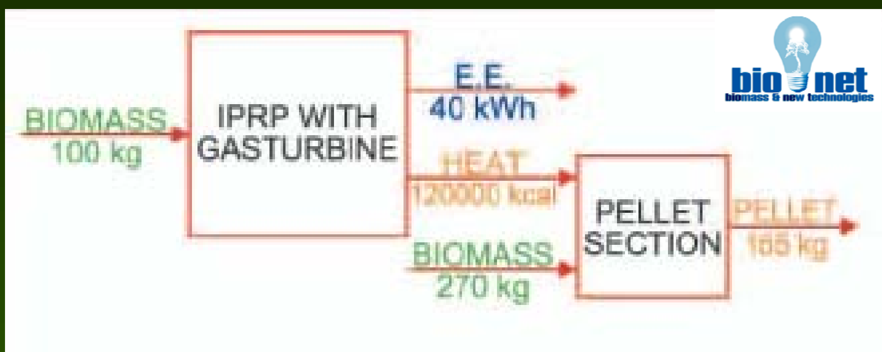
IPRP WITH GAS TURBINE



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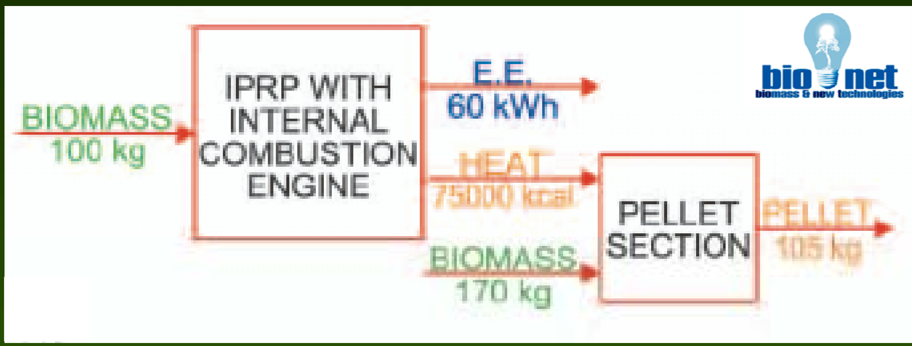
IPRP WITH IC ENGINE



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MASS & ENERGY BALANCE

	A	B	C
Biomass LHV (wb)	7,300	3,700	6,100
Moisture (%)	20	50	30
Biomass flow (kg/h wb)	200	320	708
Gross electric power (kW)	80	80	80
Net electric power (kW)	65	60	0
Thermal cogeneration (kW)	140	0	0
Electric efficiency (%)	16	16	0
Global Efficiency (%)	50	16	68
Pellet production (kg/h)	0	0	375
yearly production (@ 7000 h/year)			
Electricity sold to grid (MWh/y)	455	420	0
Heat recovered (GJ/y)	3,528	0	0
Pellet production (ton/y)	0	0	2625
CO_2 Reduction (ton/y)	540	540	3,000

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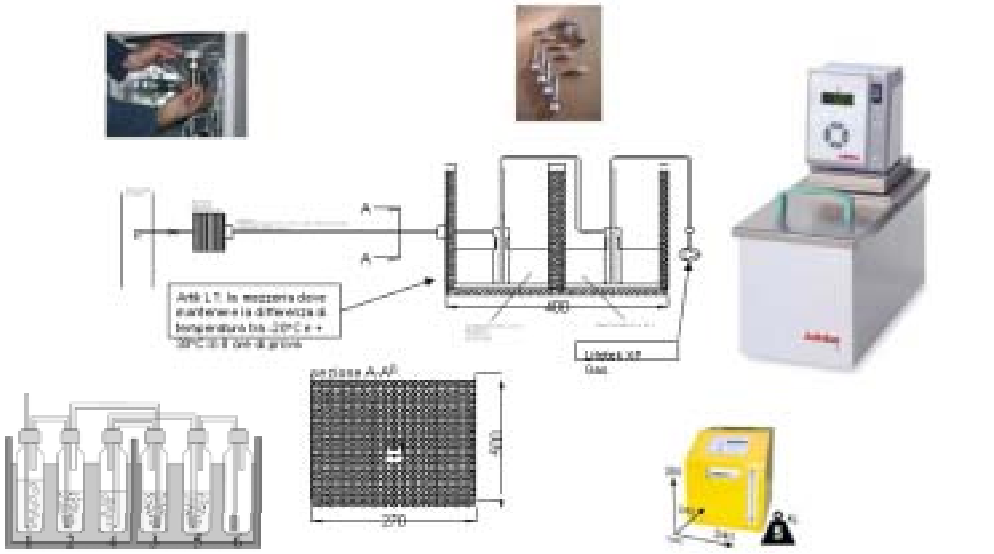
Tar sampling

Tar sampling line, attending CEN/BT/TF143 Standard "Biomass Gasification — Tar and Particles in Product Gases — Sampling and Analysis" published in 2005



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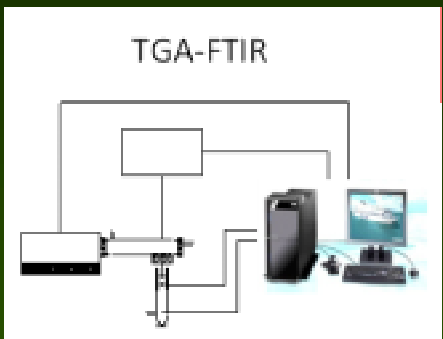
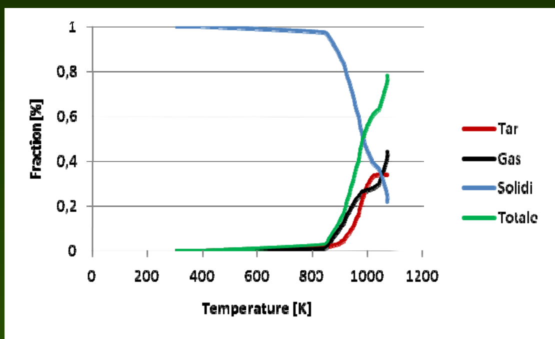
Numerical modeling

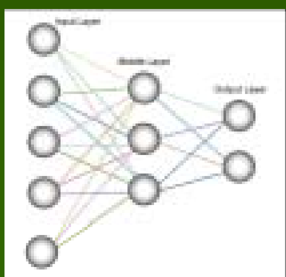
Coupling DAE (Distributed Activation Energy) models with devolatilization model





FANTOZZI F., B.D'ALESSANDRO, P.BARTOCCI, G.BIDINI (2009). Syngas heating value calculation: integration between distributed activation energy modelling (DAEM) and minimization of Gibbs free energy. In: Proceedings of the 17th European Biomass Conference. Hamburg, Germany, 29 June - 3 July 2009

Pyrolysis products forecast through Neural Networks



FANTOZZI F. (2003). Neural networks as a free model approach for waste and biomass pyrolysis products forecasting. In AA. VV. Pyrolysis and Gasification of Biomass and Waste. (pp. 125-132). ISBN: 1872691773. LONDON: A V Bridgwater (UNITED KINGDOM).

CFD modeling of syngas in GT

University of Perugia

Biomass Research Centre

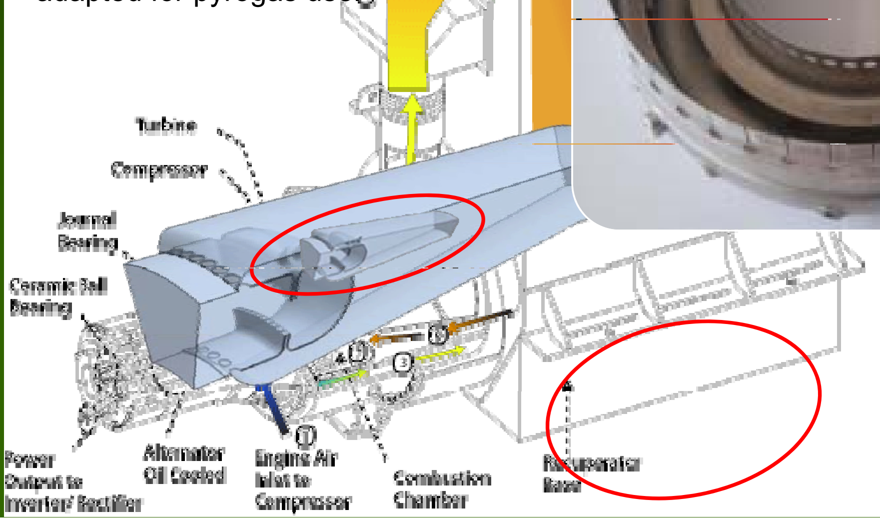
GASIFICATION 2009 Stockholm

Biomass Gasification Research in Italy

Prof. Dr. Ing. F. Fantozzi

MICROTURBINE ELLIOTT TA-80

It is a radial geometry turbocompressor with an annular combustion chamber adapted for pyrogas use



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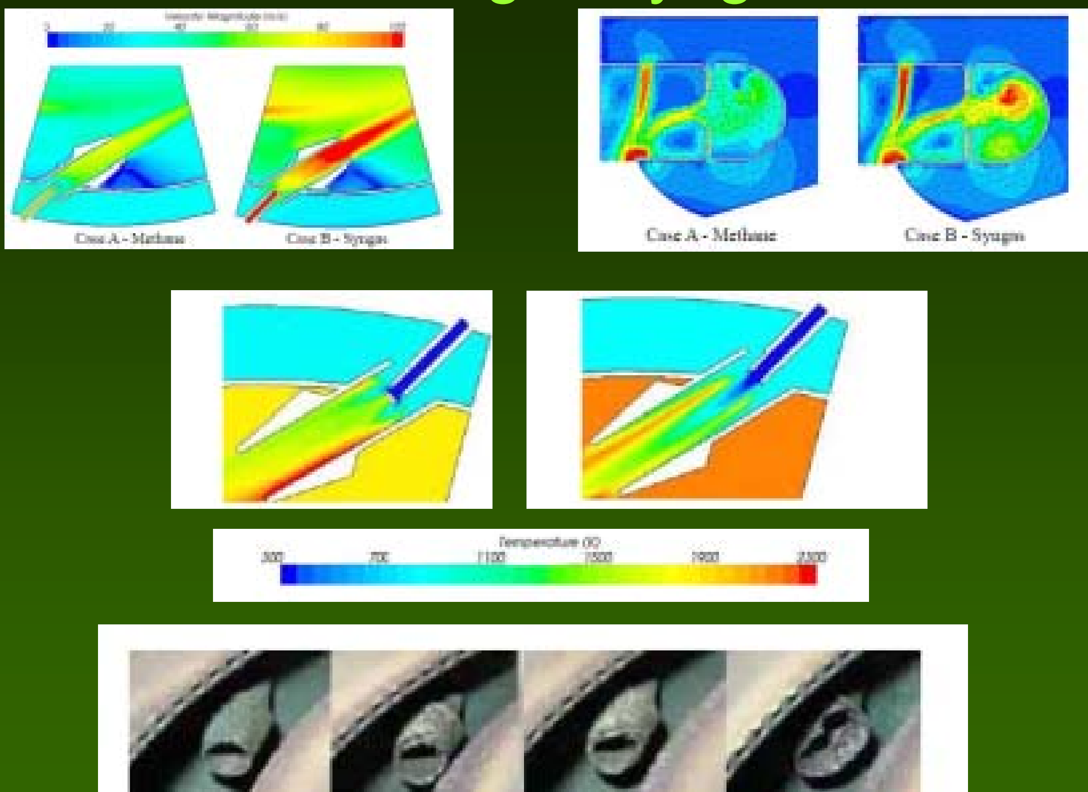

FANTOZZI F., P. LARANCI, M. BIANCHI, A. DE PASCALE, M. PINELLI, M. CADORIN (2009). CFD simulation of a microturbine annular combustion chamber fuelled with methane and or biomass pyrolysis syngas – Preliminary results. In: ASME Turbo Expo 2009 Power for Land, Sea, and Air. Orlando FL USA, 8-12 giugno 2009

University of Perugia

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Biomass Gasification Research in Italy

Prof. Dr. Ing. F. Fantozzi

Other activities

S. COLANTONI, S. DELLA GATTA, R. DE PROSPERIS, A. RUSSO, FANTOZZI F., U. DESIDERI (2009). Gas turbines fired with biomass pyrolysis syngas: analysis of the overheating of hot gas path components. In: General Electric – GE - Technology Insight - 2009

FANTOZZI F., B. D'ALESSANDRO, P. BARTOCCI, U. DESIDERI, G. BIDINI (2009). Performance evaluation of the IPRP technology when fuelled with biomass residuals and waste feedstocks. In: ASME Turbo Expo 2009 Power for Land, Sea, and Air. Orlando FL USA, 8-12 giugno 2009

Thank you for your attention

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ECN

Energy research Centre of the Netherlands

RD&D needs and recommendations for the production of high-efficient bioSNG

Robin Zwart

www.ecn.nl

ECN

RD&D needs and recommendations for the production of high-efficient bioSNG

Supporting organisations:

- NoE Bioenergy
- ERA-NET Bioenergy

Bioenergy NoE

ERA-NET Bioenergy

Co-authors:

- Tuula Mäkinen and Carl Wilén (VTT)
- Philip Peck and Andrius Plepys (IIIEE)
- Gerfried Jungmeier and Johanna Pucker (Joanneum Research)

ECN iiiee Internationella Miljöinstitutet VTT JOANNEUM RESEARCH

Outline

- Motivation for bioSNG
- Production of bioSNG

- Methanation issues
- ECNs bioSNG production concept

- RD&D needs and recommendations

Motivation for bioSNG

Large market

- Natural gas consumption is significant
- Targets for renewable and sustainable energy also valid for natural gas

Easy to implement

- Conventional fuel in an existing distribution grid

Efficient as well as sustainable fuel

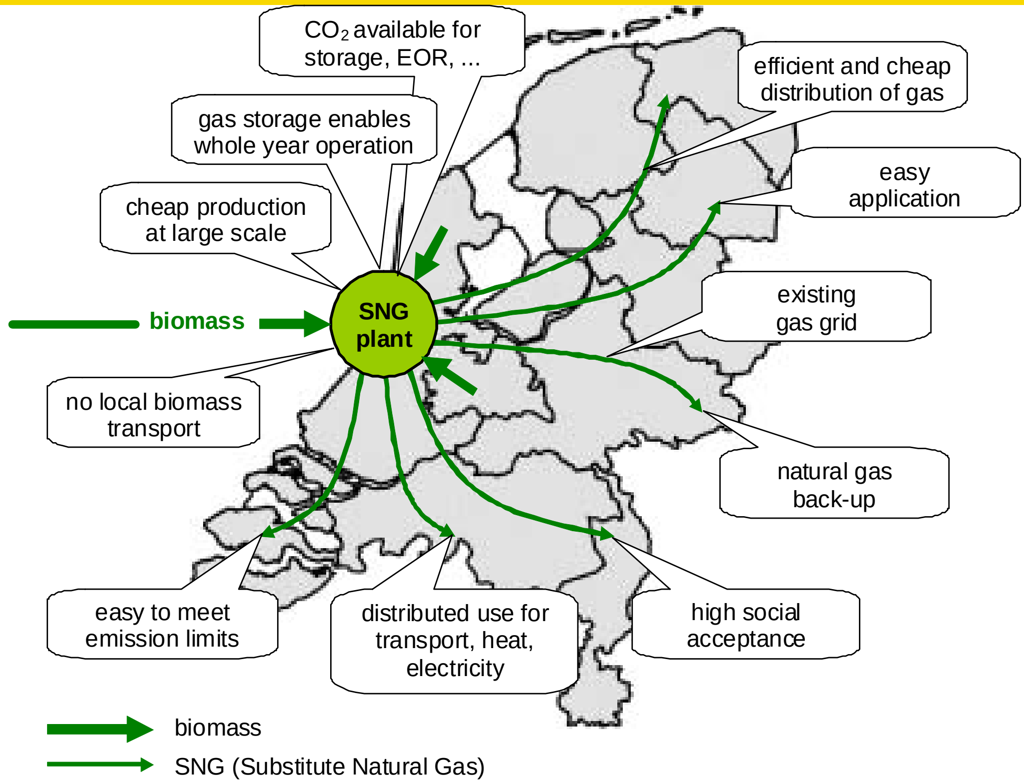
- High production efficiencies
- Excellent Green House Gas emission reduction

Increasing interest from the industry

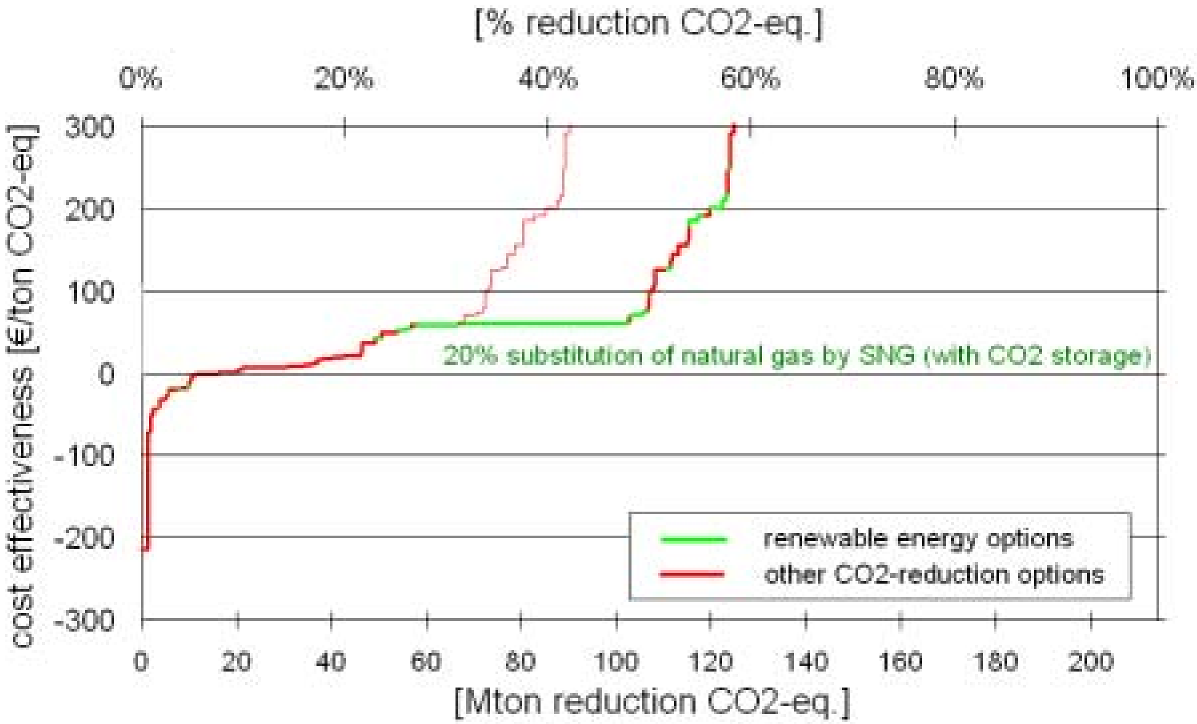
2005 Primary Energy Consumption in EUROGAS Member Countries and EU25

Mt.o.e.	Oil	Solid fossil fuels	Natural gas	Nuclear el	Hydro el.	El. Imports	Renew-ables	Others	Total	Gas : Total [%]
Austria	14.6	3.9	**8.1**	0.0	3.3	0.0	4.2	0.0	34.2	24
Germany	122.0	82.1	**77.0**	42.5	4.1	-0.7	12.5	0.0	339.5	23
Denmark	8.2	3.7	**4.5**	0.0	0.0	0.1	3.1	0.0	19.6	23
France	92.0	13.6	**40.8**	117.7	5.0	-5.2	12.5	0.0	276.4	15
Finland	8.7	4.7	**3.6**	5.8	1.2	1.5	6.5	0.6	32.5	11
Netherlands	29.8	8.2	**35.5**	0.9	0.0	1.7	0.4	2.4	78.9	45
Poland	18.0	56.4	**12.2**	0.0	0.5	-0.6	4.7	0.0	91.3	13
Sweden	16.5	2.4	**0.9**	18.0	5.2	-0.6	9.5	1.1	53.0	2
UK	78.5	40.1	**93.6**	18.5	0.5	0.7	3.7	0.0	235.6	40
EU 15	595.4	220.6	**390.5**	230.8	26.5	2.8	67.9	4.2	1538.6	25
EU 25	639.3	316.9	**434.3**	251.2	28.4	3.1	75.6	4.7	1754.2	25

Source: Eurogas (2006) EU25 : Natural Gas Trends 2004-2005. Statistical Data & Taxes




gte
Gas Transmission Europe
THE EUROPEAN
NATURAL GAS
NETWORK


[% reduction CO2-eq.]
0%
20%
40%
60%
80%
100%
cost effectiveness [€/ton CO2-eq]
300
200
100
0
-100
-200
-300
20% substitution of natural gas by SNG (with CO2 storage)
renewable energy options
other CO2-reduction options
0
20
40
60
80
100
120
140
160
180
200
[Mton reduction CO2-eq.]

Motivation for bioSNG

Technology developers and suppliers

DAHLMAN · PSI (Paul Scherrer Institut) · TU Wien · Biomasse Kraftwerk Güssing · ECN · Conzepte Technik Umwelt · repotec

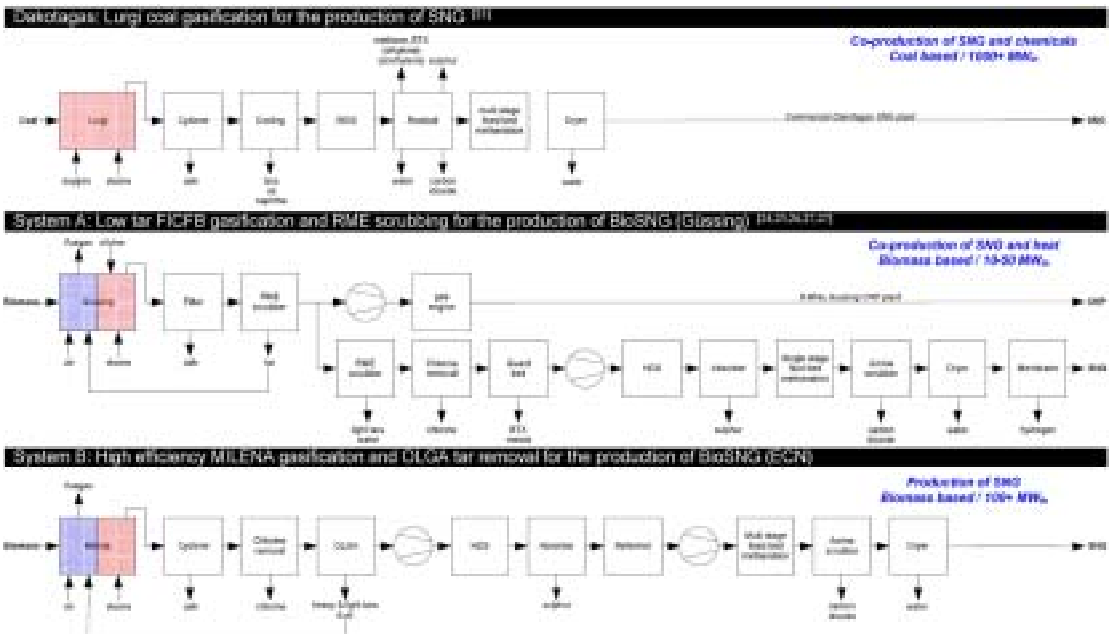
Utility companies

Göteborg Energi · e.on · HVC · GDF SUEZ

Timeline

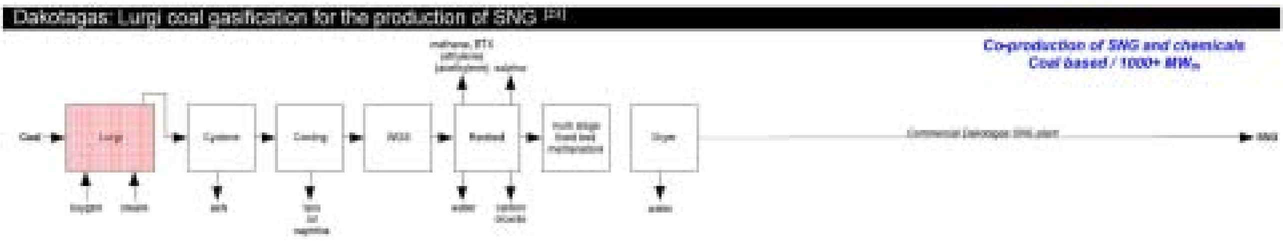
- 2009:
  - Final decision on GoBiGas project
  - Decision on HVC project
- 2010:
  - Construction phase 1 GoBiGas project
  - Design 200 MW_{th} E.On project
- 2012:
  - Operation phase 1 GoBiGas project
- 2013:
  - Construction phase 2 GoBiGas project
  - Design 300 MW_{th} E.On project
- 2014:
  - Construction 50 MW_{th} HVC project
- 2015:
  - Operation 50 MW_{th} HVC project
  - Operation 200 MW_{th} E.On project
- 2016:
  - Operation phase 2 GoBiGas project

Production of bioSNG



Production of SNG

Dakotagas (USA): Lurgi coal gasification



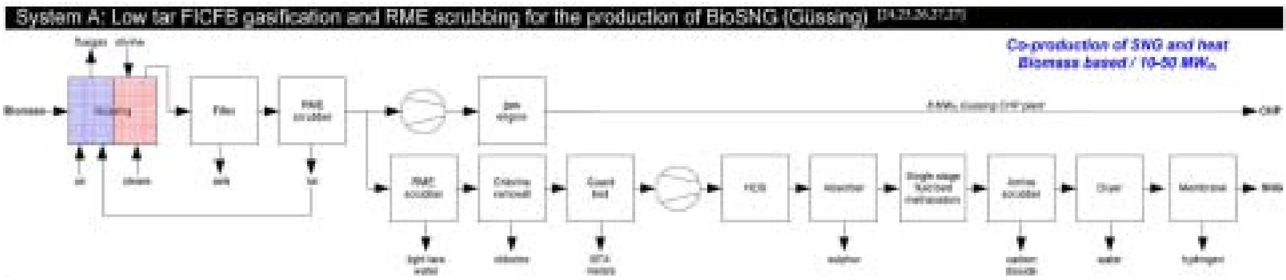
Large scale coal based SNG production:

- The gasifier is not suitable for conversion of biomass and/or tars
- The gas cleaning and conditioning applied is operating at pressure levels and sulphur loads being (for the moment) not realistic for biomass based systems
- The Rectisol unit removes to many high valuable gas components

ECN

Production of bioSNG

Güssing (Au): FICFB gasification & RME scrubbing

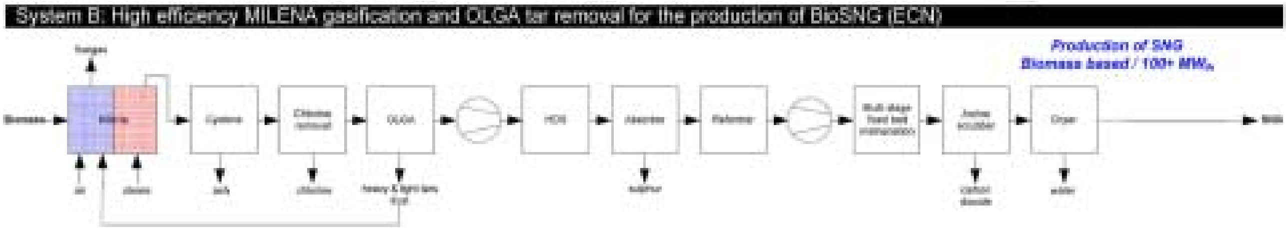


Small scale biomass based heat and SNG production:

- The gasifier is not optimised for SNG production
- The gas cleaning and conditioning applied starts with the conventional RME scrubber of Güssing and does not allow high tar contents in the initial product gas
- Water is condensed out before the methanation

Production of bioSNG

Petten (Nl): MILENA gasification & OLGA tar removal



<u>Large scale biomass based SNG production</u>:

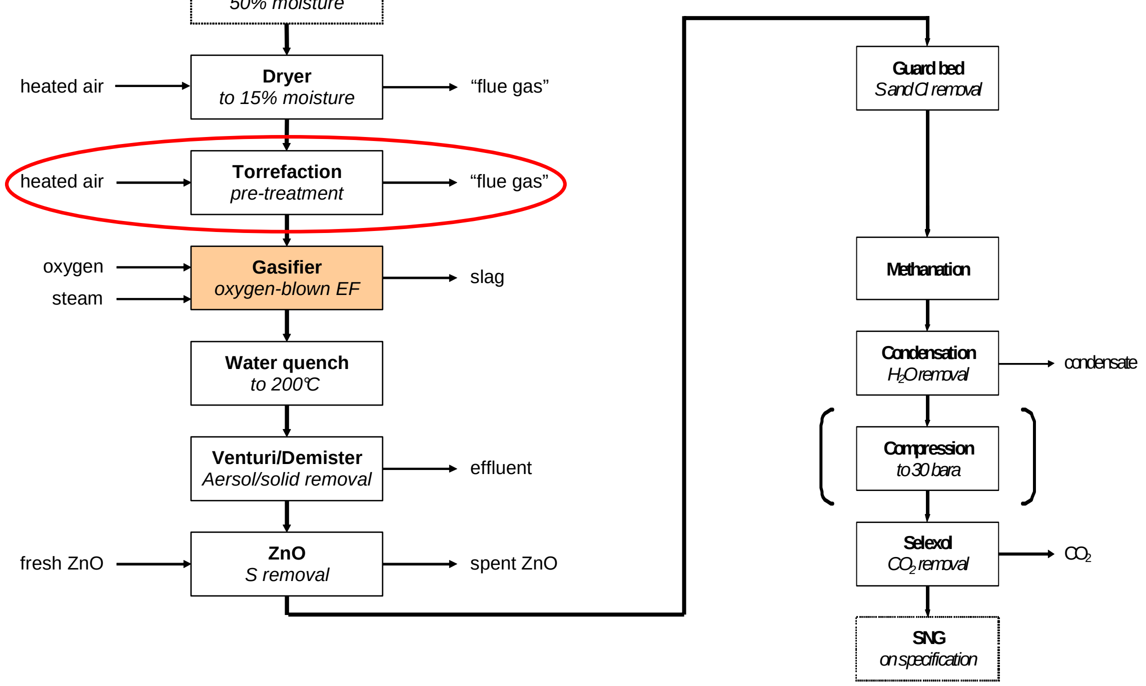
- The gasifier is optimised for SNG production
- The gas cleaning and conditioning applied starts with the flexible OLGA tar removal technology and hence does allow high tar contents in the initial product gas
- Water is not condensed out before the methanation

Production of bioSNG

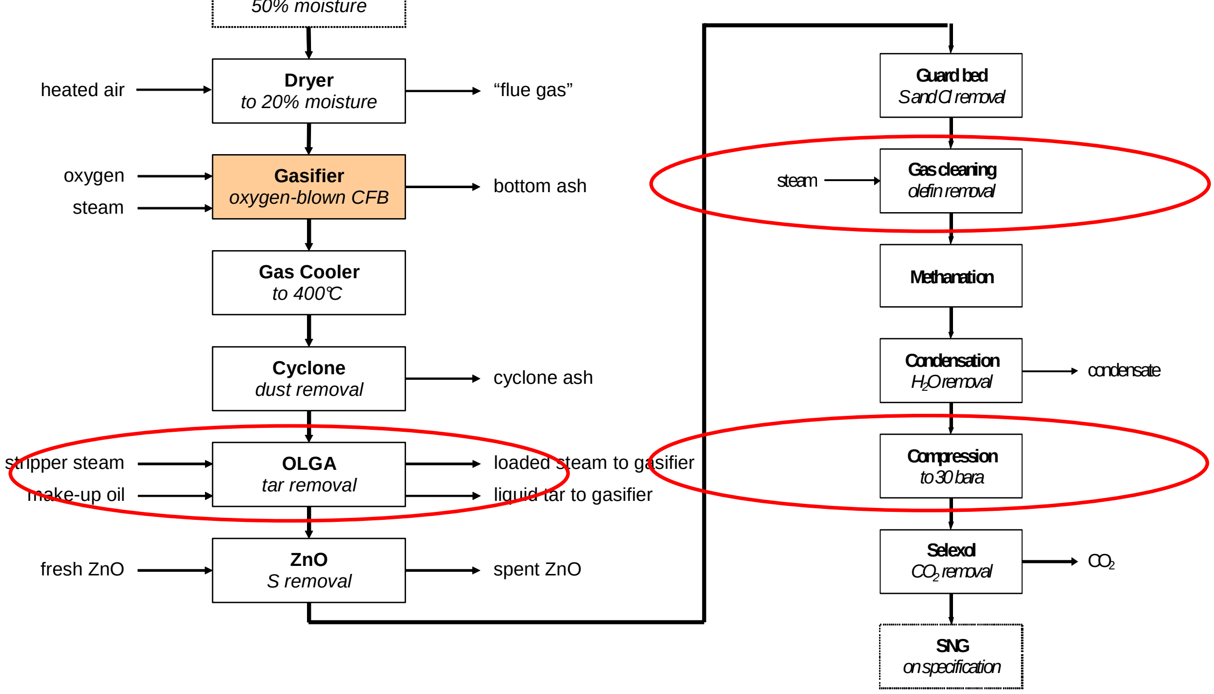
Comparison with entrained flow and pressurised O_2 blown

- Entrained flow:
  - operated at elevated pressure ↑
  - no tars in product gas ↑
  - no methane in product gas ↓
  - complicated feeding ↓
- Oxygen blown CFB:
  - operated at slightly elevated pressure ↑
  - methane in product gas ↑
  - tars and organic sulphur in gas ↓
  - “limited” char conversion ↓
- Indirect/allothermal:
  - methane in product gas ↑
  - no oxygen plant requied ↑
  - tars and organic sulphur in gas ↓
  - atmospheric, compression required ↓

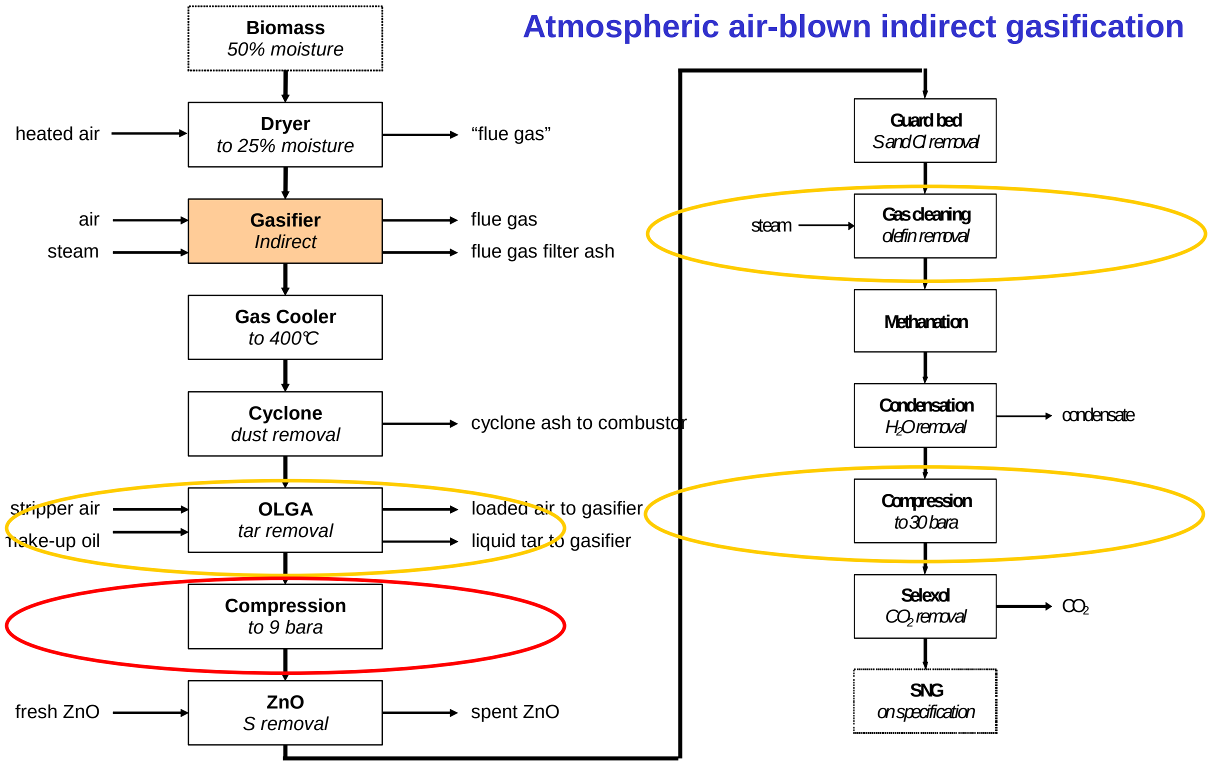
Pressurised O_2-blown EF gasification



Pressurised O_2-blown CFB gasification

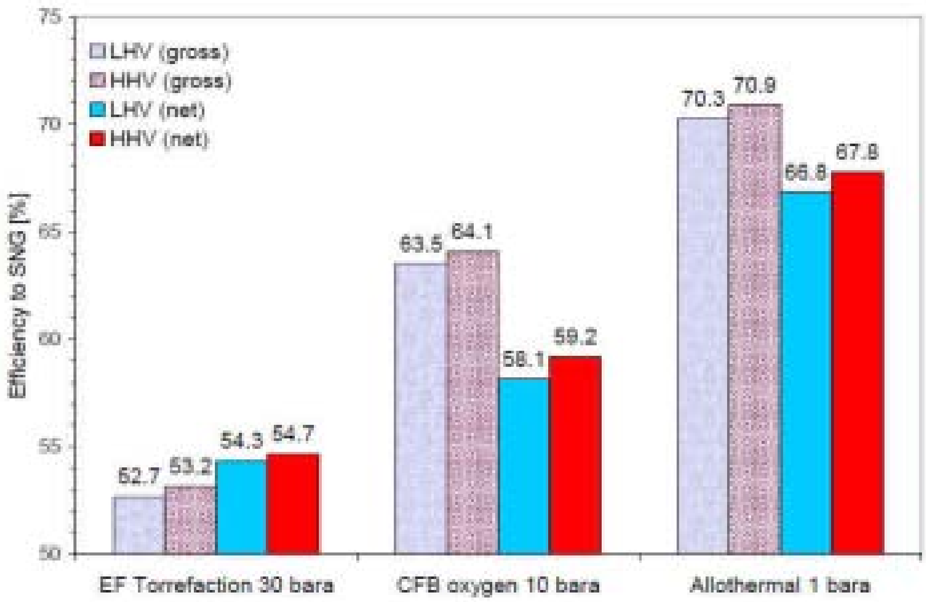


Atmospheric air-blown indirect gasification



Production of bioSNG

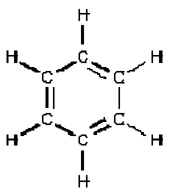
Others: entrained flow, pressurised O_2 blown, …



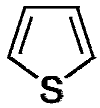
Methanation issues

Problematic components for methanation

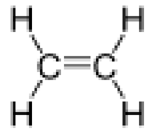
Benzene:



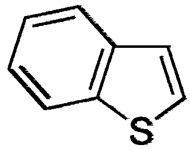
Thiophene:



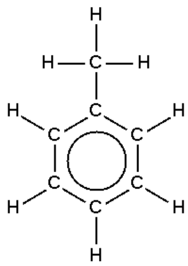
Ethylene:



Benzothiophene:

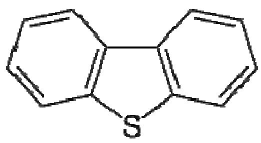


Toluene:



Acetylene:

Dibenzothiophene:



Methanation issues

Non-problematic components for methanation

Saturated hydrocarbons:

Saturated hydrocarbons are converted into methane

Phenol:

Phenol is converted

Ammonia and hydrogen cyanide:

Hydrogen cyanide is converted into ammonia

Chlorine:

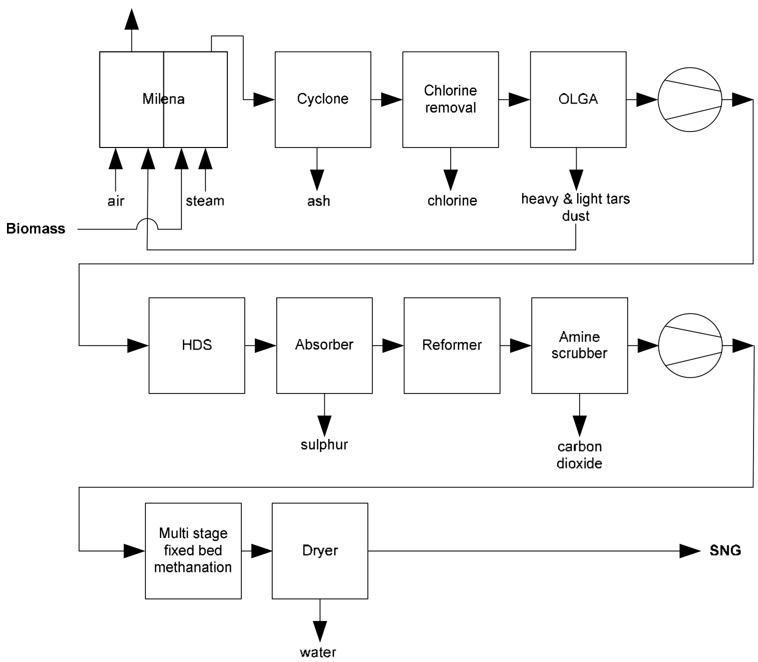
Although not problematic for the catalyst it can result in corrosion of materials!

ECNs bioSNG production concept

Based on MILENA gasification and OLGA tar removal

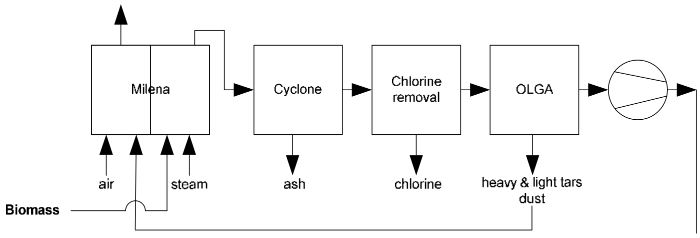
Component		Downstream MILENA	Downstream OLGA
CO	vol%	30.1	30.6
H2	vol%	32.0	32.5
CO2	vol%	19.2	19.4
O2	vol%	0.0	0.0
CH4	vol%	12.2	12.4
N2+Ar	vol%	0.1	0.1
C2H2	vol%	0.2	0.2
C2H4	vol%	3.9	3.9
C2H6	vol%	0.2	0.2
C6H6	vol%	1.0	0.5
C7H8	vol%	0.1	0.0
Tar	g/mn3	52.1	0.2

ECNs bioSNG production concept



RD&D needs and recommendations

Upscaling gasification and tar removal

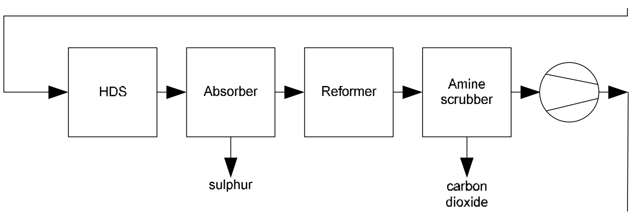


Biomass gasification has still not yet matured:

- Commercial Güssing gasifier has a capacity of 8 MW_{th}
- Pilot MILENA gasifier has a capacity of 1 MW_{th}
- Goteborg Energi wants 20-100 MW_{th}
- HVC starts with 50 MW_{th}
- E.ON wants 200+ MW_{th}

RD&D needs and recommendations

Demonstrating the critical gas cleaning steps

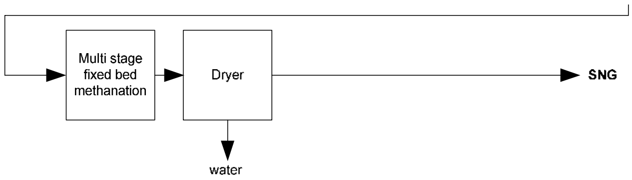


Cleaning was developed for fossil fuel based systems:

- The critical gas cleaning systems did not have to handle unsaturated hydrocarbons, tars, organic sulphur, not were optimised for being able to handle these components
- Demonstration of the critical gas cleaning steps up till now has been limited to lab and pilot scale testing for limited amount of time

RD&D needs and recommendations

Adjusting the methanation catalyst



There is only 1 commercial methanation unit in operation:

- The methanation catalyst was optimised for this specific coal based application and has over the last 25 years hardly been improved
- Optimisation of the catalyst, either in order to be able to handle specific biomass related contaminants in the product gas or in order to produce CH_4 more efficiently will require realistic long-term testing

RD&D needs and recommendations

ERA-NET Bioenergy: Gasification for SNG and FT

Meeting on October 23rd in Stockholm (15:00 - 16:00)

Recommendations for support:

Demonstration of the critical gas cleaning steps

- application of commercial catalysts in real gases
- optimisation of catalysts to improve performance
- demonstration of the overall system

Adjustment of the methanation catalyst

- catalysts tolerant to sulphur
- catalysts tolerant to unsaturated hydrocarbons

Keep in mind the differences between FT and SNG

Contact information

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publications: www.ecn.nl/publications
fuel composition database: www.phyllis.nl
tar dew point calculator: www.thersites.nl
IEA bioenergy/gasification: www.ieatask33.org
Milena indirect gasifier: www.milenatechnology.com
OLGA tar removal: www.olgatechnology.com
SNG: www.bioSNG.com and www.bioCNG.com

Vienna University of Technology

Cleaning and Usage of Product Gas from Biomass Steam Gasification

Dr. Reinhard Rauch

Institute for Chemical Engineering

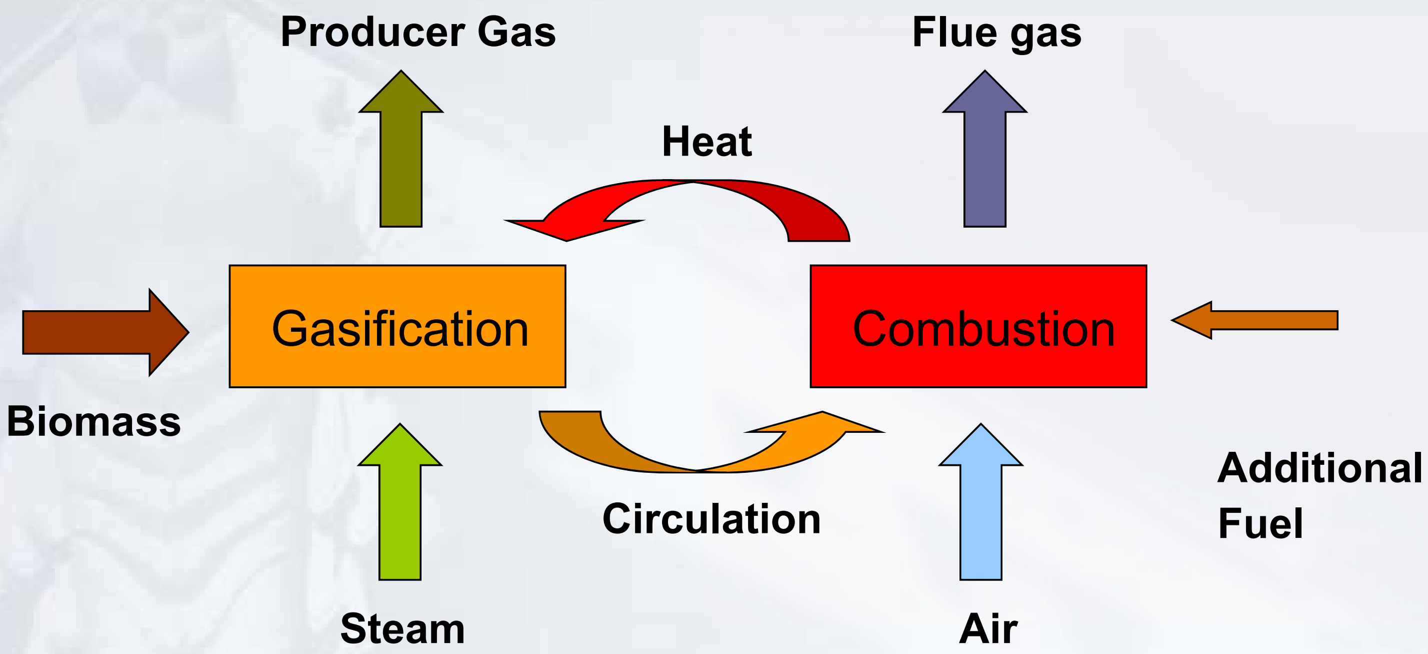
Vienna, University of Technology

Gasification 2009 – gas clean up and treatment
October 22-23, Clarion Hotel Sign, Stockholm, Sweden

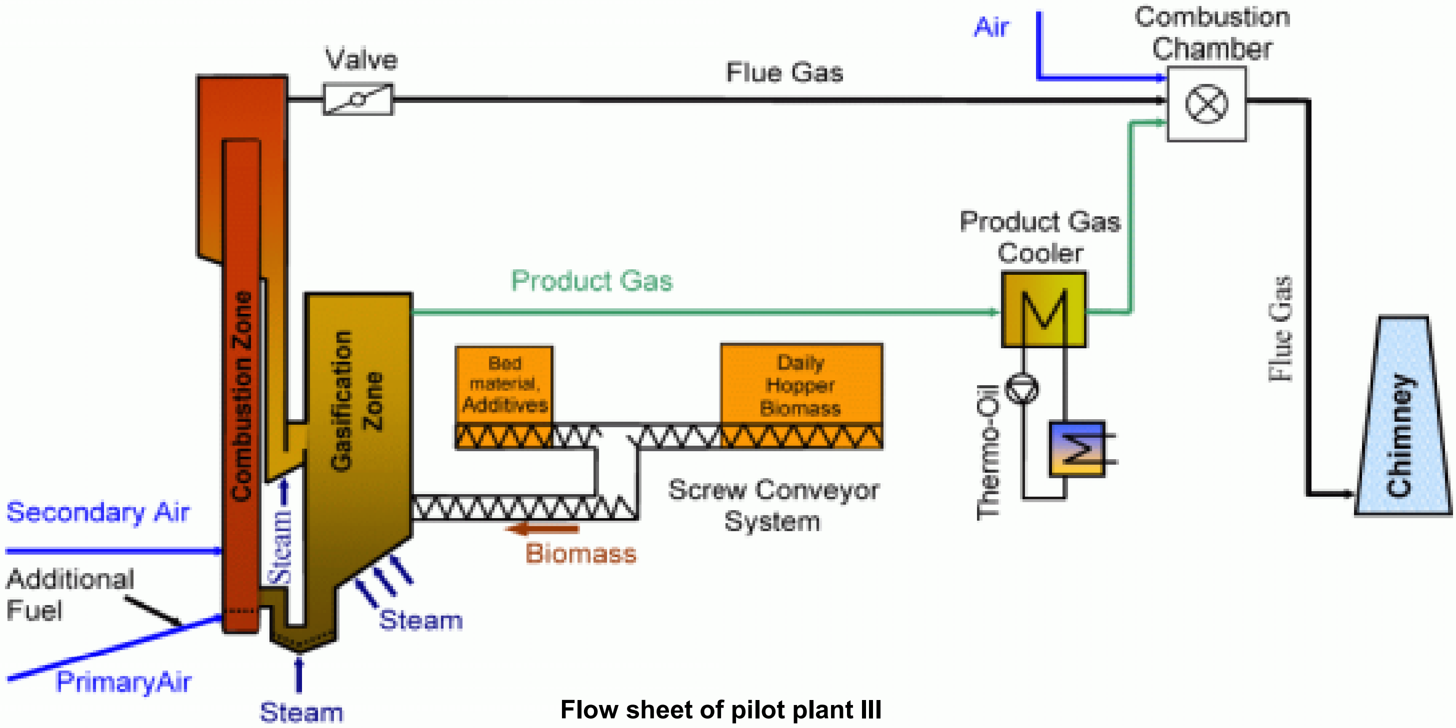
Content

- Description of gasification system
- Gas treatment and cleaning
  - Steam Reforming
  - Removal of poisons
- Synthesis applications
  - BioSNG
  - FT synthesis

Gasification Concept



100kW FICFB gasifier



Flow sheet of pilot plant III

Change of bed material and influence on gas composition

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

Bed material		Olivine	Calcite (AER-Process)	Catalyst (Nickel)
Gasification temperature		850 °C	640 °C	840°C
H_2	[mol%]	37.7	67.5	43.9
CO	[mol%]	29.1	3.3	27.2
CO_2	[mol%]	19.6	10.3	18.8
CH_4	[mol%]	10.4	13.1	8.3
C_2H_4	[mol%]	2.8	1.7	1.3
C_2H_6	[mol%]	0.3	3.0	< 0.1
HC (C_3-C_5)	[mol%]	0.1	1.1	< 0.1

Biomasses tested in the 100kW pilot scale FICFB gasifier

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

- Wood chips
- Wood pellets
- Saw dust
- Coal
- Sewage sludge pellets
- Animal residue
- Straw
- Willow

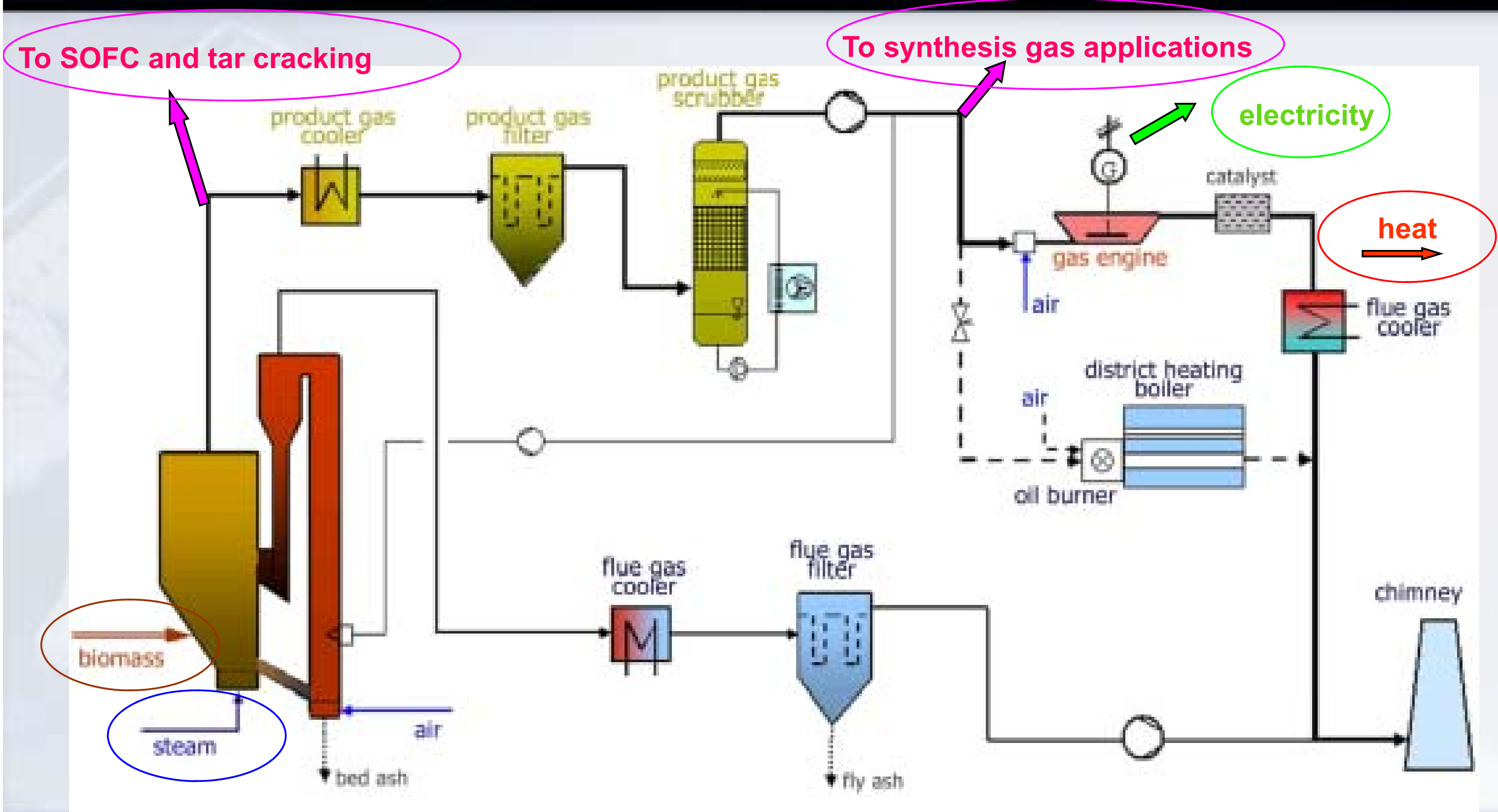
All fuels can be used, if the ash melting point is above 1000°C as pure fuel.
Fuels with lower ash melting point have to be used as mixture (e.g. 15% straw works well)

Biomass CHP Güssing design data

- Start of construction September 2000
- Start up January 2002
- Fuel 2,2 to/h (Wood chips)
- Water content 15 % (35 %)
- Fuel power 8 MW
- Electrical power 2 MW
- Thermal power 4,5 MW
- Electrical efficiency 25 % (20%)
- Total efficiency 80 %
- Owner and operator Biomass Power Station Güssing Association

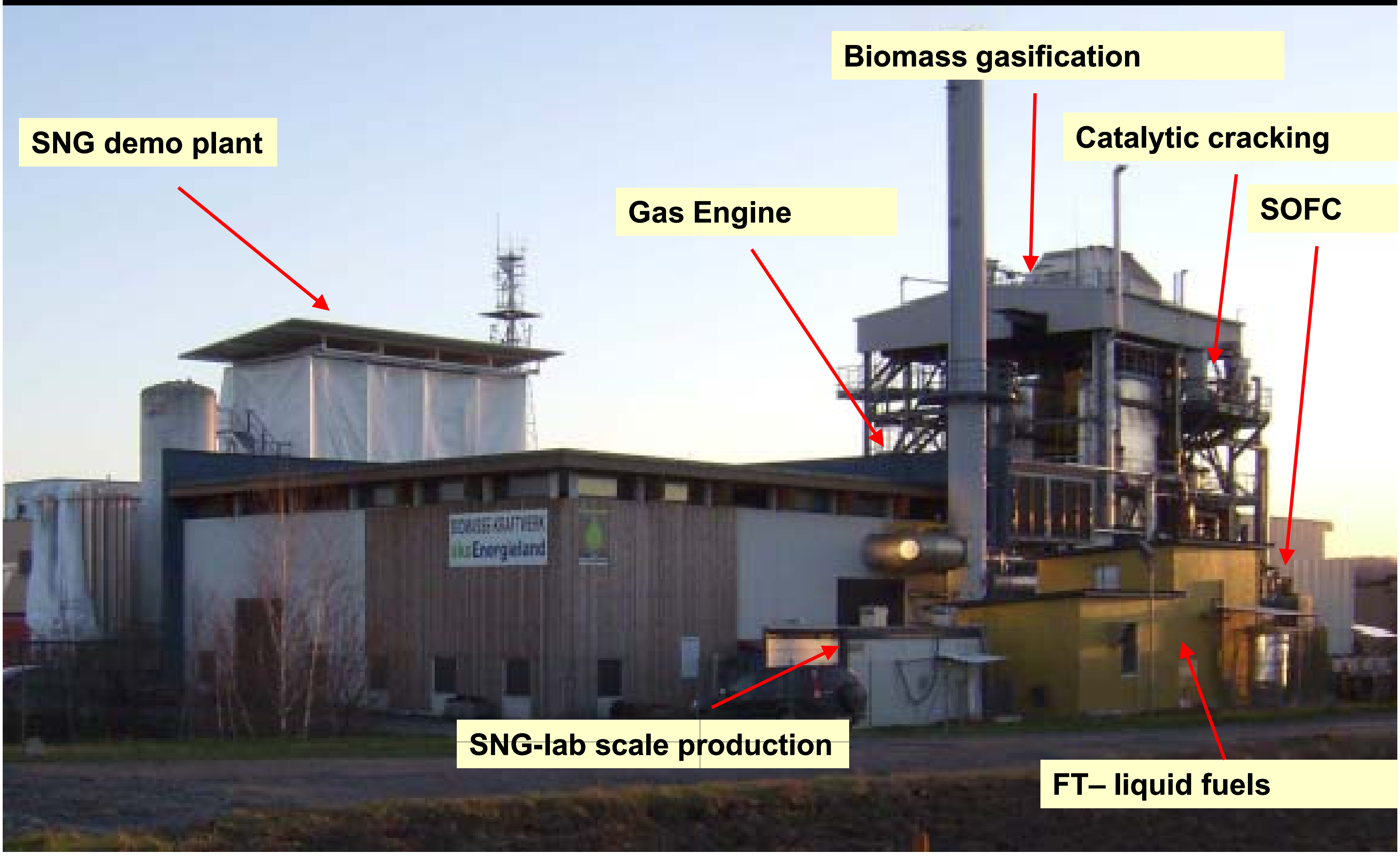
Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

CHP-PLANT GÜSSING



Biomass CHP Güssing

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology



Gas Composition (after gas cleaning)

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

Main Components		
H_2	%	35-45
CO	%	22-25
CH_4	%	~10
CO_2	%	20-25
Minor Components		
C_2H_4	%	2-3
C_2H_6	%	~0.5
C_3H_6	%	~0,4
O_2	%	< 0,1
N_2	%	1-3
C_6H_6	g/m³	~8
C_7H_8	g/m³	~0,5
$C_{10}H_8$	g/m³	~2
TARS	mg/m³	20-30

Possible poisons		
H_2S	mgS/Nm³	~200
Mercaptans	mgS/Nm³	~30
Thiophens	mgS/Nm³	~7
HCl	ppm	~3
NH3	ppm	500-1000
Dust	mg/Nm³	< 20

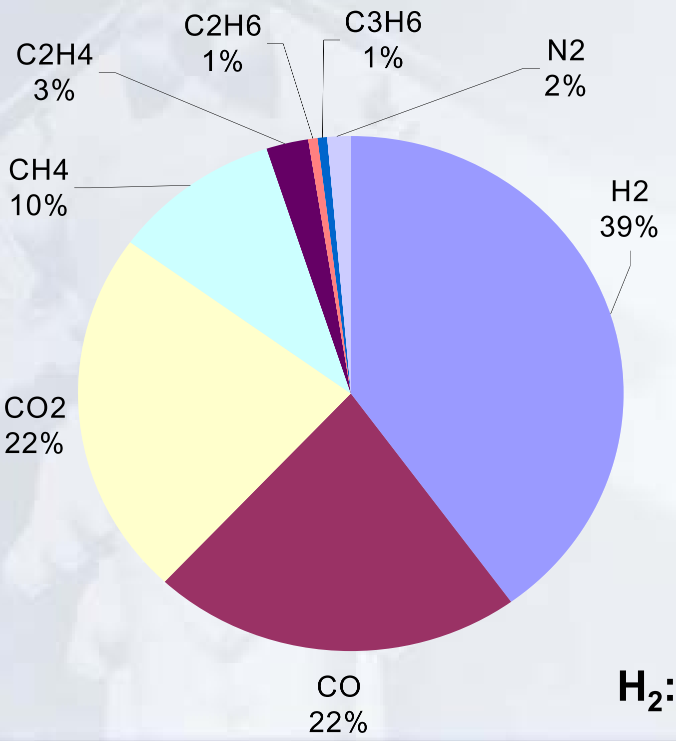
H_2:CO = from 1.5:1 to 2:1

Content

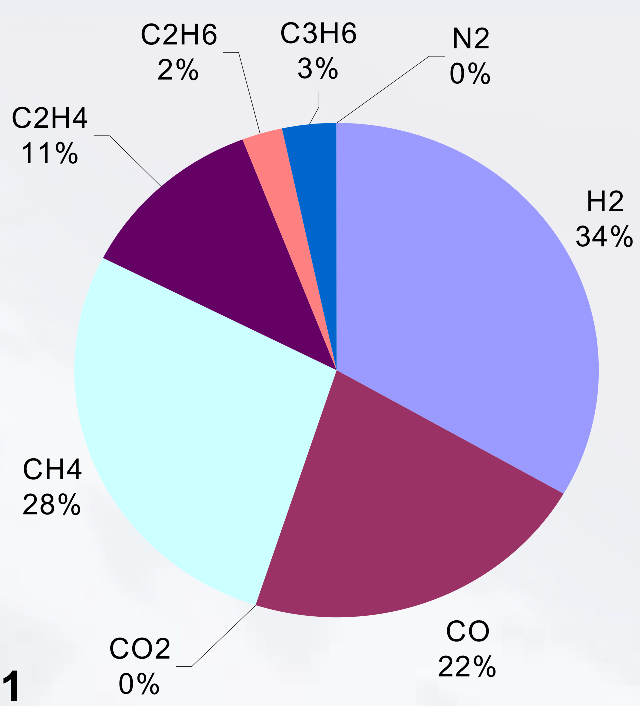
- Description of gasification system
- Gas treatment and cleaning
  - Steam Reforming
  - Removal of poisons
- Synthesis applications
  - BioSNG
  - FT synthesis

Gas composition

On volume basis

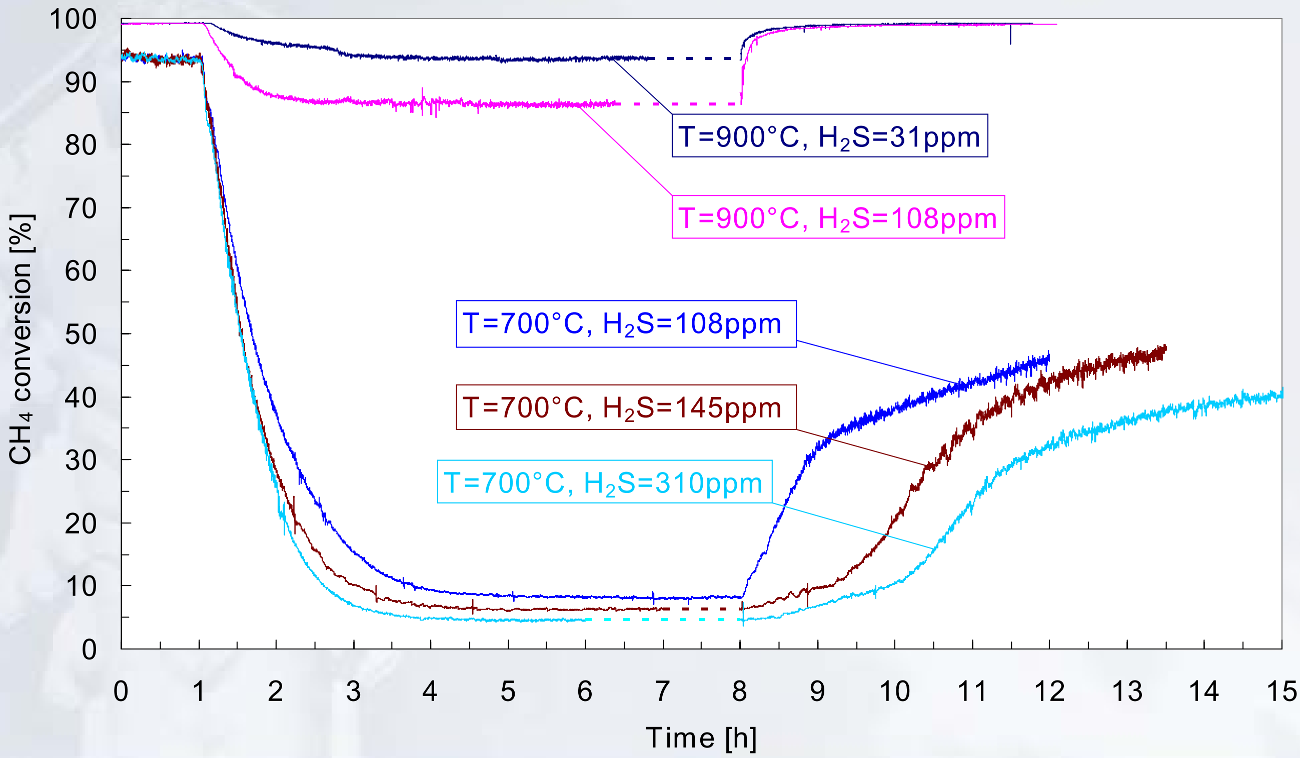


On energy basis



H_2:CO = 1.8:1

Catalyst performance recovery by H_2S removal (lab scale)



Steam reformer integrated into FT unit at the biomass CHP Güssing

Heat exchanger for steam generation

1st reforming reactor

2nd reforming reactor

Heat exchanger for cooling

Results of the catalyst testing

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

Gascomposition after the steam reformer for each catalyst at 900°C

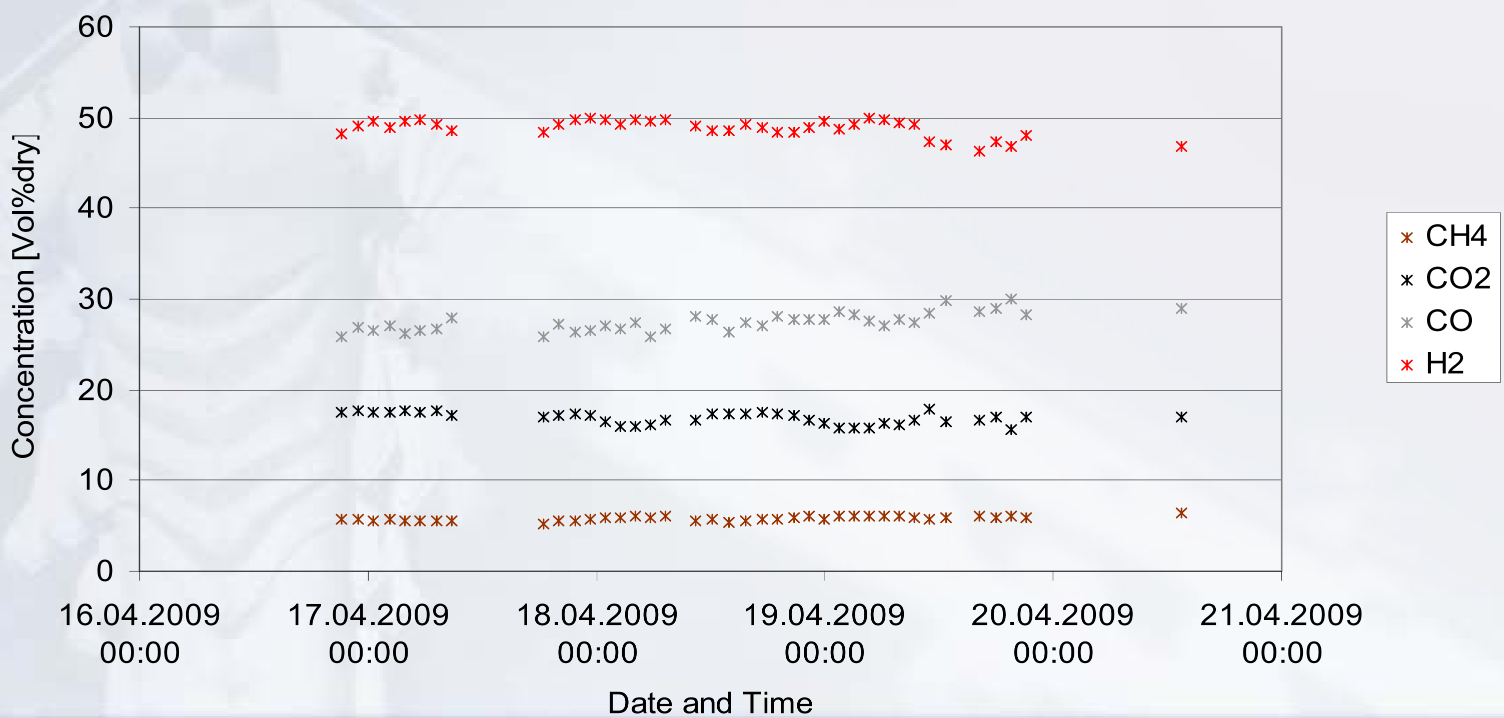
Catalyst	CH4	N2	CO2	CO	H2	H2/CO
None	10,6	1,0	24,0	23,4	37,5	1,6
Methanereformer	7,4	1,1	23,4	26,7	40,7	1,5
Aromaticreformer	5,8	1,0	16,9	27,5	48,8	1,8
Naphtareformer	6,4	1,1	16,0	30,5	45,9	1,5

Catalyst	C2H4	C2H6	C3H6	C3H8
None	3,1	0,2	0,2	0,0
Methanereformer	0,6	0,1	0,0	0,0
Aromaticreformer	0,0	0,0	0,0	0,0
Naphtareformer	0,1	0,0	0,0	0,0

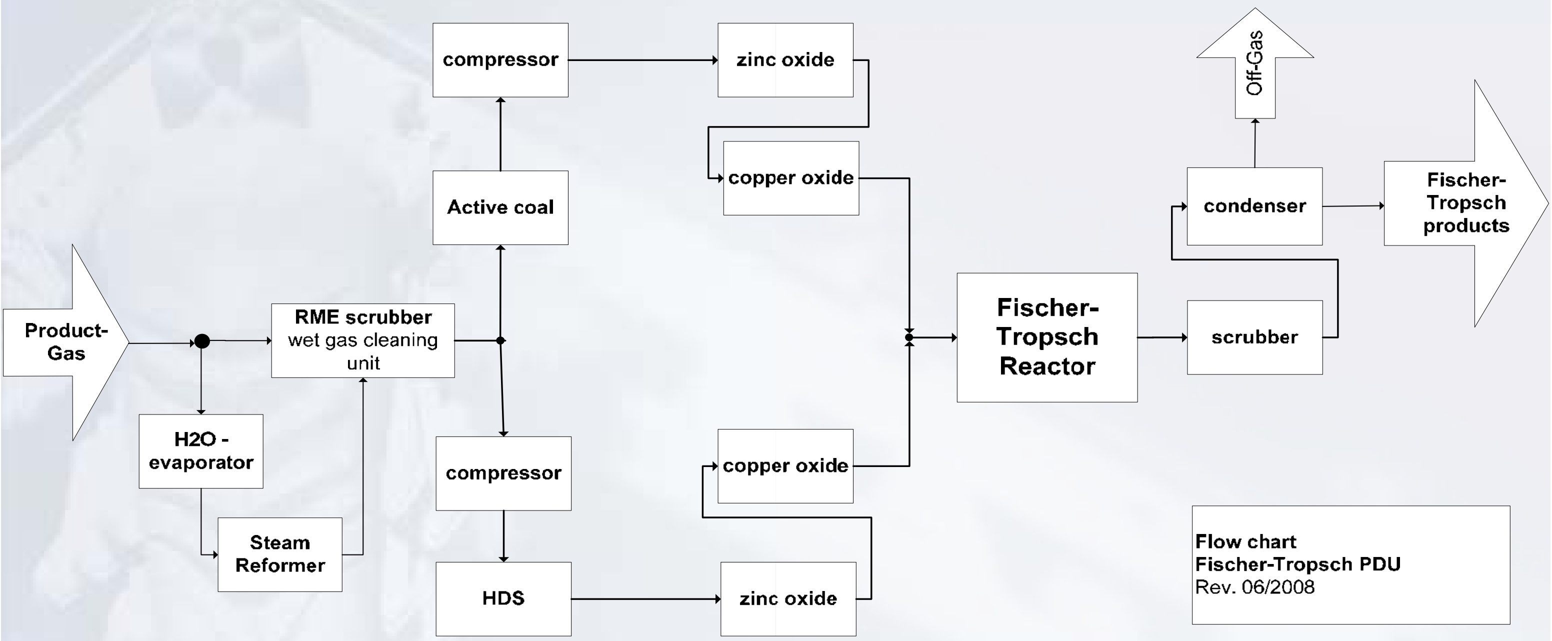
Long term testing (aromatics reformer)

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

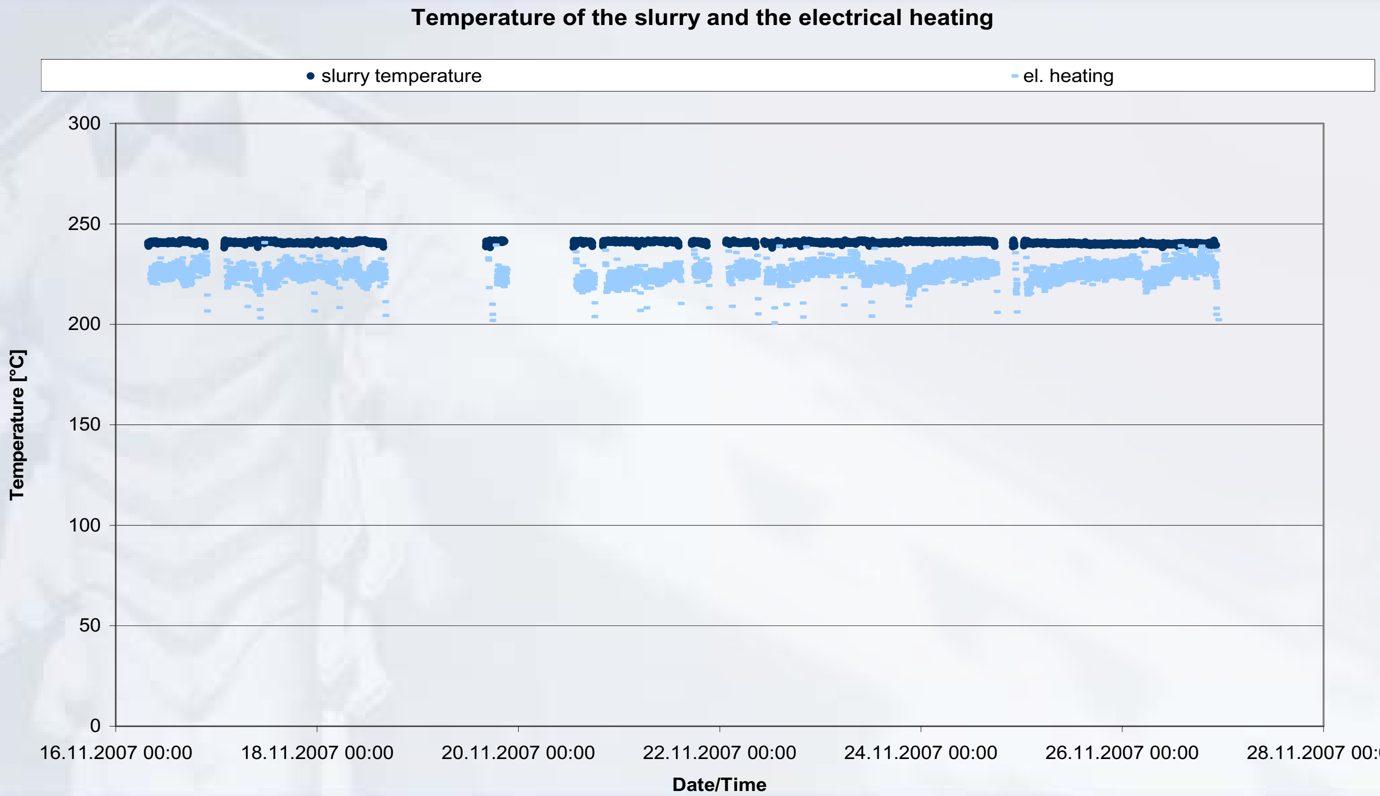
Gascomposition after the aromatics reformer - main components



Schema of gas treatment for synthesis applications



No deactivaton of FT catalyst



Content

- Description of gasification system
- Gas treatment and cleaning
  - Steam Reforming
  - Removal of poisons
- Synthesis applications
  - BioSNG
  - FT synthesis

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

Renewable liquid fuels

Fischer-Tropsch Syntheses

BioFiT

BIOMASS-TO-FISCHER-TROPSCH

FT-Reactor and catalysts

A Slurry-Reactor is used. A slurry reactor is a 3-phase reactor, where the solid catalyst is suspended in the liquid product and the gas keeps the catalyst in suspension.

The main advantages are:

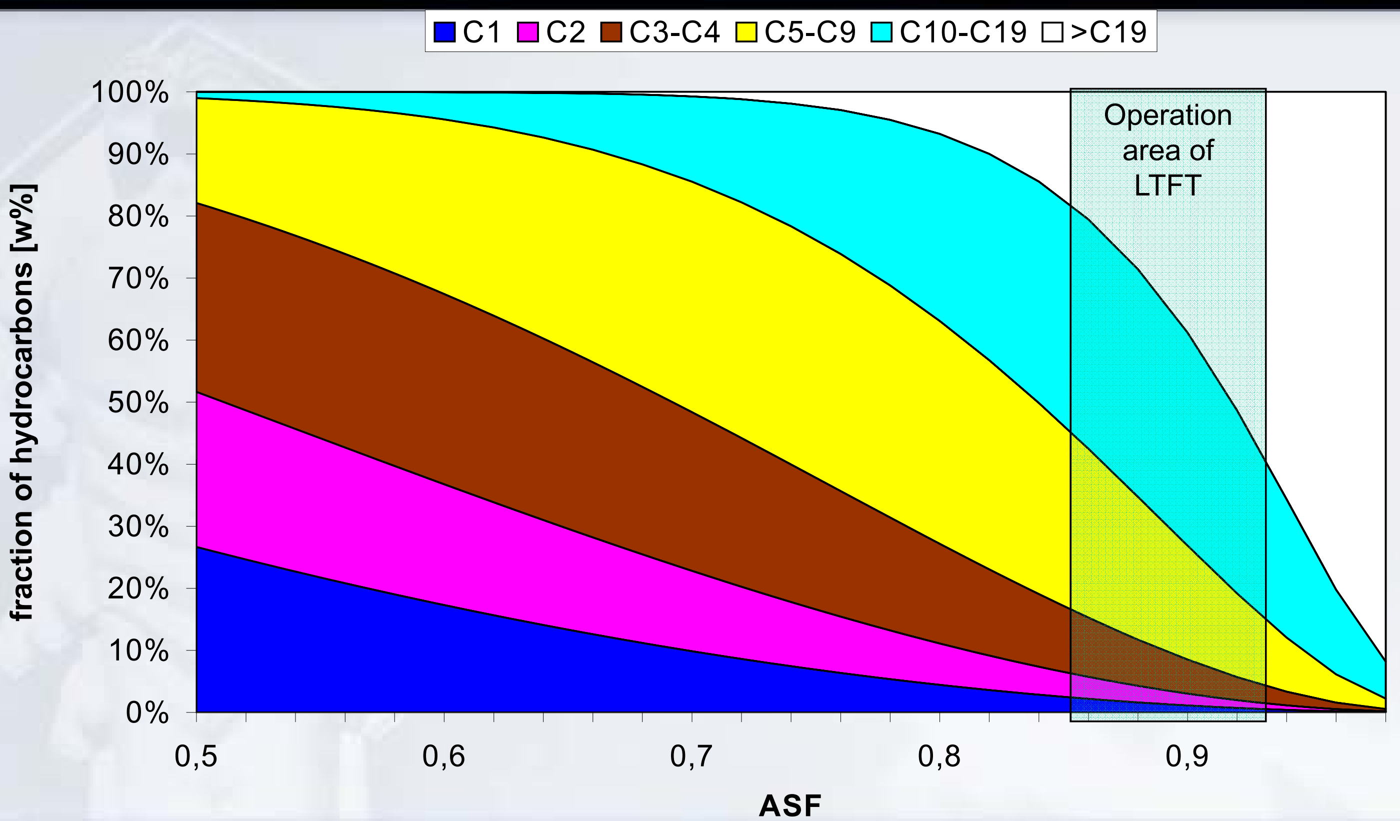
- Simple and cheap construction
- Excellent heat transfer
- No hot spots and no temperature profile along the reactor
- Easy to scale up
- **Integration of isomerisation and hydrotreating possible**

The following catalysts were used till now:

- Haber Bosch catalyst (mainly for start up)
- Research catalyst (based on cobalt ruthenium, produced from University of Strasbourg)
- Commercial cobalt catalyst
- Commercial iron catalyst

Anderson Schulz Flory distribution by weight

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology



$$Log\ (W_n / n) = n \log \alpha + const.$$

Renewable natural gas

Synthetic natural gas (BioSNG)

BioSNG

BIOMASS-TO-SYNTHETIC-NATURAL-GAS

BioSNG Demo Plant

TU VIENNA
Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

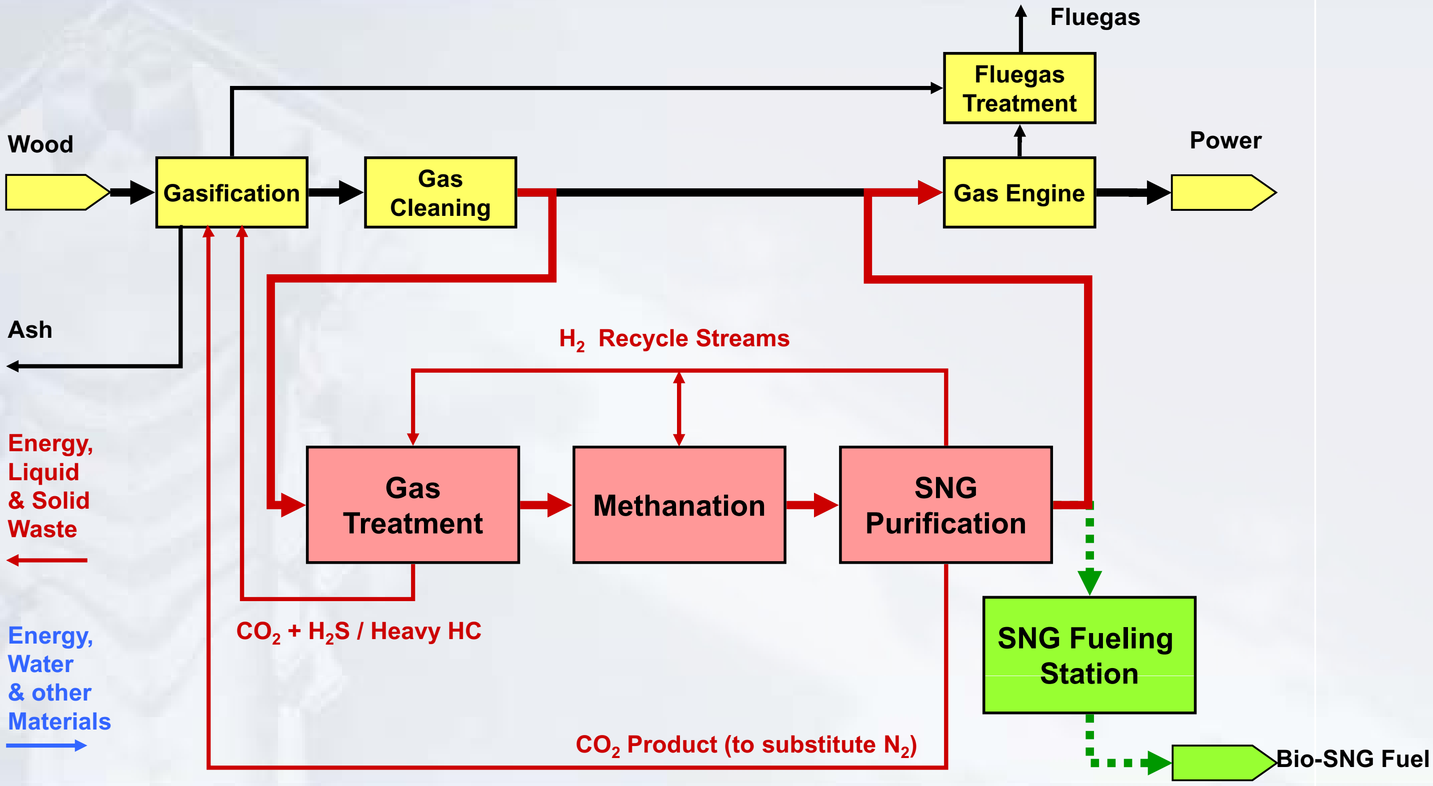
A 1 MW SNG Process Development Unit (PDU) is erected within the EU project BioSNG and allows the demonstration of the complete process chain from wood to SNG in half-commercial scale.

A consortium consisting of four partners is responsible for the PDU:

ü CTU – Conzepte Technik Umwelt AG
ü Repotec GmbH
ü Paul Scherrer Institute
ü Technical University Vienna

The project BioSNG is co-funded by
- the European Commission
- 6th Framework Programme
  PrNo TREN/05/FP6EN/S07.56632/019895
- Swiss electric research
- Bundesförderung Österreich
- WIBAG

Schema BioSNG demonstration



Rev. 4 / DU / 24.9.2006

1MW BioSNG demonstration plant

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

Results of the PDU

- December 2008: First conversion of product gas into rawSNG
- June 2009: BioSNG at Natural Gas quality produced
- June 24th : inauguration – CNG cars were fuelled using BioSNG from wood
- June 2009 CNG-car was successfully used for 1000km with BioSNG

Institute of Chemical Engineering
Working group: Zero Emission Energy Technology

Results BioSNG

	unit	Germany DVGW regulation G260	Austria ÖVGW regulation G31	BioSNG
Wobbe Index	[kWh/m³]	12,8-15,7	13,3-15,7	14,15
Relative density	[-]	0,55-0,75	0,55-0,65	0,56
Higher heating value	[kWh/m³]	8,4-13,1	10,7-12,8	10,7

Current Status and Outlook

- Successful scale up of a dual fluidized bed steam gasification system from laboratory to industrial scale **(within 10 years)**

- Industrial plant available with
  - High electrical efficiency (> 30 % with combined gas engine and ORC-process)
  - No solid residues (without ash, carbon content <0,5 %)
  - No liquid condensates
  - European emission requirements are met
  - High availabilities (>93 %)
  - Next plant is in operation (10 MW_{fuel})

- High potential for biofuels (BioSNG, BioFiT)
  - BioSNG, most suitable, 1 MW (100 m^3/h BioSNG), demonstration plant is in operation
  - BioFiT, research ongoing, ready for scale up!

Biomass CHP Oberwart

Owner:	Energie Oberwart GmbH
Constructed by	Ortner Anlagenbau
Power production	2750 kW
Heat production	1500-6000 kW
Biomass type used	Wood chips
Status:	In operation

Information

http://www.ficfb.at

Visits under
+43 3322 9010 850

turning knowledge into practice

Biomass Gasification and Tar Cracking Process Development

David C. Dayton and Raghubir Gupta
Center for Energy Technology

Gasification 2009
Gas Cleanup and Gas Treatment
October 23, 2009

www.rti.org

Outline

- Overview of RTI International
- Energy R&D at RTI
- Biomass Gasification Gas Cleanup Technology Development
  - Leverage clean coal technology development
  - Process Development for Biomass Gasification
- Summary
- Acknowledgments

RTI History and Mission

- Established 1958 as collaboration between state government, area universities and business leaders
- Mission: to improve the human condition by turning knowledge into practice
- One of the world's leading research institutes

Research Triangle Park Campus

Centrally located between:

Duke University (Durham)

NC State University (Raleigh)

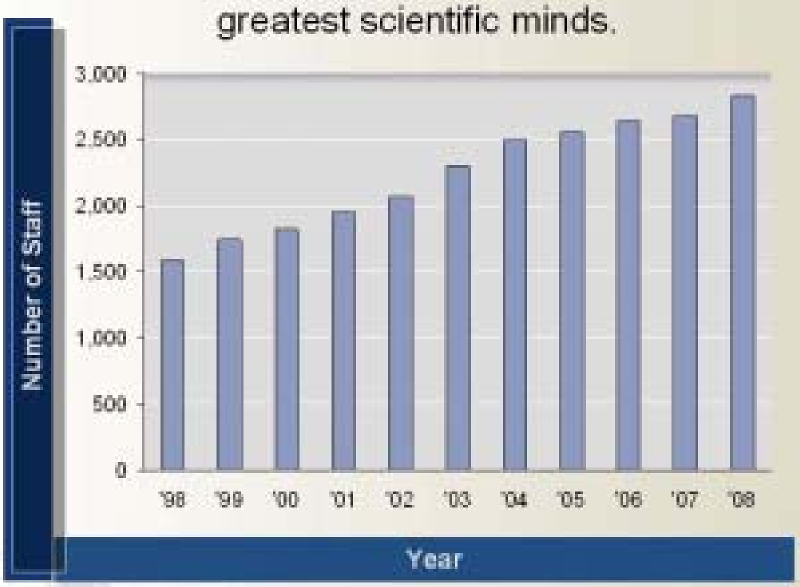
UNC (Chapel Hill)

RDU Airport is 5 minutes away

- *180 Acre Campus*
- *24 Buildings*
- *810,000 sq ft Space*

Staff

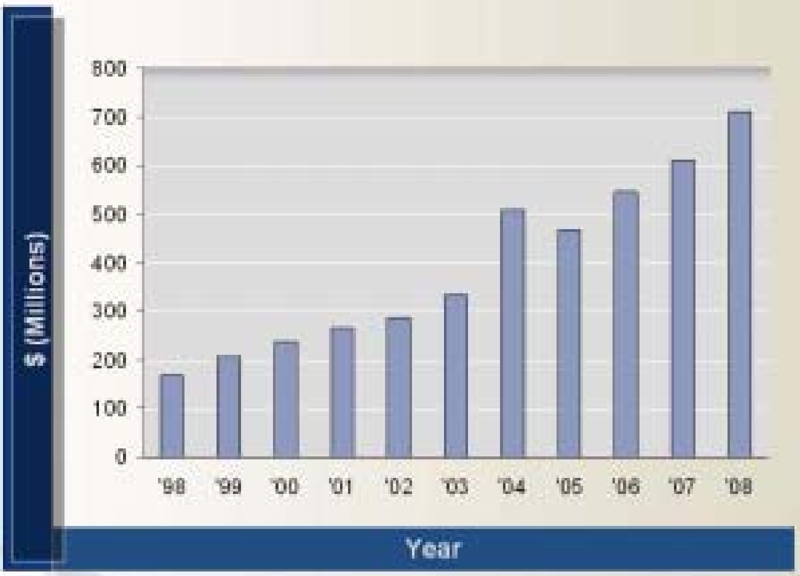
RTI is home to some of the world's greatest scientific minds.



2,827*

* In addition to our regular staff members, RTI employs about 1,400 term employees who support international projects in more than 40 countries around the world.

Revenue

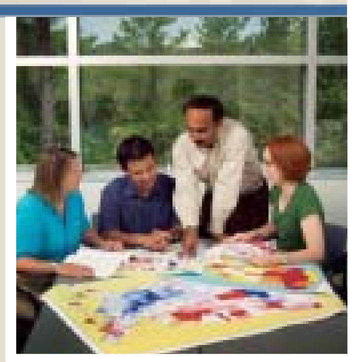


$709.7 million

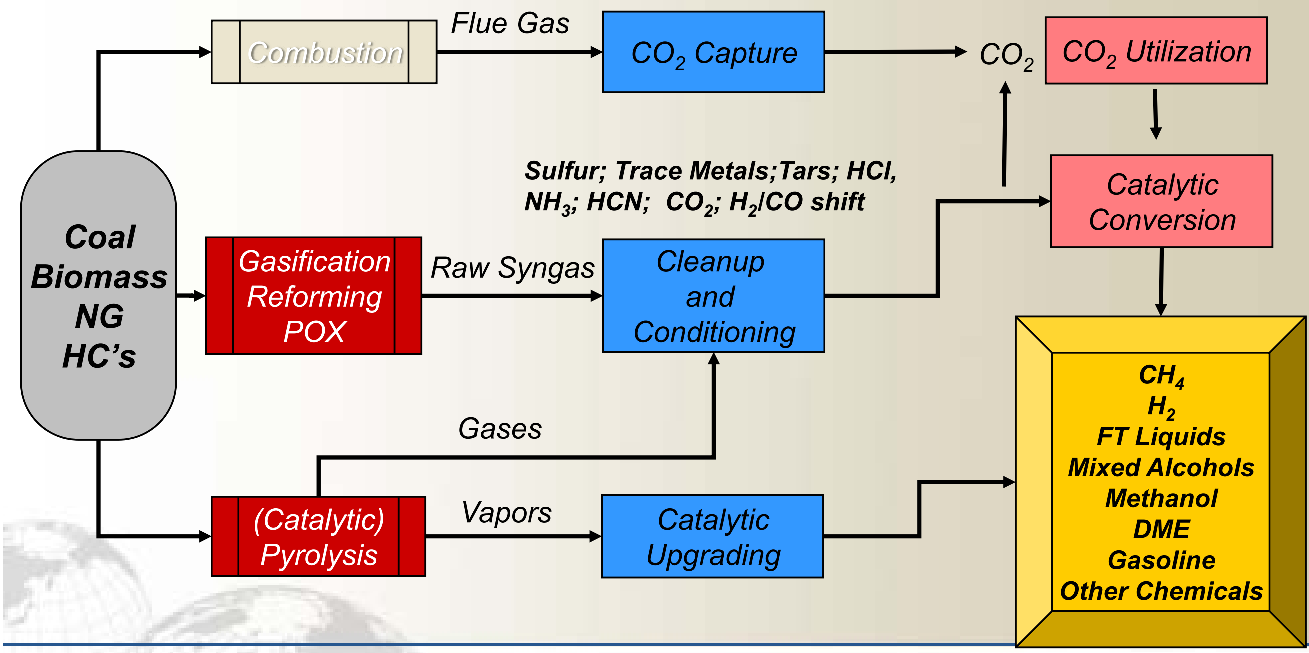
RTI Expertise

RTI is home to some of the world's greatest scientific minds, providing innovative research and technical expertise in:

- Health
- Drug discovery and development
- Education and training
- Surveys and statistics
- International development
- Economic and social policy
- Advanced technology
- ***Energy and the environment***
- Laboratory and chemistry services



Center for Energy Technology Areas of Expertise



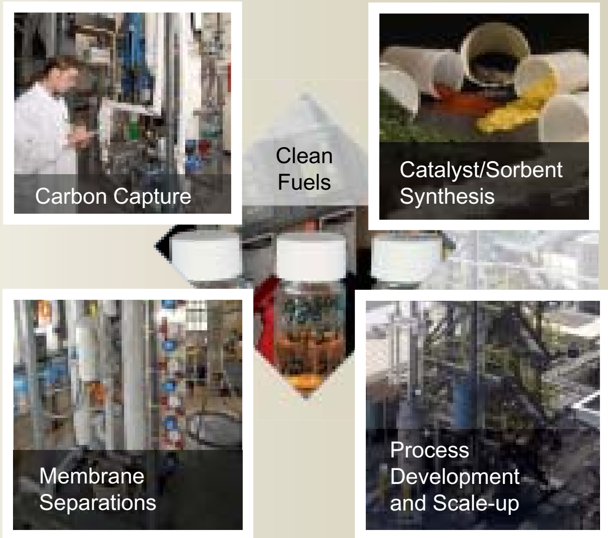
Center for Energy Technology

Highly experienced group

- 35 staff: 13 Ph.D., 6 M.S., 7 B.S.
  - Chemical Engineers
  - Chemists
  - Mechanical engineers
  - Support staff

Research revenue

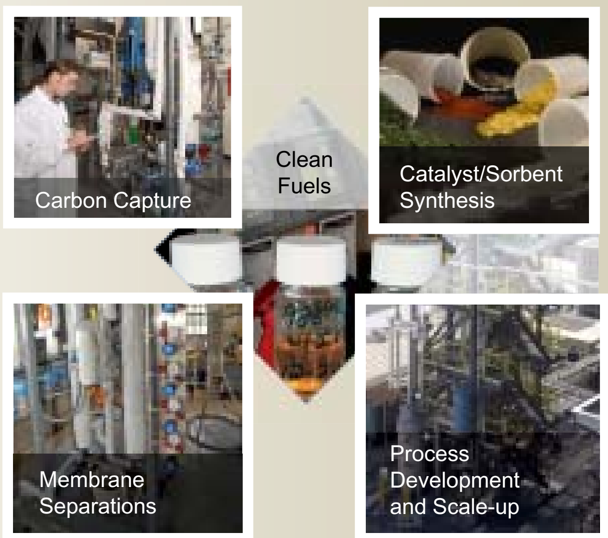
- ~$6-7 million
- 75% government
- 25% commercial clients



Center for Energy Technology

Program Areas

- Advanced Gasification
  - Syngas Clean-up / conditioning
  - Substitute natural gas production
- Clean Fuels
  - Syngas to fuels and chemicals
  - Hydrocarbon desulfurization
- Coal Combustion & CO_2 Capture
  - Pre- and post-combustion CO_2 capture
  - Chemical Looping Combustion
- Biomass Conversion
  - Biomass gasification
  - Syngas Clean-up / conditioning
  - Biomass pyrolysis
- Hydrogen Production and Purification
  - Membrane separation
  - Iron-steam process



Process Development and Scale-Up Approach

Phase I

Catalyst Development

- Productivity
- Attrition resistance
- Stability

Process Development

- Reaction kinetics
- Integration strategy

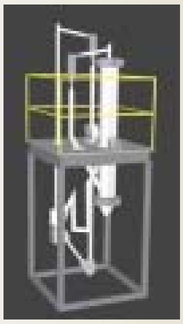
Phase II

Catalyst Development

- Catalyst scale-up

Process Development

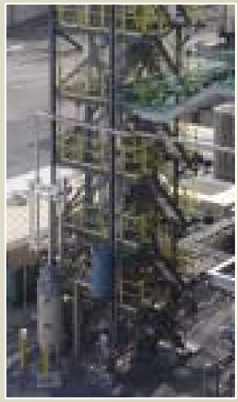
- Reactor scale-up
- Continuous operation
- Performance evaluation



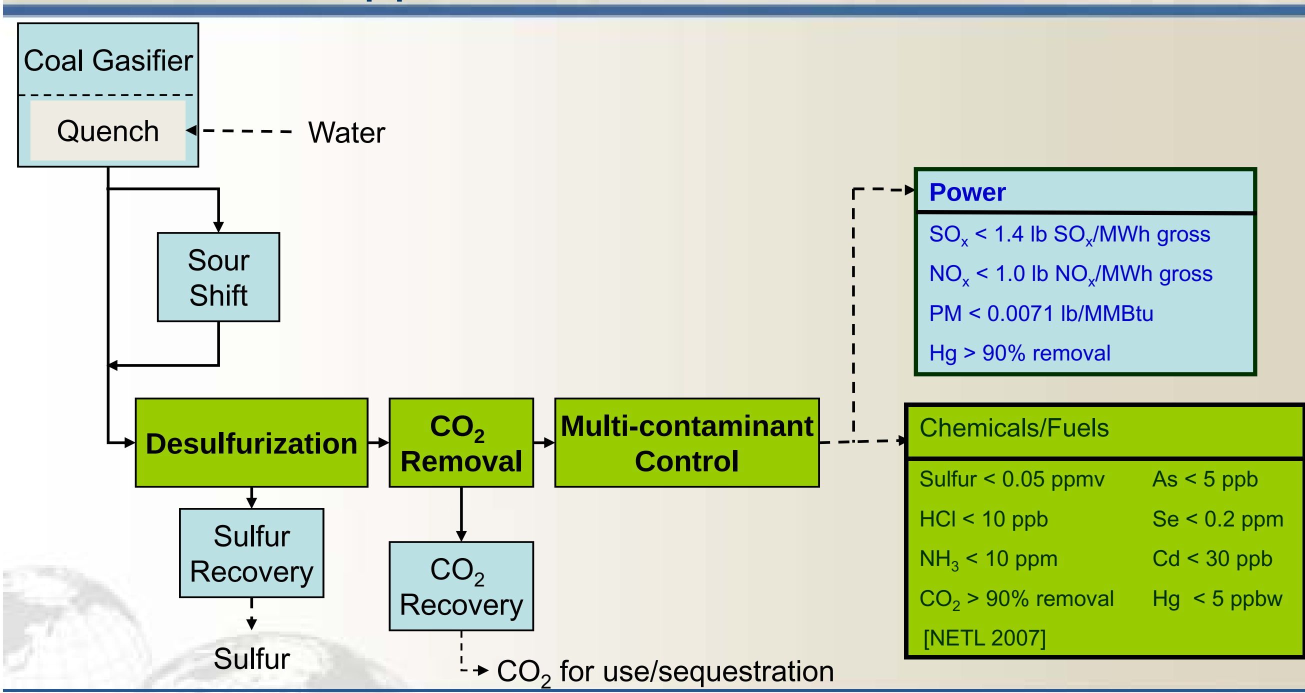
Phase III

Process Development

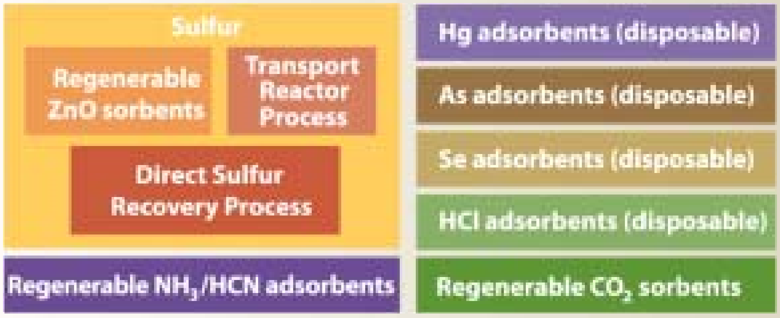
- Pilot-plant demonstration



Warm Syngas Clean-up Technology – Modular Approach



Warm Syngas Clean-up Technology Platform



Unique Features

- Operating temperatures > 450ºF
- Pressure independent
- Effective for both H_2S and COS
- Fully compatible with conventional and warm CO_2 capture
- Flexible modular approach meets
  - Power specifications
  - Chemical production (methanol, SNG, FT,…) specifications

Clean Coal Technology Development
Syngas Desulfurization Process Development

Eastman Pilot Plant Testing (2004 - 2007)

Key Accomplishments:

- 3,000 hours of operation with syngas with > 99.9% H_2S and COS removal
- Low sorbent attrition losses
- Integrated HTDP and DSRP operation
- As, NH_3 and Hg sorbents tested

50 MW Demonstration at Tampa Electric Company's Polk Station (2009-2014)

Objectives:

- Demonstrate HTDP, DSRP, and muticontaminant sorbents
- Mitigate scale up risk for commercial plant
- Establish RAM
- Develop operational experience

COMMERCIAL DEPLOYMENT (~2014)

Electric power generation

Electric power generation with CCS

Chemical production

Benefits*

Reduced emissions

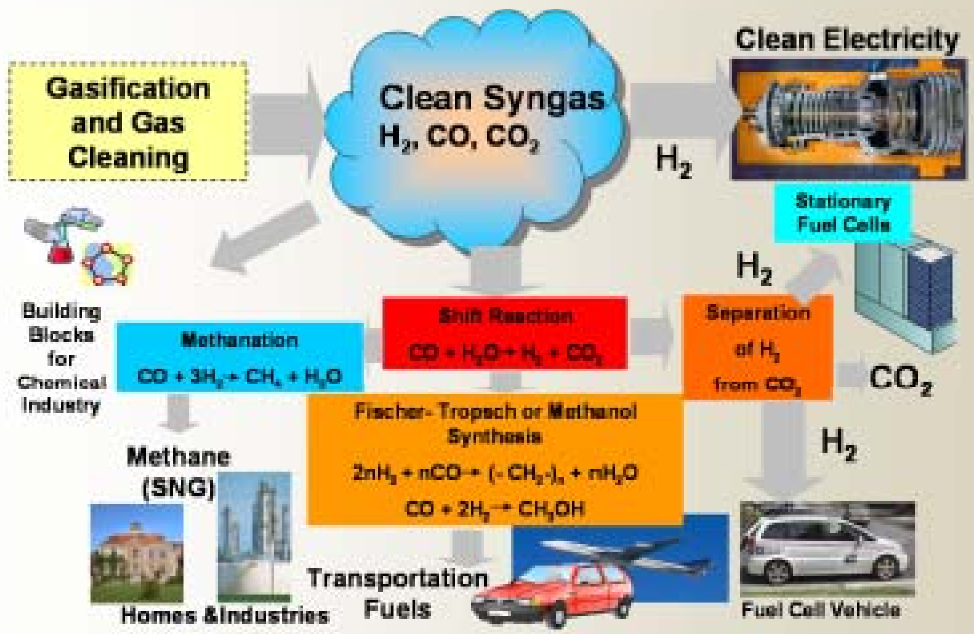
6% Higher thermal efficiency

2.5 ¢/kW lower electricity costs

$500/kW lower capital costs

*as compared to IGCC with conventional CCS technology

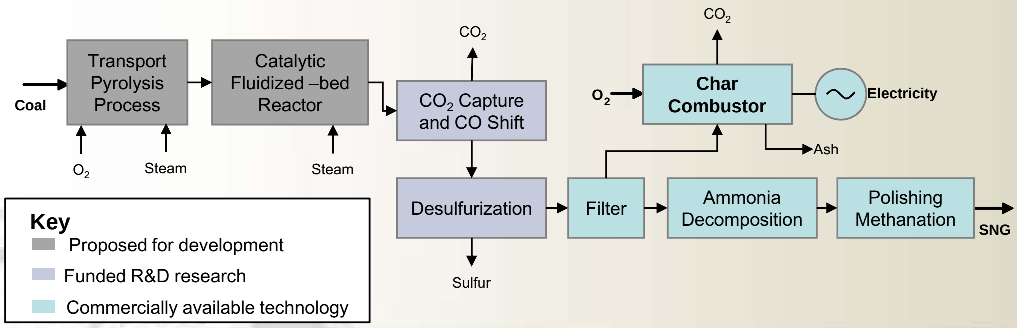
Syngas Utilization



Co-Production of Substitute Natural Gas/Electricity via Coal Gasification

Objective: To develop a commercial process for co-producing substitute natural gas (SNG) and electricity from coal gasification

- SNG cost of ~ $5/MMBtu
- Capture > 90% of CO_2 produced
  - High pressure high purity byproduct
- Sub-bituminous and lignite coals (low-rank coals)



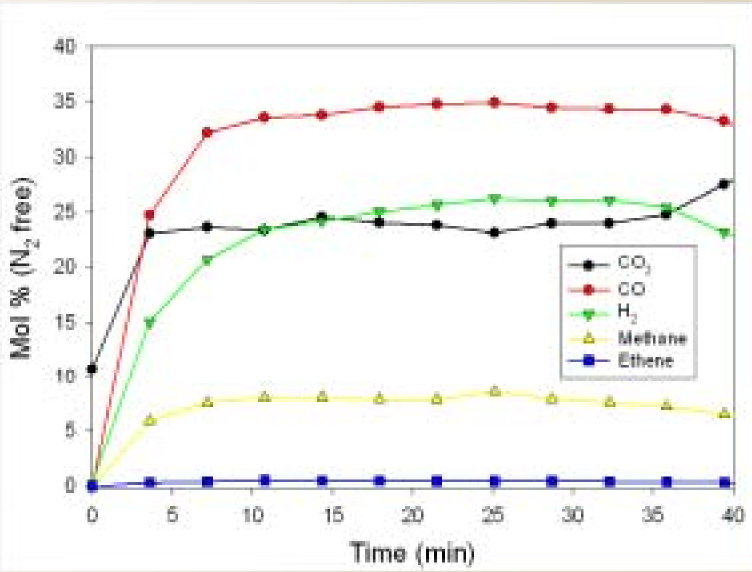
Transport Reactor System

- Temperature: Up to 925 °C
- Pressure: 0-650 psig
- Gas feeds
  - Nitrogen
  - Steam
  - Air
- Feeder for coal and coal/biomass blends
  - 1-2 kg/h
- Hot sampling point for condensable hydrocarbons
- Cold sampling point for non-condensable products
- Reactor height: 12 ft.
- Riser diameter: 0.75 in.
- Standpipe diameter: 2 in.

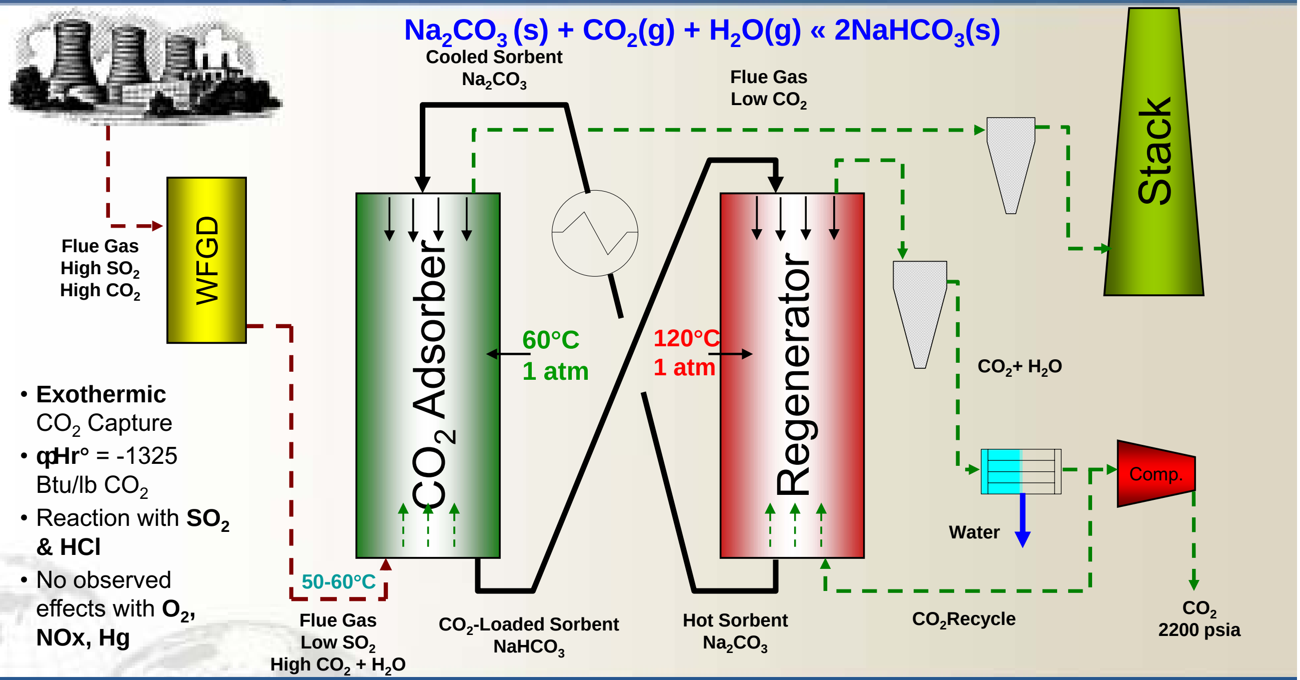
Current use: Gasification of coal/biomass to produce substitute natural gas (SNG) and power

Pressurized Biomass Gasification

Test Conditions for Biomass Gasification Screening Tests			
Test	1	2	3
Temperature (ºF)	1,600	1,600	1,600
Pressure (psig)	150	150	150
Biomass feed (g/min)	~10	~10	~10
O/C ratio (atomic)	0.3	0.5	0.5
Residence time (s)	2	2	2
Duration (min)	~40	~40	~40



Post-Combustion CO_2 Capture
RTI's Dry Carbonate Process



- **Exothermic** CO_2 Capture
- **φHr°** = -1325 Btu/lb CO_2
- Reaction with **SO_2 & HCl**
- No observed effects with **O_2, NOx, Hg**

RTI INTERNATIONAL

Post-combustion CO_2 Capture
Membrane Process for Power Plant Flue Gas

Overall Objective

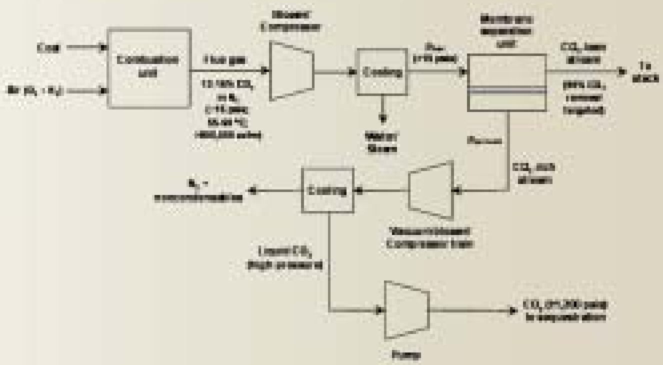
To develop an advanced polymeric membrane-based process that can be cost-effectively and reliably retrofitted into existing pulverized coal (PC)-fired power plants to capture >90% CO_2 from plant's flue gas with <35% increase in Cost of Electricity

Specific Objectives

(i) Develop novel fluorinated polymer membrane materials with high flux for CO_2, high selectivity for CO_2 over N_2, and good chemical stability to moisture and flue-gas contaminants SO_2 and NO_x

(ii) Develop and fabricate improved membrane hollow fibers and improved hollow-fiber membrane module designs;

(iii) Develop power- and cost-effective process design/integration strategies



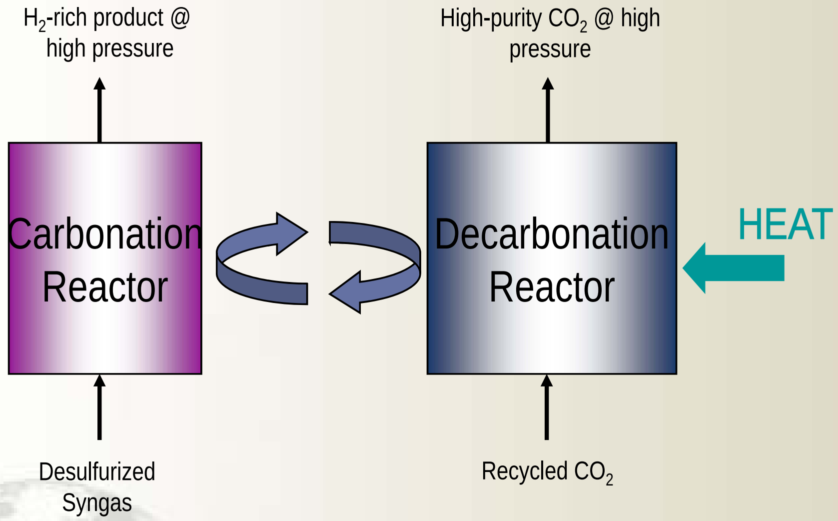
Membrane-based CO_2 capture from flue gas

RTI INTERNATIONAL

Pre-combustion CO_2 Capture

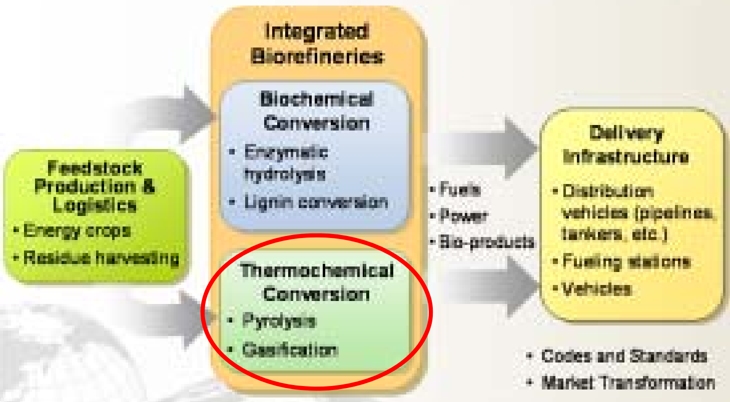
Objective:

CO_2 capture from shifted syngas stream at high pressure



2nd Generation Biofuels

Second-generation fuels are made from ligno-cellulosic biomass feedstock using advanced technical processes.



Benefits

Sustainable, domestic transportation fuels

Maximum utilization of non-food biomass (and land) resources

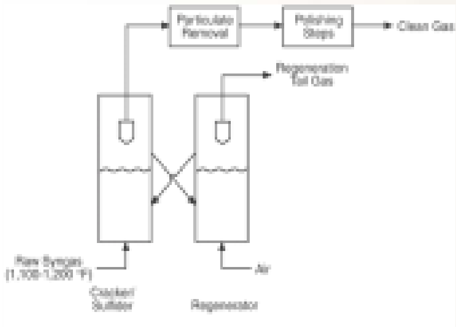
Improved energy security

Global climate change mitigation

Biochemical and thermochemical conversion provide robust technology options

Biomass Gasification Gas Cleanup
Tar Cracking Technology Development

Feed Processing & Handling → Biomass Gasification → Syngas Cleanup → Syngas Conditioning → Catalytic Fuel Synthesis → Next Generation Biofuels



Targets
Tar < 0.1 g/Nm³
NH_3 < 10 ppm
H_2S < 100 ppb
HCl < 10 ppb

Technical Goals
- Reduce syngas cleanup process complexity
- Validate technology with biomass-derived syngas

Economic Target

Reduce syngas cleanup/conditioning capital and operating costs to achieve biofuel production cost goals

Process Advantages
- Thermally efficient
- Cleaner and reduced-volume water product
- Process intensification (i.e., fewer unit operations)

Approach

- Catalyst development and testing
  - High-temperature desulfurization sorbents for coal-derived syngas
  - Tar cracking catalysts
  - Sulfur-tolerant NH_3 decomposition catalyst
- Process design and development
  - Process modeling; material and energy balances
  - Cold flow testing
  - Process design
  - Detailed engineering design
  - Fabrication
  - Installation and hot testing

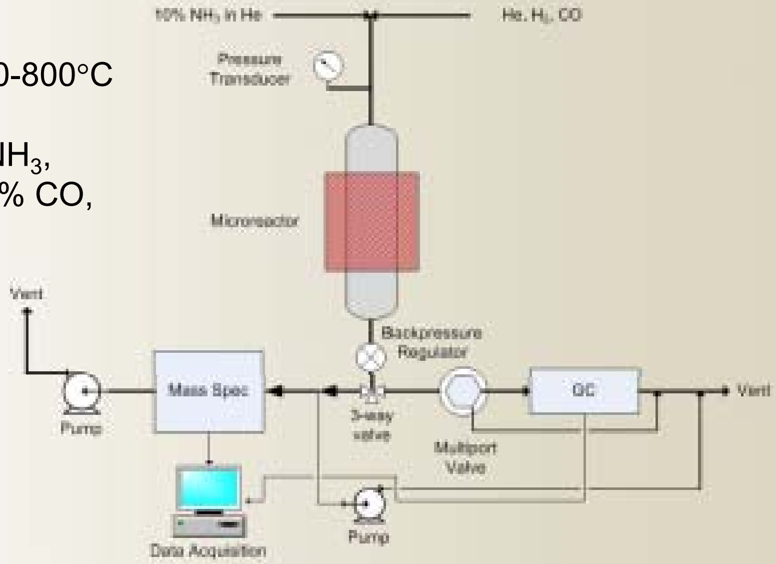
Tar Cracking Catalyst Development Microreactor Testing (Clemson University)

Reaction conditions: 1 atm, 300-800°C

Feed composition: 4000 ppm NH_3, 3000 ppm toluene, 10% H_2, 15% CO, balance He

Flow rate: 100 sccm

Sample size: ~0.5-g

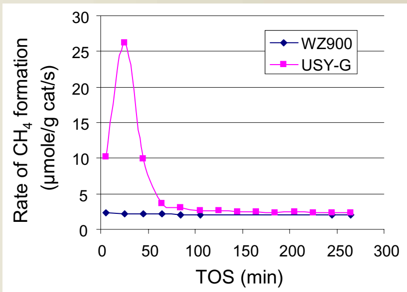


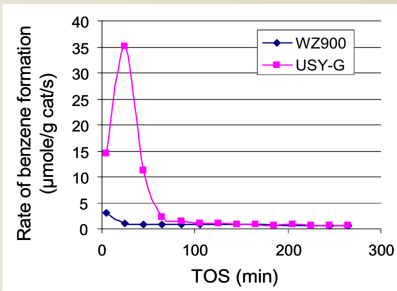
Tar Decomposition Tungsten Catalyst Testing

Rationale for Using WC and WZ for Tar Cleanup

- Tungsten carbide (WC)
  - Modification of surface electronic properties of W by C, resulting in Pt-like behavior[1]
  - Excellent catalyst for NH_3 decomposition reaction
  - Complete NH_3 decomposition observed at 600 °C[2]
- Tungstated zirconia (WZ)
  - Highly acidic catalyst due to presence of WO_3 on the surface
  - Ability to catalyze cracking reactions
  - Possibility of *in-situ* formation of WC in the presence of H_2 and CO, resulting in a bi-functional catalyst for NH_3 decomposition and toluene cracking

Simulated Tar Decomposition with FCC/Zeolite Catalysts at 700°C in 10%H_2 in He



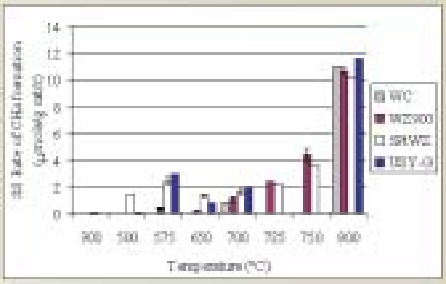


[1] Levy, R. B., and Boudart, M., *Science*, **181** (1973) 547.
[2] Pansare et al., *Catal. Commun.*, **8** (2007) 649.

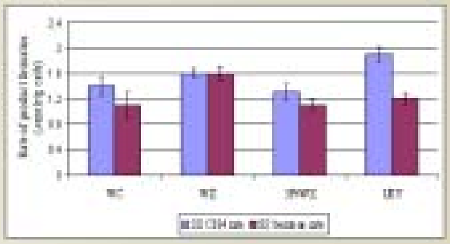
Tar Decomposition Catalyst Testing Summary

Tungsten Catalysts (tungsten carbide and tungstated zirconia)

- High NH_3 decomposition activity in the absence of syngas, presence of CO reduces activity
- High tar (toluene) cracking activity, comparable to commercial acid (zeolite) cracking catalysts (USY-G)
- Robust physical properties
  - Extreme hardness
  - Good thermal stability
  - Sulfur resistance



100 sccm total flow (10% H_2, 15% CO, 2500-3000 ppm of toluene in He.



Steady state rates of product formation on a "per-gm-catalyst" basis at 700°C and 1 atm

Tar Cracking Catalyst Development RTI Catalyst Testing

Objectives

- Measure tar cracking rates and activity
- Determine carbon deposition rates
- Develop operating conditions for Therminator

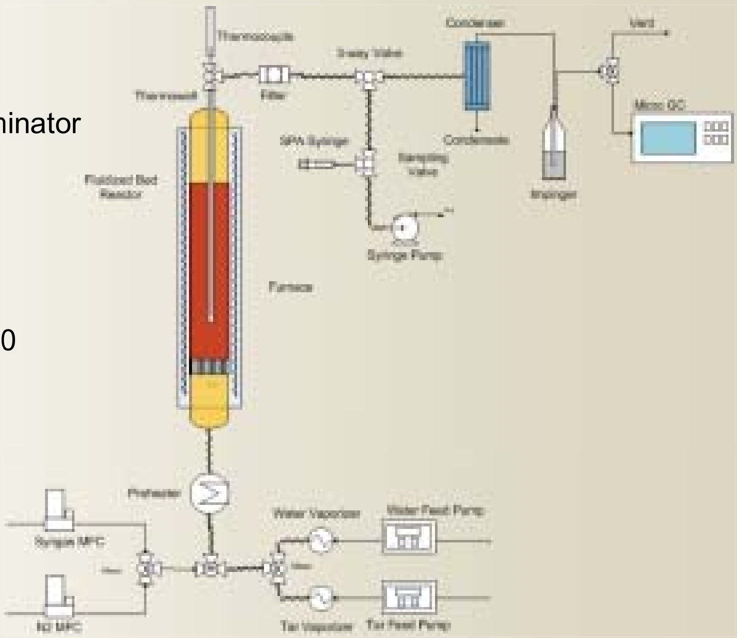
Reaction conditions: 1 atm, 600-700°C

Feed composition: 30% H_2,15% CO, 5% CO_2, 40% H_2O, 10% N_2, 35 g/Nm^3 Tar, 100 ppm H_2S

Tar Composition: phenol, guaiacol, and naphthalene in toluene

Flow rate: ~20 slpm

Solid loading: ~500g



Tar Cracking Process Development
Process Modeling

Absorber (R-150) - 1112°F (600°C)

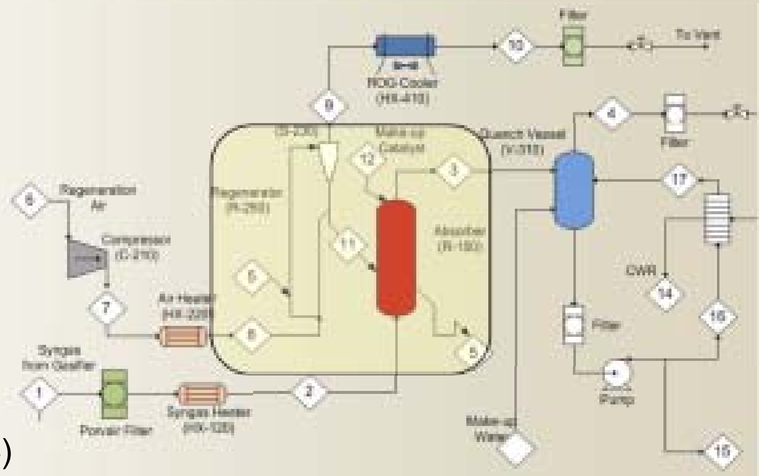
Tar Decomposition (99%)
$C_{10}H_8$ (Tar) $\rightarrow$ 4 H_2 + 10 CH_x (Char)

Ammonia Decomposition
2 NH_3 $\rightarrow$ 3 H_2 + N_2

Sulfur Capture
H_2S + $ZnTiO_3$ $\rightarrow$ ZnS + TiO_2 + H_2O

Regenerator (R-250) - 1202°F (650°C)
C + O_2 $\rightarrow$ CO_2

ZnS + TiO_2 + 1.5 O_2 $\rightarrow$ $ZnTiO_3$ + SO_2



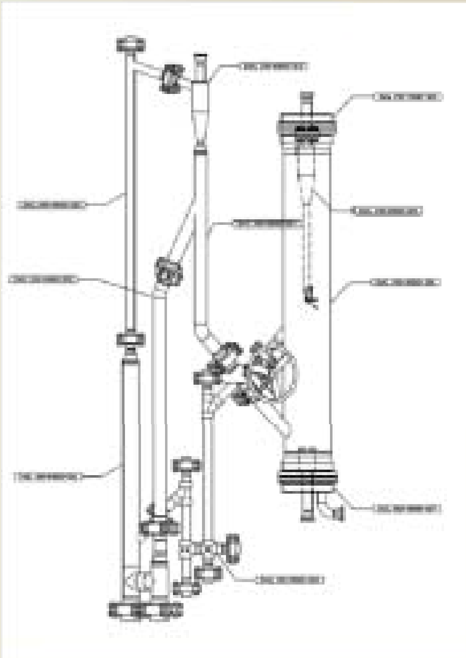
Syngas (Stream # 2) at 800°F (427°C) and 32.5 psia (2.24 bara)

Syngas heated (HX-120) to 1202°F (650°C)

RTI International

Tar Cracking Process Development
Reactor Design

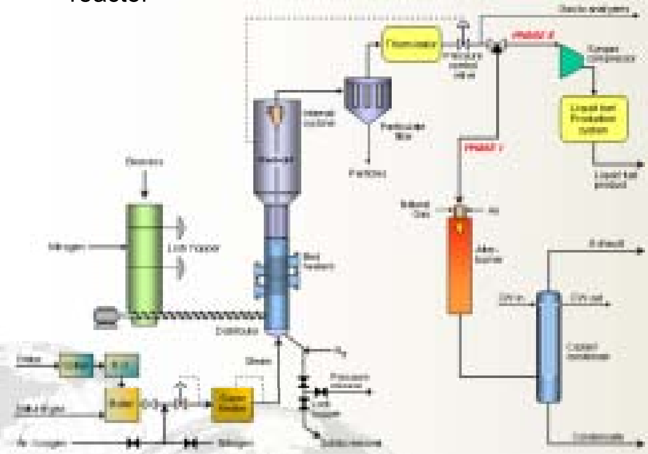
- *New design philosophy to accommodate higher syngas flow with reasonable increase in size to fit test-site space requirements*
- *Bubbling bed for tar cracking, ammonia decomposition, and sulfur capture coupled with a circulating regeneration loop*
- *Original design for 10lb/hr slipstream (420 SCFH) in a pressurized air blown gasifier.*
- *Re-design for 20 kg/hr indirect biomass gasifier (2900 SCFH syngas)*
- *Design basis: 22 psig, 600°C, 2900 SCFH syngas*
- *Design limits: 150 psig, 650°C, 3400 SCFH syngas*



RTI International

Validation of RTI Therminator Syngas Cleanup Technology in Integrated Biomass Gasification/Fuel Synthesis Process

- Woody biomass and lignin-rich hydrolysis residues
- Pressurized, indirect biomass gasification
- Therminator gas cleanup technology
- FT synthesis in slurry bubble column or fixed bed reactor



Process Configuration for DOE Project

University of Utah's Gasification Research Facility

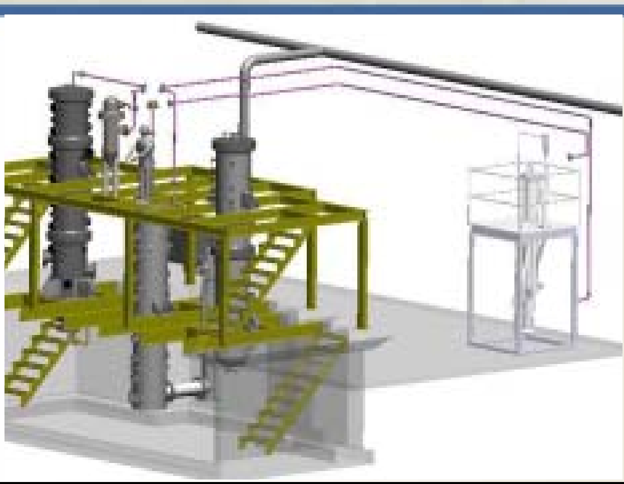
NC STATE UNIVERSITY

THE UNIVERSITY OF UTAH

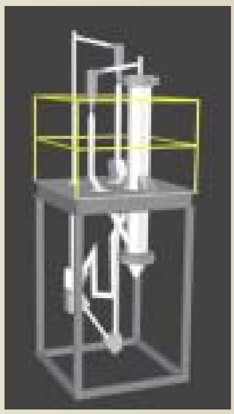
GOLDEN LEAF

RTI INTERNATIONAL

Thermintor Integration University of Utah Gasification Facility



Operating Conditions	Value
Syngas Flow	3000 SCFH
Regeneration Air Flow	20 SCFM
Operating Pressure	20 PSIG
Operating Temperature	650°C
Superficial Velocity	1.5 ft/sec
Solids Circulation Rate	636 lb/hr



Max. reactor operating pressure	**1033 kPa**	**150 psia**
Max. reactor operating temperature	**815 °C**	**1500 °F**
Max. biomass feed rate	**30 kg/h**	**65 lb/h**
Steam feed rate	**130 kg/h**	**286 lb/h**
Superficial gas velocity	**1.5 m/s**	**5.00 ft/s**
Bed diameter	**0.25 m**	**10.0 inch**
Bed height (typical)	**1.65 m**	**60.0 inch**
Mass of bed solids (Al_2O_3 particles)	**140 kg**	**310 lb**

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Summary

RTI has an R&D program to develop an enabling syngas cleaning technology:

- To achieve cleanup levels suitable for catalytic fuel synthesis
- To scale up technology, enabling maximum effectiveness for biomass fuel production facilities
- To validate technology with real biomass-derived syngas
- To reduce syngas cleanup/conditioning capital and operating costs

Progress

- Bench-scale catalyst micro-activity tests to determine activity, kinetics, and ideal operating conditions for simultaneous tar cracking, sulfur removal, and ammonia decomposition.
- Scale-up identified catalysts for pilot-scale operation
- Therminator design for pilot-scale gas cleanup testing
- Evaluate techno-economic advantages of integrated syngas cleanup and temperatures approaching the gasifier exit temperature

Acknowledgments

- RTI Team
  - Atish Kataria
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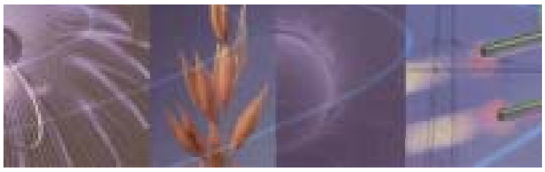
  - Professor James Goodwin
  - Sourbah Pansare*
- Funding Resources
  - US DOE Office Of Biomass Program (DE-FG36-04GO14312 & DE-PS36-07GO9703)
  - Biofuels Center of North Carolina (Grant Agreement 2009-129-M)
  - DOE/NETL Fossil Energy Program

Fraunhofer UMSICHT

»Syngas Cleaning with Catalytic Tar Reforming«

23. October 2009
Presentation at Gasification 2009, Stockholm

Dipl.-Ing. Tim Schulzke



Fraunhofer UMSICHT

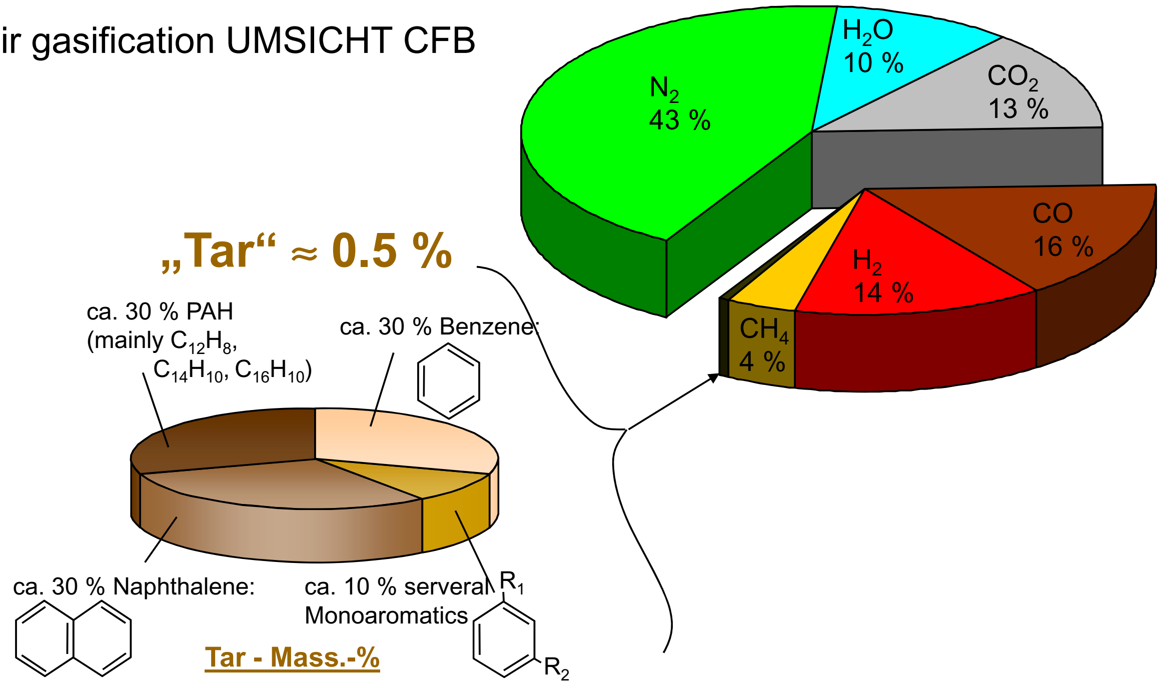
Outline

1. Introduction
2. Process Development at Oberhausen
3. Test at Güssing
4. Outlook

Fraunhofer UMSICHT

Gas Composition

air gasification UMSICHT CFB



Fraunhofer UMSICHT

Pilot Plant 0.5 MW

Height
8 m

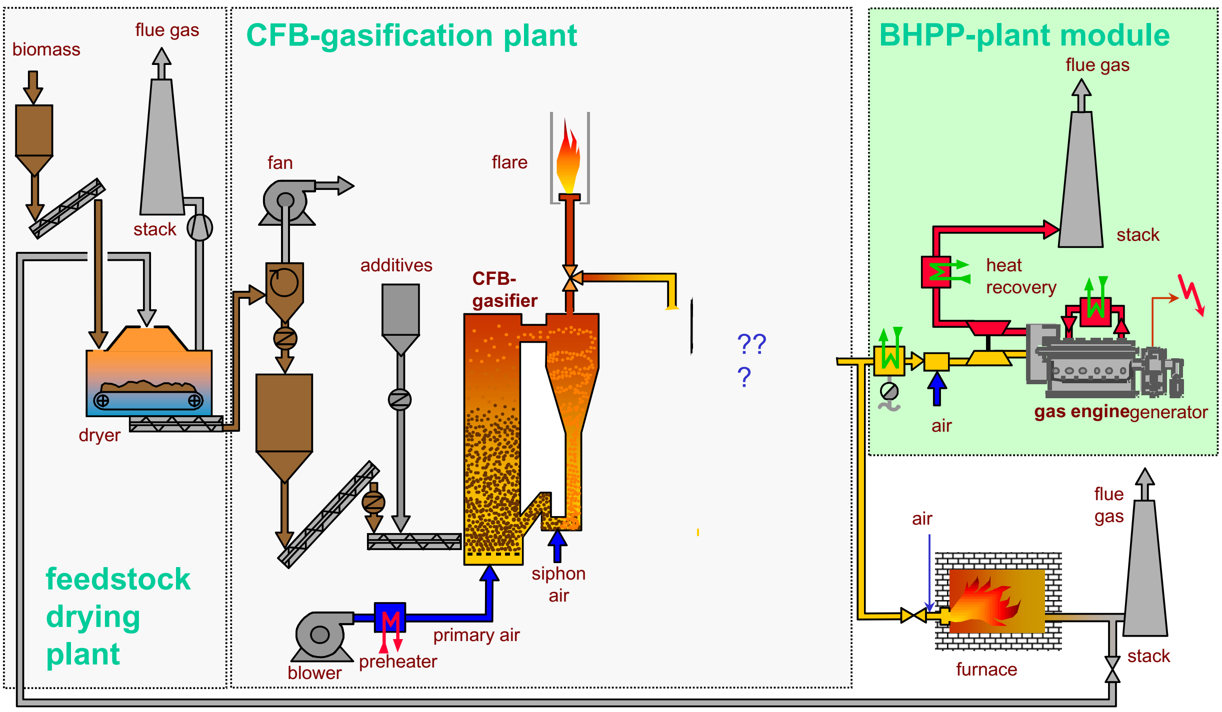
Diameter
310 mm

Temperature
850 – 915 °C

Fuel input
75 -100 kg/h

Air ratio
0.25 – 0.45

Producer gas
≈ 250 Nm³/h



Fraunhofer UMSICHT

Primary Measures of Tar Reduction

Tar content depending on bed material

10,000 mg/Nm³

- Silica sand

  4,250 mg/Nm³
- Dolomite (fresh)

  300 mg/Nm³
- Other materials (natural and artifical)

  120 - 350 mg/Nm³
- Olivine

  2,500 mg/Nm³
- Contamination limit for IC enginge

  50 mg/Nm³

Reactions in Catalytic Tar Conversion

- Steam Reforming of Hydrocarbons

  $CH_4 + H_2O \Leftrightarrow CO + 3\ H_2$ $\Delta_rH = +206$ kJ/mol

  $C_nH_mO_y + (n-y)\ H_2O \Leftrightarrow n\ CO + (n-y+m/2)\ H_2$ $\Delta_rH >> 0$ kJ/mol
- Dry Reforming of Hydrocarbons

  $CH_4 + CO_2 \Leftrightarrow 2\ CO + 2\ H_2$ $\Delta_rH= +247$ kJ/mol

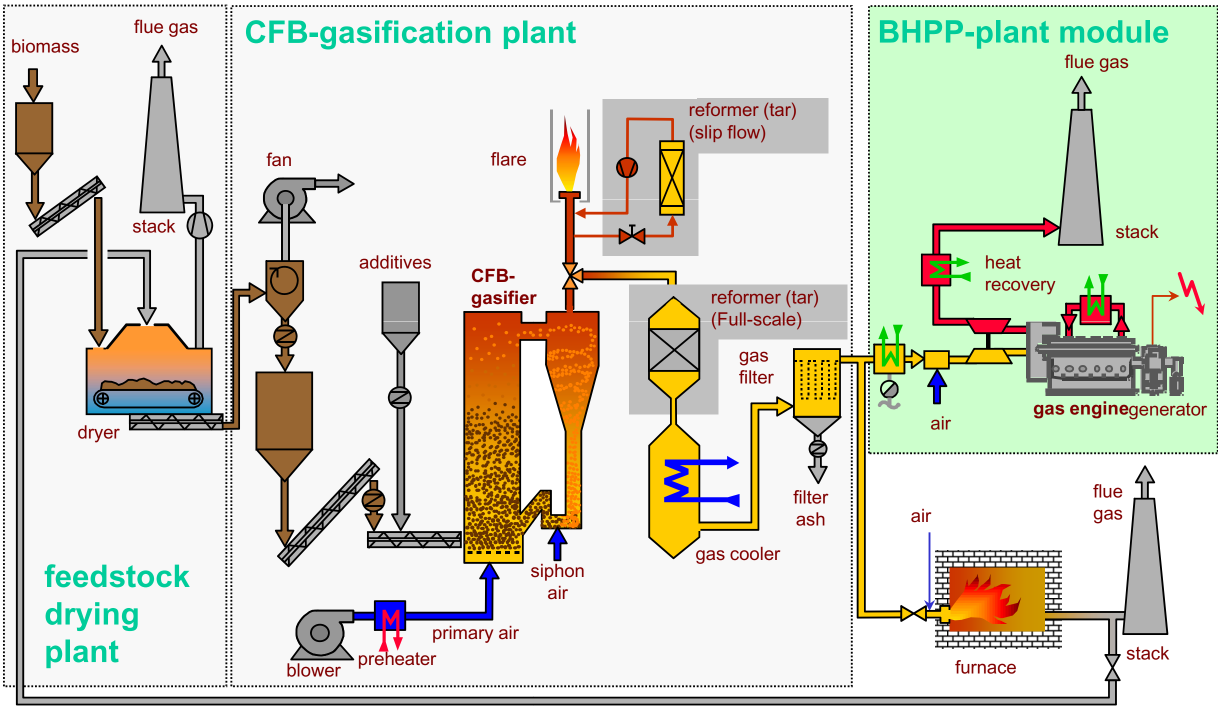
  $C_nH_mO_y + (n-y)\ CO_2 \Leftrightarrow (2n-y)\ CO + m/2\ H_2$ $\Delta_rH >> 0$ kJ/mol
- Water Gas Shift Reaction

  $CO + H_2O \Leftrightarrow CO_2 + H_2$ $\Delta_rH = -41$ kJ/mol

Pilot Plant 0.5 MW

Slip Stream

- Fixed bed
  - Ni
  - NiCo
  - CoMo
- Monolith
  - Ni



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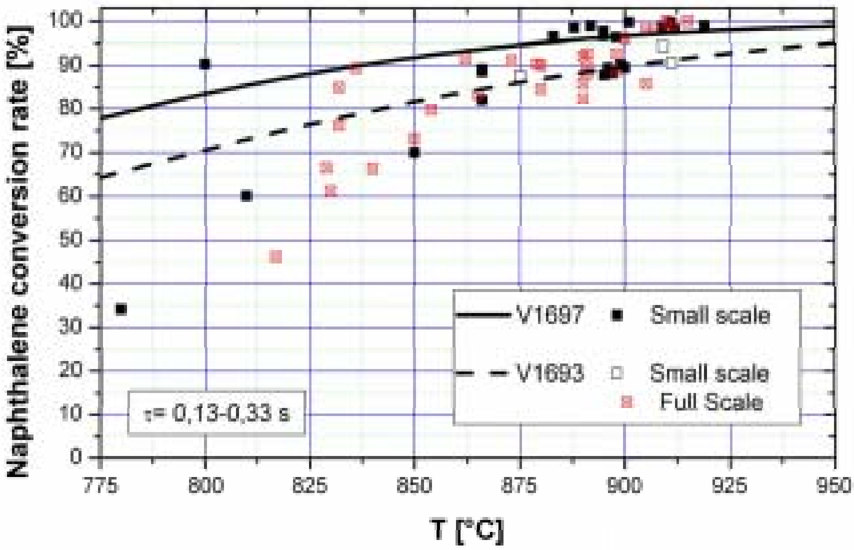
Naphthalene conversion



Naphthalene

- most difficult to convert
- high concentration in raw gas

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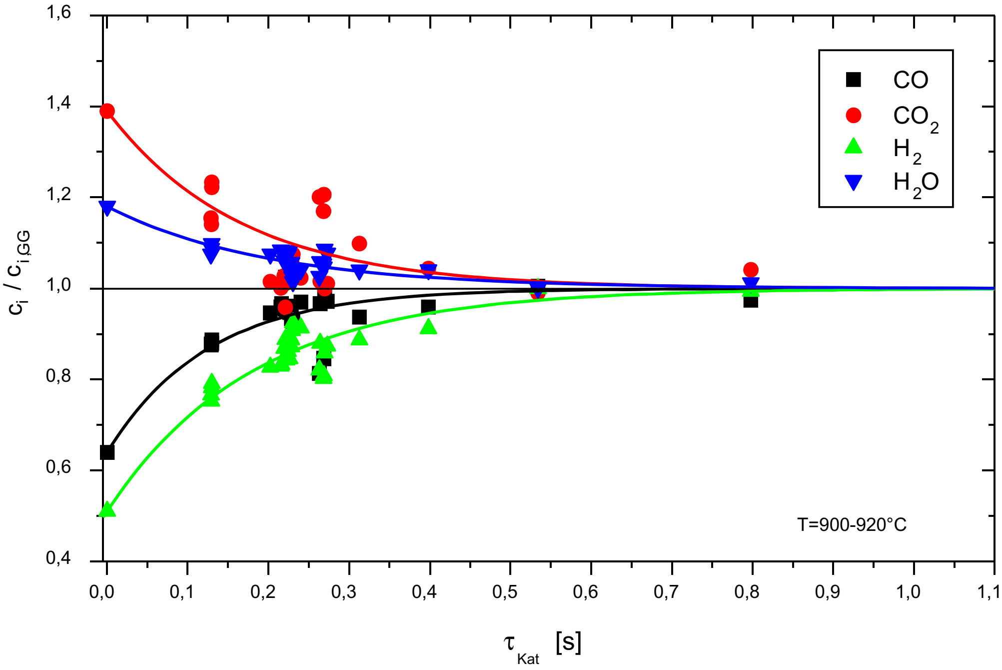
Thermodynamic equilibrium

Raw gas not in equilibrium

Clean gas approaches equilibrium

H_i increases



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Design of Catalytic Tar Reformer

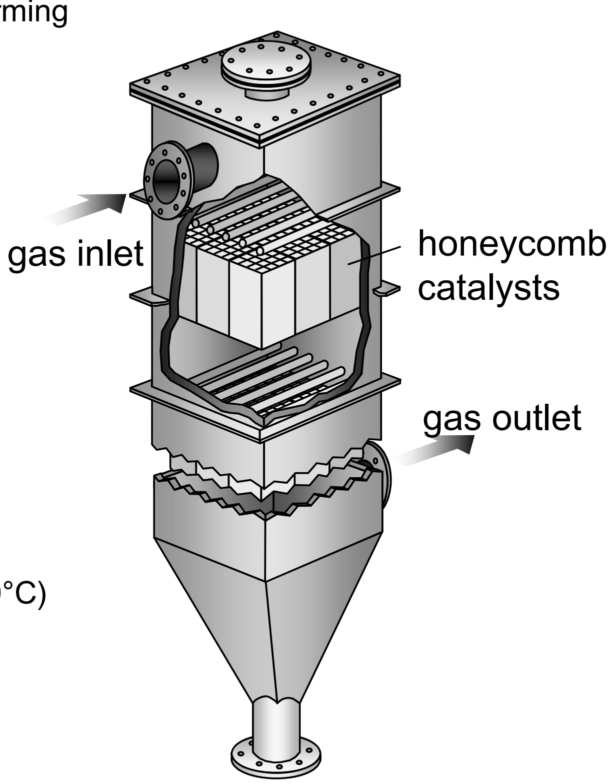
- 2 layers 3x3 of Ni-monolith
  - laminar flow in channels (u_G < 1.5 m/s)
  - residence time ≈ 0.4 sec
- Pulse cleaning for dust removal

  1 sec N_2-pulse every 1.5 hour

  spatially distributed over time
- Air addition between both layers

  temperature control (inlet of second layer above 900°C)
- Air treatment between experimentasl runs

  regeneration (sulfur and coke removal)



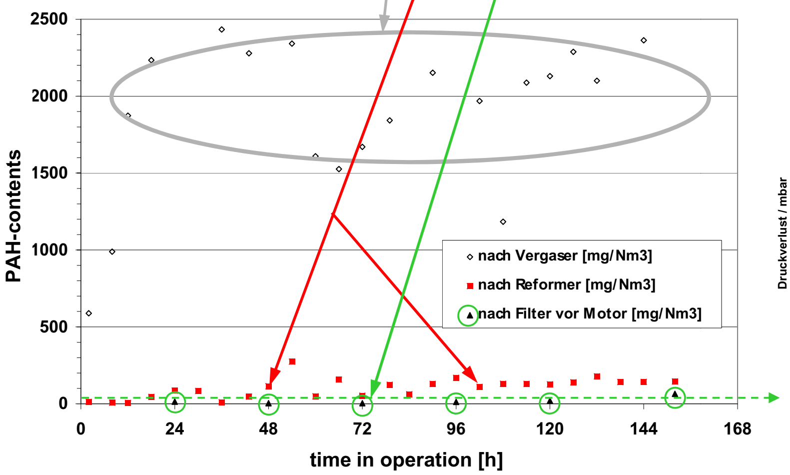
Fraunhofer UMSICHT

Results of Catalytic Tar Decomposition (typical test run)

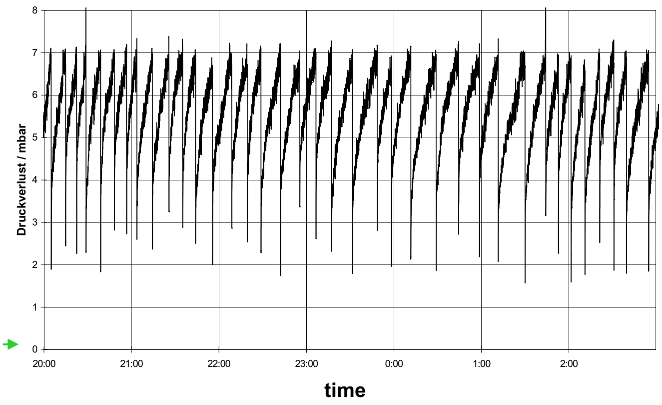
→ tar level behind CFBG: 2000 mg,

→ tar level behind reformer: 160 mg → bag house filter works properly and regularly ✓

→ tar level at entry of engine: < 50 mg → gas engine works properly ✓



Pressure drop cycles of bag house filter operating on wood gas (T = 120°C)



Catalyst deactivation / poisoning

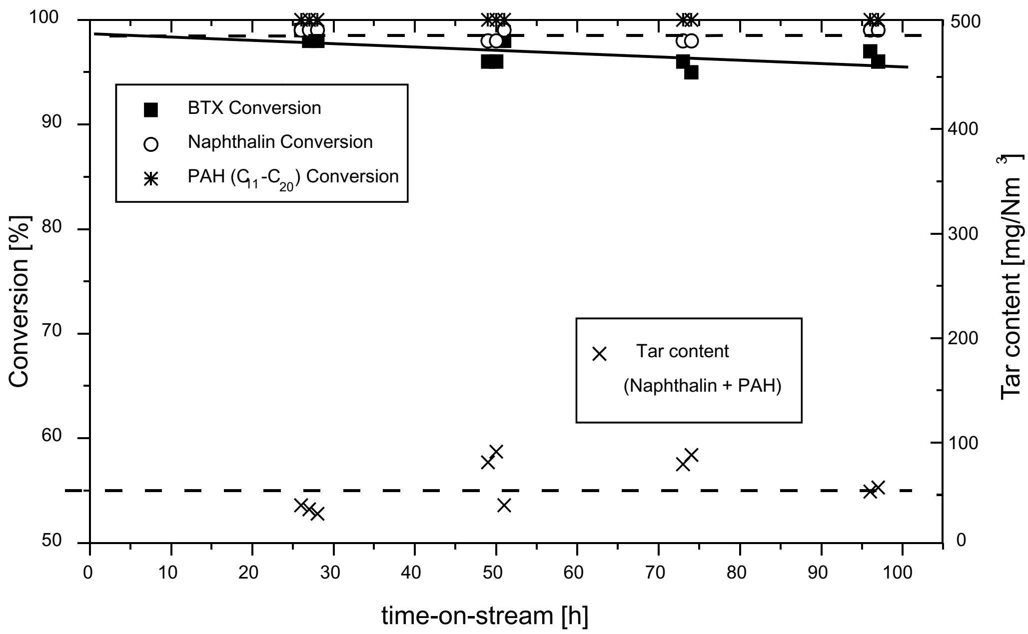
Deactivation mechanisms

- sulfur poisoning
  Ni + $H_2S \Leftrightarrow NiS + H_2$

  → methane reformation decreases very fast, tar reformation hardly

- carbon deposition / coking

  → tar reformation decreases linearly, light tars more affected



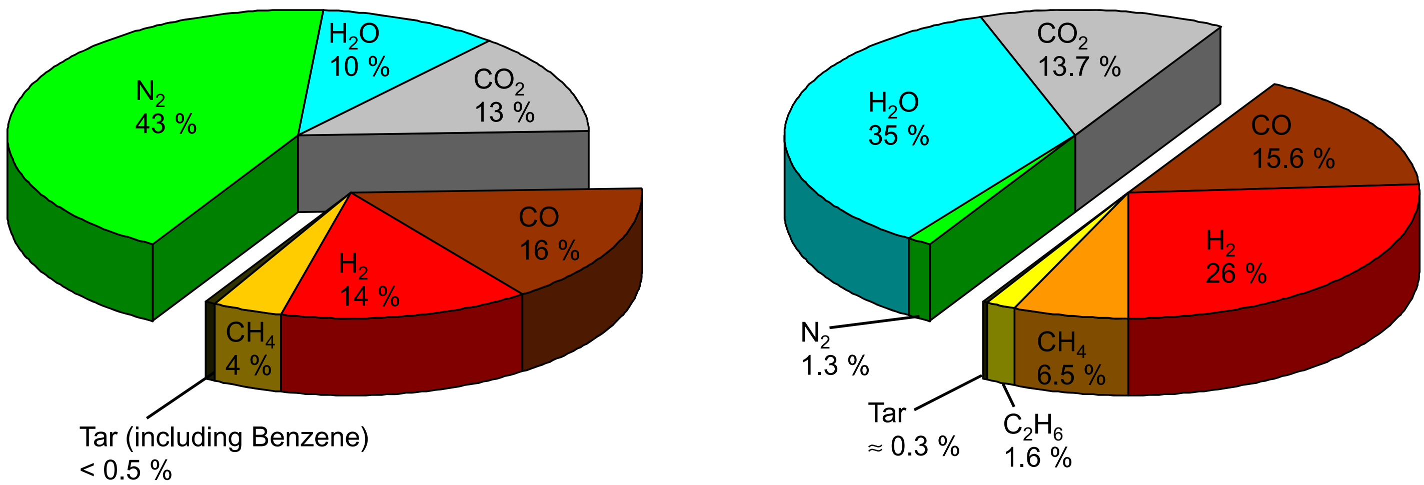
Summary of results at Oberhausen

- Ni(0) supported on Al_2O_3 ceramic monoliths reforms tars sufficiently
  - if operating temperature is around 900°C
    - ♥ temperature control by air (O_2) addition between monolith layers
  - if inlet tar contamination level is sufficiently low
    - ♥ active bed material is recommended (e.g. olivine) for fluidized bed gasifiers
- Blocking of flow channels by dust can be avoided by distributed pulse cleaning
- Sulfur poisoning and coke deposition appear, but are reversible
  - fast decrease of catalytic activity with respect to lower hydrocarbons (< 1 h)
  - slow decrease of catalytic activity with respect to tars (≈ 1 week)
  - Regeneration by cautious air treatment (2-4 h) ♥ in-situ, on-line
- Activation with producer gas very fast, no pretreatment necessary

Gas Composition Comparison

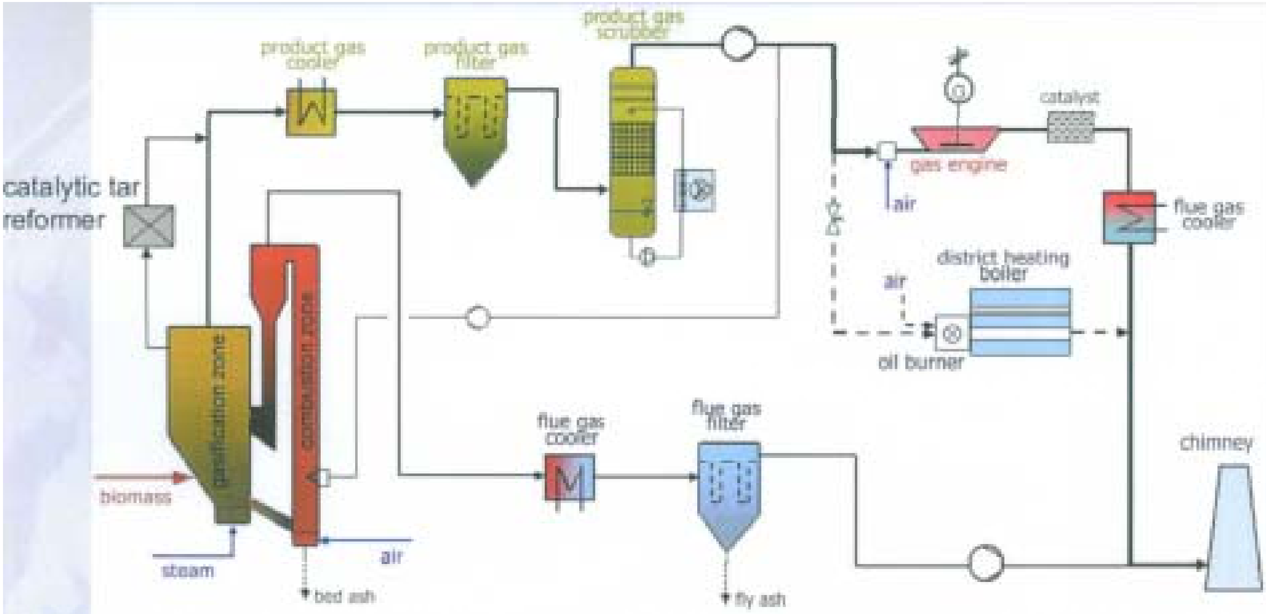
air gasification
UMSICHT CFB (≈ 900°C)

steam gasification
Güssing FICFB* (≈ 840°C)



*Pfeifer et al., Presentation at 15th European Biomass Conference, Berlin, 2007

Test installation at Güssing

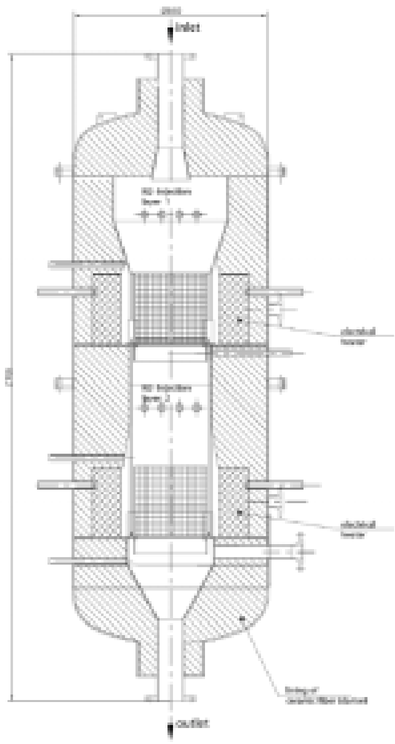


Tar reformer

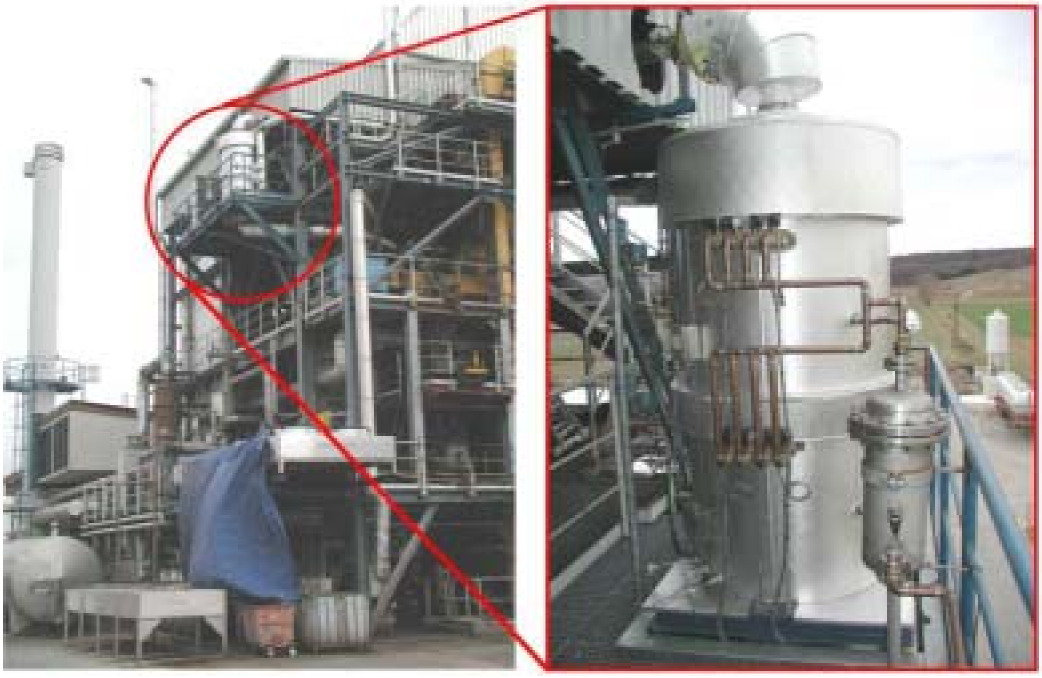
2 layers 2x2 Ni-monolith for 100 Nm^3/h slip stream

Dust removal by pulse cleaning

Air injection for temperature control



Test installation at Güssing



Results from test run

Tar levels

Raw gas

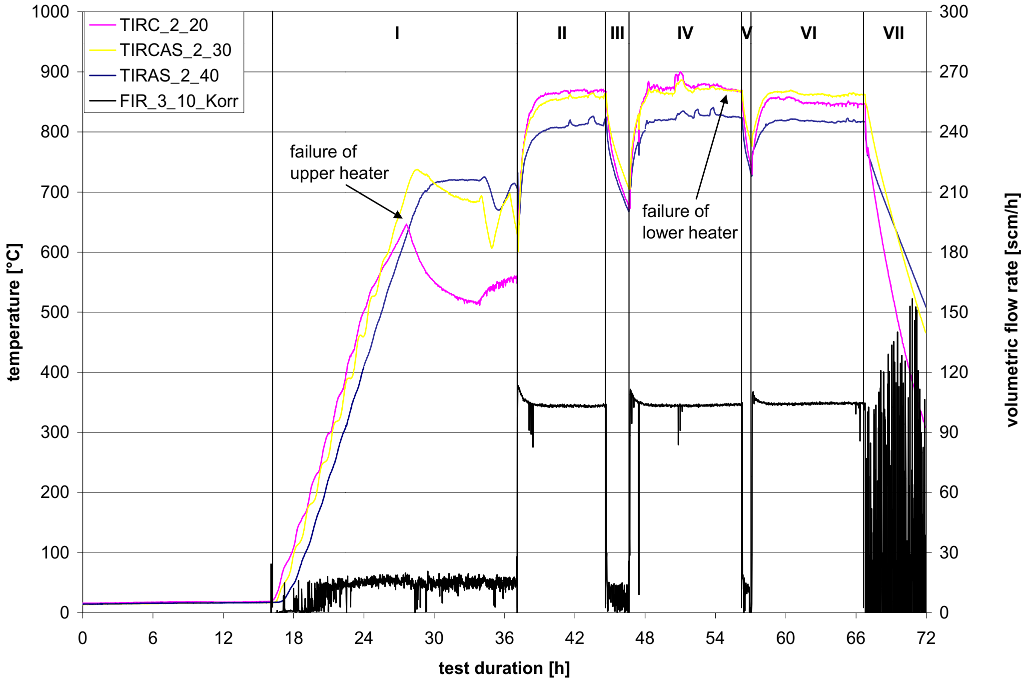
10 – 20 g/Nm^3

Clean gas

1 – 3 g/Nm^3

Conversion

> 80 %



Utilization of Producer Gas

- CHP in IC engine / turbine
- Methane-synthesis

no methane reformation desired

- Alcohol-synthesis / DME
- Fischer-Tropsch-Synthesis

complete methane reformation desired

Alternative Catalysts

- Ni-based Catalysts (BASF, Süd-Chemie, Haldor Topsøe, Johnson Matthey, …)
- ZrO_2-based Catalysts
  more poison resistant at lower temperatures (750 – 850°C)
- Noble metal catalysts
  Rh, Pd, Pt, Ru on CeO_2/SiO_2 or other supports
  high activity of Rh already at 550°C

Outlook

- Ni-based monoliths work well for air blown gasifiers for CHP
  - high gasifier exit temperature allows high operating temperature of reformer
  - long time demonstration in operation (Skive plant)
- Fixed Bed downdraft gasifier need better tar removal
  - gasifier exit temperature 500 – 750 °C ♥ catalytic tar reforming not possible with Ni
- Different syngas applications have different reforming needs
- 3 year project started to identify catalyst (combination) which are
  - highly active at lower temperatures
  - resistent against sulfur and soot

Thank you for your Attention!

Feel free to ask Questions…

Biomass Gas Cleaning and Utilization
The Topsøe Perspective

RESEARCH | TECHNOLOGY | CATALYSTS

John Bøgild Hansen
Company Management
Haldor Topsøe A/S

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Greenhouse Gas Emission Mitigation Strategies

- Reduce consumption
- Increase Efficiency
- Use of biomass
- Use of renewable physical energy
  - Wind
  - Sun
  - Geothermal

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Energy Consumption and Reserves 2008 - Gton Oil Equivalent

	Consumpt. per year	"Reserves"	R/P
NG :	2.8	167	60
Oil :	3.9	171	43
Coal :	3.3	454	122
Σ Fossil :	10.0	742	74
Growth in world energy consumption 2001-05:			13%

	Potential	Total	
Biomass	4.5 - 11	56/year	1 * 10^9 ?

BP Statistical Review of World Energy (2009 Edition)
Berndes et. al.: Biomass and Bioenergy **25** (2003) 1

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Haldor Topsøe group – Key figures 2008

Head quarter in Lyngby, DK

- Turnover: DKK 5.0 billion ($ 920 MM)
- Result: DKK 533 MM ($ 97 MM)
- 2052 employees

Catalyst plant in Frederikssund, DK

Catalyst plant in Houston, Texas

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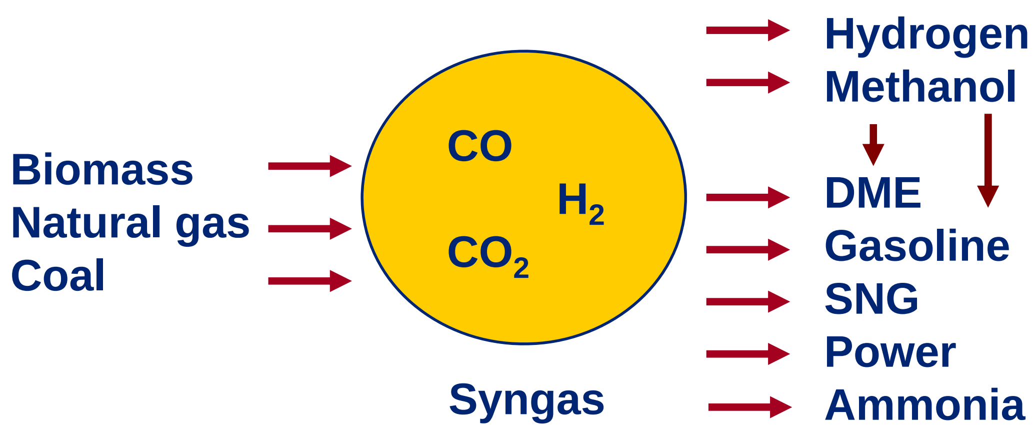
Topsoe and Renewables

- Gas cleaning in Gasification
  - Tar Reforming
  - Ammonia Decomposition
  - Sulphur Management
    - Hot gas cleaning
    - COS hydrolysis, Fine desulfursitaion
    - WSA
  - Shift
- Chemicals from biomass
  - Example Acetic Acid from Ethanol
- On board Ether production from Methanol or Ethanol
- Biogas to Syntheses: $H_{2,}$ SNG, MeOH, DME, Gasoline
- Solid Oxide Fuel Cells & Electrolysis and Synthesis

Gasification



Is Biogas Suitable for Synthesis?

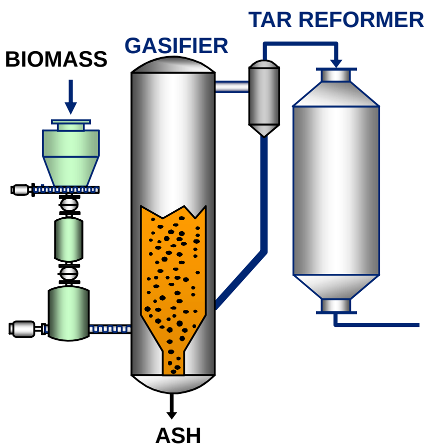
No!

Is conditioning possible?

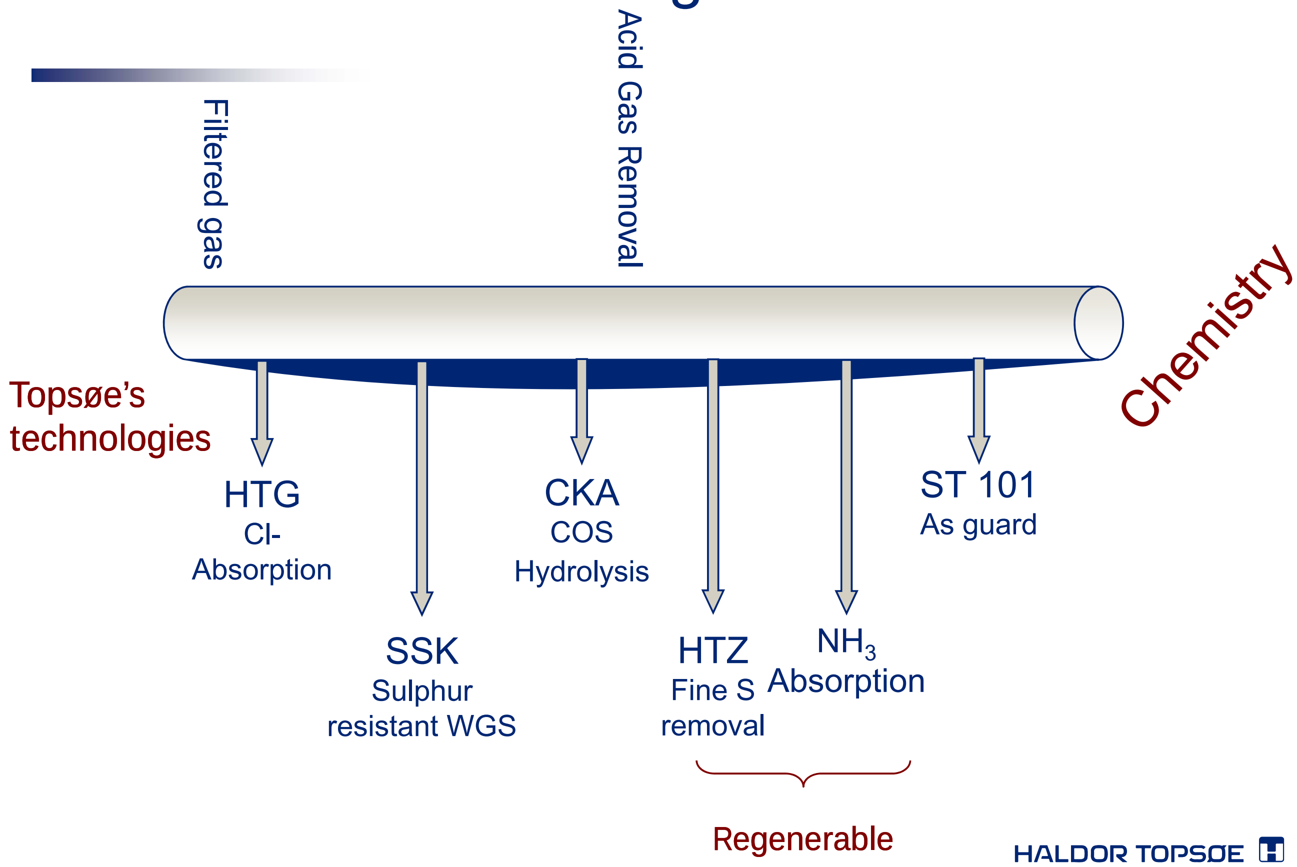
Yes! (but it is challenging)

Tar reforming – Enabling Technology for Biomass Gasification

- Gasification of biomass results in a syngas that contains tars and contaminants
  - 2500 ppm tar (toluene, benzene, naphthalene)
  - 100 ppm S, particulates
  - 850-930 °C, 1-20 bar g
  - Ammonia Decomposition



Sour Gas Conditioning



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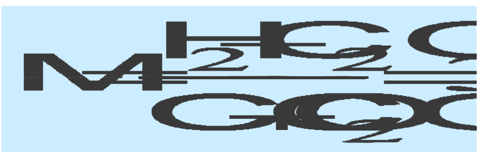
Methanation reactions

$$CO + 3H_2 \;=\; CH_4 + H_2O \qquad + 206 \text{ kJ/mol}$$

$$CO_2 + 4H_2 \;=\; CH_4 + 2H_2O \qquad + 165 \text{ kJ/mol}$$



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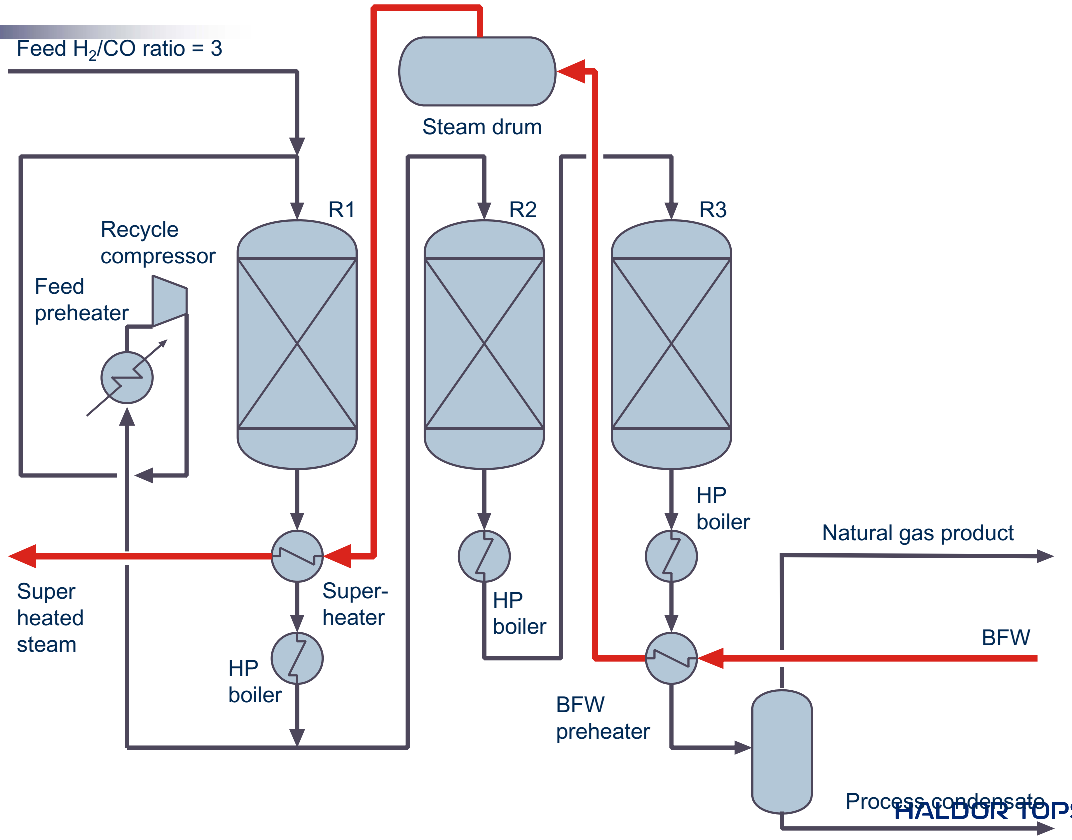
TREMP™ technology



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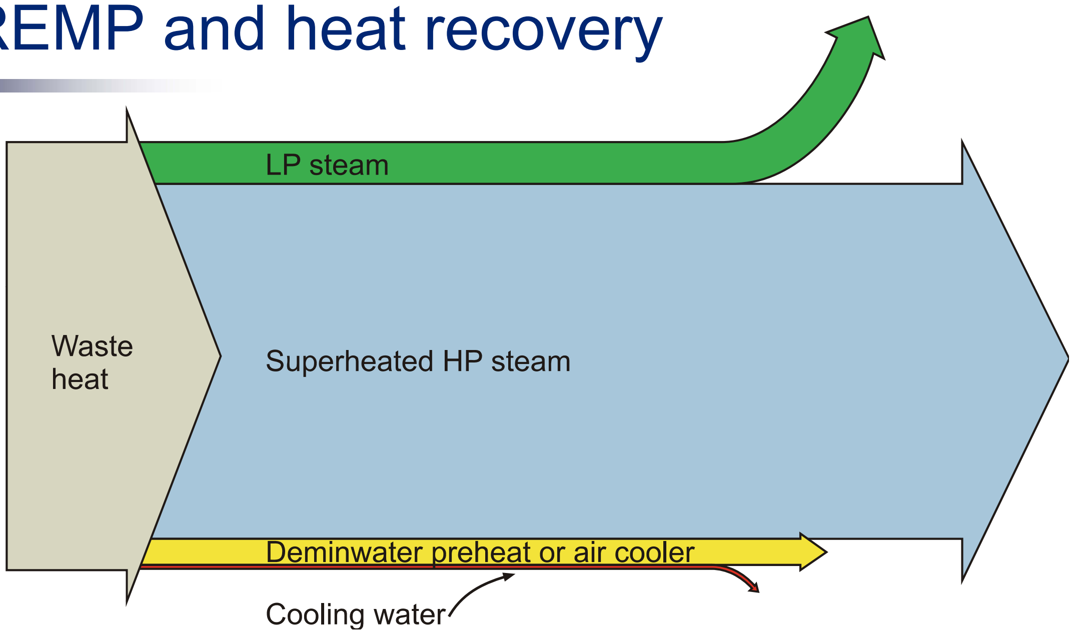
TREMP and heat recovery



One of the features of the TREMP technology is that 84% of the waste heat has been recovered as high pressure superheated steam for export. Only 0.5% of the waste heat ends up in cooling water.

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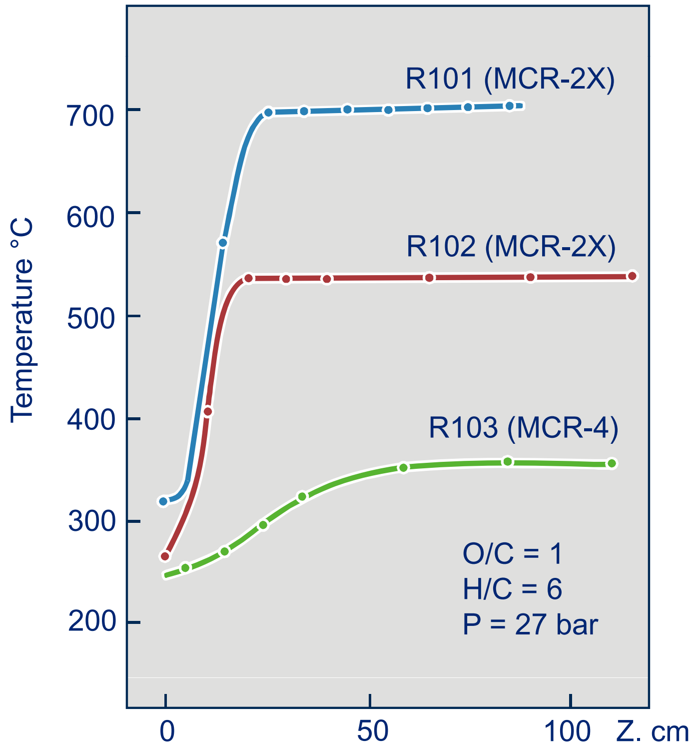
Data from test unit. Temperature profiles



Temperature profiles from adam 1

Methanol Synthesis reactions

$$CO_2 + 3\,H_2 = CH_3OH + H_2O \quad + 41\ \text{kJ/mol}$$

$$CO + H_2O = CO_2 + H_2 \quad + 50\ \text{kJ/mol}$$

$$M = \frac{H_2 - CO_2}{CO + CO_2} = 2$$

CO + $2H_2$ Gas Ideal for MeOH Synthesis

Á Once-through production is possible

Á Very high reaction rates (special reactor is needed)

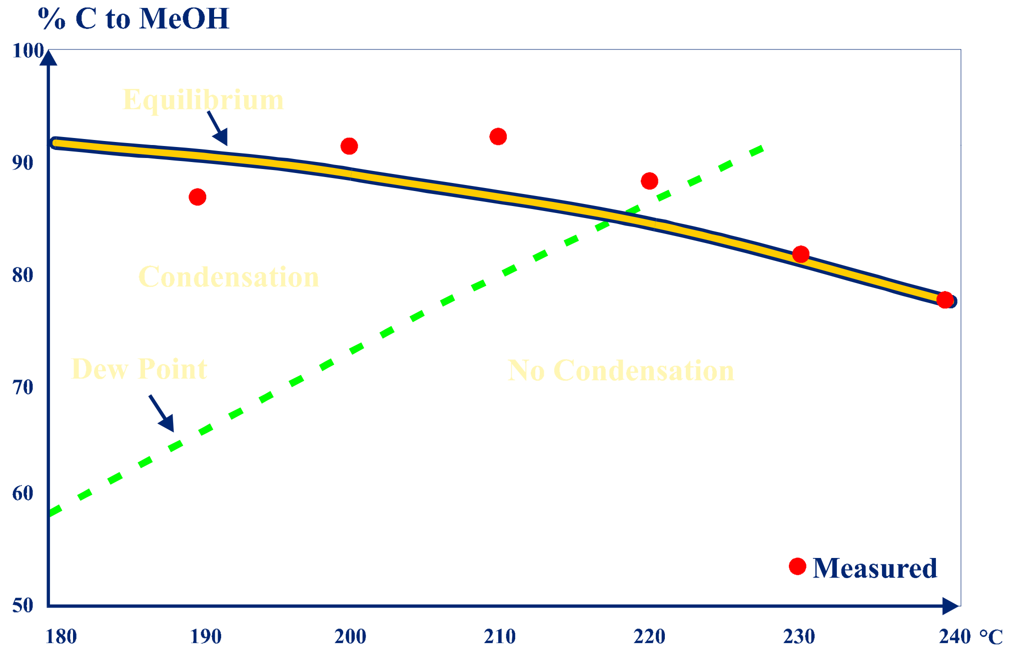
Á Direct production of fuel methanol

Á Very good catalyst stability

Today

Á Small amounts of CO_2 are needed and optimal

Once-through Conversion of CO and CO_2 at 9.6 Mpa, 30% CO, 2% CO_2



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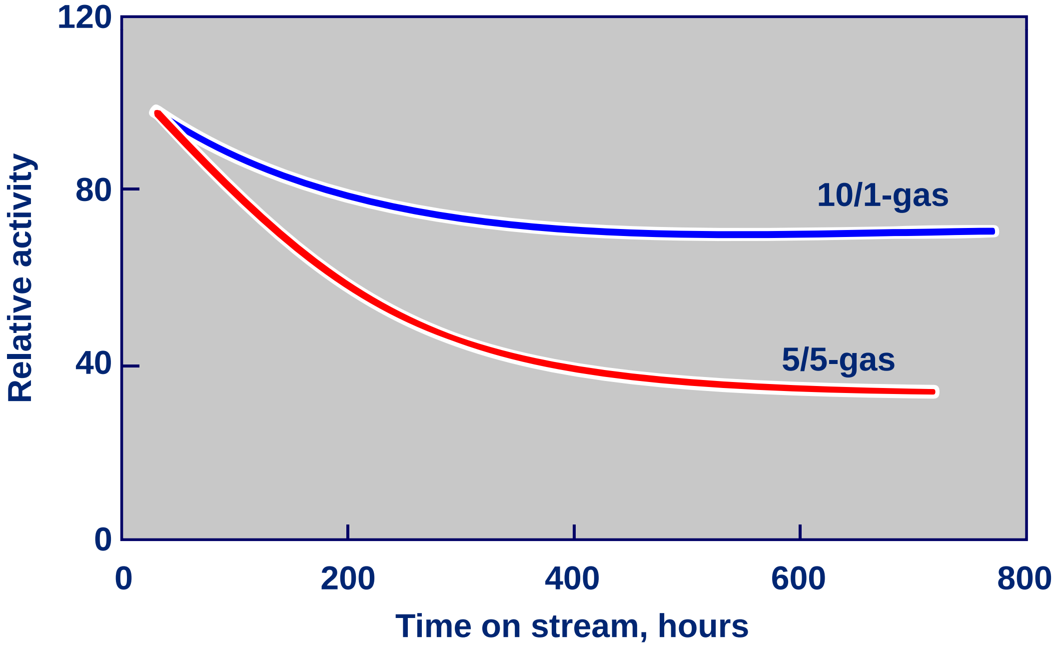
MK in Normal and Dry Syngas



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MeOH/DME Synthesis

– Low H_2/CO

	– æH (kJ/mol)
$2H_2 + CO = CH_3OH$	90.7
$2CH_3OH = CH_3OCH_3 + H_2O$	23.6
$CO + H_2O = CO_2 + H_2$	41.1

$$3H_2 + 3CO = CH_3OCH_3 + CO_2$$

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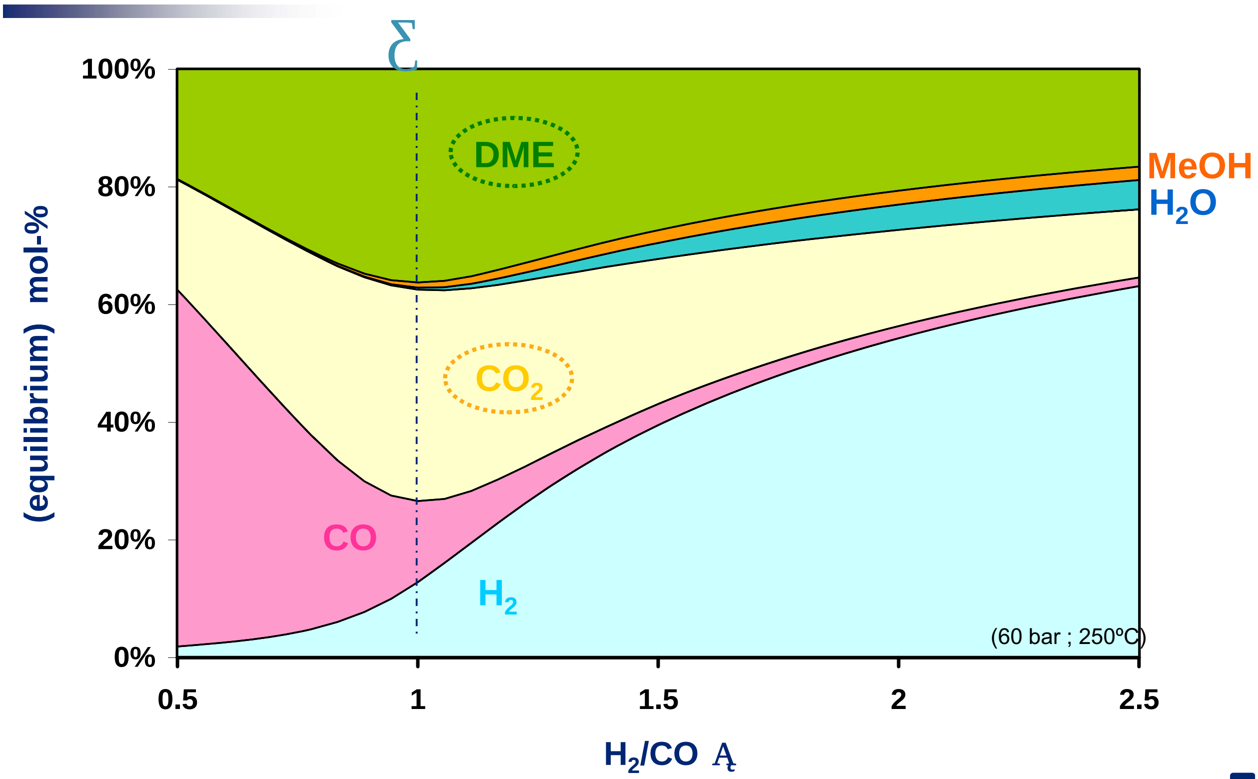
H_2/CO = 1 is optimum for DME



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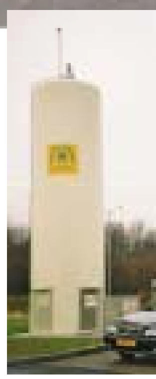
Demonstration of biomass ”waste” to transportation fuel (DME)

Á Black Liquor Ą DME Ą Filling Stations Ą Trucks



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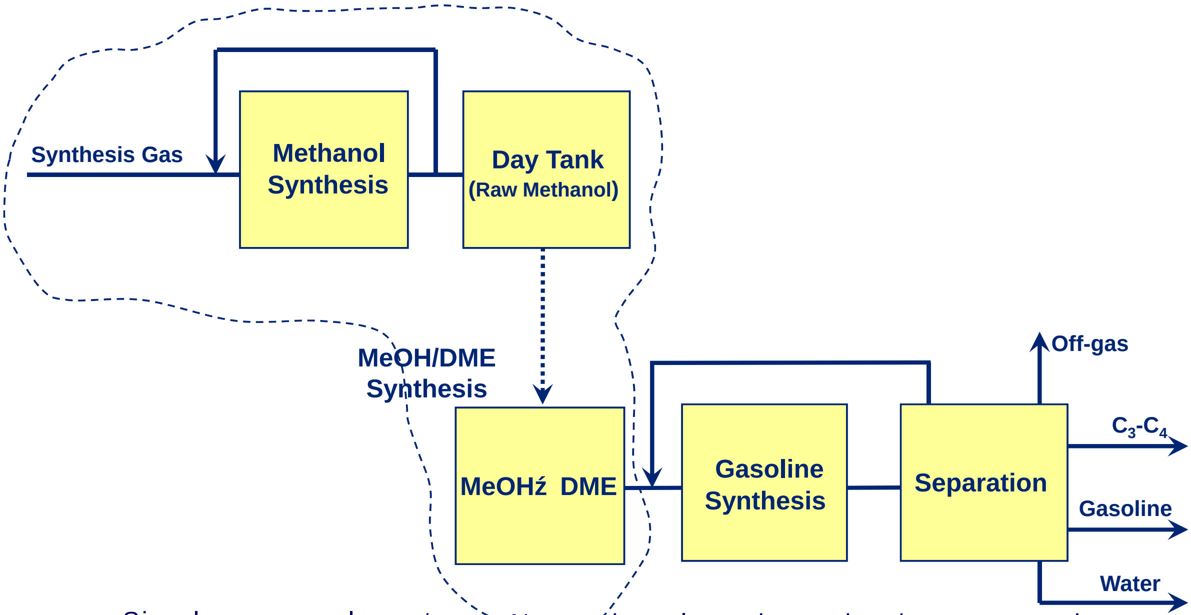
TIGAS / MTG

Topsøe Integrated Gasoline Synthesis / Methanol To Gasoline



- Simple process layout
- Low recycle rates
- No methanol condensation / re-evaporation
- Moderate pressure

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TIGAS Demonstration Plant

1 T/d **7000+ Runhours** **Houston,TX**

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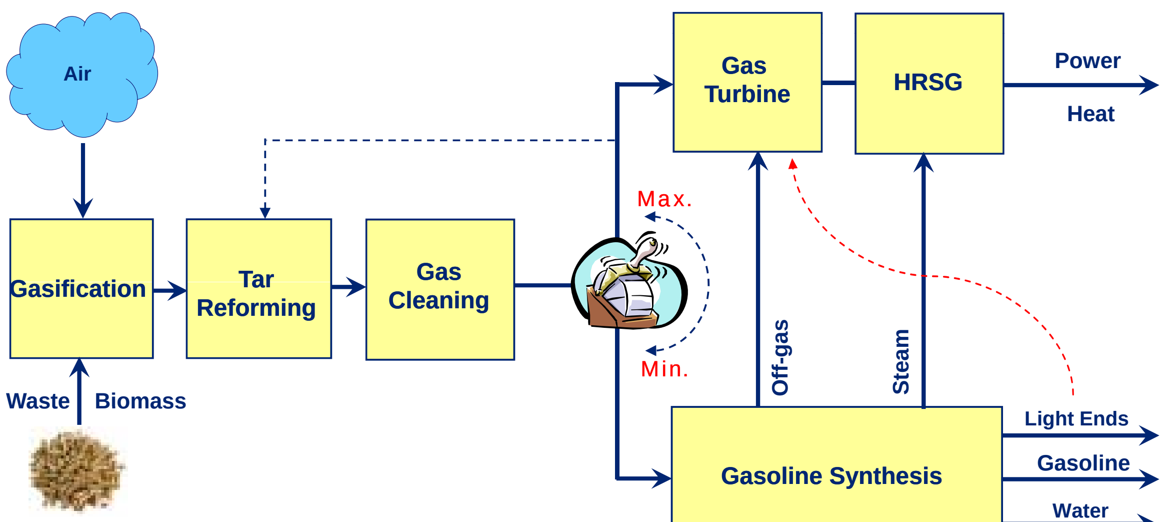
Fuel/Power Co-Generation

- Fluctuating power prices
  - Varying electricity demand
  - Fluctuating production from wind/wave/solar
  - Increasing contributions from waste and renewables
- Objectives
  - Increase operational flexibility at low additional investment
  - Improve energy system flexibility
  - Maximize product value at any time

Biomass to Gasoline & Power



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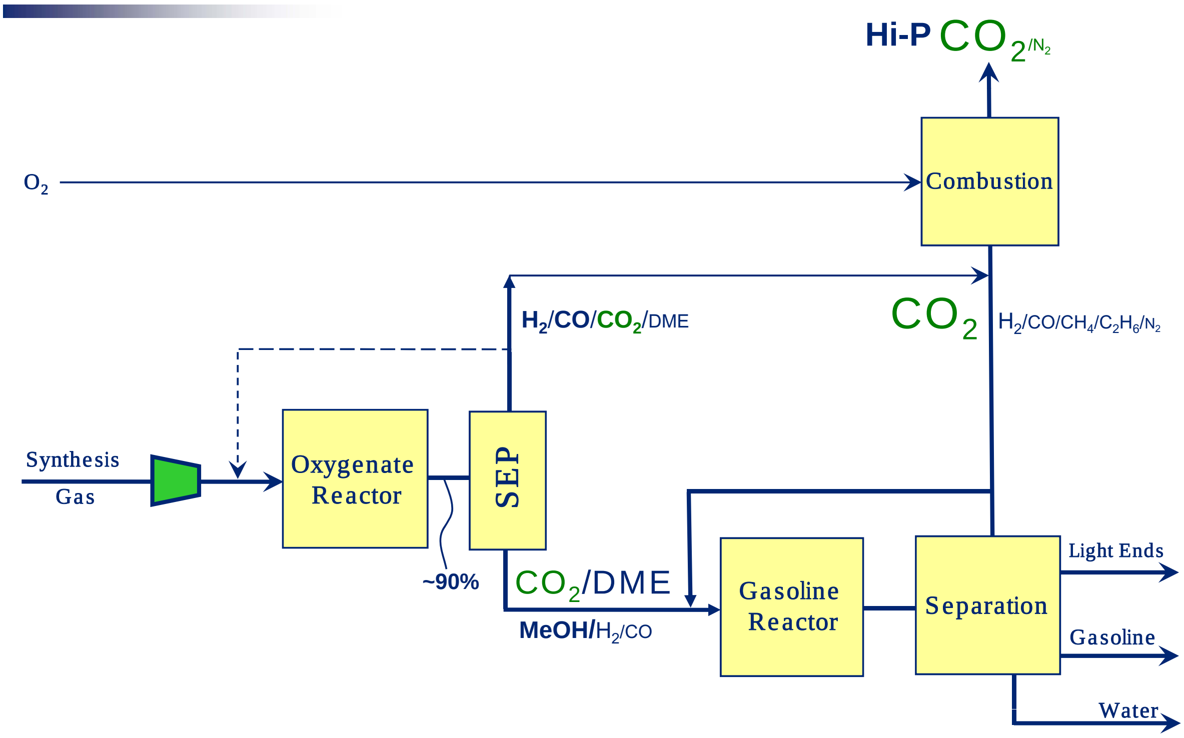
TIGAS[CCSR]



Conclusions

- Gas clean up is crucial for succesfull deployment of biomass gasification
- Tar Reforming is a truly enabling technology
- Many options and synergies
- The choice of end product depends on local conditions
  - Power price
  - Existing infrastructure (SNG)
  - Energy supply security
- Transportation fuels probably preferred choice in the long run

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DAHLMAN

Renewable Energy Technology

Jan-Willem Könemann

October 23rd 2009

Ministry of Economic Affairs

The tests in Petten & Moissannes were partly funded by the Dutch ministry of Economic affairs, specifically by ERS (Energy Research Subsidy)

SGC Svenskt Gastekniskt Center AB

Presentation contents

- Biomass gasification & tar problems
- OLGA tar removal concept
- OLGA performance
- OLGA & Dioxins [new information]
- OLGA flexibility
- OLGA projects & future

Gasification

- Thermal conversion of solid matter into a combustible gas
- Thermal energy is usually supplied by combusting a limited amount of the solids (limited oxygen supply)
- Biomass or waste gasification (800 – 900 °C) gives a product gas containing mainly CO, CO2, H2, H2O, CH4
  (and N2 for air blown gasification)

Gasification product gas cleaning

- Simplified..
- Solids particulates
- Organic impurities (tars)
  dependant upon gasifier type and operational characteristics
- Inorganic impurities (H2S, HCl, NH3 etc.)
  dependant upon composition feedstock
- Other impurities (heavy metals, alkali metals etc.)
  dependant upon composition feedstock

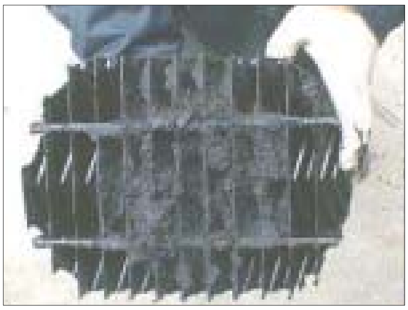
- A dirty feedstock (waste) is attractive, but results in more cleaning efforts

The tar problem

1. Heavy tars

- Condensation leads to fouling < 350 °C
- Tar dew point is critical parameter

Deactivation of catalyst



Fouling of equipment

Plugging of an intercooler

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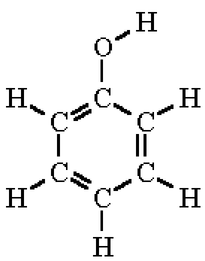
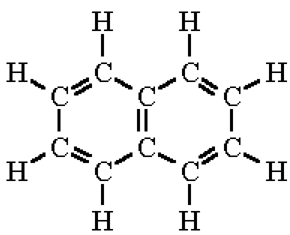
The tar problem

2. Light tars

- Heterocyclic compounds (phenol) are water soluble, condensate & scrubber water is poisoned
- Naphthalene can cause crystallization problems





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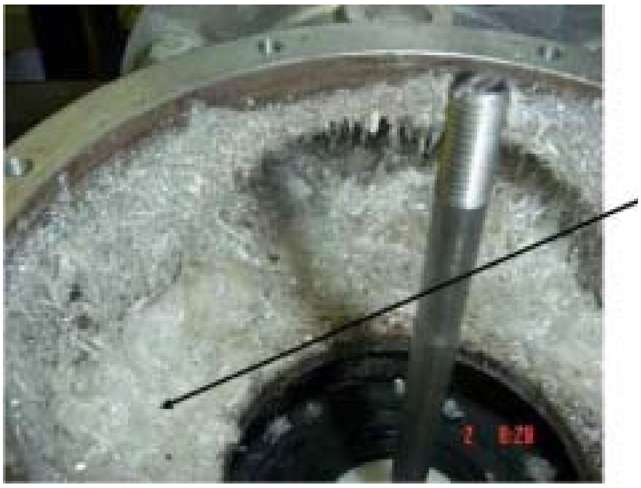
The tar problem



Naphthalene crystals on gas engine control valve

Presentation contents

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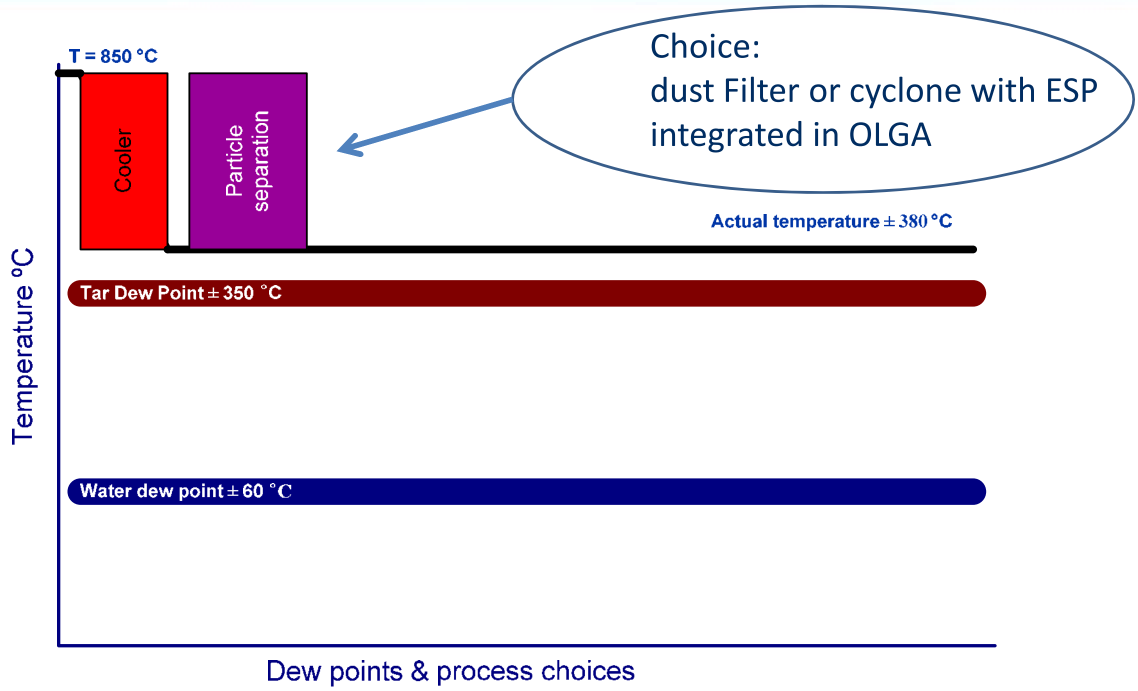
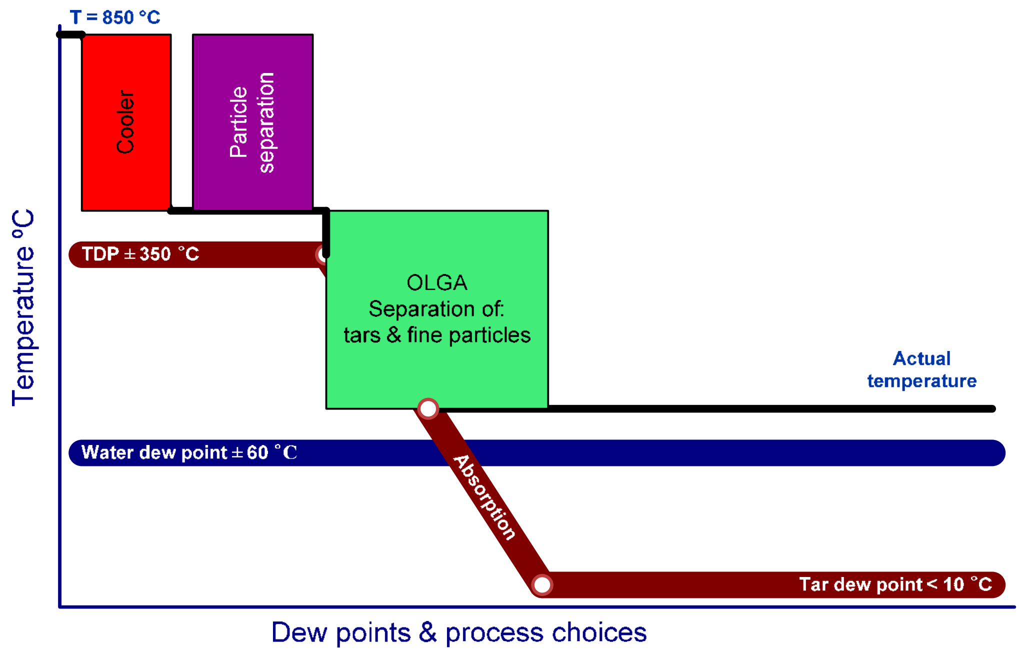
- OLGA projects & future

OLGA & dewpoints



DAHLMAN

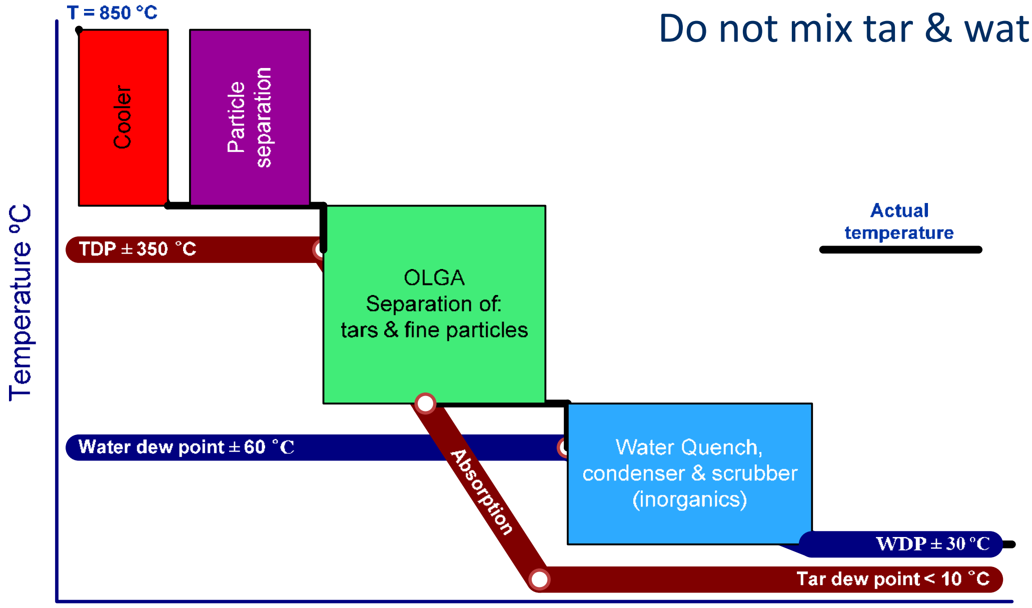
Dew points are important!



DAHLMAN

Dewpoints are important!

Do not mix tar & water!



Dew points & process choices

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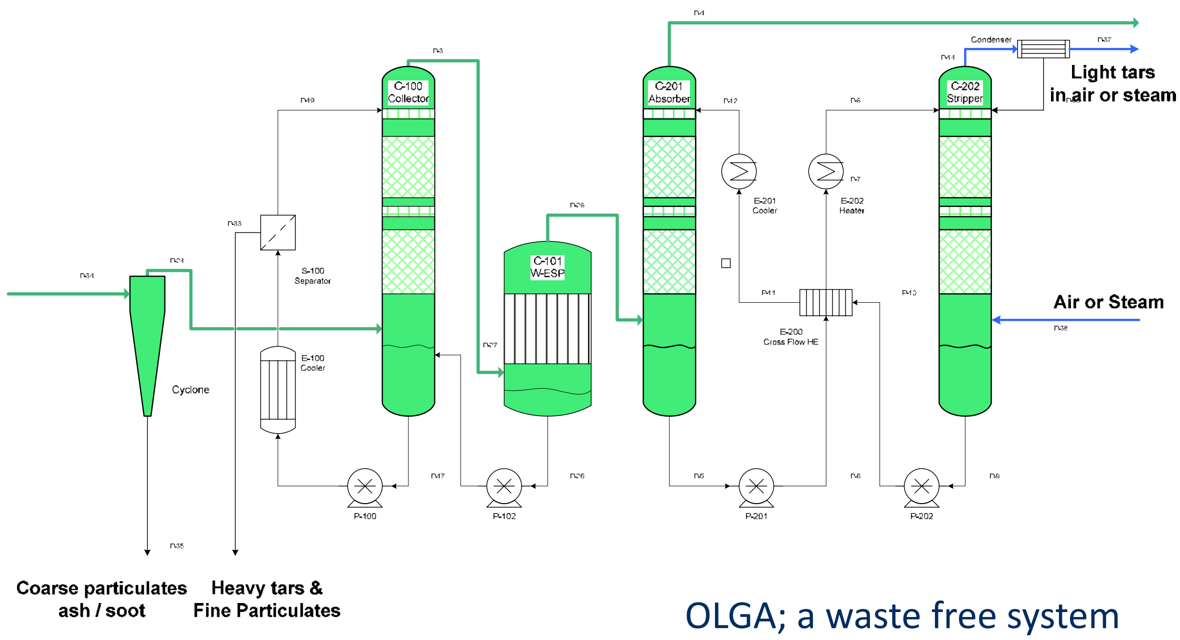
PFD - OLGA with cyclone



OLGA; a waste free system

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Presentation contents

- Biomass gasification & tar problems
- OLGA tar removal concept
- OLGA performance
- OLGA & Dioxins [new information]
- OLGA flexibility
- OLGA projects & future

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OLGA Performance

OLGA is tested on:

- Lab scale (5 kWth BFB & Milena, ECN Petten)
- Pilot scale tests (CFB 500 kW, ECN Petten)
- Commercial demo (FB 4 MWth, Moissannes France)
- Milena pilot scale (800 kW indirect gasifier, ECN Petten)

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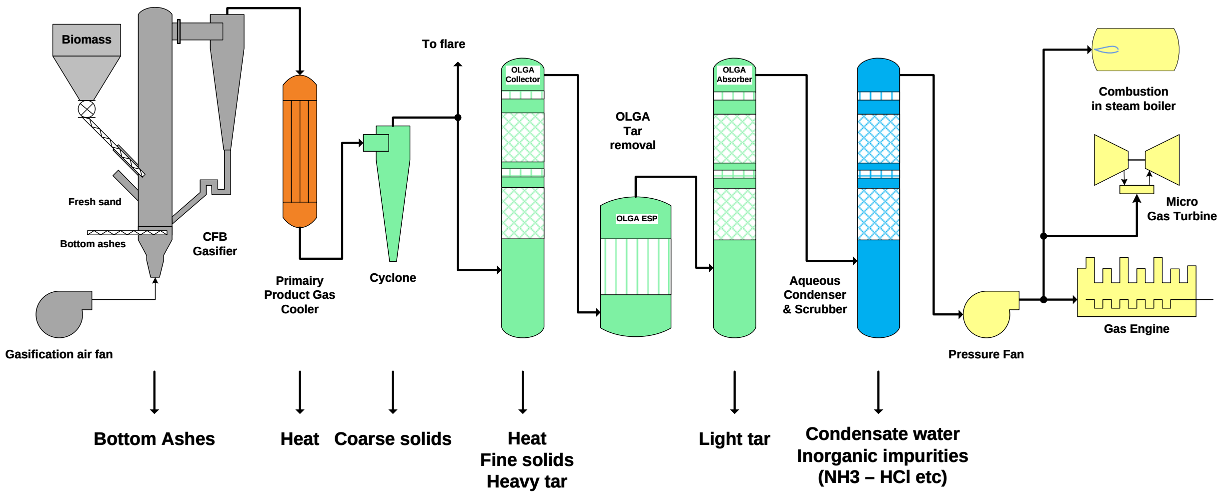
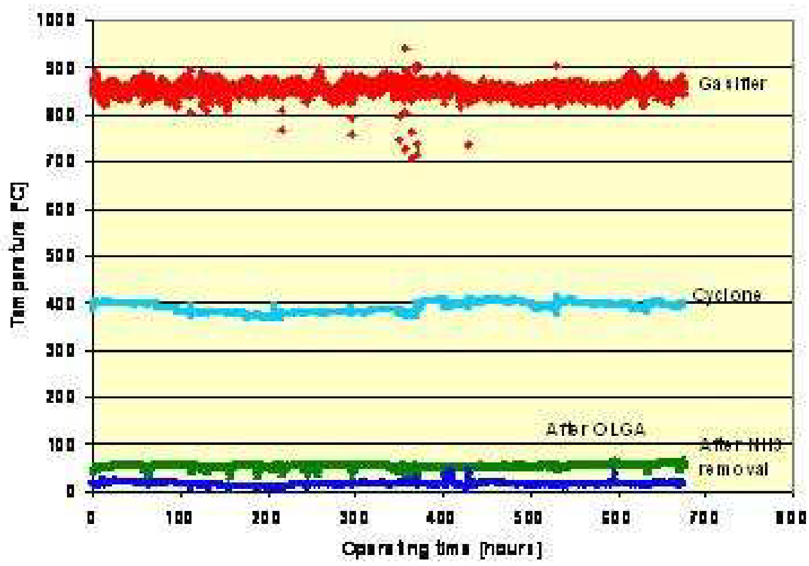
Commercial demonstration in France

Commissioning, start-up & success in 2006

Set up 0.5 MWt duration test

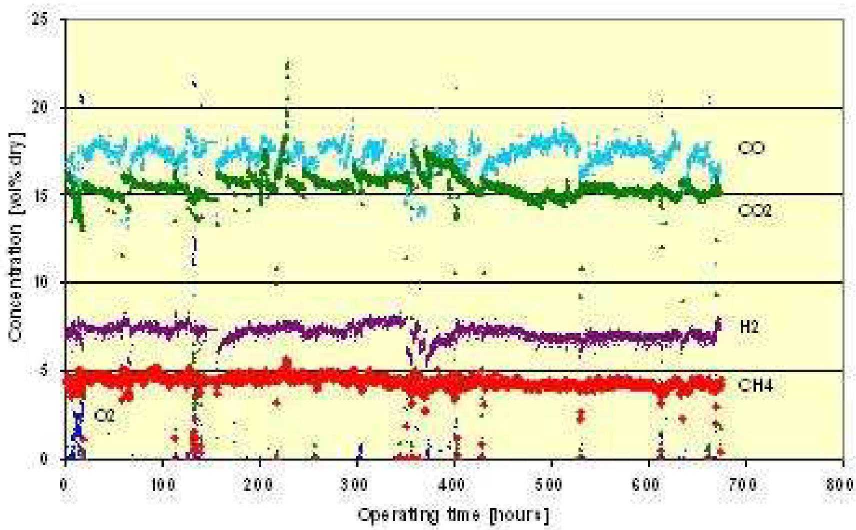


OLGA Performance



Stable
Temperatures

OLGA Performance



Stable
Gas composition

OLGA Performance, gas analysis

Compound	Unit	Raw product gas	After OLGA
Total tar	mg/Nm³ (dry)	16855	197
Tar dewpoint	° C	≈ 350	< 5
Naphthalene	mg/Nm³ (dry)	4023	38
Phenol	mg/Nm³ (dry)	386	< 2,5
Tar aerosols (incl. dust)	mg/Nm³ (dry)	--	10

OLGA Performance

- All lab scale tests were successful (BFB & Milena, ECN Petten)
  - (various feedstock's & conditions)
- Successful pilot scale tests (CFB 500 kW, ECN Petten)
- Successful tests in commercial demo (FB 4 MWth, France)
  - (grape residue & wood chips)
- Successful tests Milena pilot scale (800 kW indirect gasifier)
  - (OLGA was not changed, success after 3 years stop without maintenance and with the same absorber oil)

Conclusion OLGA Performance

- OLGA efficiency is excellent
- Clean water condensate after OLGA
- Gas engines operated problem free and proved to be clean after inspection, lube oil quality similar to natural gas operation
- All tested performances were:
  - According to the OLGA process model (predictable)
  - Identical, reproducible, hence reliable)

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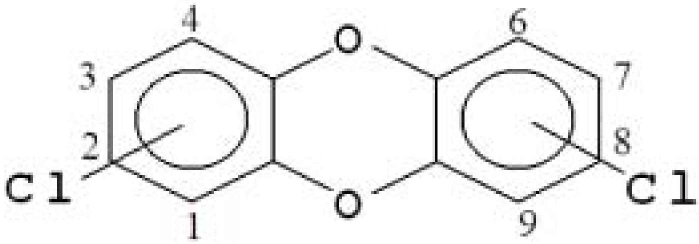
Gasification & Dioxins



'Dioxins' is a common name for a group of 210 compounds isomers of polychlorinated-dibenzo-para-dioxins and -dibenzofurans (PCDD/Fs)

Gasification & Dioxins

- Dioxins are toxic at low concentrations (0.000000001 g/m3)
- I-TEQ = International Toxicity Equivalent
  (measure for dioxins toxicity)
- European emission limit (flue):
  0.1 ng I-TEQ/mn3 (at 6% O2 in flue gas)

Gasification & Dioxins

Dioxin Formation:

- Carbon source
  - residual carbon on ash gas-phase Products of Incomplete Combustion (PICs, TAR) (fly) ash/char-adsorbed PICs
- Elevated temperature
  - 700-900°C gas-phase reactions
  - 250-400°C catalytic reactions (surface = wall/ash catalyzed)
- Chlorine source
  - Organic, inorganic chlorides & free Cl_2

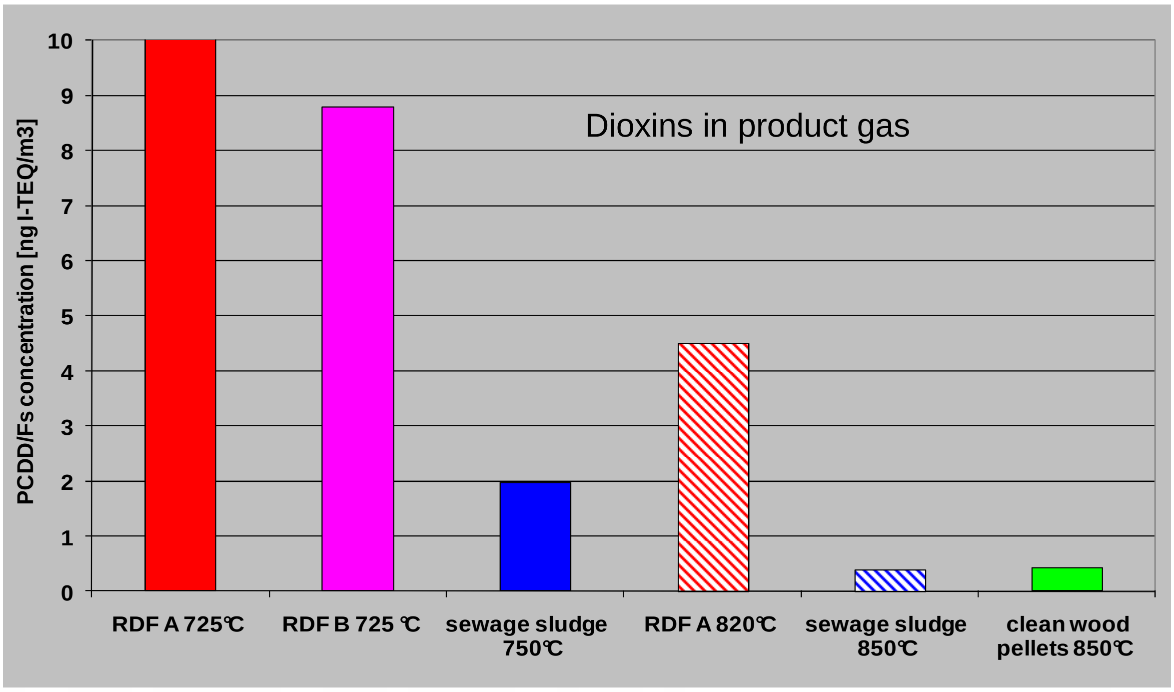
Gasification & Dioxins

Are dioxins formed in biomass gasification?

Yes

DAHLMAN ECN

Gasification & Dioxins



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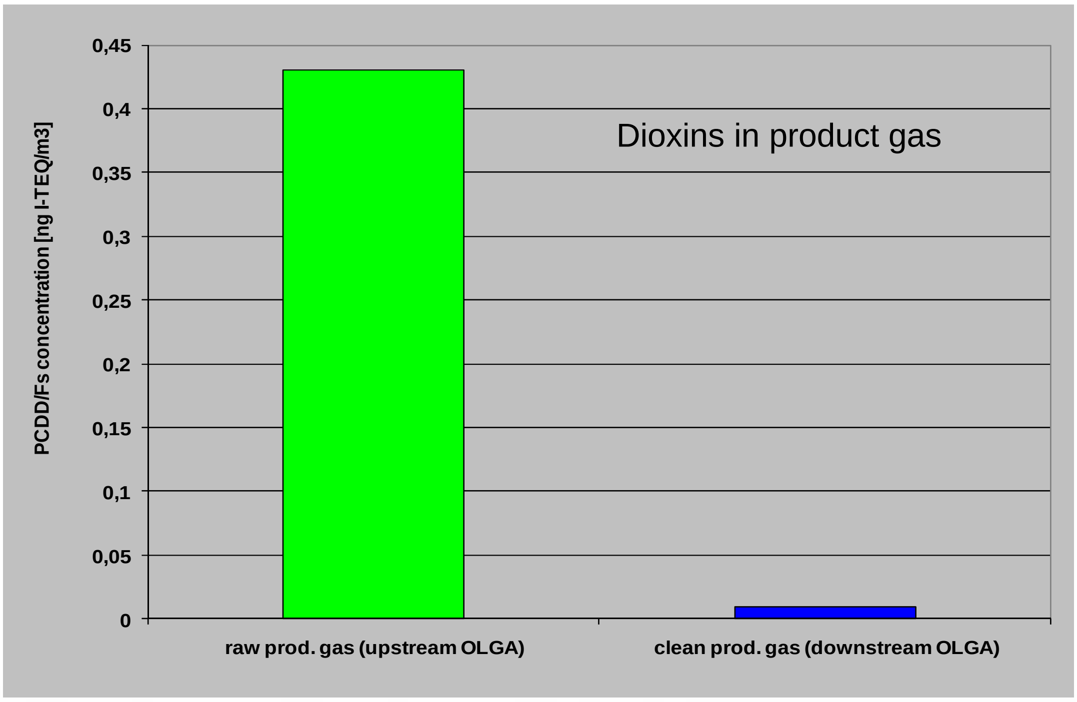
Gasification & Dioxins



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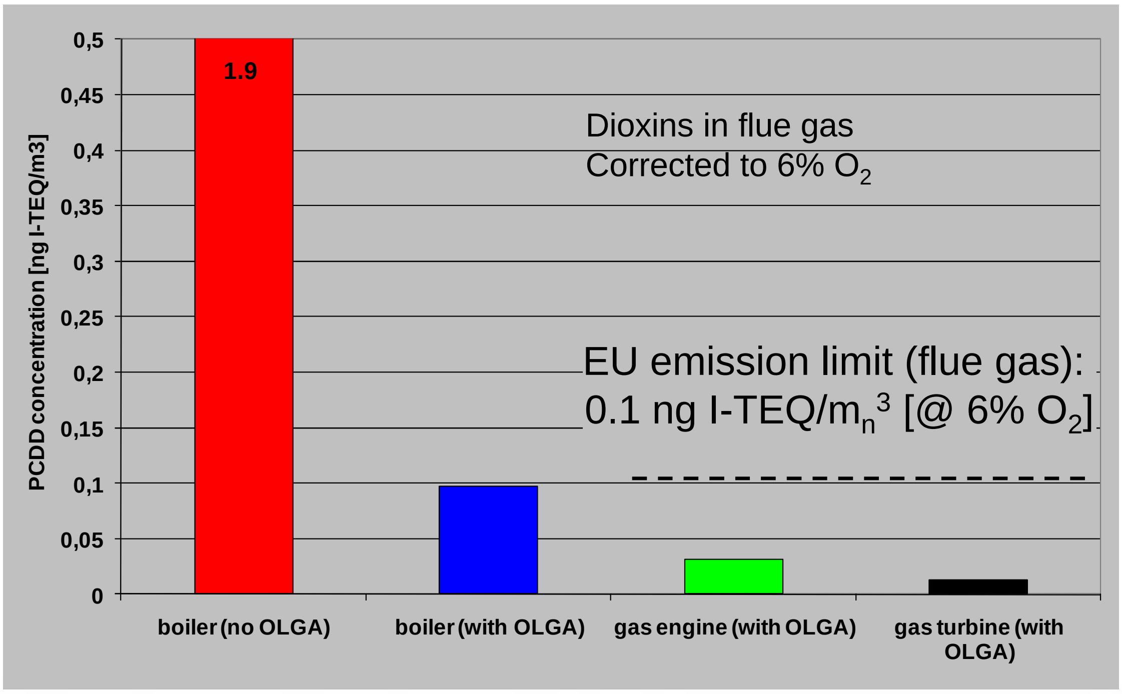
ECN

Gasification & Dioxins



Presentation contents

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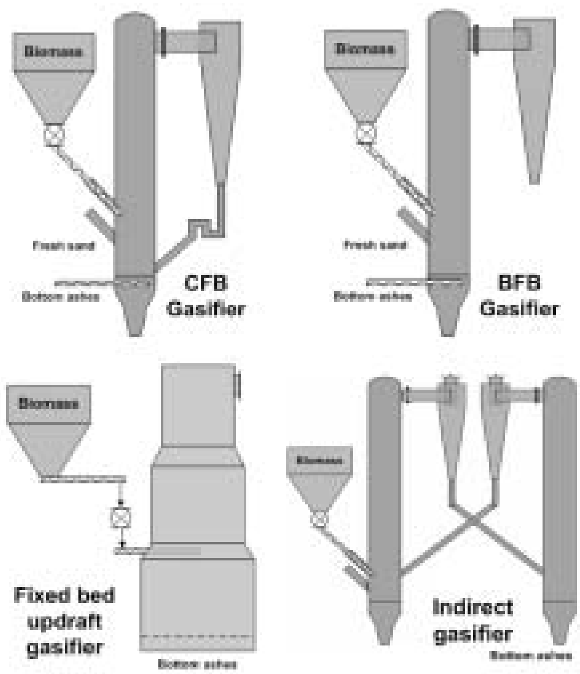
OLGA Flexibility; feedstock


a. Wood sawdust
b. Wood chips
c. Grape residues
d. Refuse Derived Fuel (RDF)

- Saw dust (lab scale)
- Wood chips (pilot scale & France)
- Grape (wine) residue (France)
- RDF (lab scale)
  (chlorine content is important)
- Chicken litter (Portugal)

Tars are more depending on gasifier type and operation than on the feedstock.

OLGA Flexibility; gasifier



- Bubbling fluidized bed gasifiers
- Circular fluidized bed gasifiers
- Indirect gasifiers
  (SilvaGas, Repotec, Milena)
- Fixed beds
  (not fully commercial for all types)

- Experience with tar levels from 5 – 40 g/Nm3, but levels are not limited
- Air, oxygen or steam blown
  Operational temperature is important
  (Preferably 800-900 °C)

OLGA Flexibility; upstream process

Gas Engines, Gas Turbines, SNG Synthesis, FT waxes, H_2

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Presentation contents

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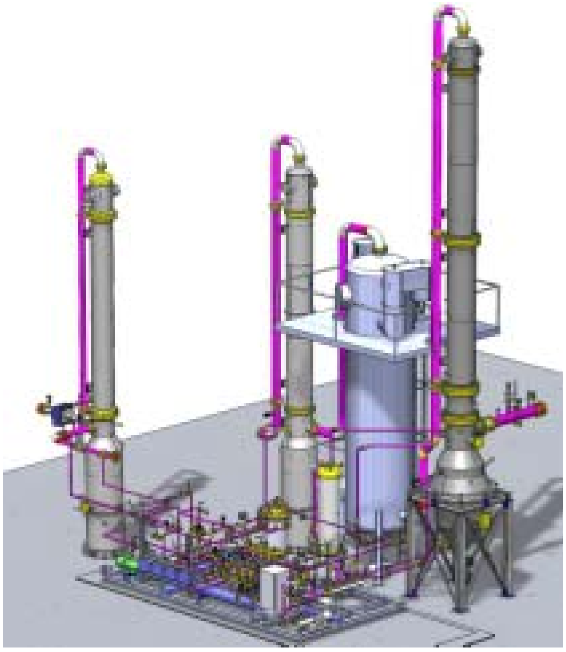
4 MWt Portuguese plant

- Gasification of chicken litter or forest residue
- CFB gasifier
- From 1 t/h chicken litter to approx. 1 MW electricity with Gas Engine
- Multiple 3-5 MWe plants planned for the future



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140 MWt USA plant basic design

- Gasification of woody biomass
- Indirect fluidized bed gasifier (steam blown)
- 45 MW electricity by 2 gas turbines and one HRSG with steam turbine
- Additional plans for H_2 production by PSA

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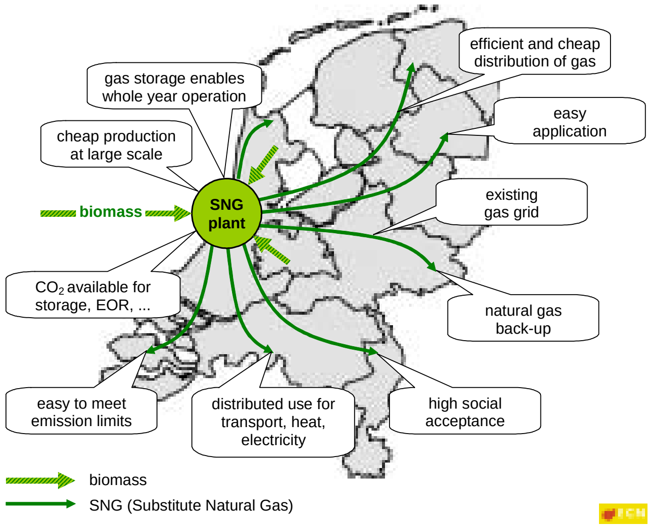
Green gas production in Holland

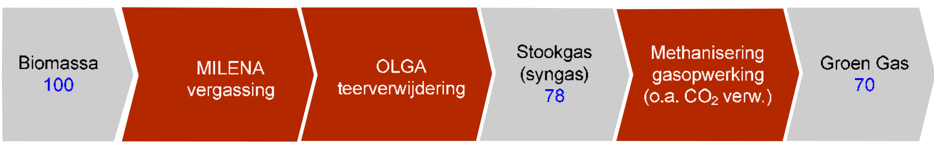
- Cooperation between HVC, ECN & Dahlman.
- Green gas production with MILENA - OLGA combination most efficient technology available



ECN

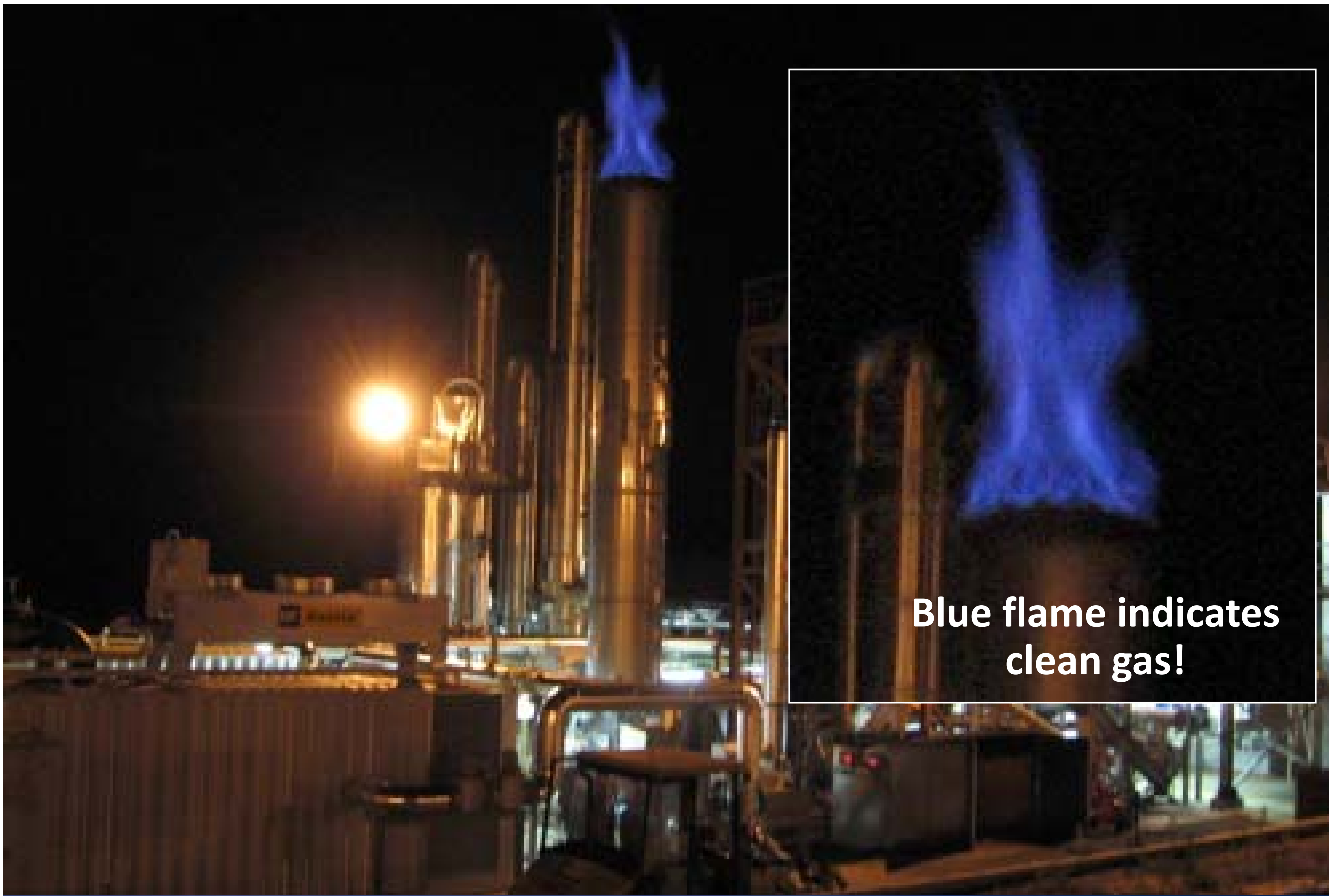
HVC

Typical net energy balance



Green Gas efficiency with MILENA - OLGA

WKK efficiency with MILENA - OLGA



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Thank You!

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Bio-SNG - Strategy and Activities within E.ON

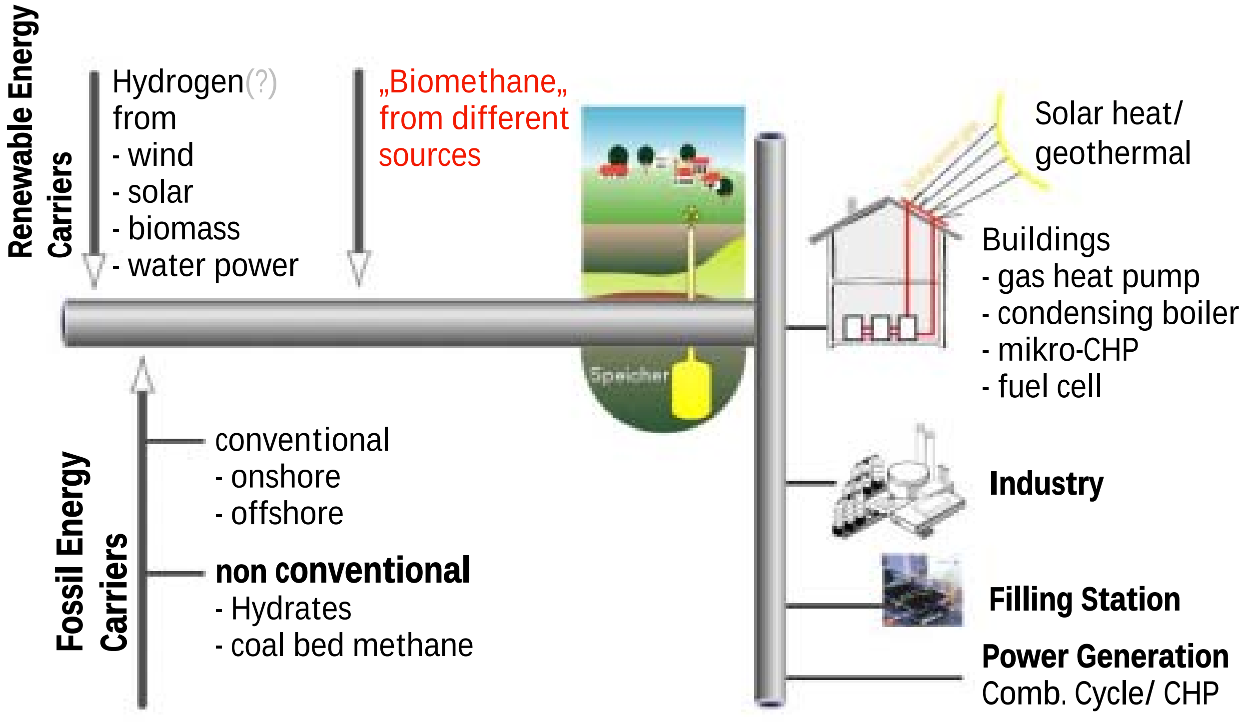
22nd/23rd October 2010, Stockholm
Alexander Vogel, E.ON Ruhrgas AG

The Role of Biomethane in Future Low Carbon Cities?

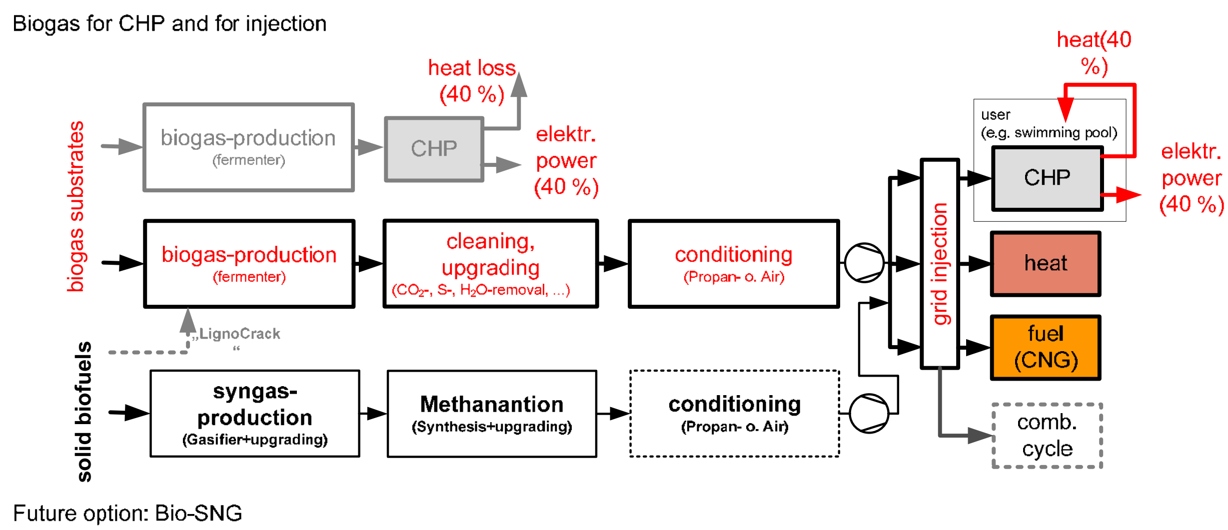
Content

1. Biomethane in Today´s and Future Energy System
2. Perspectives of Biomethane
3. Biogas & Bio-SNG Injection
4. Preparation of Commercial Bio-SNG-Projects
5. Summary

Biomethane in Today´s and Future Energy System – A real Vision



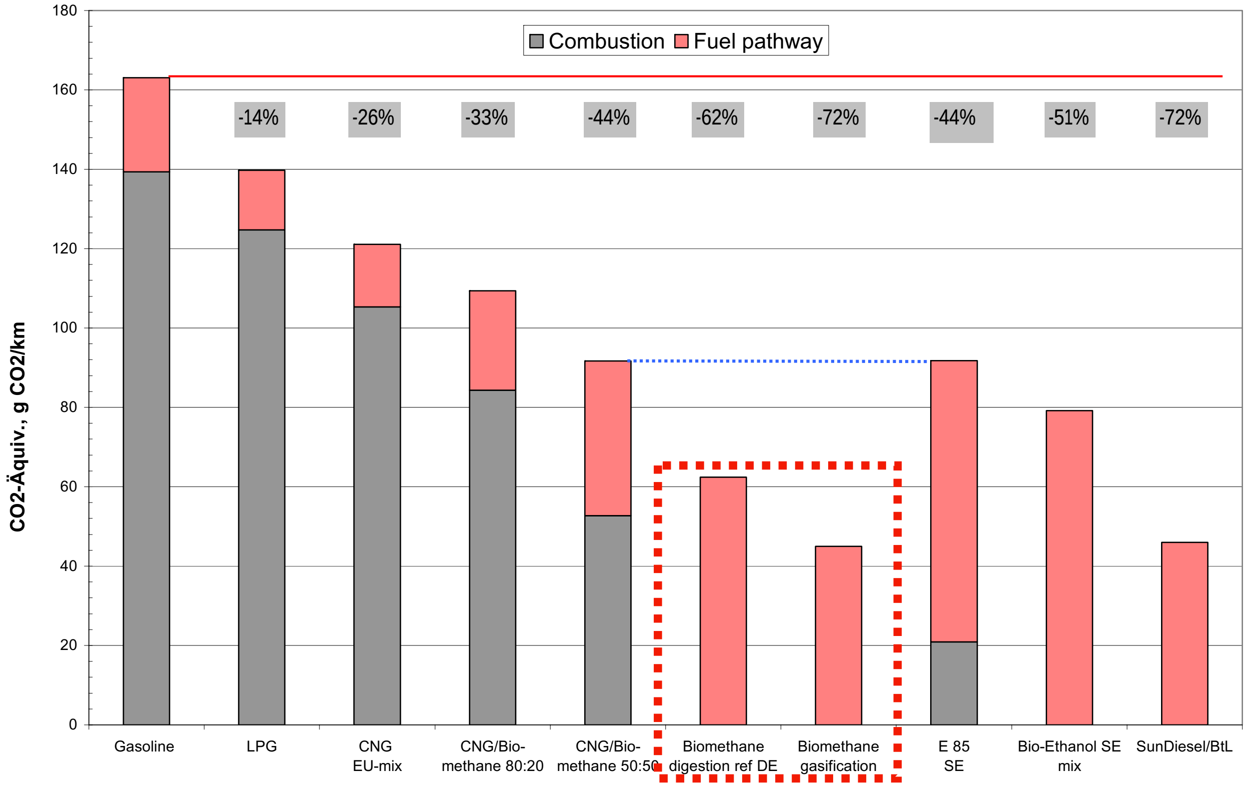
Biomethane in Today´s and Future Energy System – Chains



E.ON´s Targets

- Participate in production of biomethane from anaerobic digestion
- Control upgrading and injection into the gas grid
- Actively participate in Bio-SNG development

Perspectives of Biomethane – Life Cycle Assessment



Perspectives of Biomethane – Example CNG-Vehicle (I)

Engine 1.4l TSI CNG
Achieves future Euro-5-Norm standard

Power 110 kW / 150 PS
Torque 220 Nm (1.500 – 4.000 U/min)
Speed 210 km/h

Consumption **4,6 kg / 100 km**
CO_2-emission* **119 g / km**

Equipment Instrument panel including
Filling level for gasoline and CNG

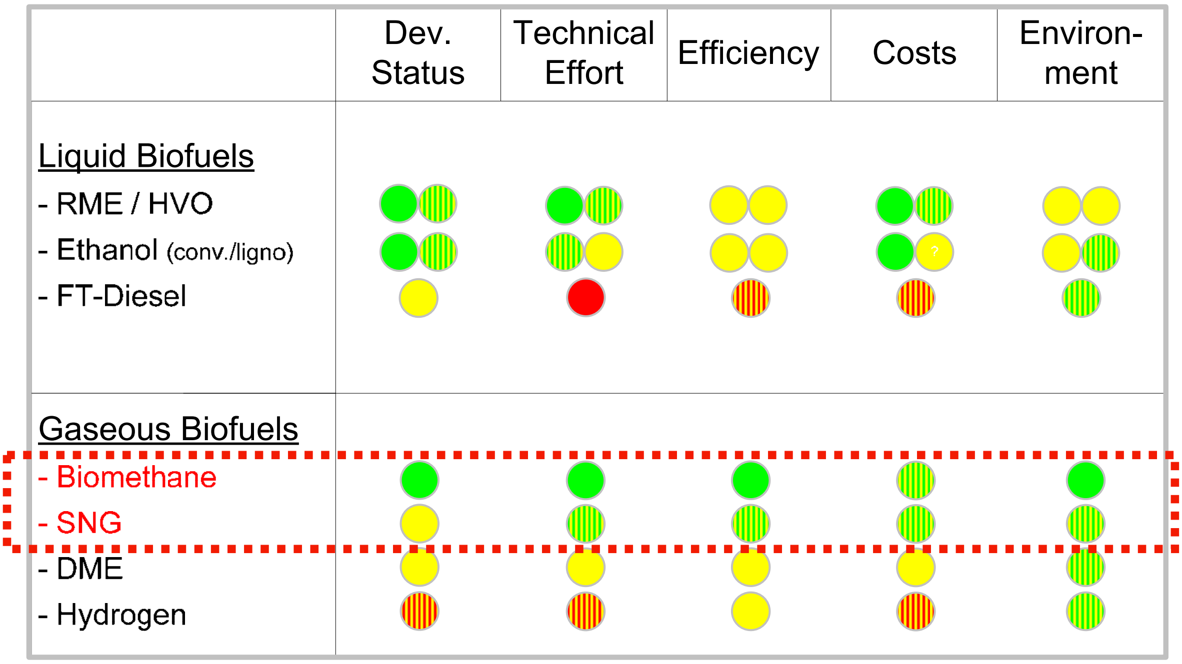
Distance Total ca. 900 km
CNG > 460 km

3-underfloor-bottles, 135 Liter (22 kg)
plastic-gasoline-tank 31 Liter (400 km)

available since January 2009

Source: Volkswagen AG

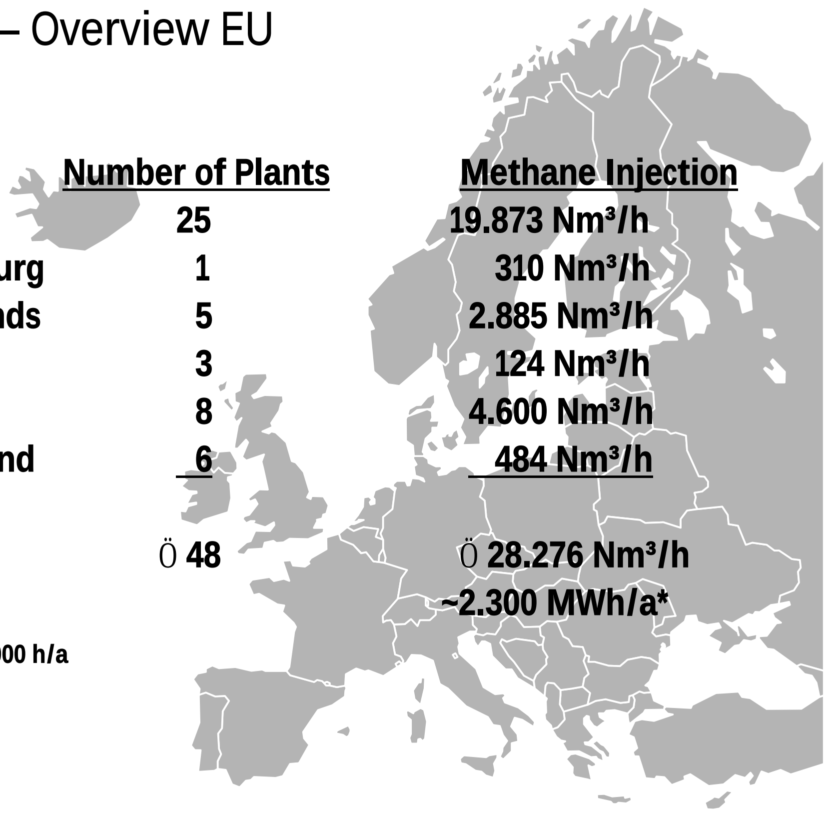
Perspectives of Biomethane – Summary Assessment Biofuels



(… there are further criteria and sub-criteria like e.g. product flexibility or improvement potential)

Source: u.a. DBFZ: CTI Fachkonferenz Biokraftstoff, Mannheim, 2008; KTBL: Gasette, 2008

Status Biogas Injection – Overview EU



	Number of Plants	Methane Injection
Germany	25	19.873 Nm³/h
Luxembourg	1	310 Nm³/h
Netherlands	5	2.885 Nm³/h
Austria	3	124 Nm³/h
Sweden	8	4.600 Nm³/h
Switzerland	6	484 Nm³/h
	Ö 48	Ö 28.276 Nm³/h
		~2.300 MWh/a*

status 10/2009 * 8000 h/a

Source: Dena

Status Biogas Injection – Germany

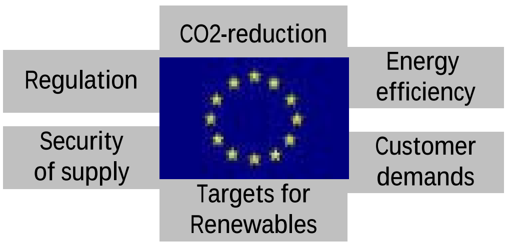
- 25 plants in operation
- 32 plants under construction/ engineering
- 14 E.ON plants

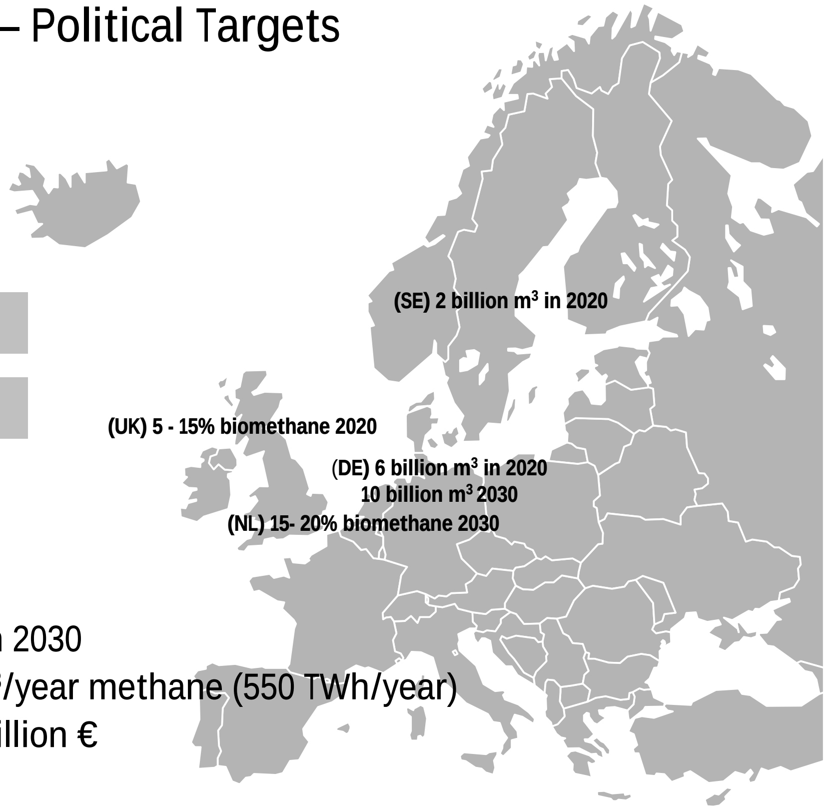
Schwandorf II	1000 Nm³/h	02/2008
Ketzin	200 Nm³/h	04/2008
Hardegsen	550 Nm³/h	02/2009
Könnern	1700 Nm³/h	08/2009
Einbeck	500 Nm³/h	09/2009
Aiterhofen	1000 Nm³/h	10/2009
Merzig	550 Nm³/h	2010
...	750 Nm³/h	2010
...	700 Nm³/h	2010
...	350 Nm³/h	2010
...	350 Nm³/h	2011
...	1000 Nm³/h	2011
...	550 Nm³/h	2011
...		

× 9800 Nm³/h (~78 Mio m³/a)
~ 784 MWh/a*

10/09; * 8000 h/a

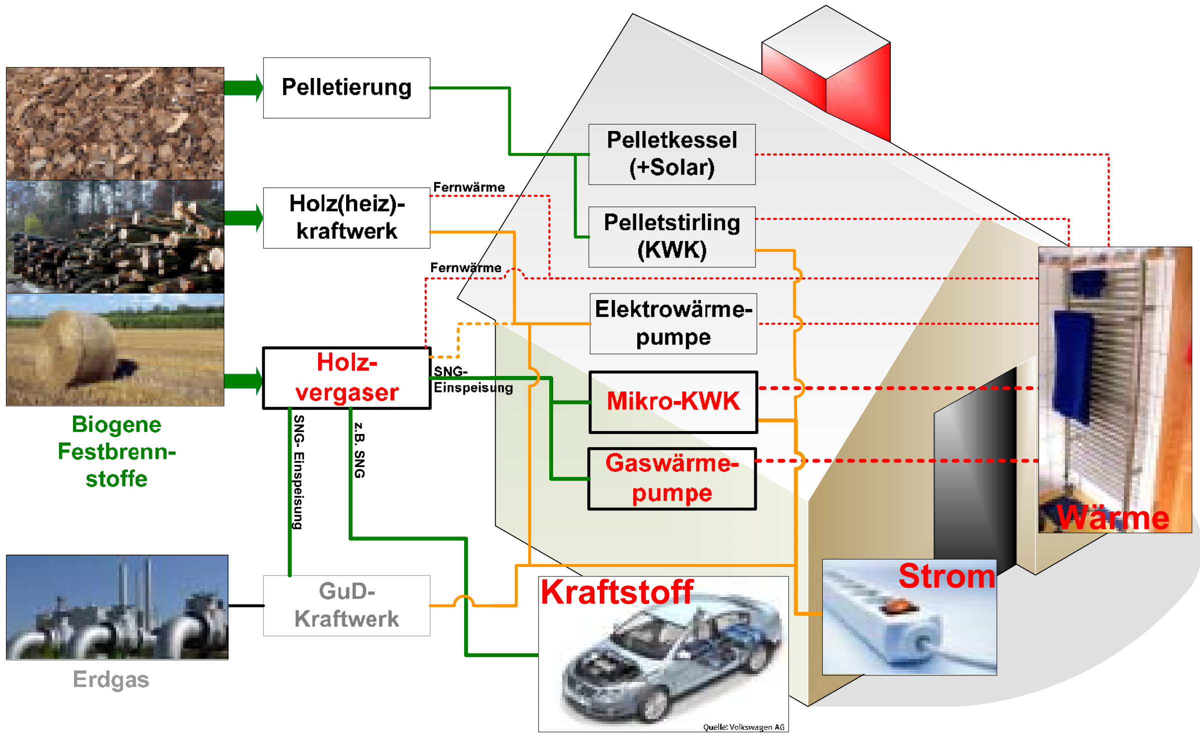
Status Biogas Injection – Political Targets



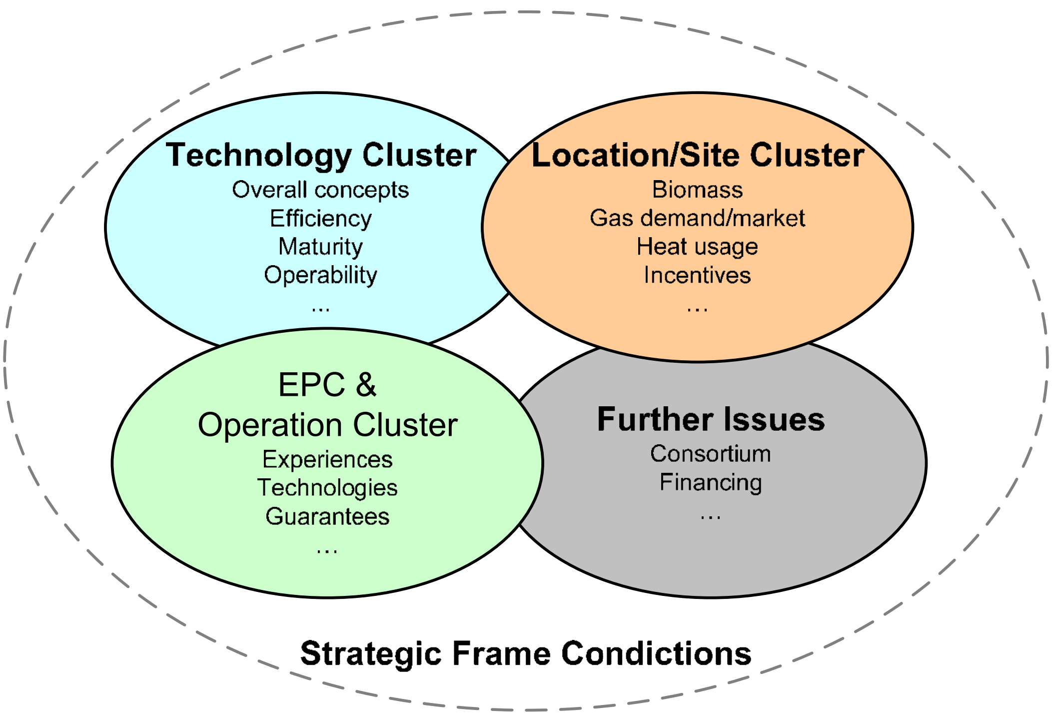


- ~10% renewable methane in 2030
- Corresponds to 55 billion m³/year methane (550 TWh/year)
- investment volume of +60 billion €

Commercial Bio-SNG-Projects – Part of the Future Energy System?



Preparation for Commercial Projects – Strategy on European Context



Preparation of Commercial Projects – Targets on European Context

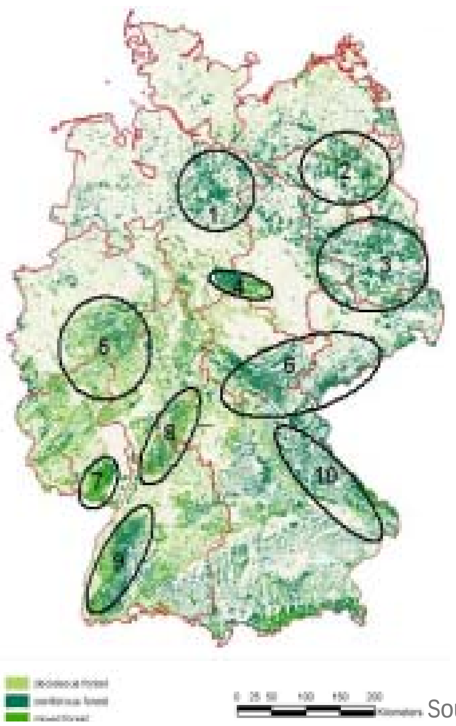
1. System Studies – Selected Targets:

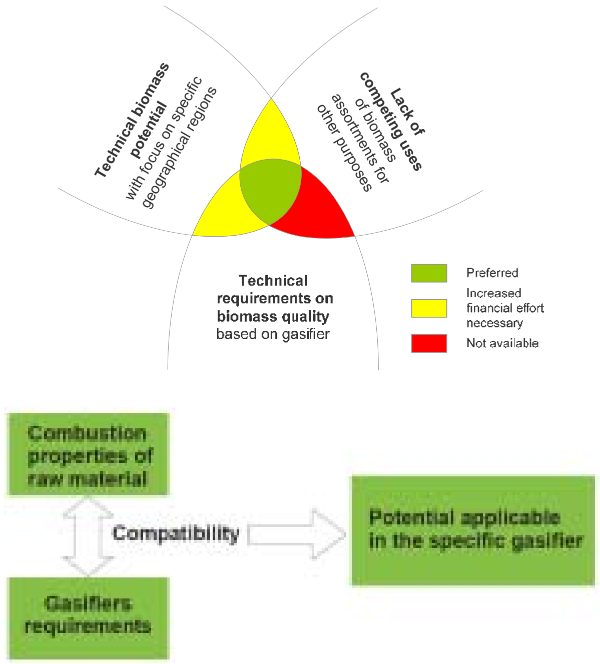
- Market Potential of Bio-SNG – Feedstock & Logistics
- Assessment of Improved Plant Concepts – Convoy Strategy
- Production Side Studies

2. OEM- and EPC-Partner Assessment:

- Technology & Risk Analysis (dev. status/references, upscale, fuel quality demands, competitors, …)
- Project Experience (large projects, gasification, synthesis, …)
- Cooperation and EPC-possibilities

Preparation for Commercial Projects – Potential Analysis

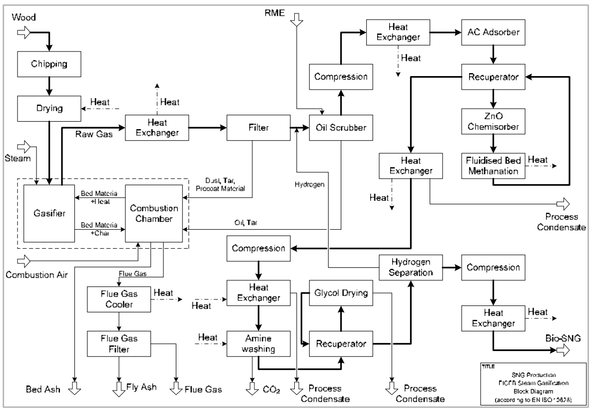


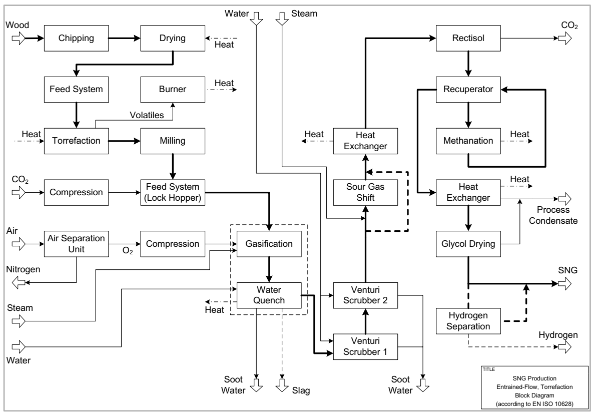


Source: DBFZ

Preparation for Commercial Projects – Technology Analysis

Examples on Process Simulation of "Today's" and Future Chains



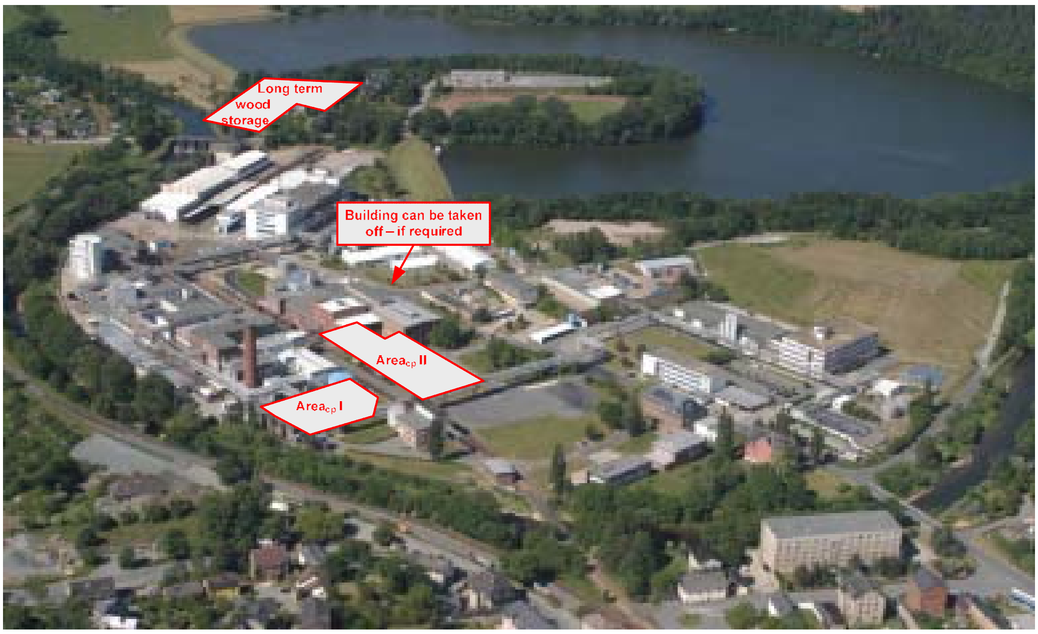


Test and Verification of Selected Plants

- operability assessment
- efficiency assessment
- operation expenses
- …
- waste water analysis

-Gas Composition
-Sulfur compounds and total chlorines
-higher hydrocarbons and polyaromatics
-higher hydrocarbons and polyaromatics
-Alkali and heavy metal
-Non-metal hydrides, metal carbonyls, …

Preparation for Commercial Projects – Example on Site Analysis



Summary

- The production and application of **gaseous biofuels** is **established** (e.g. 4000 biogas plants in Germany). This is also true for biogas upgrading & injection.
- Biogas injection is one of the **most efficient and climate friendly** option (e.g. 50 % greenhouse gas reduction compared to the most climate friendly energy carrier natural gas).
- Thus, a future **increase in the demand of „green gas“ can be expected** from viewpoint of consumer and government's priorities for environmental and energy policy.
- Under the different biomethane options **Bio-SNG** promises an efficient options for **feedstock diversification** and fast and **cost efficient supply of significant amounts of „green gas“**
- Based on the existing know how a fast boosting of demonstration- and semi-**commercial SNG-plants** is **required**; E.ON will be get involved with this process.

Bio-SNG - Strategy and Activities within E.ON

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Strategy and Gasification Activities in Sweden

Henrik Kusar

Energy Technology Department –

Fuel-based Energy Systems & Transport Unit

Swedish Energy Agency

Swedish Energy Agency

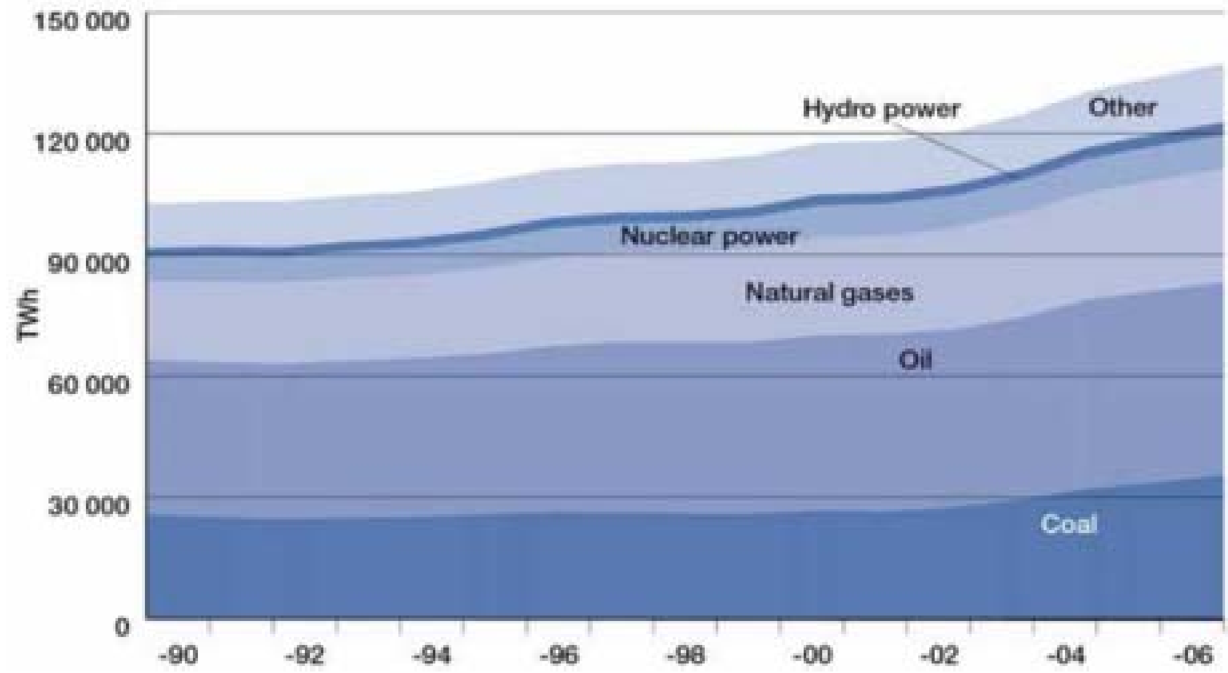
International Seminar on Gasification 22-23 October 2009, Stockholm

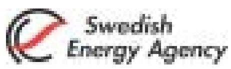
Outline

- Energy use - Global and Sweden
- Vision and Strategy
- Demo-projects
- National Gasification Centre

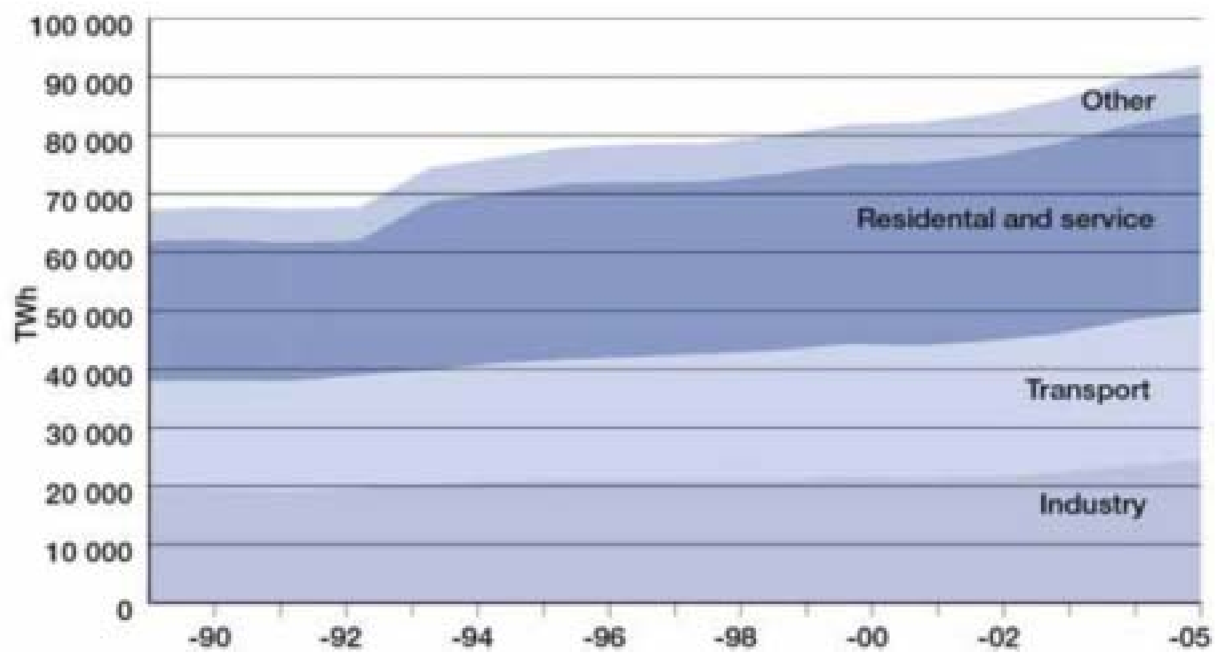
Swedish Energy Agency

Global primary energy supply, 1990-2006

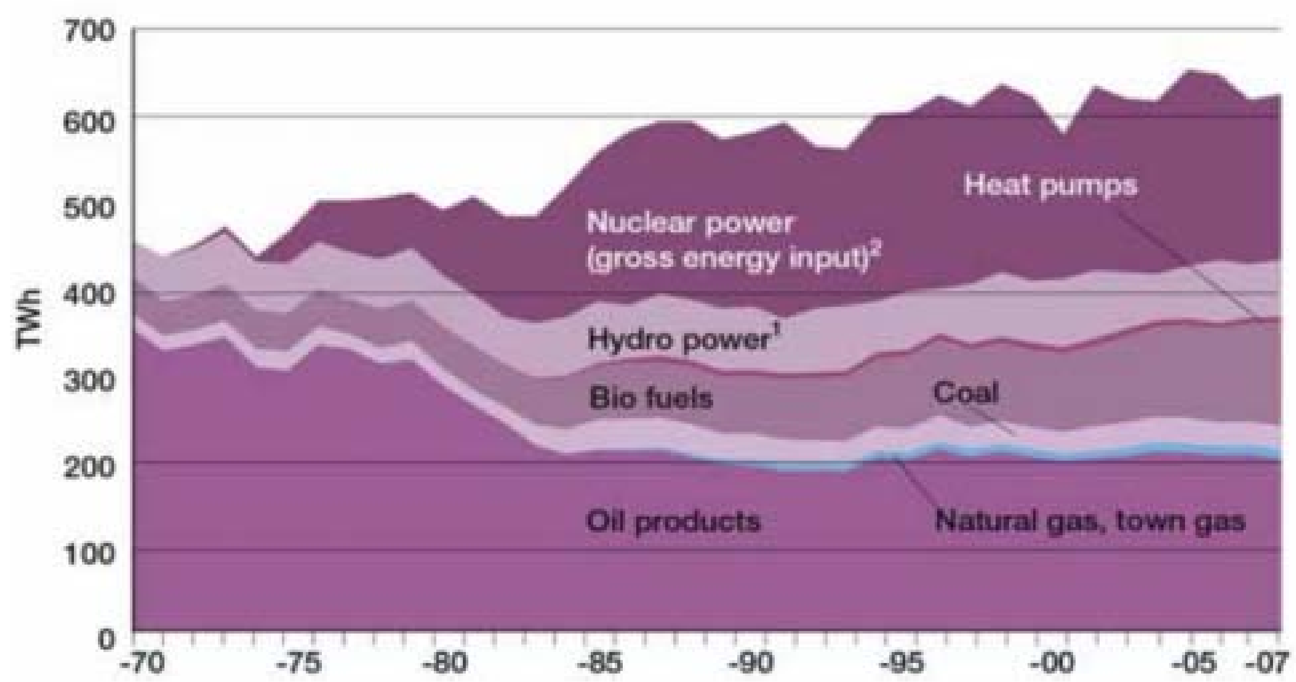




World energy use, by sectors, 1990-2005

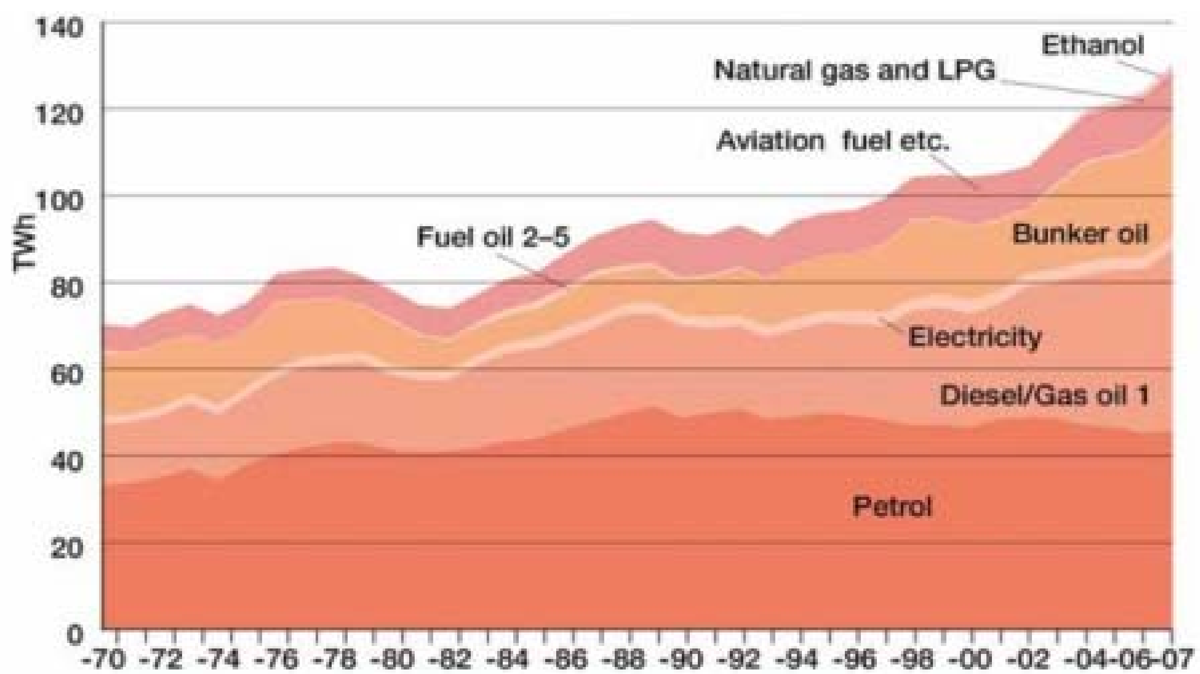


Total energy use in Sweden, 1970-2007, excl. net electricity exports



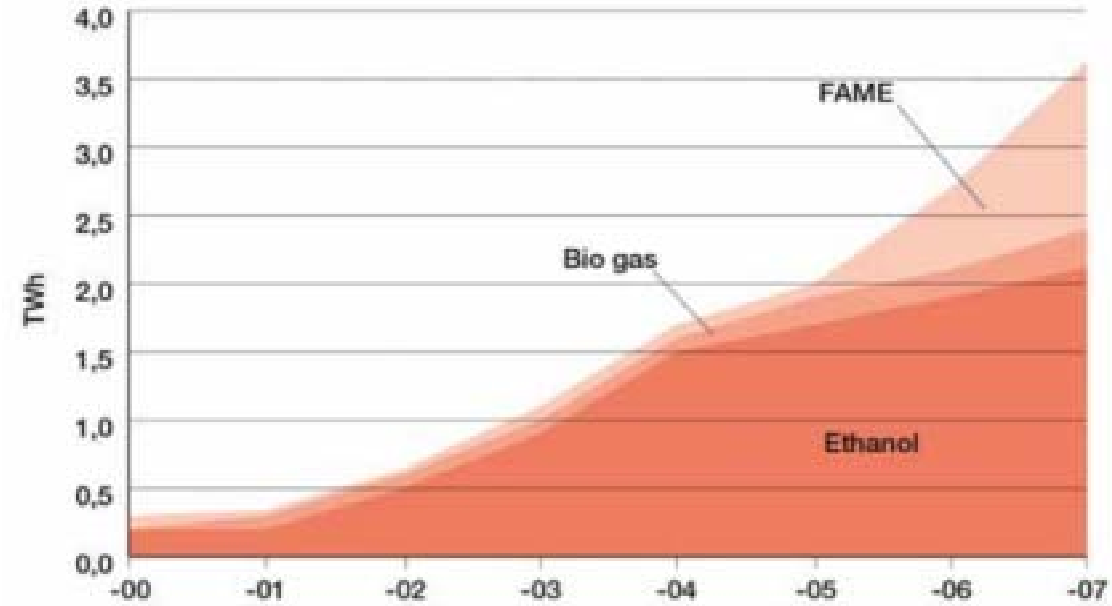
Swedish Energy Agency

Final energy use in the transport sector, 1970-2007, incl. foreign maritime traffic



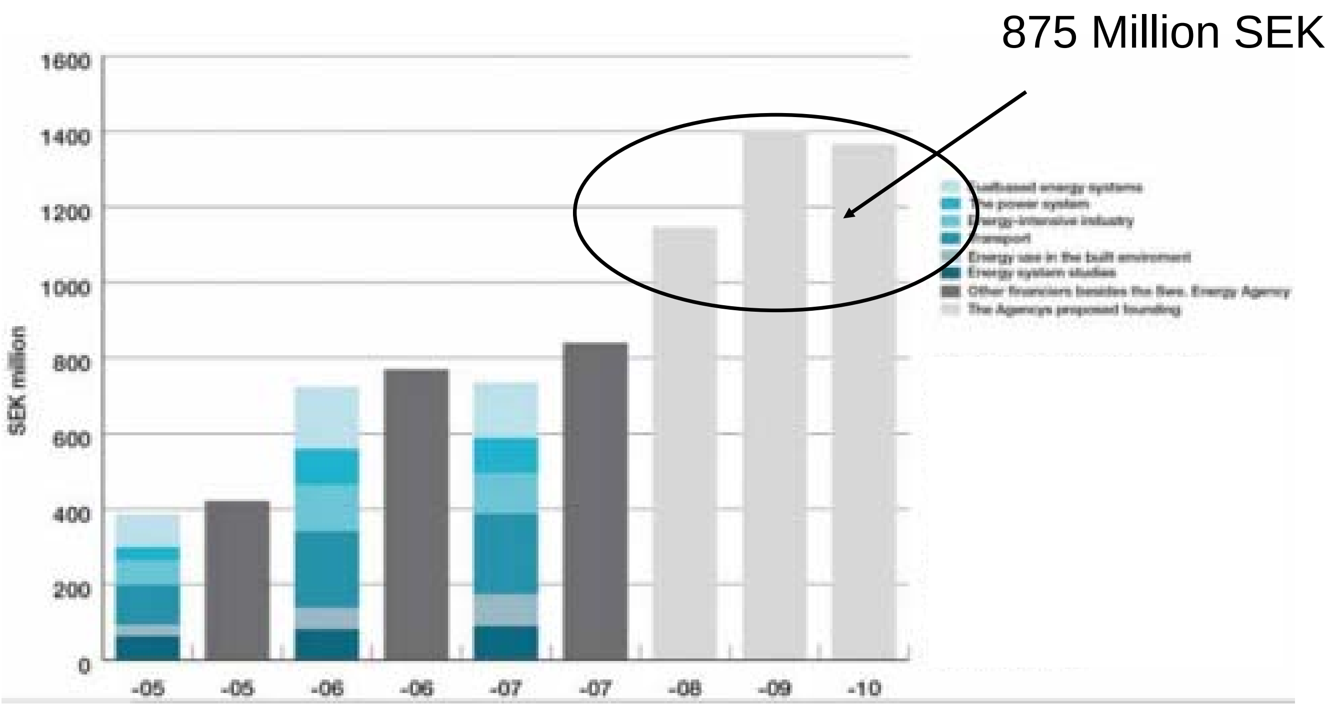
Swedish Energy Agency

Final energy use of renewable motor fuels, 2000-2007



Swedish Energy Agency

Funding for research, development and demonstration activities



Swedish Energy Agency

Vision & Scenario 2050

- Ref. 2008 Ą continuously increased demand of energy for transportation
- Big challenge! To reduce greenhouse gas emissions... with increased transportation (GDP)
- Increased share of non-fossil energy

Ą electricity as an energy carrier desirable

Swedish Energy Agency

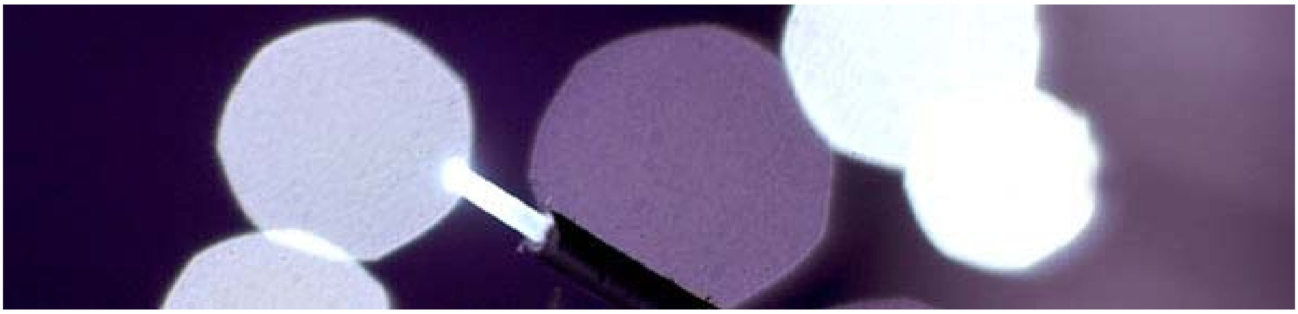
Vision for 2050

- The transport system is sustainable. Availability and mobility is good for everybody and efficient freight transport exists
- The use of energy carriers that are CO2-effcient, and which have a high system efficiency

Swedish Energy Agency

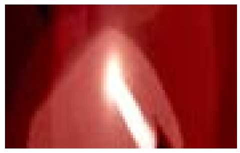
Vision for 2050

- Commercialisation of production technology for carbon dioxide efficient motor fuels
- A successful automotive industry will be producing energy efficient vehicles, and Sweden will have a successful vehicle development industry.



Swedish Energy Agency

The EU's Strategic Energy Technology Plan (SET-Plan)



- In 2007, the European Commission published its proposal "A European Strategic Energy Technology Plan (SET Plan) – Towards a low-carbon future". One key element of the SET Plan involves setting out a long-term energy research, demonstration and innovation agenda for Europe, to guide the research and development of new energy technologies and promote their uptake by the market.

Swedish Energy Agency

SET Plan

- It is important for Swedish energy R&D to take account of the joint European efforts in the SET Plan. Some of the Industrial Initiatives are highly relevant to important parts of Swedish industry. The work is also essential in ensuring fulfilment of EU and national targets for 2020

Swedish Energy Agency

SET Plan

The Set-plan contains a number of European industrial initiatives. The aim of these initiatives is to strengthen industrial research and innovation, and to achieve key objectives in six priority sectors:

- Solar energy
- Wind power
- Bioenergy
- CO_2 capture, transport and storage
- European electricity grid
- Sustainable nuclear fission

Swedish Energy Agency

Targets 2020

- EU targets:- 20/20/20 targets
  - Fuel Quality Directive
  - Energy efficiency of new cars(130g CO_2/km)
- Energy carriers from ligno-cellulosic or priority biomass. Replacing diesel!

Swedish Energy Agency

Targets 2020

- Energy carriers sustainably produced with minimized impact on health
- In 2020, the processes have to be ready for commercial introduction or have received commercial breakthrough!

Swedish Energy Agency

EU's Energy Package
- Towards 2020

- Reduce CO_2 emissions by 20 %
- Save 20 % energy
- Increase share of renewable by 20 %
- Use at least 10 % biofuels in each member state

Swedish Energy Agency

The Fuel Quality Directive

- The 20/20/20 targets is complemented by the Fuel Quality Directive, which requires suppliers of motor fuels in the EU to reduce CO2 emissions, with effect from December 2008, by 6 percent per unit of energy (as seen in a life cycle perspective) from the level in 2010

Swedish Energy Agency

Energy efficiency of new cars

- In addition, there are requirements applicable to the automotive industry, under which the average value of energy efficiency of new cars within the EU must not exceed 130 g CO_2/km, with effect from 2015. The same proposal sets a preliminary target of reducing this value to 95 g CO_2/km for new private cars with effect from 2020.

Objectives for Research, Development and Demonstration for 2020

- Sweden has at least one internationally recognized and successful research environment in the area of system-efficient fuels
- Increased production of biogas.
- The construction of at least one demonstration plant for efficient conversion to biofuels
- Full-chain demonstration, including a fleet of customized vehicles, combined with a bio-fuel with high system efficiency.

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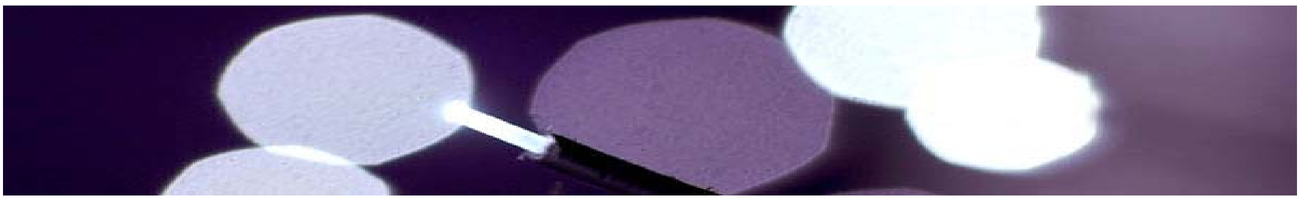
Priority areas

- Since environmental and energy supply considerations are one of the two greatest challenges for the transport sector, priority is given to achieve more ***energy efficient vehicles*** and ***renewable energy for replacement of fossil motor fuels***.

Swedish Energy Agency

Priorities - for the production of bio-based motor fuels

- Aim to achieve substantial reductions in green house gas emissions from an overall system perspective, and equally low emissions of other regulated emissions
- Have high system efficiency and a potential for large scale introduction and use, and which can also generate export revenues



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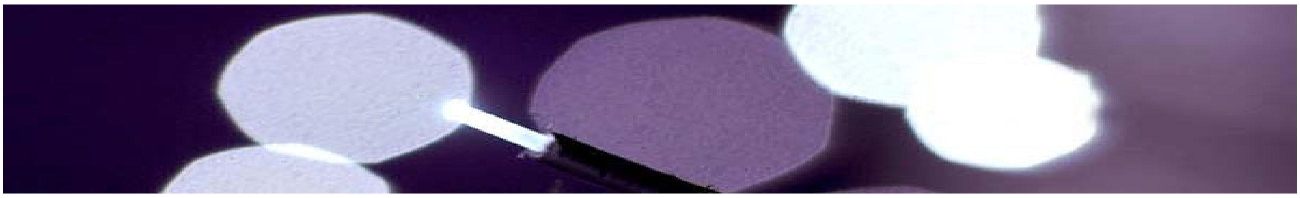
Priorities - for the production of bio-based motor fuels

- Have a potential for achieving production costs equivalent to, or less than, the price of fossil fuels



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Renewable motor fuels or energy carriers are particularly interesting if they:

- Are suitable for use in the existing infrastructure
- Can be integrated with existing motor fuels and replace diesel.
- Have synergy effects with other important export industries, e.g. the manufacture of pulp and paper.

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For vehicle related projects, priority is being given to:

- Energy efficiency of vehicles and energy converters.
- Reduction of climate gases, primarily through reduced CO_2/km emissions.

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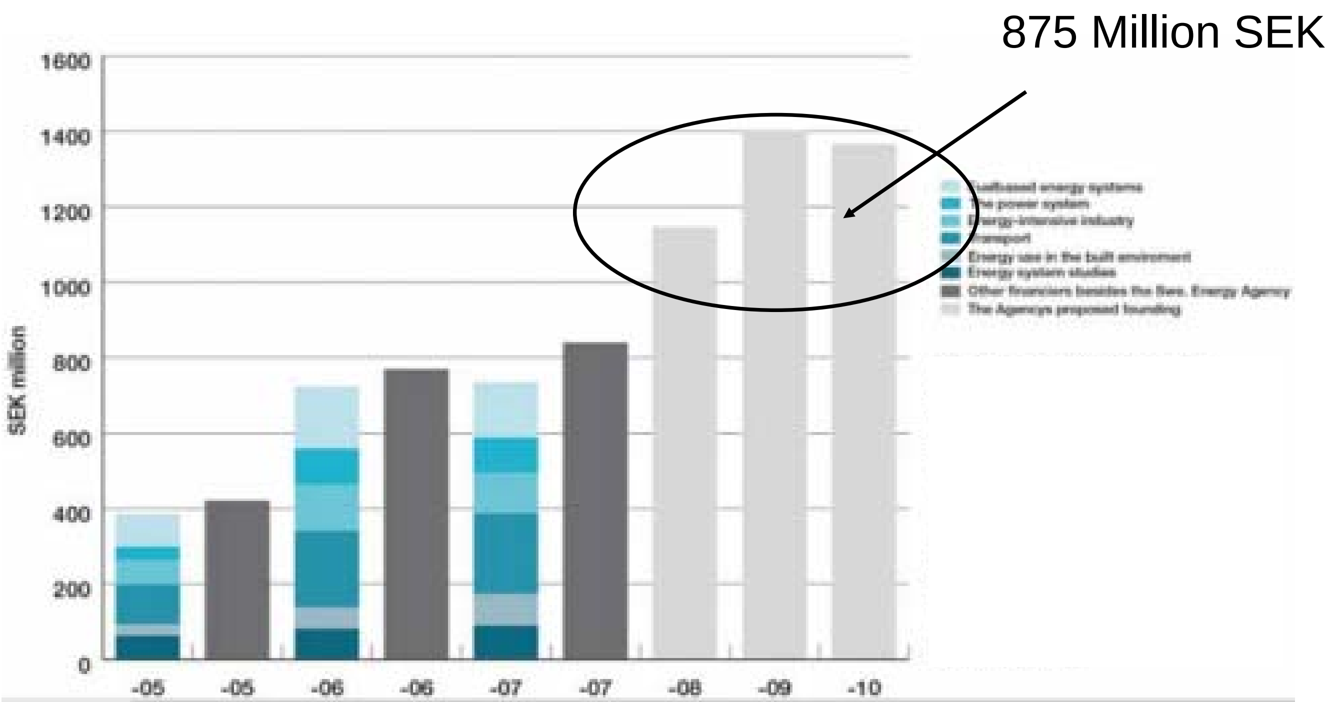
Funding for research, development and demonstration activities



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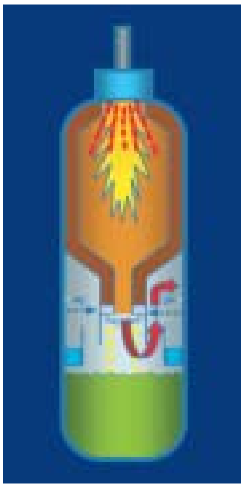
Chemrec AB

- The project concerns the production of biofuels from black liquor in an establishment in Domsjö, Örnsköldsvik. Awarded aid: up to 500 million SEK.



DP2 Chemrec

Swedish Energy Agency

Göteborg Energi AB

- Gobigas - build and operate a plant for converting low-quality wood raw material into high quality fuel – bio-methane. Awarded aid: up to 222 million SEK

GoBiGas

Swedish Energy Agency

Värnamo

- A demonstration plant for the gasification of biomass
- The gasifier and gasification technology are still of interest for the production of synthesis gas for the production of bio-based motor fuels.

Värnamo

Swedish Energy Agency

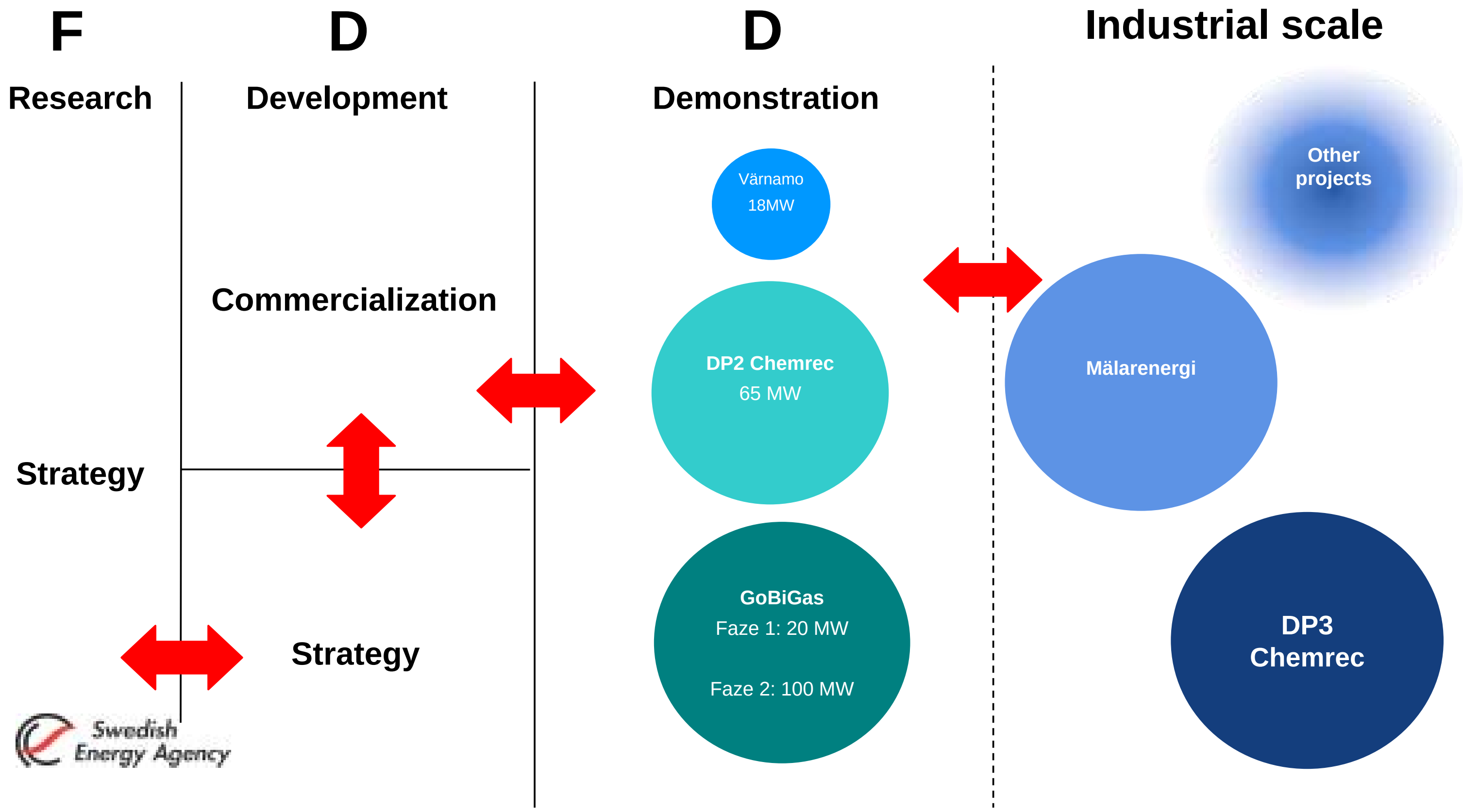
Discussion and plans for a NCG

National Centre for Gasification

NCG

Swedish Energy Agency

Background

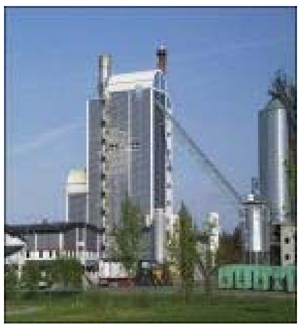


National Centre for Gasification

- Big investments for demonstration of gasification technologies are in progress/ planned in Sweden, Ą creates a need for a national gasification centre
- Research – Development - Competence

DP2 Chemrec

GoBiGas



Värnamo

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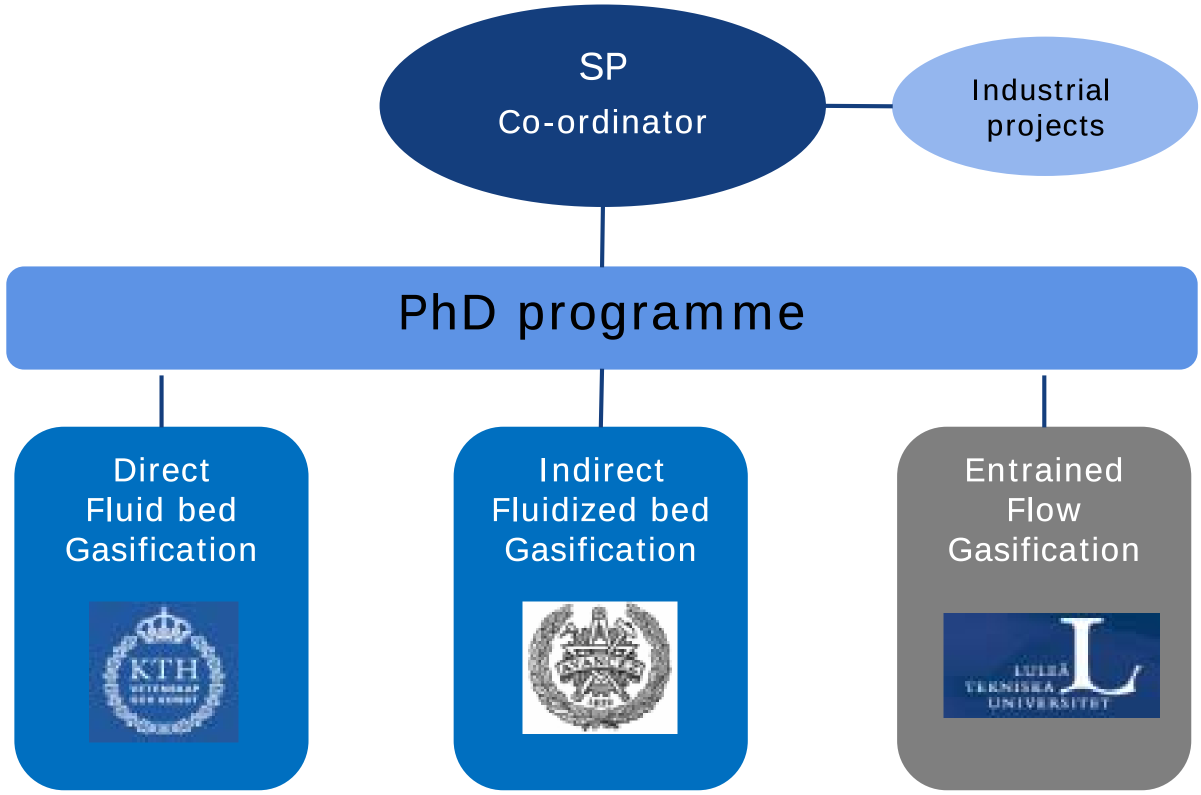
Organization - plans



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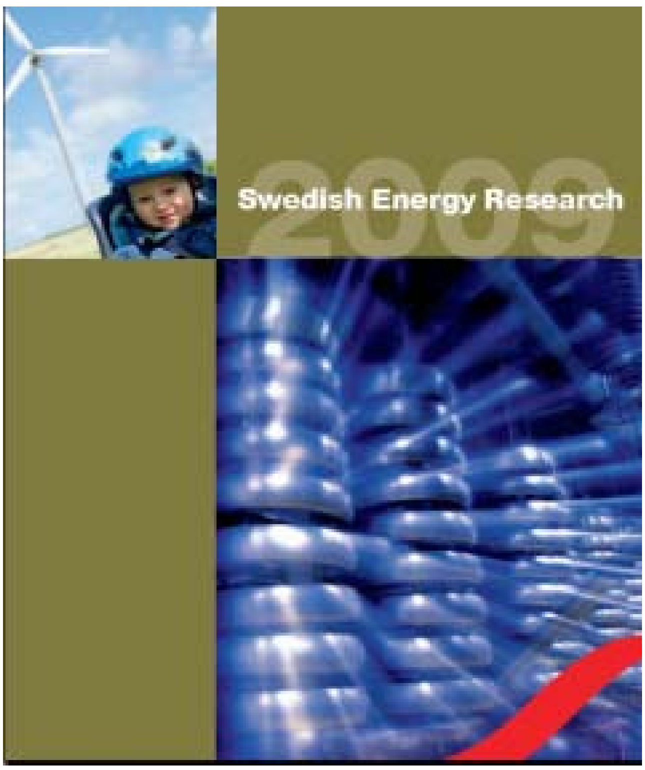
Other Universities participate as associated

Thank you!



Swedish Energy Agency

20 TWh/year biomethane 2020

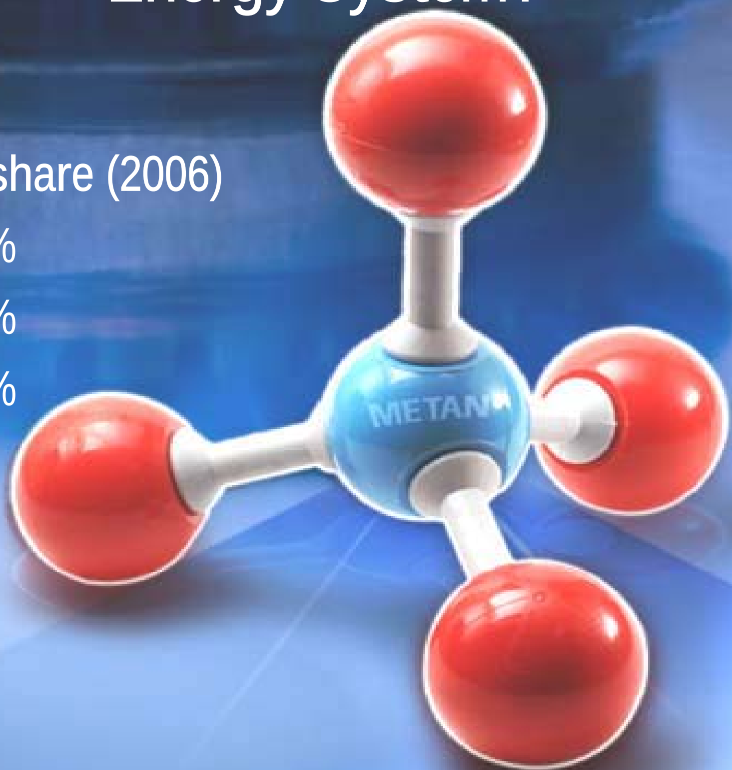
Michelle Ekman
Swedish Gas Association

GASFÖRENINGEN
SWEDISH GAS ASSOCIATION

Can Biomethane have an Impact for the Future Energy System?

Renewable energy share (2006)

- Global 12%
- EU 7%
- Sweden 43%

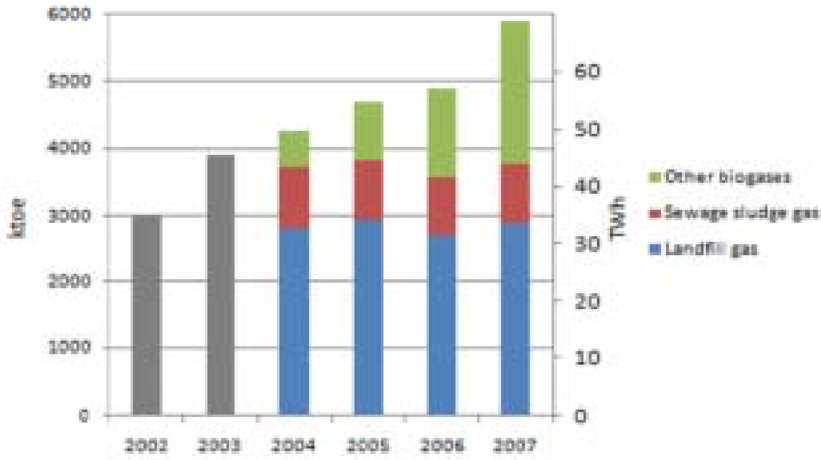


Can Biomethane have an Impact for the Future Energy System?

Biomethane share (2006)

- Global ?
- EU 0,32%
- Sweden 0,35%

Time to give up?



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There is a potential ...

... and the journey has just started

Cities

Sludge
Household waste
Industry org waste
Landfill

Agriculture

Manure
Rest-products
Energy crops

Forest

Residues from
forest & industry

The greatest potential of all biofuels!

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From waste to first-rate Energy

Swedish examples (potential):

Waste, digestion	15TWh	4%
Residues from forest, gasification	60 TWh	15%
	75 TWh	19%

40TWh is a realistic level

- 10% of all energy usage in Sweden
- 50% of the fuel consumption for the transport sector

Today: 1.5 TWh 2008

Goal 1: 3 TWh 2013

Goal 2: 20 TWh 2020

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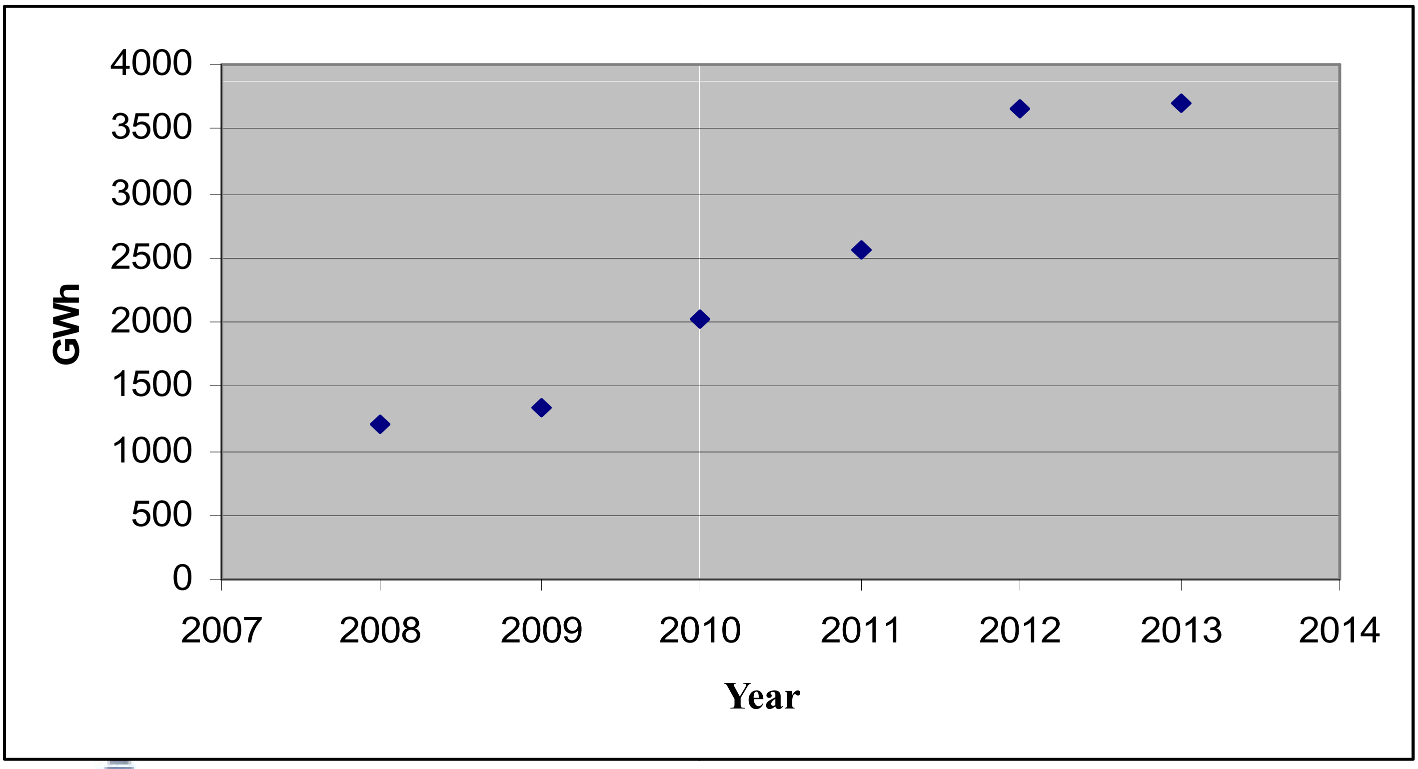
Prognosis for biogas production



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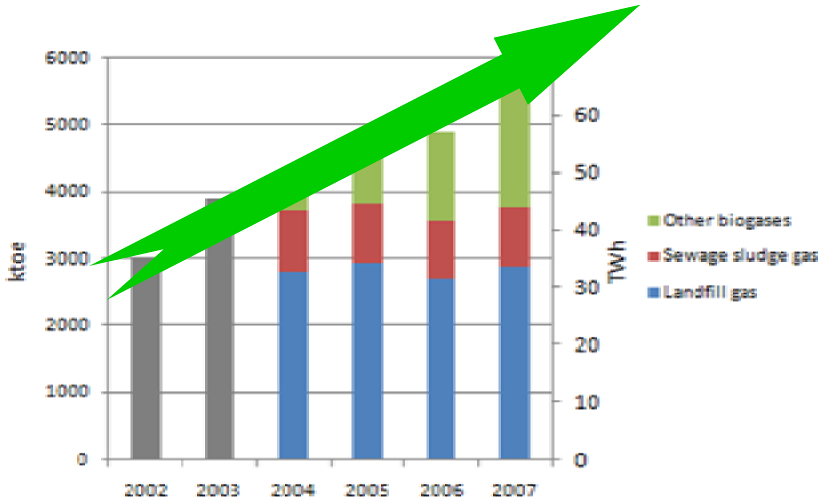
Strong development!

- New substrate, e.g. straw
- Make the digestion more efficient
- LBG opens new Markets
  - lower haulage cost
  - trucks, dual-fuel
  - ship
- Increased volume through Gasification



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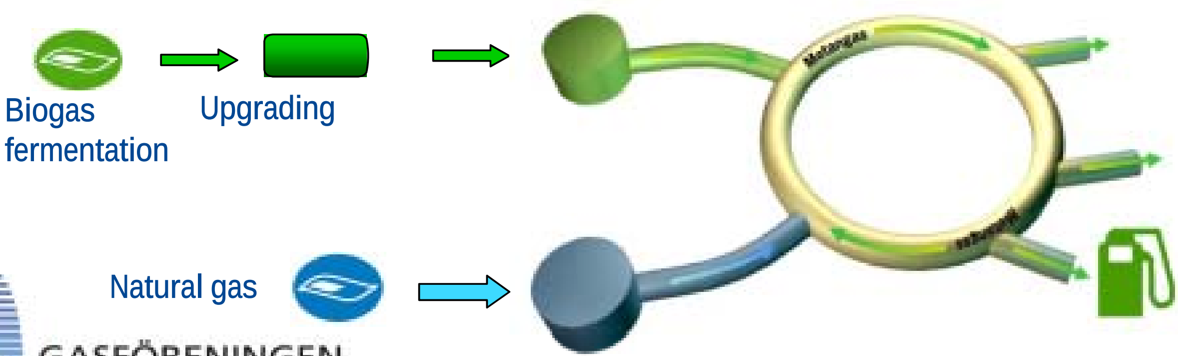
Coordination of infrastructure and synergies biogas - natural gas - hydrogen gas

- Biogas can be distributed through existing natural gas grid
  - Low distribution costs
  - New customers can be reached
  - Continuous sale
- Biomass gasification can increase share of renewable gas in the grid
- Hydrogen gas can theoretically be added to the grid



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Biomethane + Natural gas = True

BioMethane can benefit from investements taken by Natural Gas

City

injection site

Gas grid

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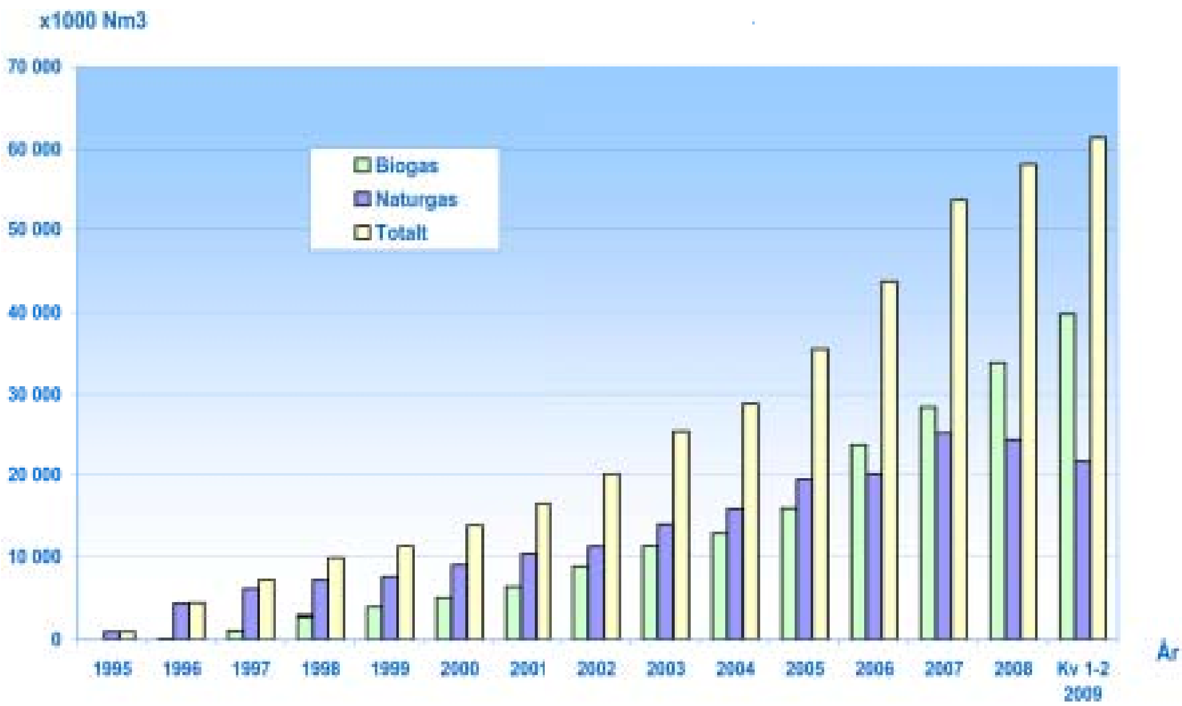
Volume methane for vehicles



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Thank you!
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