

Novel ultra-clean gas concepts of biomass gasification for liquid fuels

by

Esa Kurkela & Pat McKeough

- UltraCleanGas R&D project at VTT
- First generation bio-syngas production in 1980's
- Fuel flexible fluidised-bed gasification
- Catalytic tar and hydrocarbon reforming
- Concept development and studies
- Demonstration and commercialisation plans

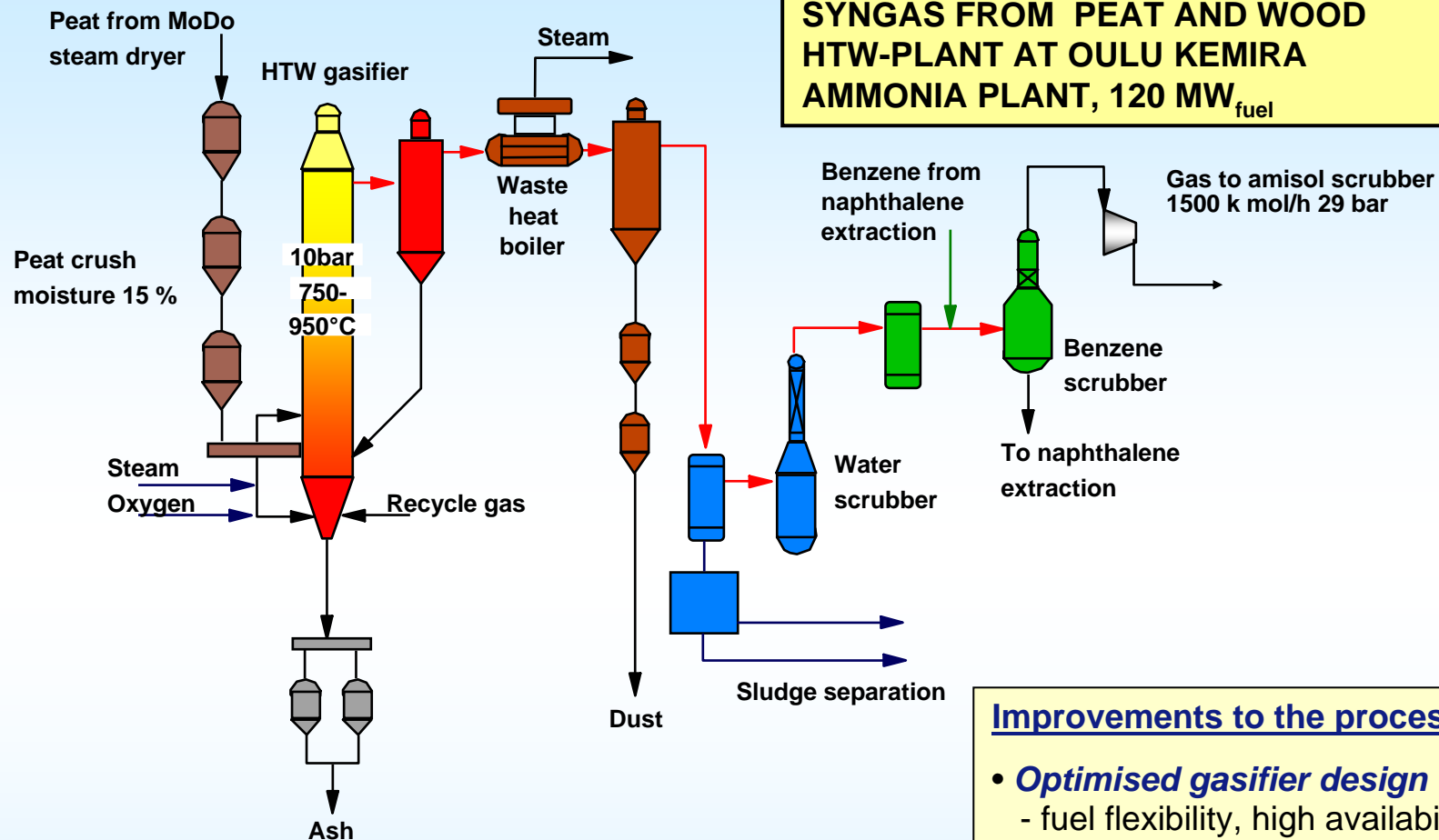
SYNBIOS: Second Generation Automotive Biofuel Conference

18-20 May 2005, Stockholm

UCG-PROJECT AT VTT

Production of Synthesis Gas and UltraClean Fuel Gas from biomass, peat and wastes (2004 – 06)

- optimised fluidised-bed gasification process
- optimised gas reforming, dirty shift and ultra cleanup
- liquid biofuel concepts integrated to pulp and paper industries
- resources: 4 M€, tests at 500 kW Process Development Plant
- design basis for industrial demonstration plant
- partners:
 - VTT and TKK: gasification and gas cleaning R&D
 - Foster Wheeler Energia Oy: CFB gasifier know-how
 - NESTE Oil: flash-pyrolysis and liquid fuel know-how
 - Andritz Oy: equipment of pulp and paper industries
 - Vapo Oy: biomass company
 - Tekes: main financier



Pressurised steam/O₂-blown gasifier

- Technology was successfully demonstrated in late 1980's (Oulu, Berrenrath)
- Single gasifier train 150-300 MW feasible
- 1st generation process can be realised immediately if needed

Improvements to the process:

- **Optimised gasifier design**
 - fuel flexibility, high availability
- **Reforming of hydrocarbons**
 - high syngas yield
 - optimal H₂/CO ratio
 - conventional final gas cleaning unit operations can be applied
- **Advanced gas filtration, gas cooler design and ash oxidation**

Fuel-Flexible Fluidised-Bed gasification

Required feedstock basis

- different wood residues
- straw, other agricultural residues
- energy crops and short rotation wood
- MSW and other solid waste streams

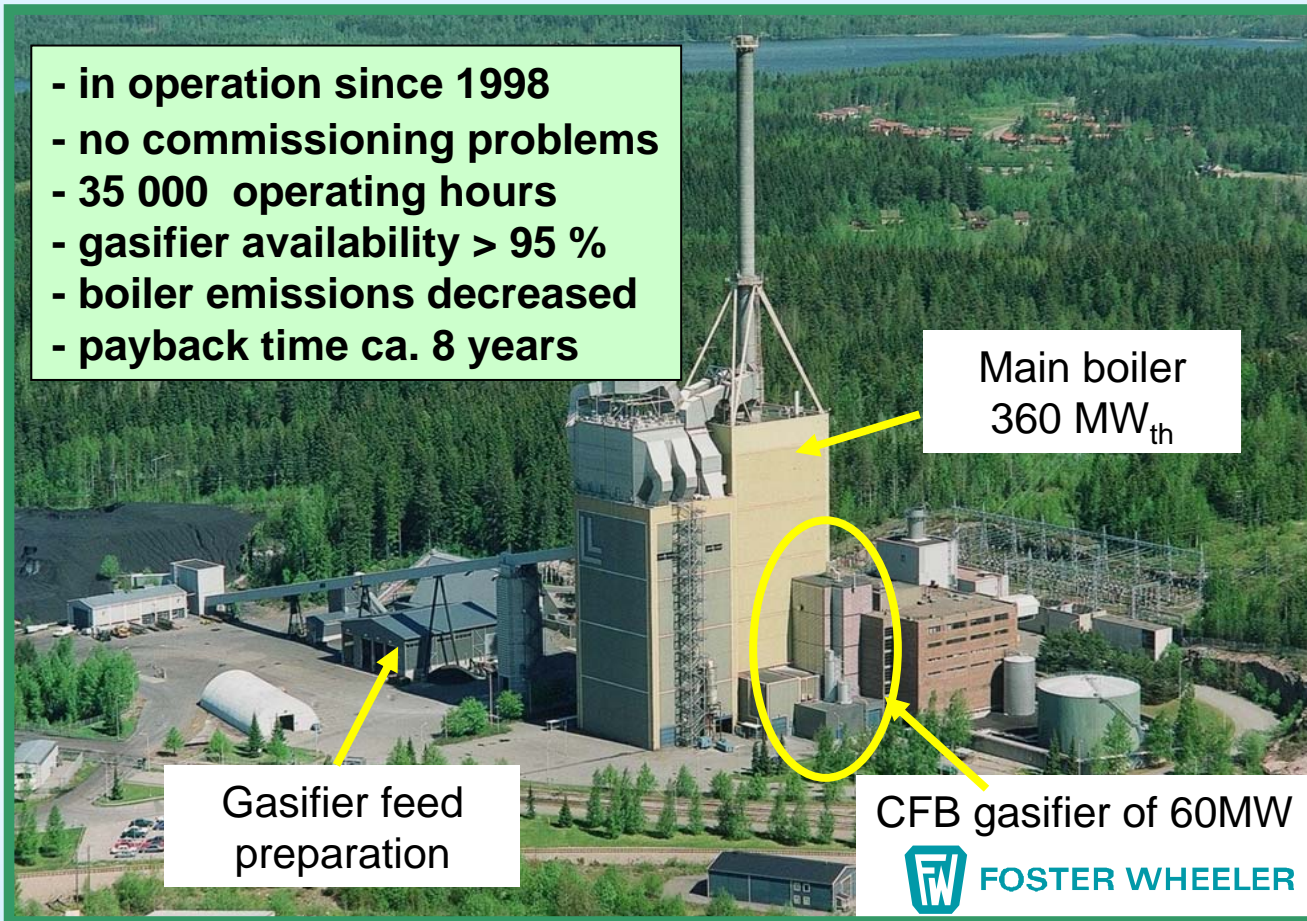
Industrial-scale experinces

- pressurised gasification and filtration for IGCC; two processes were developed in 1990's
- wood & waste gasification in Lahti since 1998
- gasification of aluminium-containing plastics in Varkaus since 2001



Fuel-Flexible Fluidised-Bed gasification

- in operation since 1998
- no commissioning problems
- 35 000 operating hours
- gasifier availability > 95 %
- boiler emissions decreased
- payback time ca. 8 years



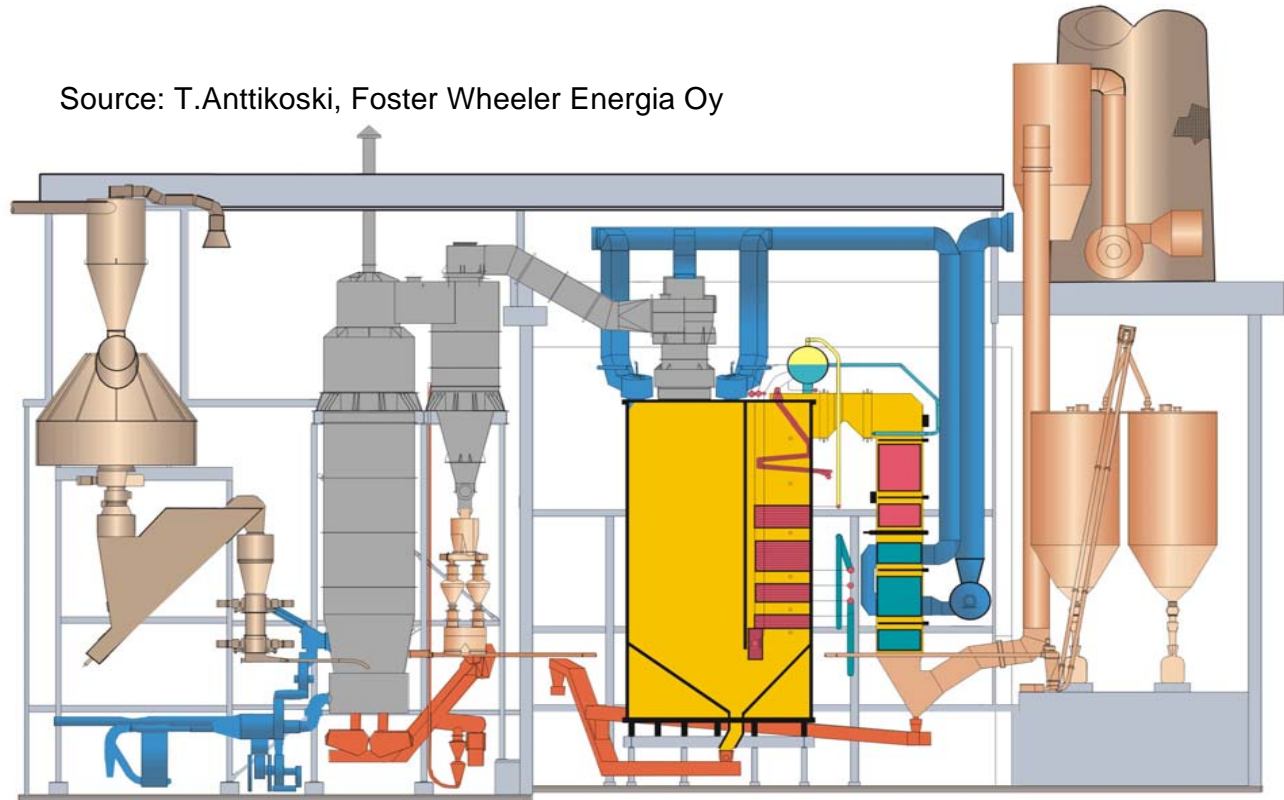
Fuel Flexible Fluidised-Bed gasification

- at a recycling plant for multi-material packaging
- 50 MW of fuel gas to boiler, 2100 t/year aluminium to re-use
- in operation since autumn 2001

Plastic reject material
with 10 % aluminium



Source: T.Anttikoski, Foster Wheeler Energia Oy



Fuel Flexible Fluidised-Bed gasification

Recent pilot-scale developments

- straw gasification process, 1997-99
 - alkali control
 - gas filtration at 300-600 °C
- clean gas process for waste 1999-2003
 - feeding and gasification
 - filtration and HCl removal
- gasification of sewage sludge, autoshredder residues and other waste materials 2002->

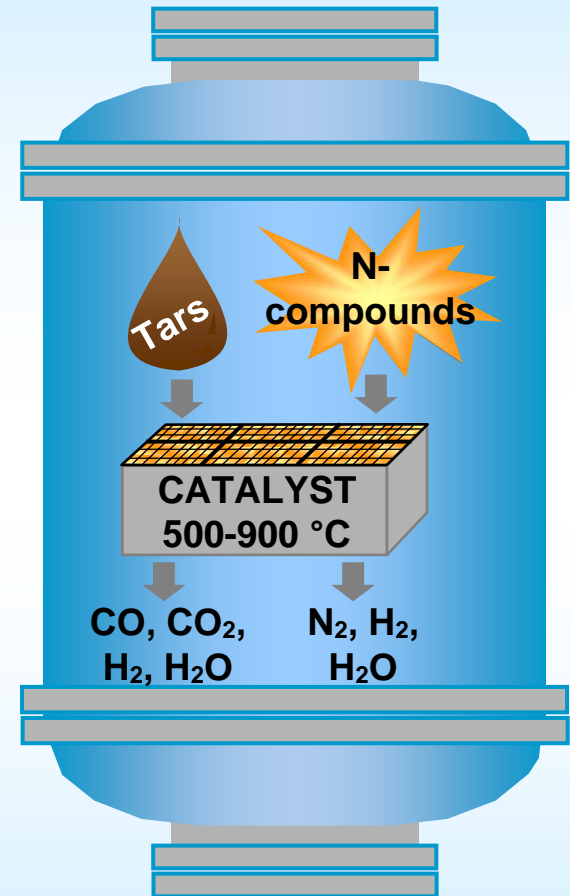
Modelling and testing of syngas production alternatives

- steam gasification with indirect heating
- steam/O₂ gasification tests
- FW Pilot tests with O₂ enriched air
- selection of gasification pressure
- design basis of the UCG-PDU



Catalytic gas treatment: recent developments at VTT

- 1) Tar decomposition with nickel monolith
 - R&D at VTT since mid 1990's
 - MW-scale demonstration at Kokemäki and Skive gas engine plants 2005-06
- 2) Tar decomposition by zirconia-based catalysts – R&D since 2000
- 3) Selective oxidation of ammonia since 1990's
- 4) Proprietary catalytic system for methane reforming and dirty shift conversion
- 5) Catalytic reforming of natural gas and light fuel oil for SOFC, 2004
- 6) Catalytic after burner for SOFC, 2005

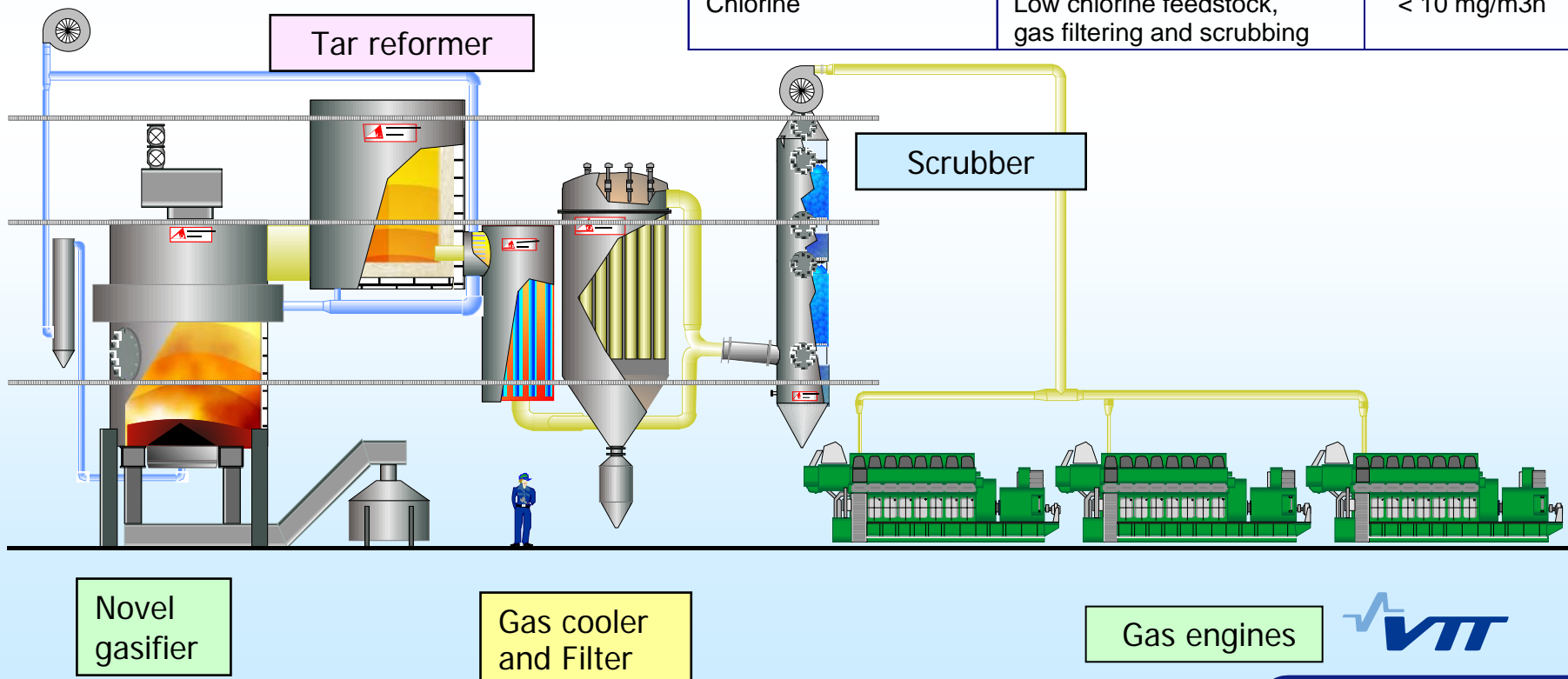


Design basis for multifunctional catalytic cleanup process for the UCG-PDU plant

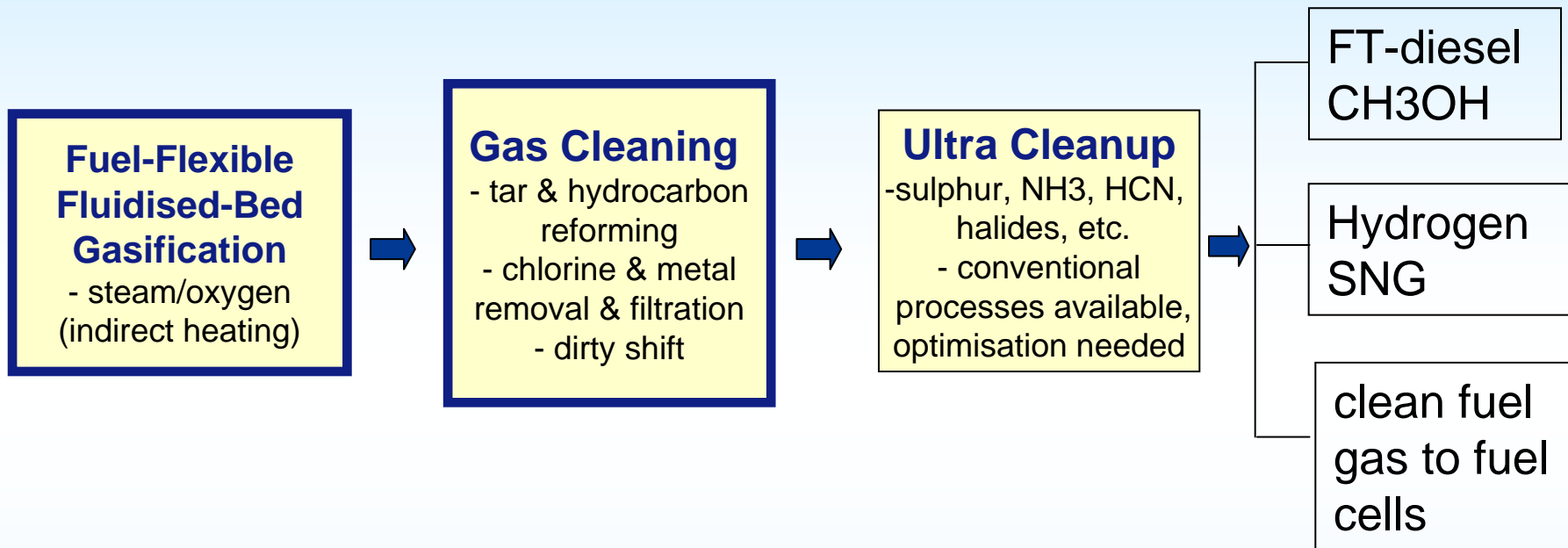
Novel power plant: 1.8 MWe + 3.3 MW heat

- Kokemäki, Finland
- plant under construction
- total investment 4.5 M€
- electric efficiency 30 %

Impurity	Control method	Content and removal efficiency
Particulates	Bag filters	< 10 mg/m ³ n (> 99 %)
Tars	Catalytic reformer	< 100 mg/m ³ n (> 95 %)
Nitrogen compounds (NH ₃ ja HCN)	Catalytic reformer and gas scrubbing	< 10 mg/m ³ n (> 95-99 %)
Sulfur	Low sulfur feedstock and gas scrubbing	< 10 mg/m ³ n
Chlorine	Low chlorine feedstock, gas filtering and scrubbing	< 10 mg/m ³ n



UCG-process development unit at VTT



Gasifier targets:

- no ash-related problems
- simple design and high reliability
- high C-conversion to gas + tars
- no need for tar decomposition
- low oxygen consumption

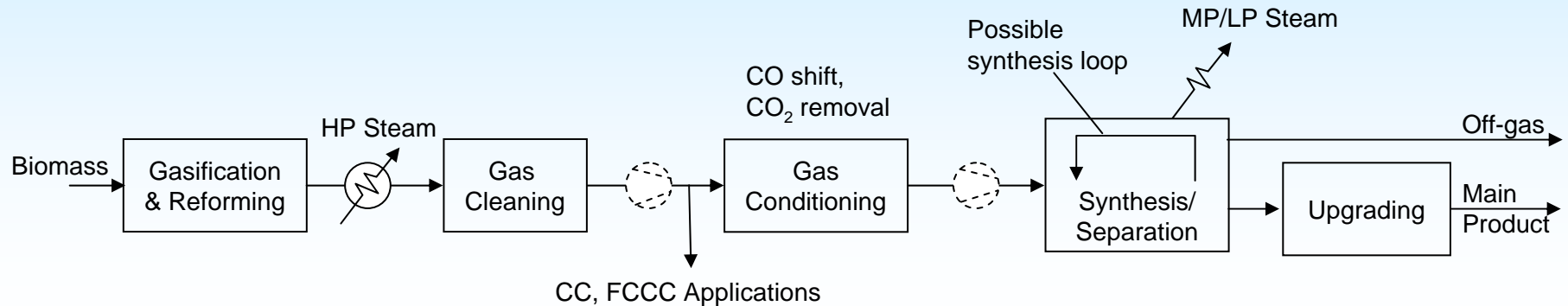
Gas cleaning targets:

- complete tar and benzene decomposition
- over 95 % methane reforming
- H₂/CO ratio suitable to FT-synthesis
- reliable operation
- minimum overall gas cleanup train costs

System studies to guide the R&D work

- ◆ Preliminary evaluation of the conversion efficiencies and costs of different process alternatives (2004)
- ◆ Studies on the effects of gasifier & reformer design (2004-05)
 - operation pressure
 - indirect steam gasification vs. steam/oxygen operation
 - reformer and dirty shift performance
 - arrangement of gas cooling, filtration and reforming
- ◆ Studies on final gas cleaning (2004-05)
- ◆ Detailed gasification process design, optimisation and cost estimation (2005-06)
- ◆ Detailed process design and costs of a mature 300 MW plant and the first demonstration plant (2005-06)

Basic Layout of Processes for Biosyngas Production and Conversion



1 – 30 bar

1 – 30 bar

30 bar

FT, SNG, H₂: 20 – 30 bar
 CH₃OH, DME: 100 bar

850 °C

40 - 280 °C (final)
 (IGCC: 500 °C)

40 - 350 °C
 (initial)

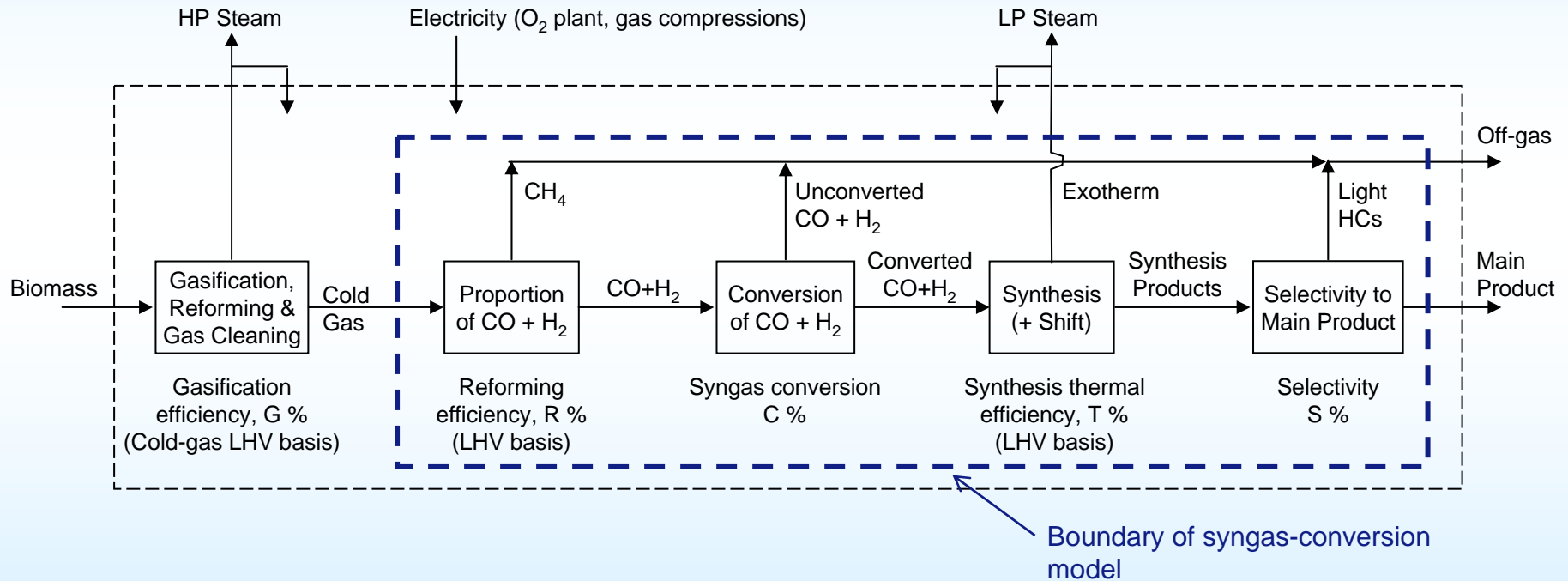
FT, CH₃OH, DME, SNG, H₂/trad: 200 – 300 °C
 H₂/PSA: 40 °C

Abbreviations:

CC	Combined-Cycle energy production
FCCC	Fuel-Cell Combined-Cycle energy production
FT	Fischer-Tropsch liquid fuels
SNG	Synthetic Natural Gas (CH ₄)
DME	Di-Methyl Ether
H ₂ /trad	Traditional process for H ₂ production from syngas
H ₂ /PSA	H ₂ production based on separation by Pressure Swing Absorption

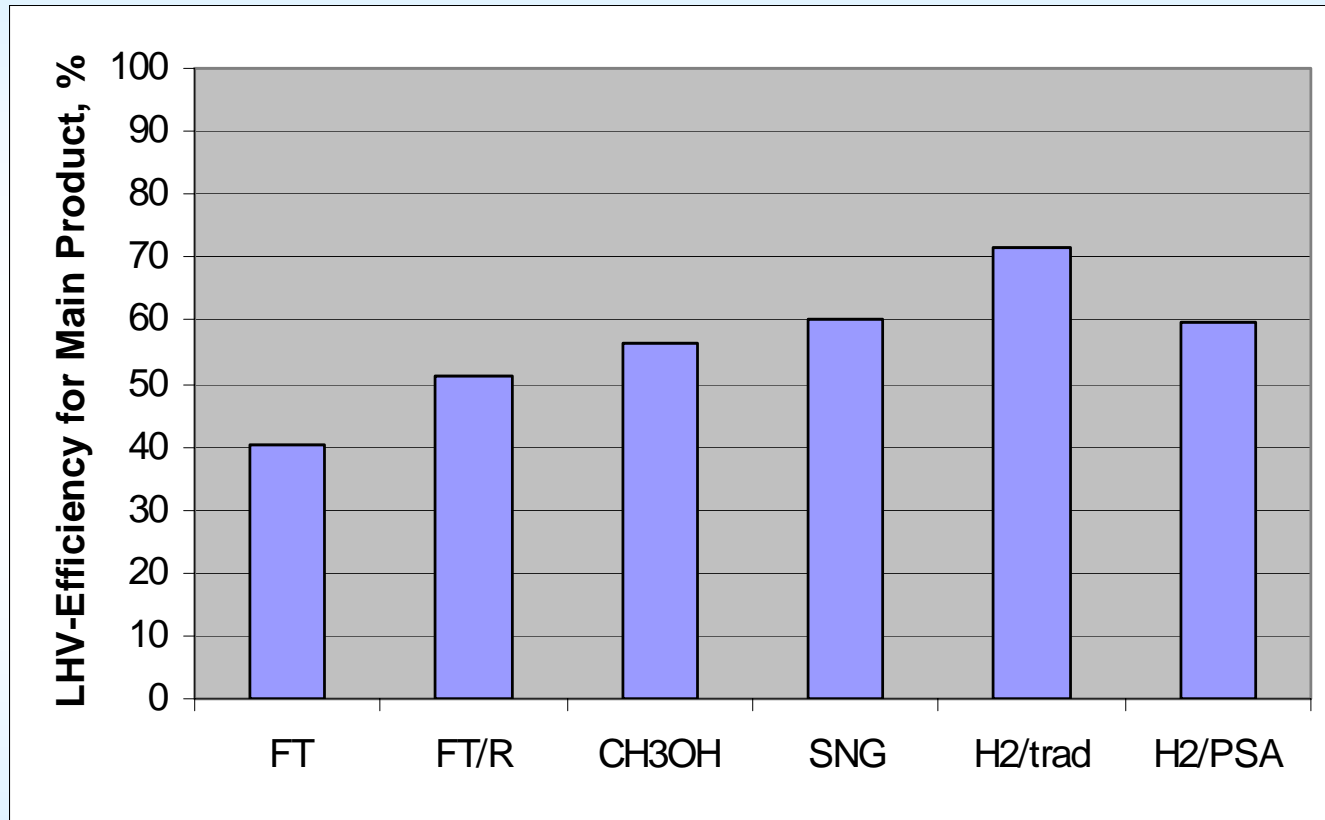
Modelling of Biosyngas Conversion

- a tool to help process selection and design work



Modelling of Biosyngas Conversion

Comparisons of Efficiencies of Base Cases

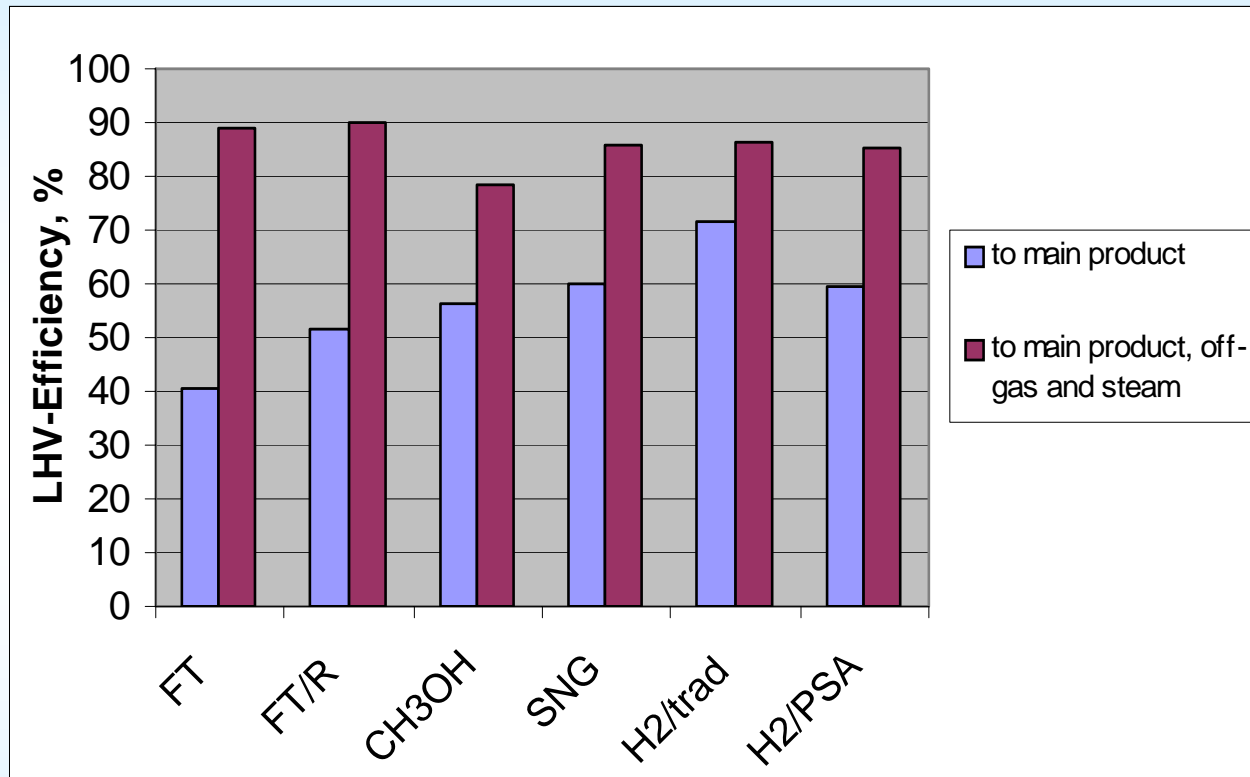


FT: Fischer-Tropsch primary liquids, once-through process with reasonably high once-through performance

FT/R: process with reforming loop; same once-through FT performance

Benefits of Integration with Energy Consumer

Overall Efficiencies for Different Applications (Base Cases)



Note: steam = HP and LP steam produced in gas cooling and MP/LP steam produced in synthesis/shift.

Conclusion: overall efficiency of FT is exceptionally high (heat of condensation of product liquids and heat of condensation of part of product H₂O recovered as LP steam) while overall efficiency of methanol is lower. Benefits of integration will vary accordingly.

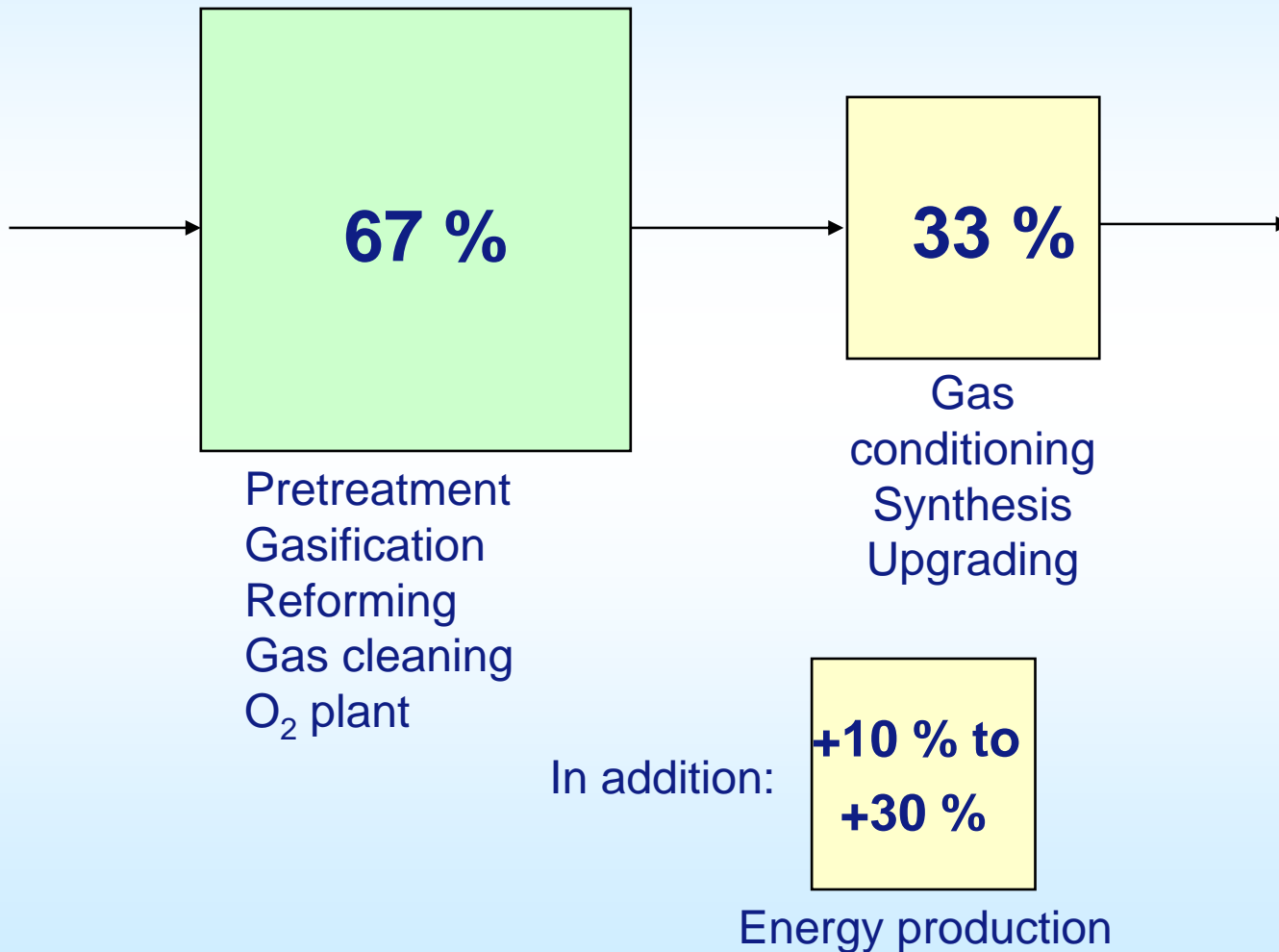
Modelling of Biosyngas Conversion

- Important Bases of the Cost Estimates

- ◆ Capacity of plant: 300 MW of feedstock (LHV basis)
- ◆ Annual operating time: 8000 h/a
- ◆ Interest on capital: 10 % for 20a
- ◆ O&M costs: 4 % of investment
- ◆ Base values for purchased/sold energy (other values applied in sensitivity cases):
 - feedstock: 10 EUR/MWh (LHV)
 - electricity: 30 EUR/MWh_e
 - HP steam: 16 EUR/MWh of transferred heat
 - MP and LP steam: 13 EUR/MWh of transferred heat
 - fuel gas: 14 EUR/MWh (LHV)
- ◆ The following estimates of the total investment costs of 300 MW_{feed} plants were derived:
 - Fischer-Tropsch primary liquids; once-through synthesis: 210 MEUR
 - Fischer-Tropsch primary liquids; with reforming loop: 230 MEUR
 - Methanol: 220 MEUR
 - Synthetic Natural Gas: 200 MEUR
 - Hydrogen, either via traditional method or via PSA separation: 195 MEUR

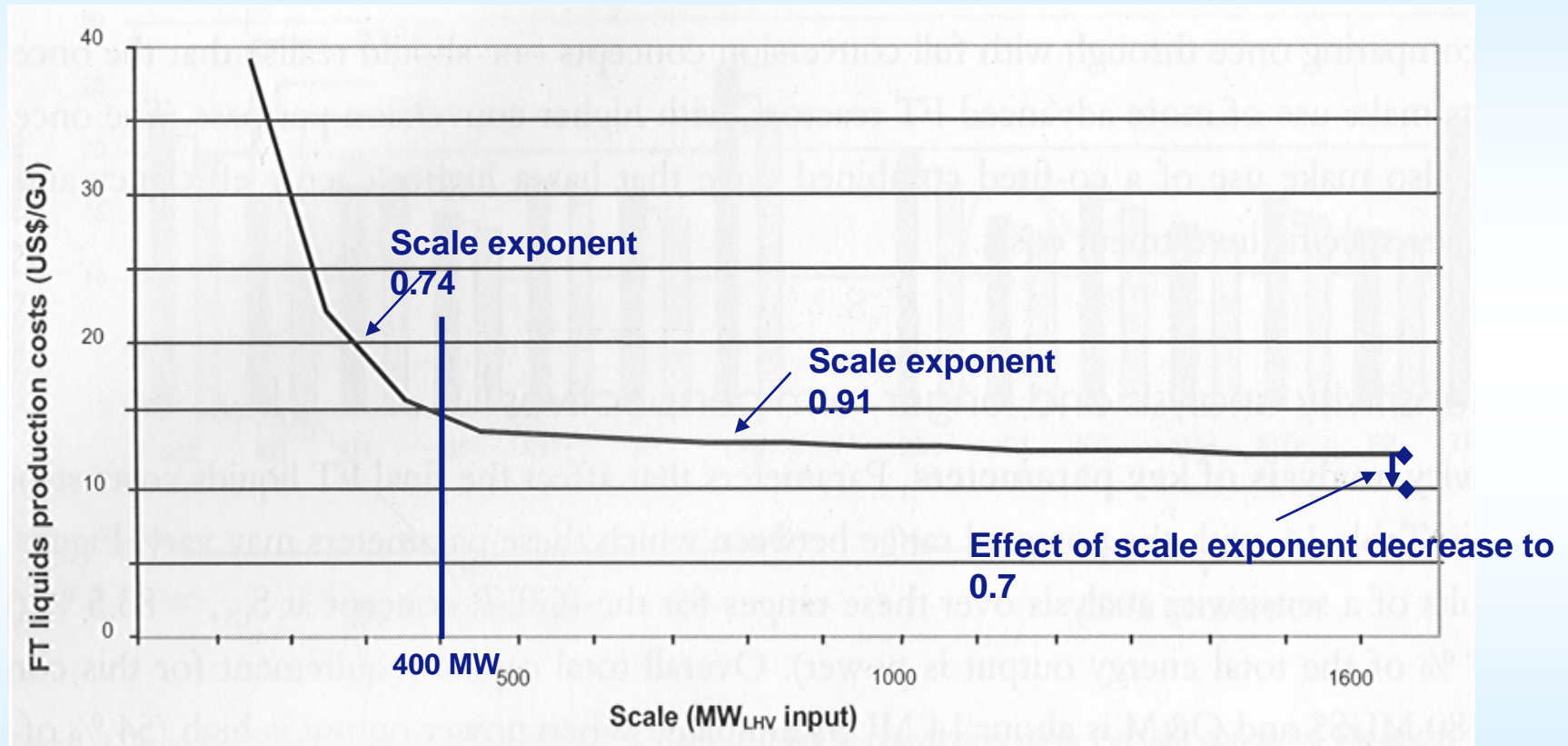
Typical Investment Breakdown

Capacity: about 300 MW input



Effect of Scale

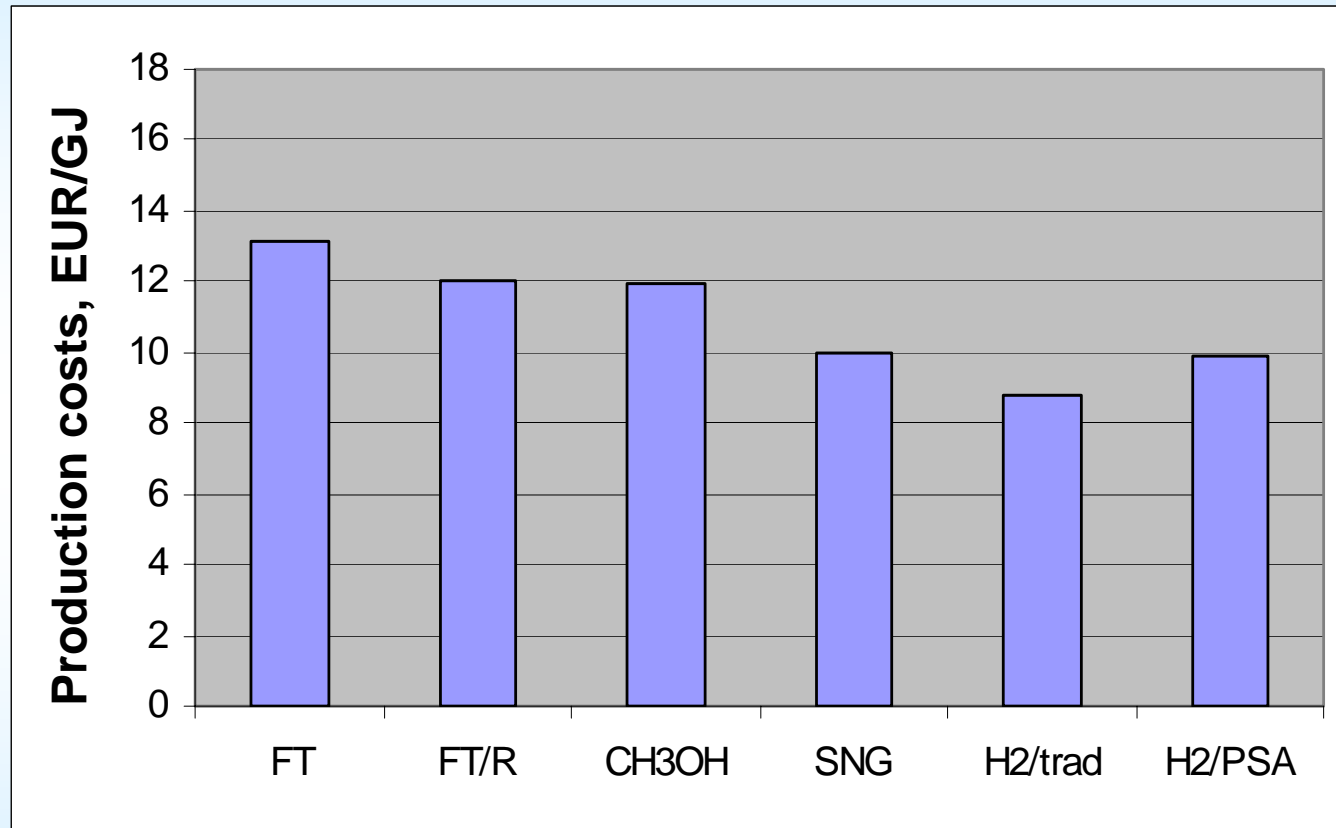
Tijmensen, et al; Maximum Single-Train Gasification Process: 400 MW input



For large scales, scale effect dominated by maximum size of single-train gasifier; for fluid-bed gasification very difficult to exceed a 400 MW single train in practice.

Modelling of Biosyngas Conversion

Comparison of Costs of Base Cases; 300 MW_{feed}; Feedstock Price 10 EUR/MWh

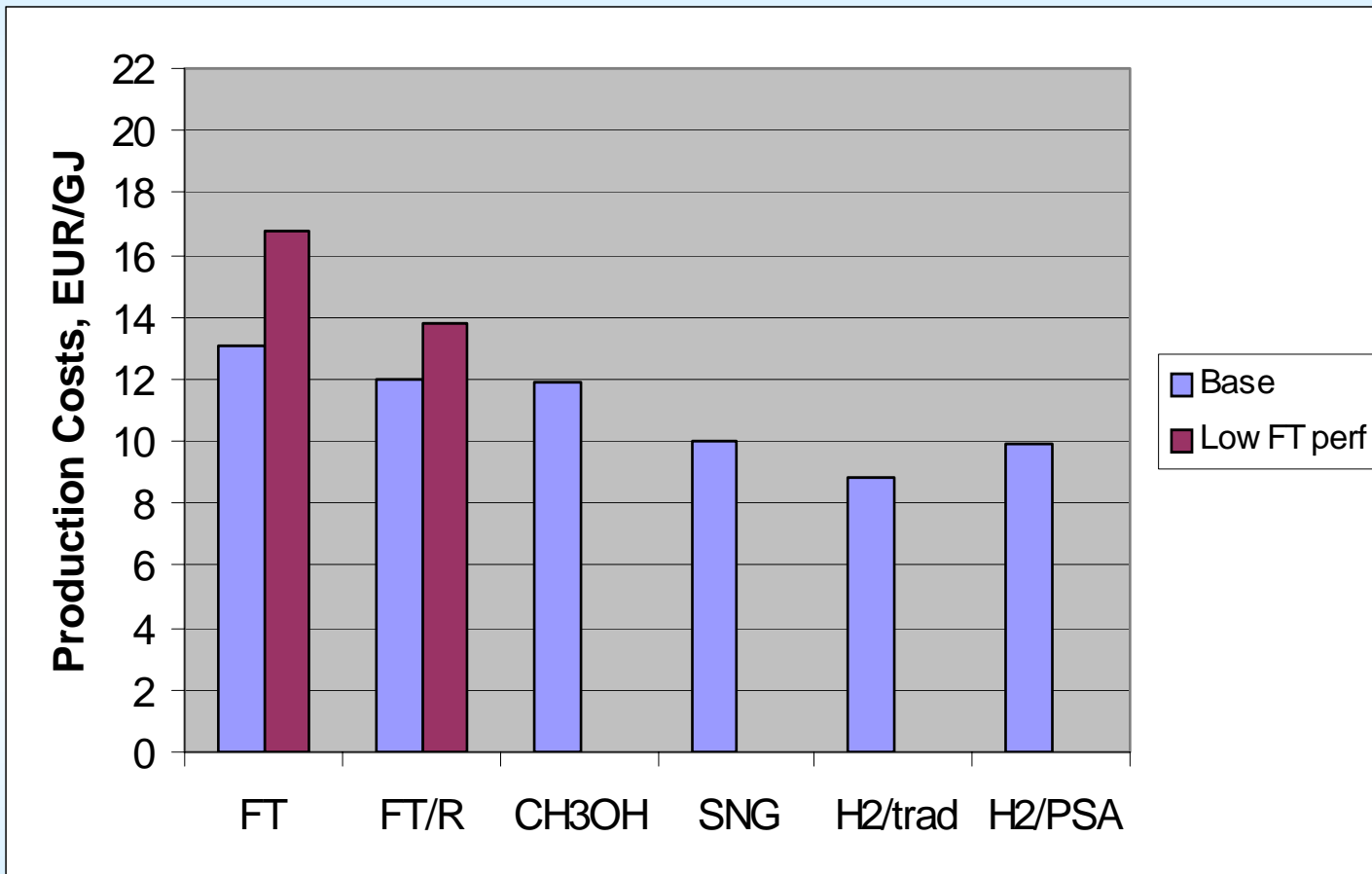


FT: primary liquids via FT process with reasonably high once-through performance. Cost of final upgrading of FT primary liquids: about 1 EUR/GJ

FT/R: process with reforming loop; same once-through FT performance

Modelling of Biosyngas Conversion

Comparison of Costs; Effect of Low FT Performance

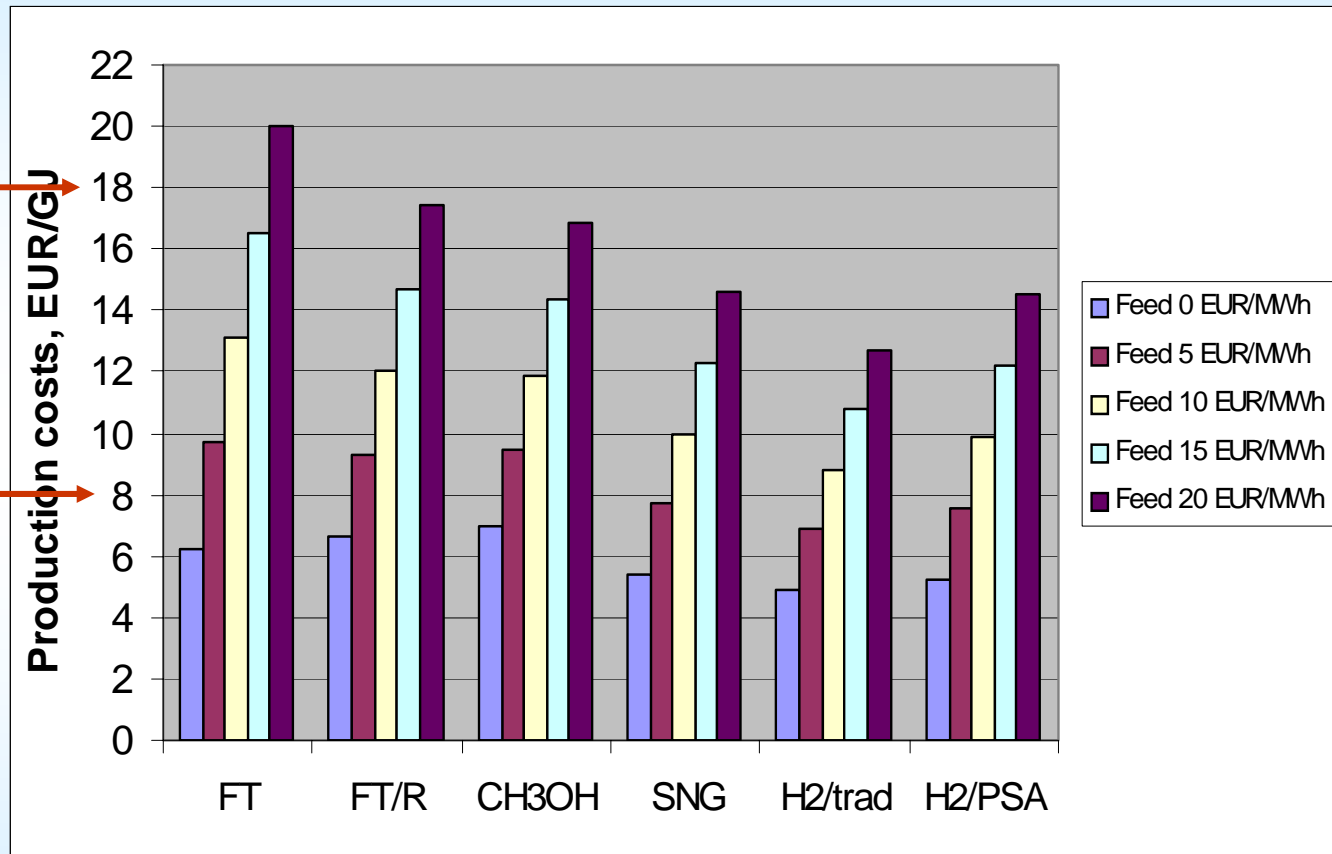


Base Case for FT:
Low FT perf::

FT process with reasonably high once-through performance
FT process with low once-through performance

Modelling of Biosyngas Conversion

Comparison of Costs; Effect of Feedstock Price



FT: primary liquids via FT process with reasonably high once-through performance. Cost of final upgrading of FT primary liquids: about 1 EUR/GJ

FT/R: process with reforming loop; same once-through FT performance

Distributed Pyrolysis-Oil Production & Centralised Syngas Plant Comparison with Centralised Gasification of Solid Biomass

Alternative based on *gasification of pyrolysis oil*

- ◆ Biomass collected at 6 x 55MW centres; e.g. at 6 pulp/paper mills
- ◆ Biomass price at collection centre: 7.5 EUR/MWh
- ◆ Biomass conversion to pyrolysis oil in integrated plant, 92% efficiency
- ◆ Pyrolysis oil price at collection centre: 16.5 EUR/MWh
- ◆ Transportation of pyrolysis oil to syngas plant, 200 km
- ◆ Pyrolysis-oil price at central plant: 21.2 EUR/MWh
- ◆ Pyrolysis-oil conversion to syngas liquids in central plant, 300 MW
- ◆ Production costs of methanol: **58 EUR/MWh, 16 EUR/GJ**
- ◆ Production costs of FT primary liquids: **68 EUR/MWh, 19 EUR/GJ**

- ◆ Total investment (pyrolysis plants + syngas plant): about **270 MEUR**

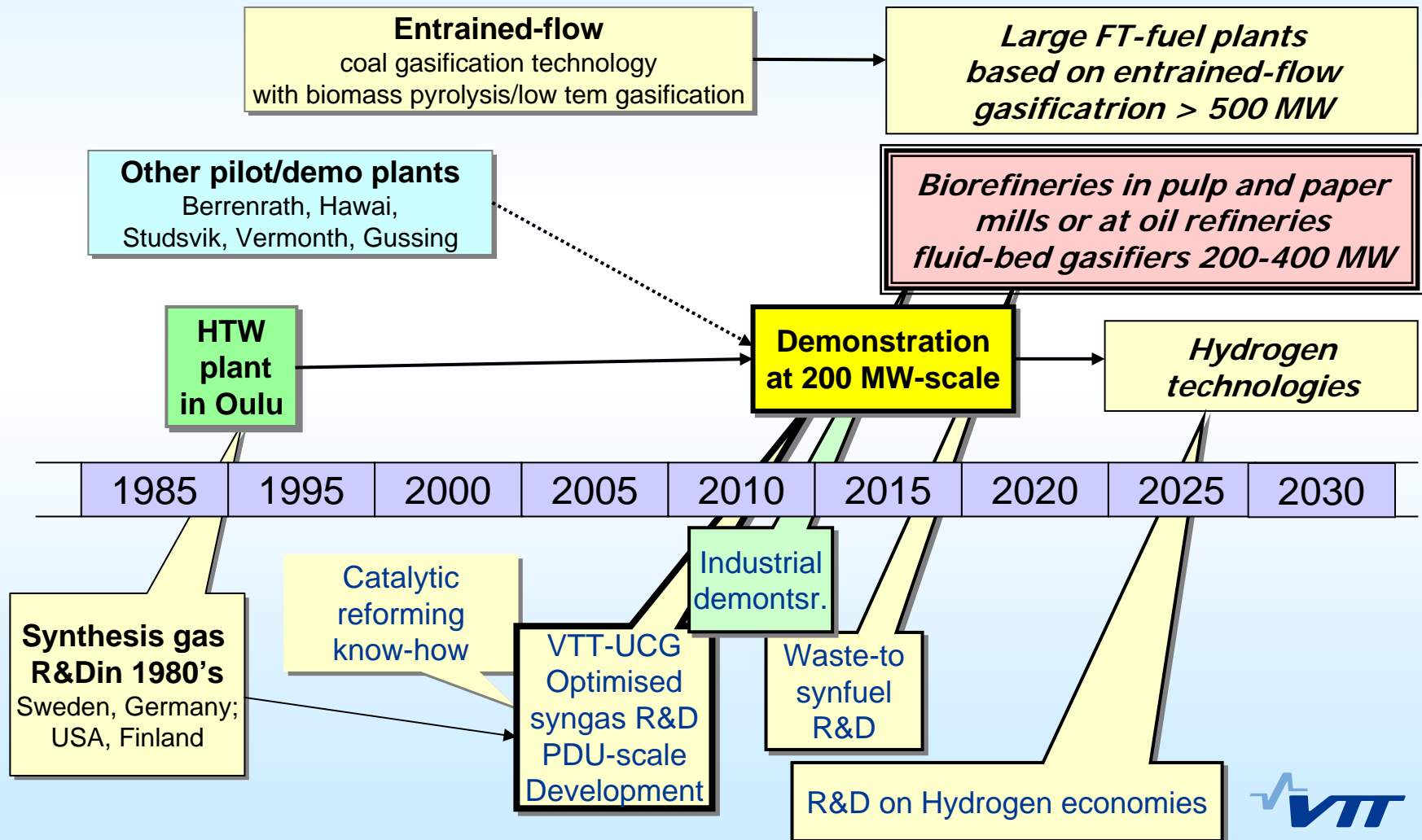
Production Concepts: Scale, Integration

Conclusions

- ◆ For Finnish conditions, the economical performance of the conventional concept based on centralised conversion of solid biomass residues appears to be superior to that of the production concept based on distributed production of pyrolysis oil.
- ◆ From the point of view of both costs and feedstock availability, a suitable capacity for a Finnish biosyngas plant appears to be in the range 200 - 400 MW. As much of the plant as possible should be built as a single train.
- ◆ Integration with an energy-consuming industrial facility, e.g. a paper mill, would be very beneficial. An ideal situation would be one coinciding with a rebuild/replacement of the boiler plant of the facility.

Synthesis gas from biomass to liquid biofuels, hydrogen, synthetic methane and chemicals

- liquid biofuels or H₂ in medium-to-large scale plants



Conclusions

- ◆ Pressurised Fluidised-Bed gasification followed by catalytic reforming offers a promising alternative to produce synthesis gas from multiple biomass and waste feedstocks in the range 200 – 400 MW
- ◆ The development of gasifiers and gas cleaning methods for power and heat applications has created unique background know-how to the second generation biomass-to-liquids processes in Finland
- ◆ Effective integration of the FT-process to the pulp and paper industry offers interesting advantages with high overall efficiency
- ◆ The new key gasification and gas cleaning processes can be developed and tested at 500 kW PDU scale with reasonable costs and flexible test arrangements
- ◆ As the second step, the gasification and gas cleaning section can be demonstrated at ca. 50 MW scale in an energy production application at a pulp mill or other industrial site (in 2008-10)
- ◆ First BTL plant can be realised in 2010-15 and the technology will be commercially available at ca. 2015