Thermochemical conversion of biomass

Liquid Fuels

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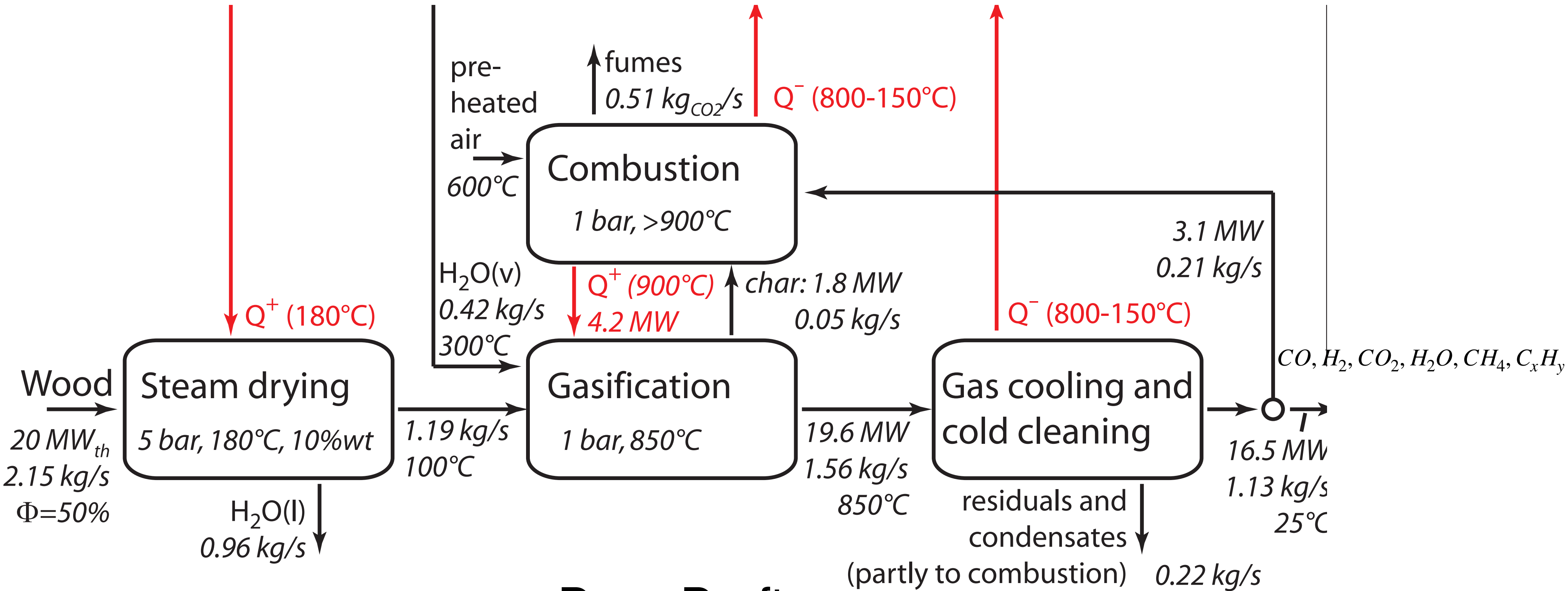
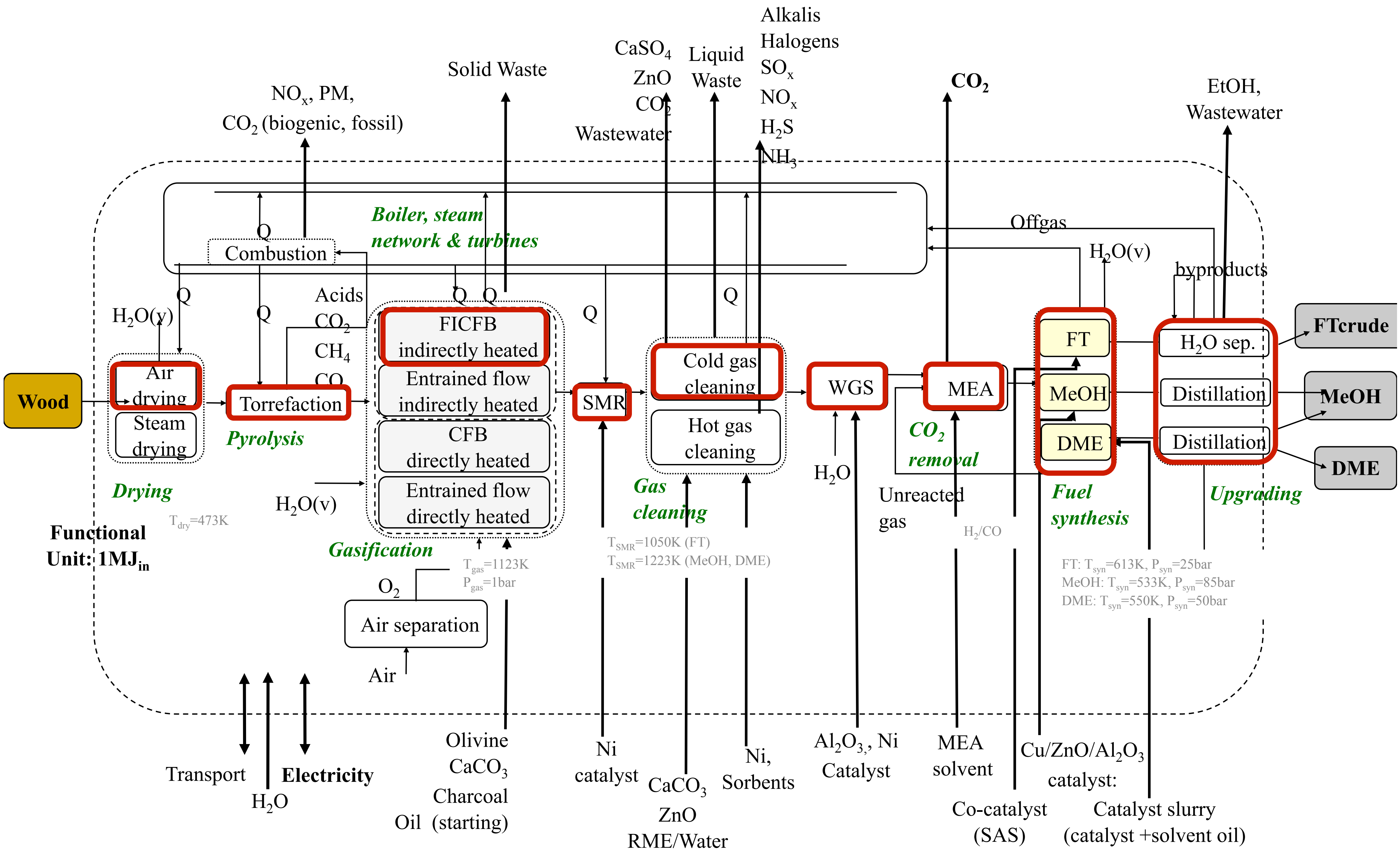
SOLID -> SYNGAS



DownDraft
Entrained flow
Indirectly heated
Multi-stage

Process Superstructure



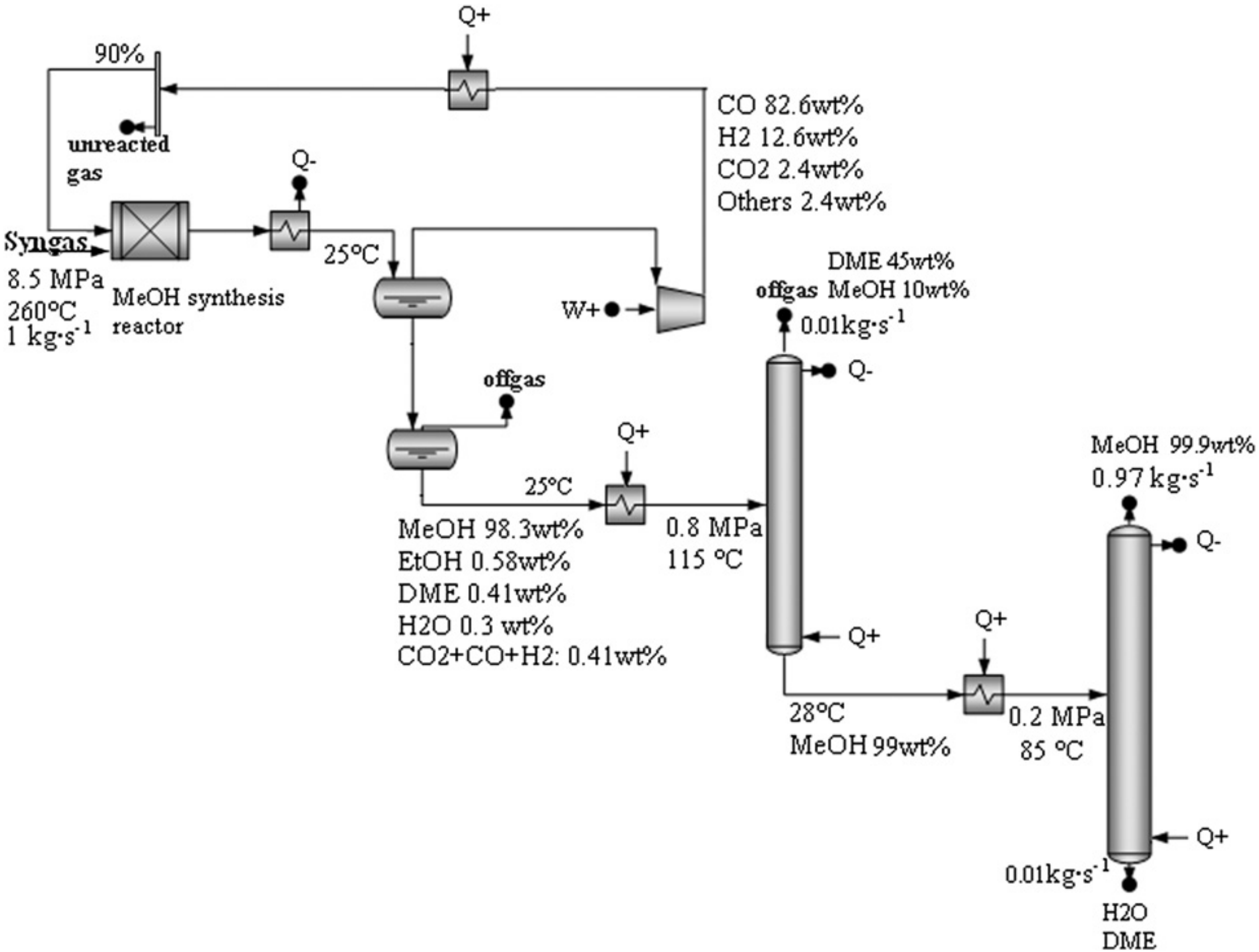
[4]Gassner, M. & Maréchal, F., Thermo-economic process model for the thermochemical production of Synthetic Natural Gas (SNG) from lignocellulosic biomass. *Biomass &Bioenergy, 33(11):1587–1604, 2009.* [5]Tock, L., Gassner, M.& Maréchal, F.,Thermo-economic process model for thermochemical production of liquid fuels from lignocellulosic biomass, submitted to Bomass & Bioenergy 2009.

FT- MEOH - DME reactions

Table 1 – Chemical reactions occurring in the process.

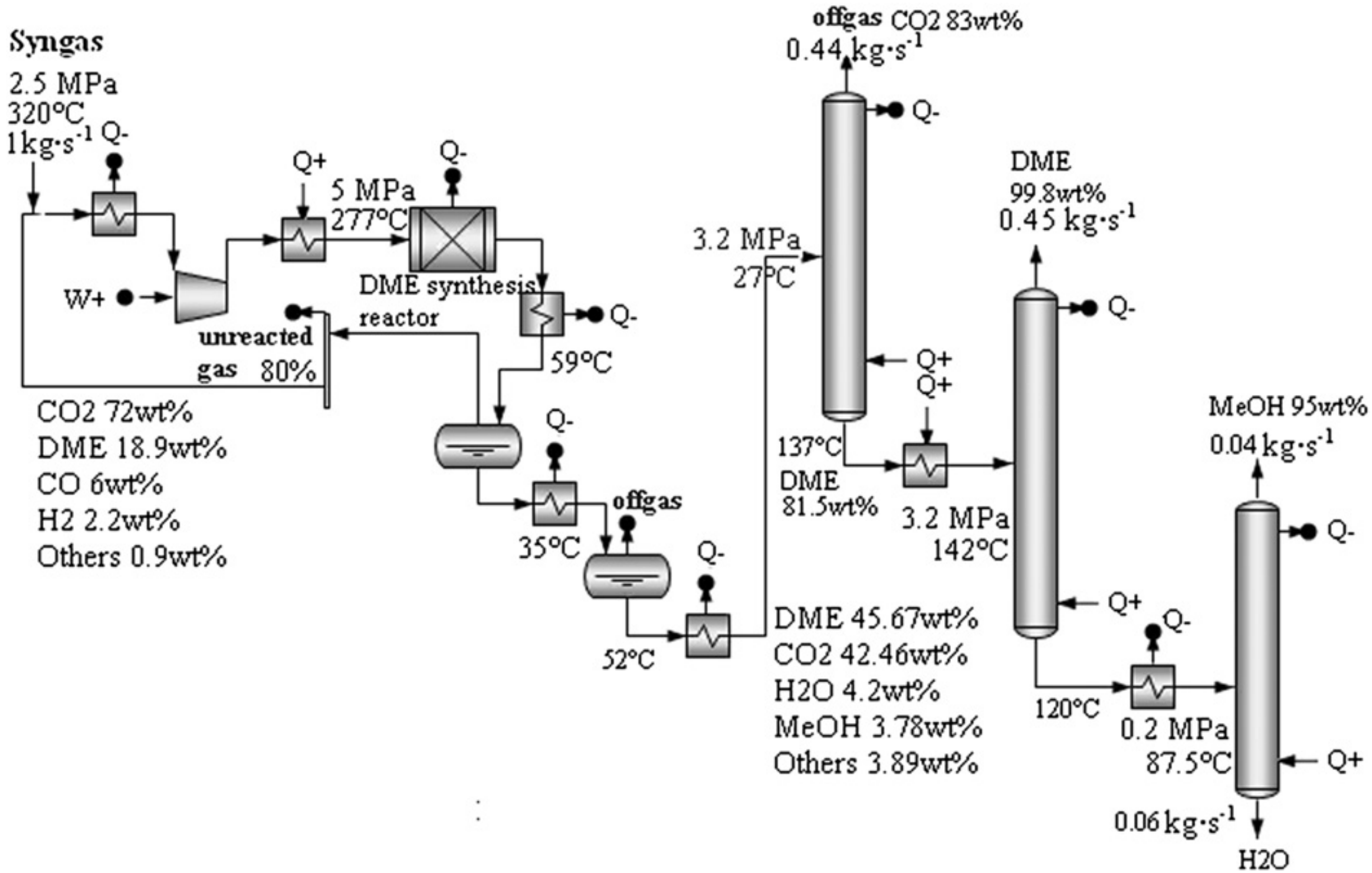
Name	Reaction		$\Delta\tilde{h}_r^0 [kJ \cdot mol^{-1}]$	Reactor
Alcohols formation	$nCO + 2nH_2 \rightarrow C_nH_{2n+1}OH + (n-1)H_2O$	(6)		FT
FT chain growth reaction	$CO + 2H_2 \rightarrow -CH_2- + H_2O$	(7)	−165	FT
Olefins formation	$2nH_2 + nCO \rightarrow C_nH_{2n} + nH_2O$	(8)		FT
Paraffins formation	$(2n+1)H_2 + nCO \rightarrow C_nH_{2n+2} + nH_2O$	(9)		FT
Methanol dehydration	$2CH_3OH \rightleftharpoons CH_3OCH_3 + H_2O$	(10)	−23.4	DME, MeOH
One-step DME synthesis	$3CO + 3H_2 \rightleftharpoons CH_3OCH_3 + CO_2$	(11)	−246	DME
Two step DME synthesis	$2CO + 4H_2 \rightleftharpoons CH_3OCH_3 + H_2O$	(12)	−205	DME
Methanol synthesis	$CO + 2H_2 \rightleftharpoons CH_3OH$	(13)	−90.8	MeOH, DME
	$CO_2 + 3H_2 \rightleftharpoons CH_3OH + H_2O$	(14)	−49.2	MeOH
Ethanol formation	$2CH_3OH \rightleftharpoons C_2H_5OH + H_2O$	(15)	−71.8	MeOH
Steam methane reforming	$CH_4 + H_2O \rightleftharpoons CO + 3H_2$	(16)	206	SMR
Ethene reforming	$C_2H_4 + 2H_2O \rightleftharpoons 2CO + 4H_2$	(17)	210	SMR
Water–gas shift equilibrium	$CO + H_2O \rightleftharpoons CO_2 + H_2$	(18)	−41	SMR, WGS DME, MeOH

MEOH production process



Flowsheet of the MeOH synthesis and upgrading for a normalized syngas stream of 1 kg s^{-1} at the inlet.

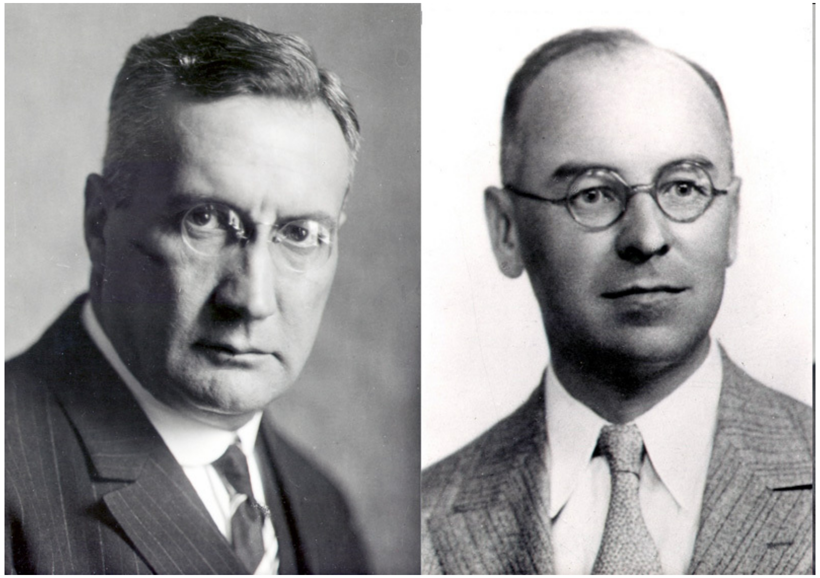
DME production



Flowsheet of the DME synthesis and upgrading for a normalized syngas stream of 1 kg s^{-1} at the inlet.

Fischer – Tropsch process

Image: Max Planck Institute of Coal Research.



Franz Fischer and Hans Tropsch developed in Germany in the 1920s

- Historical importance – Fuels from Coal
  - **WWII** – Germany
  - **Apartheid** in South Africa – Sasol
- Drop in Fuel
  - No changes in the infrastructure/fleet

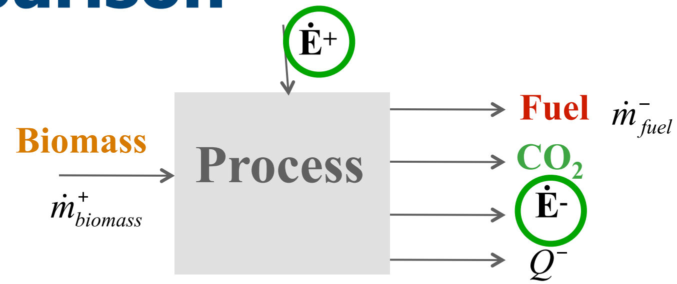
CO → **p, T, t, Catalyst** → CH_4, Ammonia, **Gasoline, Jet-fuel, Diesel**, Wax

H_2 →

$CO + 2H_2$ <-> $(-CH_2-)(l) + H_2O(l)$ ($\Delta H^0 = -231.1$ kJ/mol (1/8 of 1-octene C8H16))

Temperature is controlling the species distribution

Process Performance - Comparison



- Performance indicators
  - Overall energy efficiency ε_{tot}
    - Expressed on the basis of the lower heating value of dry substance

$$\varepsilon_{tot} = \frac{\Delta h^{0}_{fuel,out} \cdot \dot{m}^{-}_{fuel} + \dot{Q}^{-} + \dot{E}^{-}}{\Delta h^{0}_{biomass,in} \cdot \dot{m}^{+}_{biomass} + \dot{Q}^{-} + \dot{E}^{+}}$$

  - Chemical efficiency ε_{chem}
    - **Ė** substituted by a natural gas fuel equivalent: NGCC/HP

$$\eta_{NGCC} = \eta_{HP} = 55\%$$

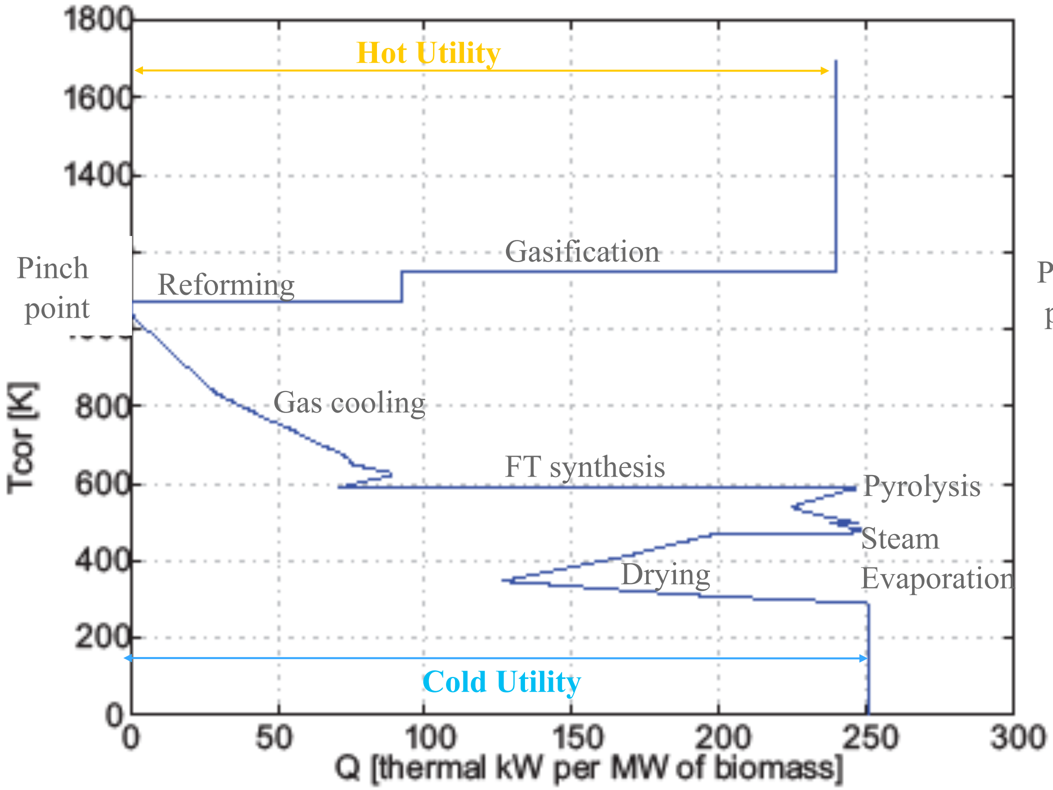
$$\varepsilon_{chem} = \frac{\Delta h^{0}_{fuel,out} \cdot \dot{m}^{-}_{fuel} + \frac{1}{\eta_{NGCC}} \frac{\Delta h^{0}_{SNG}}{\Delta k^{0}_{SNG}} \left(\frac{1}{\eta_{HP}} \dot{Q}^{-} + \dot{E}^{-} \right)}{\Delta h^{0}_{biomass,in} \cdot \dot{m}^{+}_{biomass}}$$

  - Environmental performance
    - Cradle-to-gate LCA approach[5]
    - Impact assessment method: Impact 2002+ method
    - Functional unit: 1MJ of biomass at the installation inlet
  - Plant capacity of 20MW$_{th}$ of biomass

[5] Gerber, L., Gassner, M. & Maréchal, F., Integration of LCA in a thermo-economic model for multi-objective optimization of SNG production from woody biomass. In Proceedings of the 19th ESCAPE, Cracow, Poland

FT Process Performance – Energy Integration

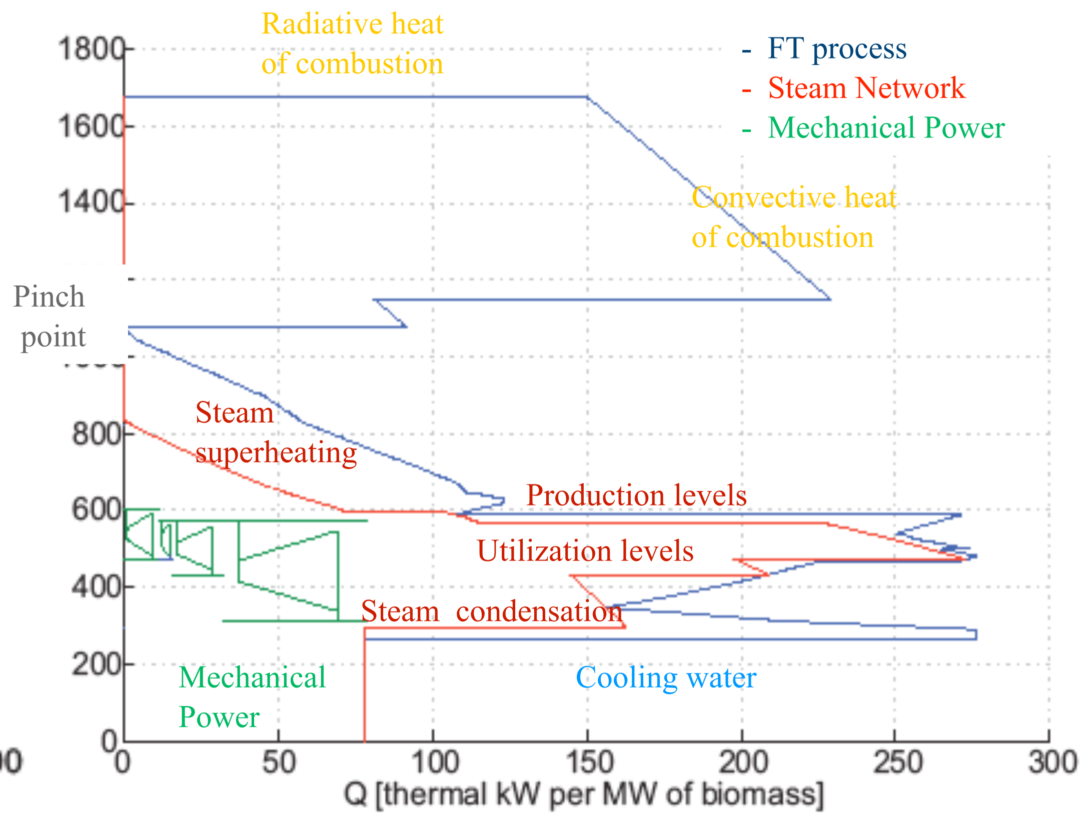
- Maximum heat recovery & heating and cooling requirements for FT process



→ ***Energy performance***

- *Valorize heat excess → Rankine cycle*

- Optimal energy conversion & combined heat and power production for FT process



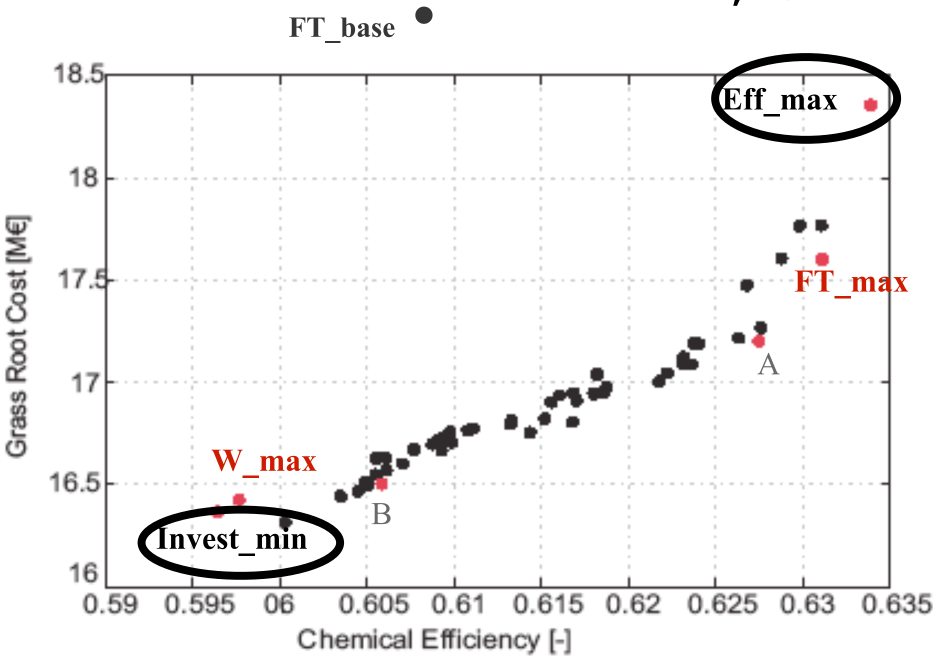
→ ***Steam network***

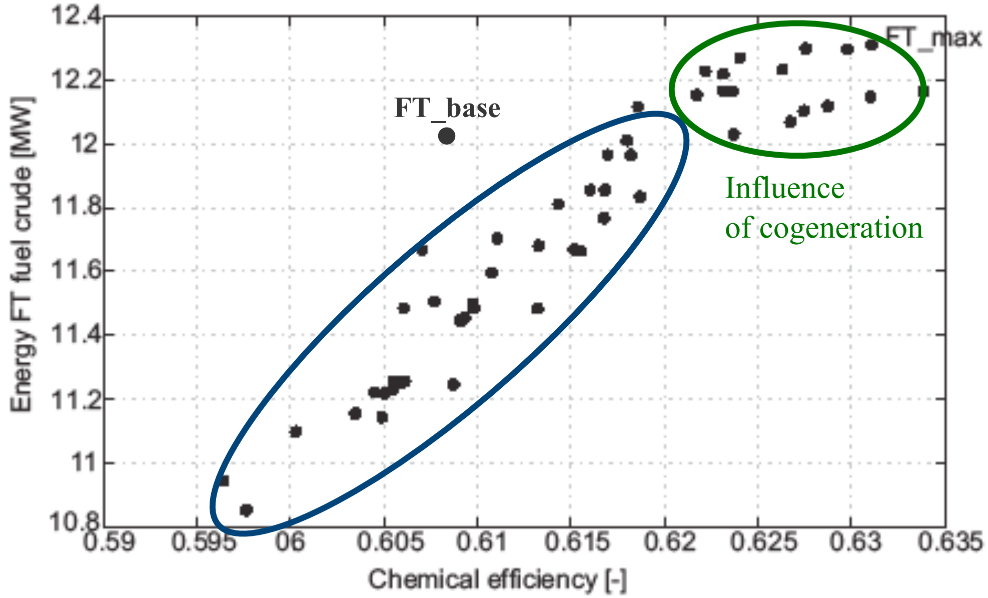
- *2 production, 2 usage & 1 condensation level → Efficiency increase of **17%***

Process Performance - Optimization

- Multi-objective optimization: Pareto optimal frontier

FT process, 20MW$_{th,biomass}$, indirect fluidized bed gasification





→ *Efficiency* ↗ Investment ↗

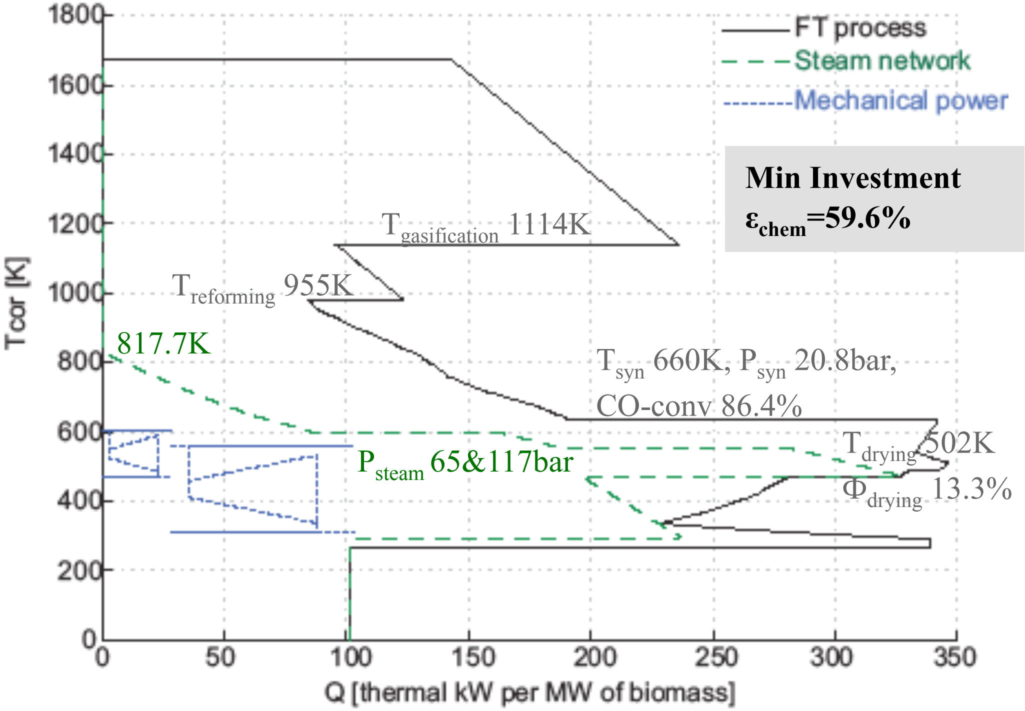
→ ***Trade-off***
mechanical power & fuel generation

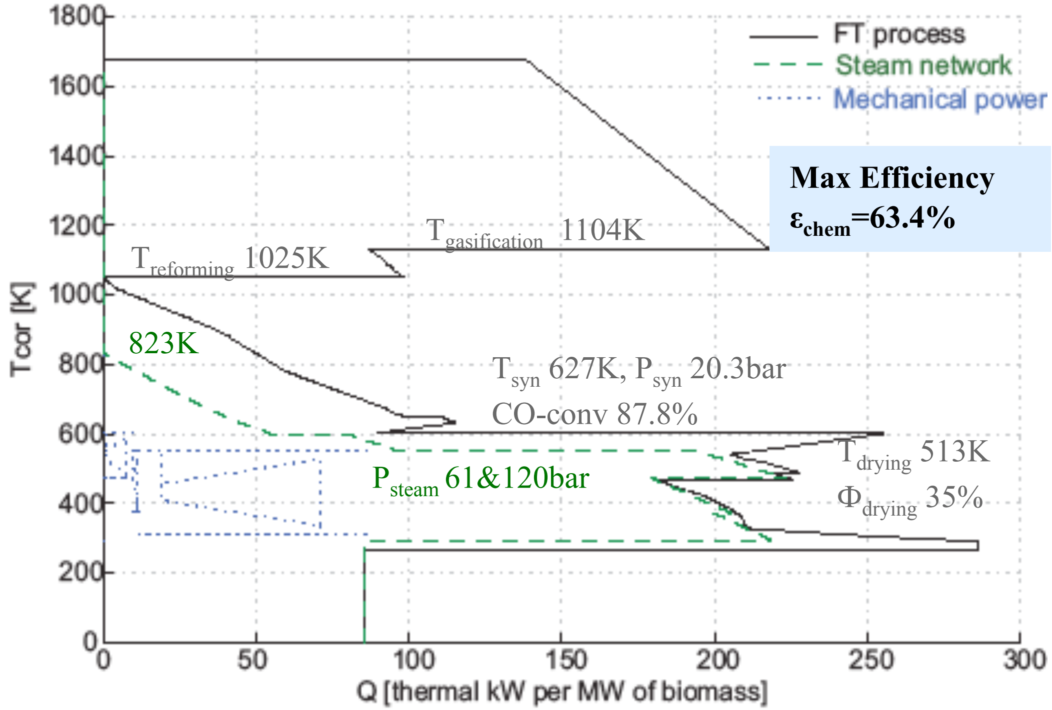
→ ***Efficiency*** ↗
FT-crude fuel ↗

→ ***Influence of process operating conditions on process integration !***

Process Performance - Optimization

- Energy Integration influence on performance

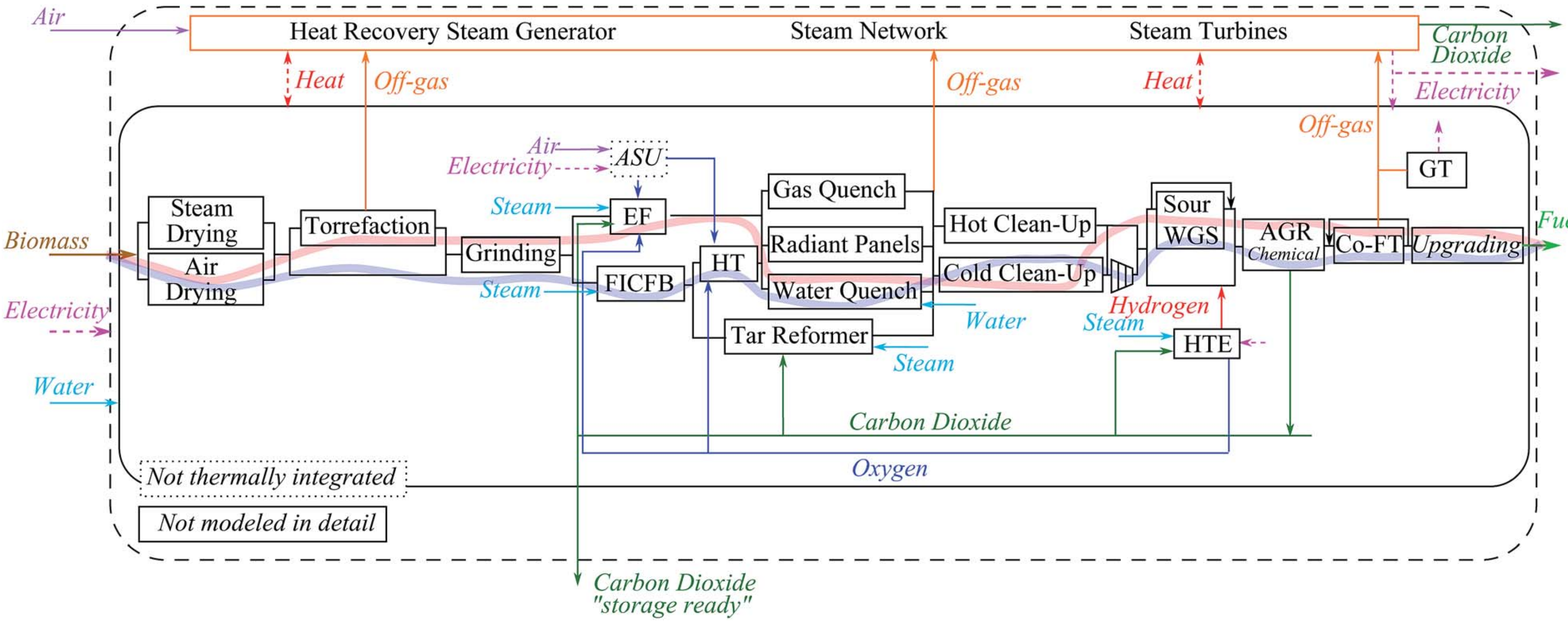


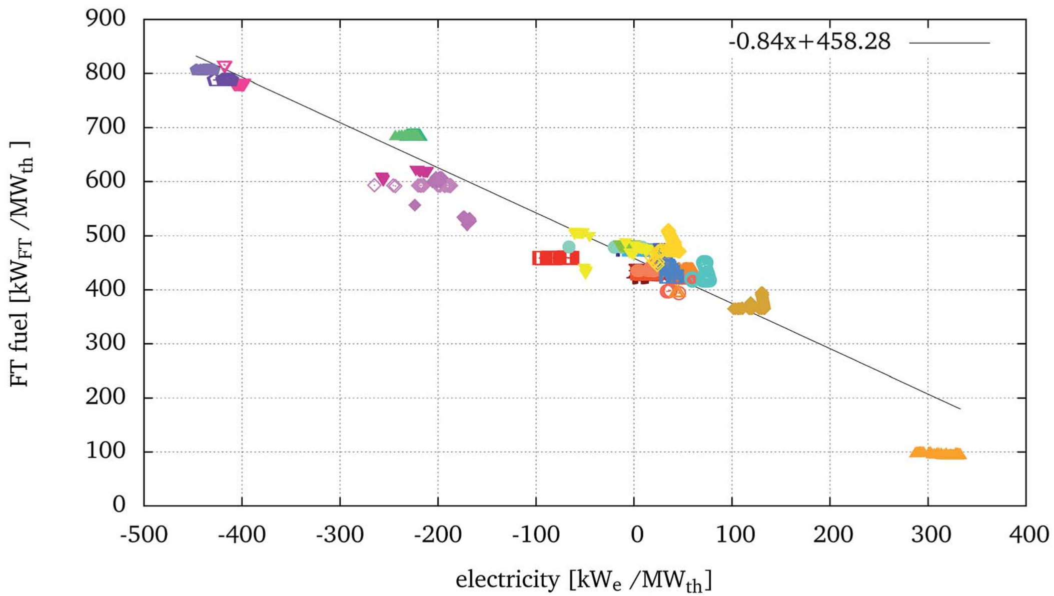


Power balance [kW/ MW]	Base case	Min Cost	Max Efficiency
Consumption	85	77	74
Generation	92.5	107	90
Net electricity	7.5	30	16

→ *Steam network well integrated*
Large amount of excess heat recovered

Different process configuration

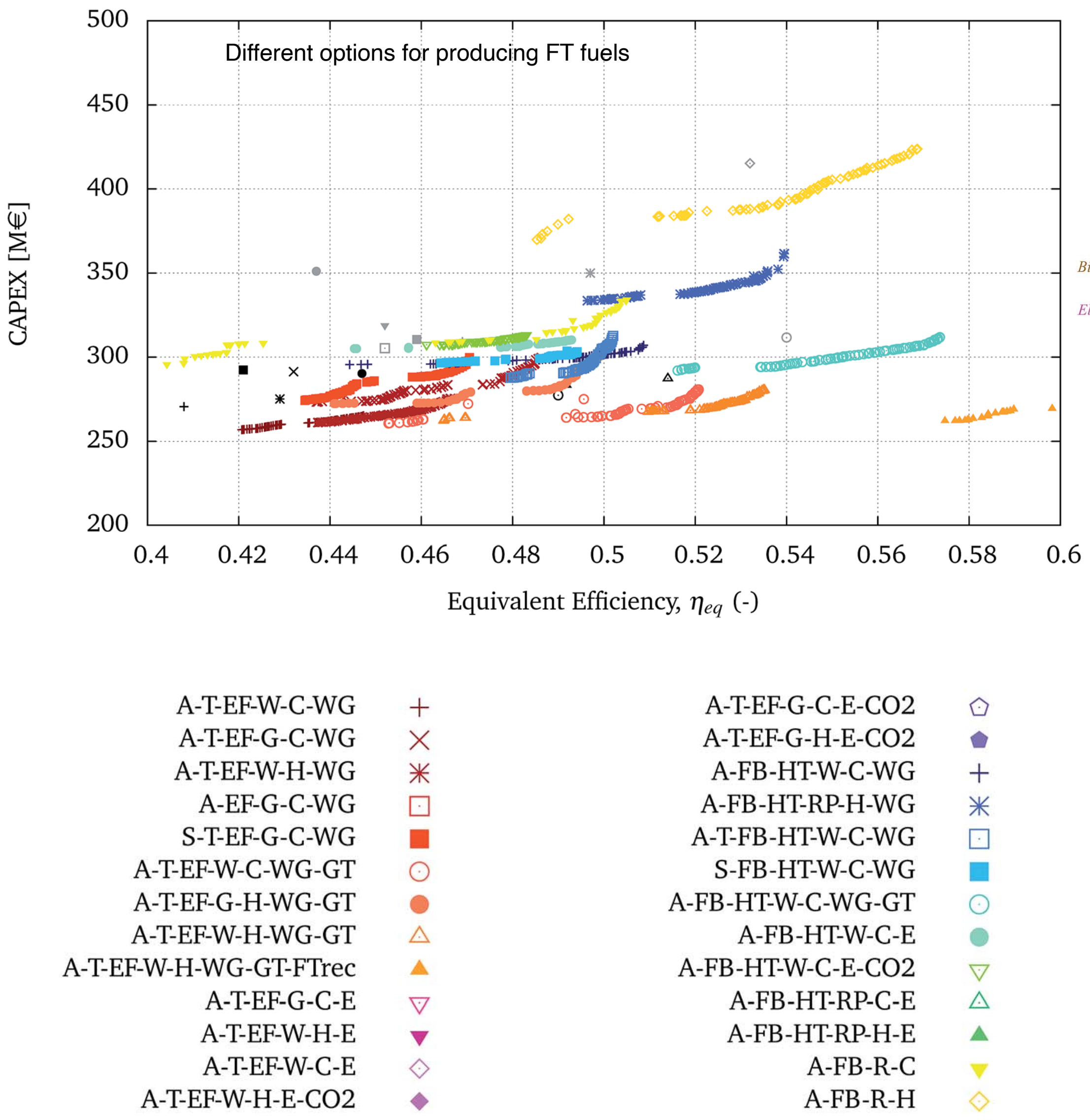


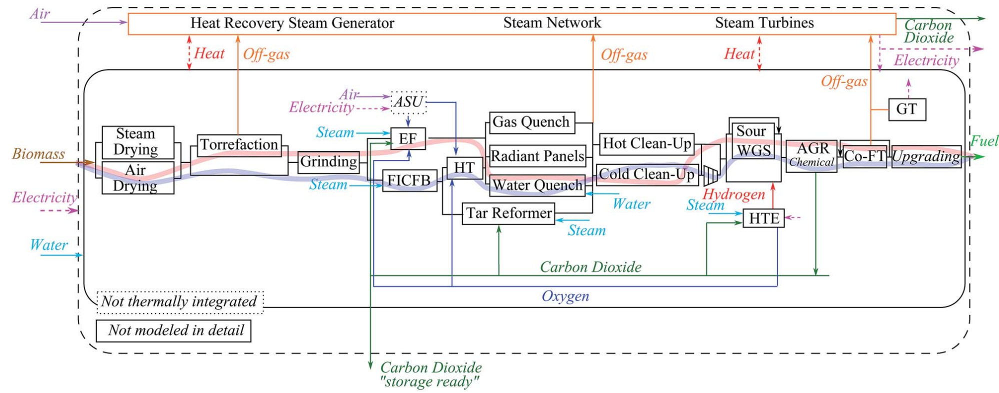


$$\eta_{el} = \frac{\Delta \dot{m} LHV_{FT}}{\Delta \dot{E}} = 0.84$$

Fig. 7 FT fuel production *vs.* electricity balance (positive if exported, negative if imported) of the optimised solutions presented in Fig. 5.

Liquid fuels





Importance of electricity import

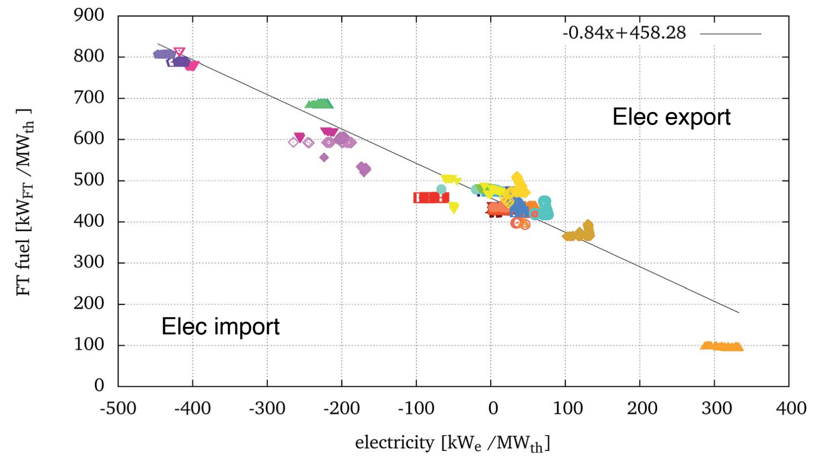


Fig. 7 FT fuel production *vs.* electricity balance (positive if exported, negative if imported) of the optimised solutions presented in Fig. 5.

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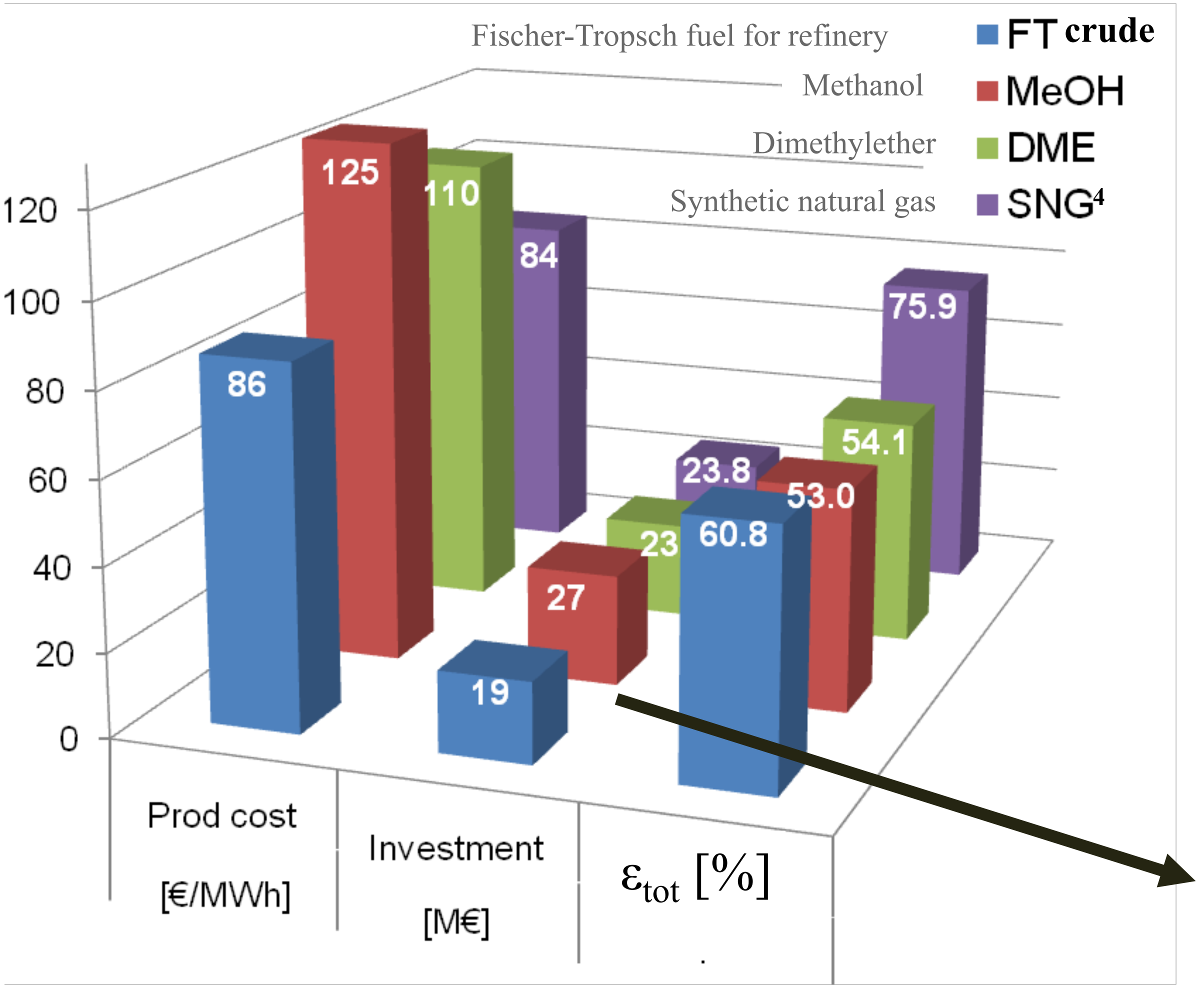
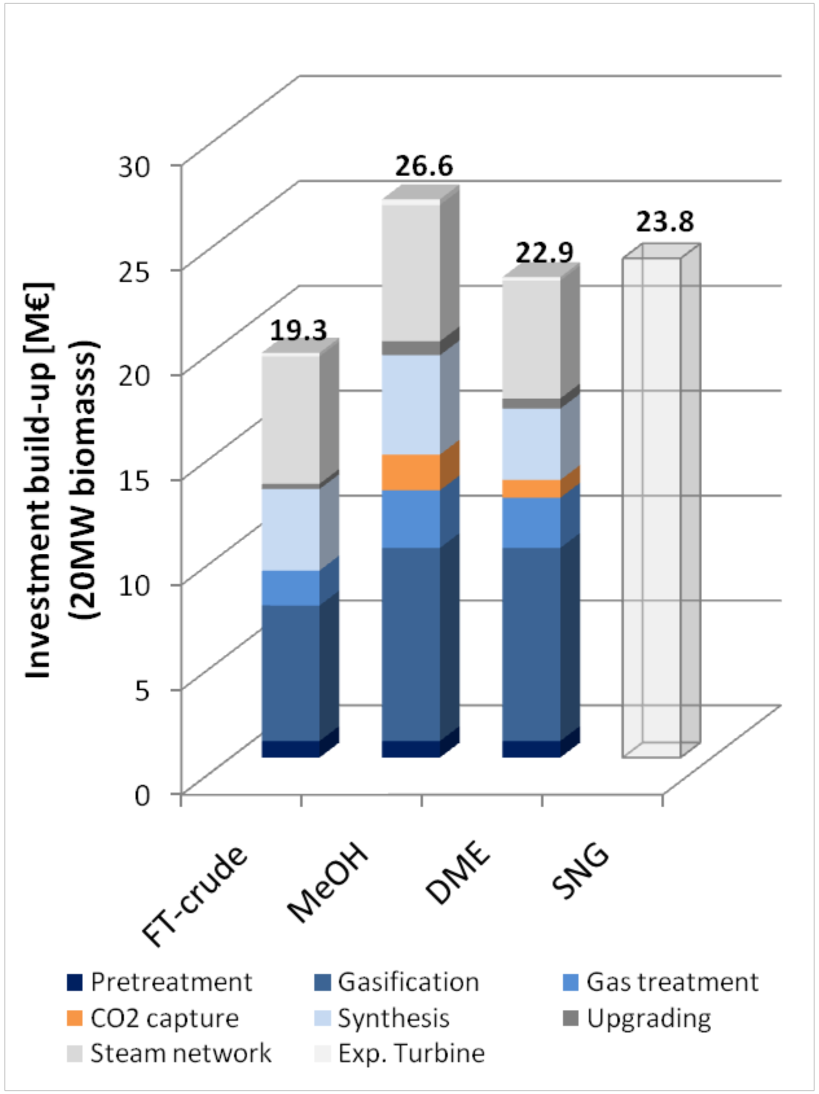
Peduzzi, Emanuela, et al. "Thermo-economic analysis and multi-objective optimisation of lignocellulosic biomass conversion to Fischer–Tropsch fuels." *Sustainable Energy & Fuels* 2.5 (2018): 1069-1084.

Process Performance - Comparison

- Base scenario: indirect fluidized bed gasification, cold gas cleaning



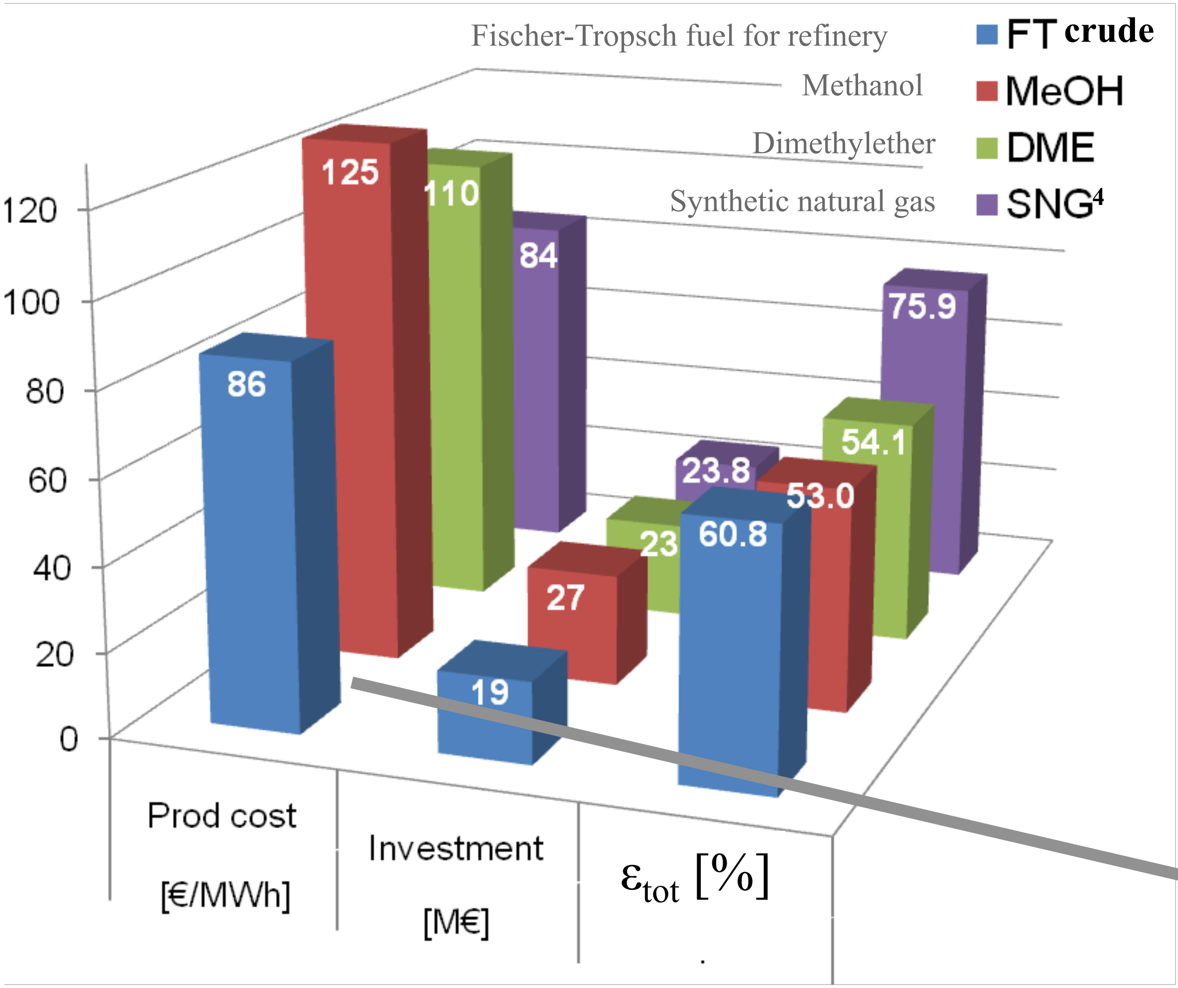


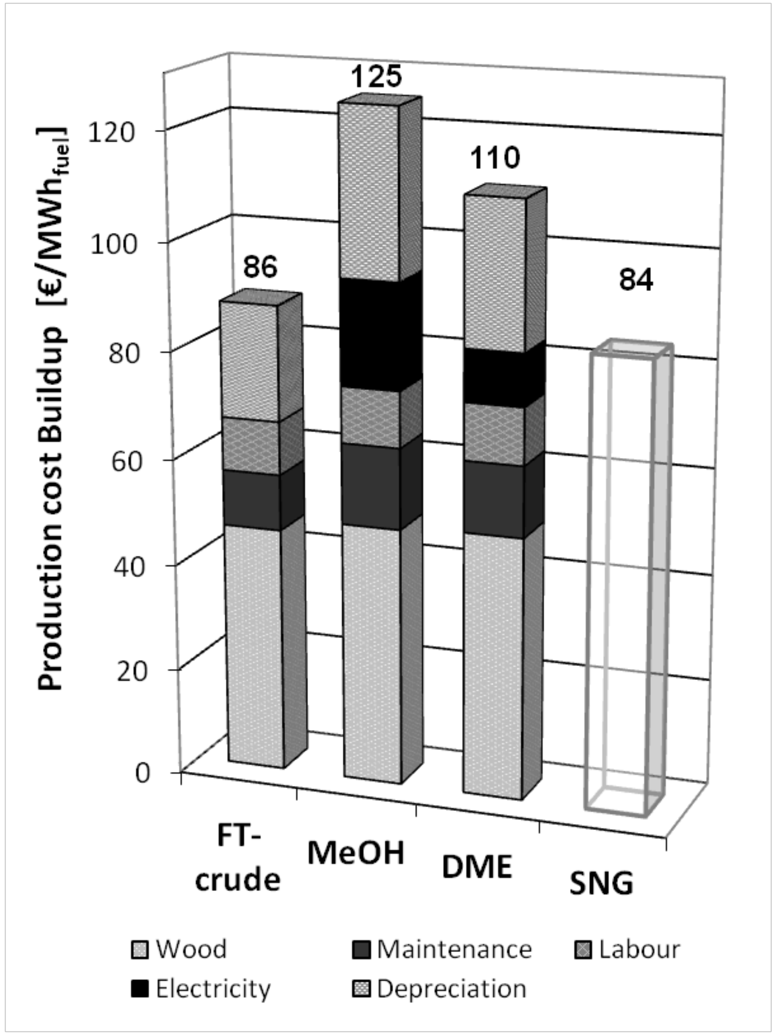
➡ ***FT process highest performance***

- *FT-upgrading not included*
- *No CO_2 removal unit required*
- ***Power demand variation***

Process Performance - Comparison

- Base scenario: indirect fluidized bed gasification, cold gas cleaning



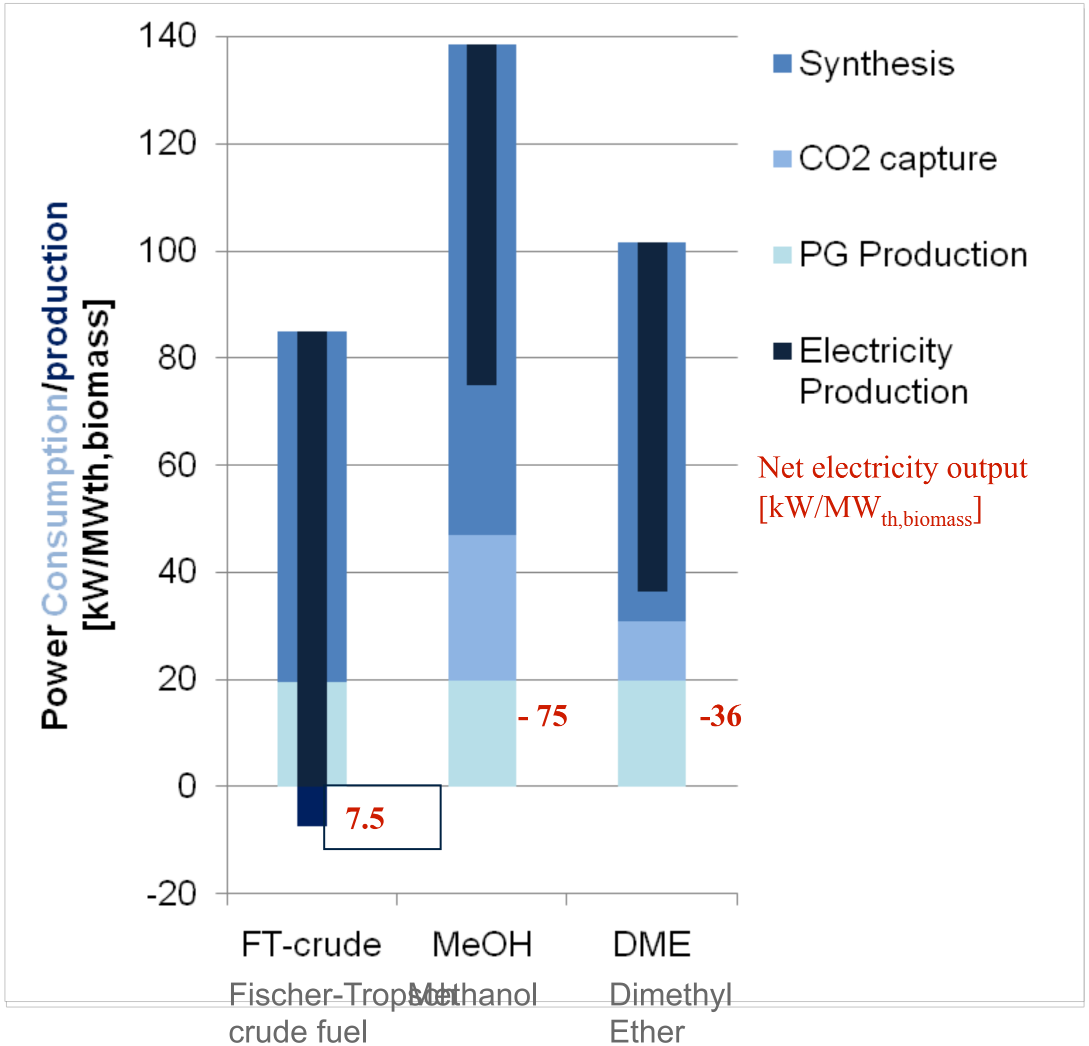


Biomass price: 33 €/MWh[4,5]
Electricity price: 180 €/MWh[4,5]

➡ ***FT process highest performance***
- *FT-upgrading not included*
- *No CO_2 removal unit required*
- ***Power demand variation***

Process Performance - Comparison

- Base scenario: Power balance



➡ ***Power consumption***

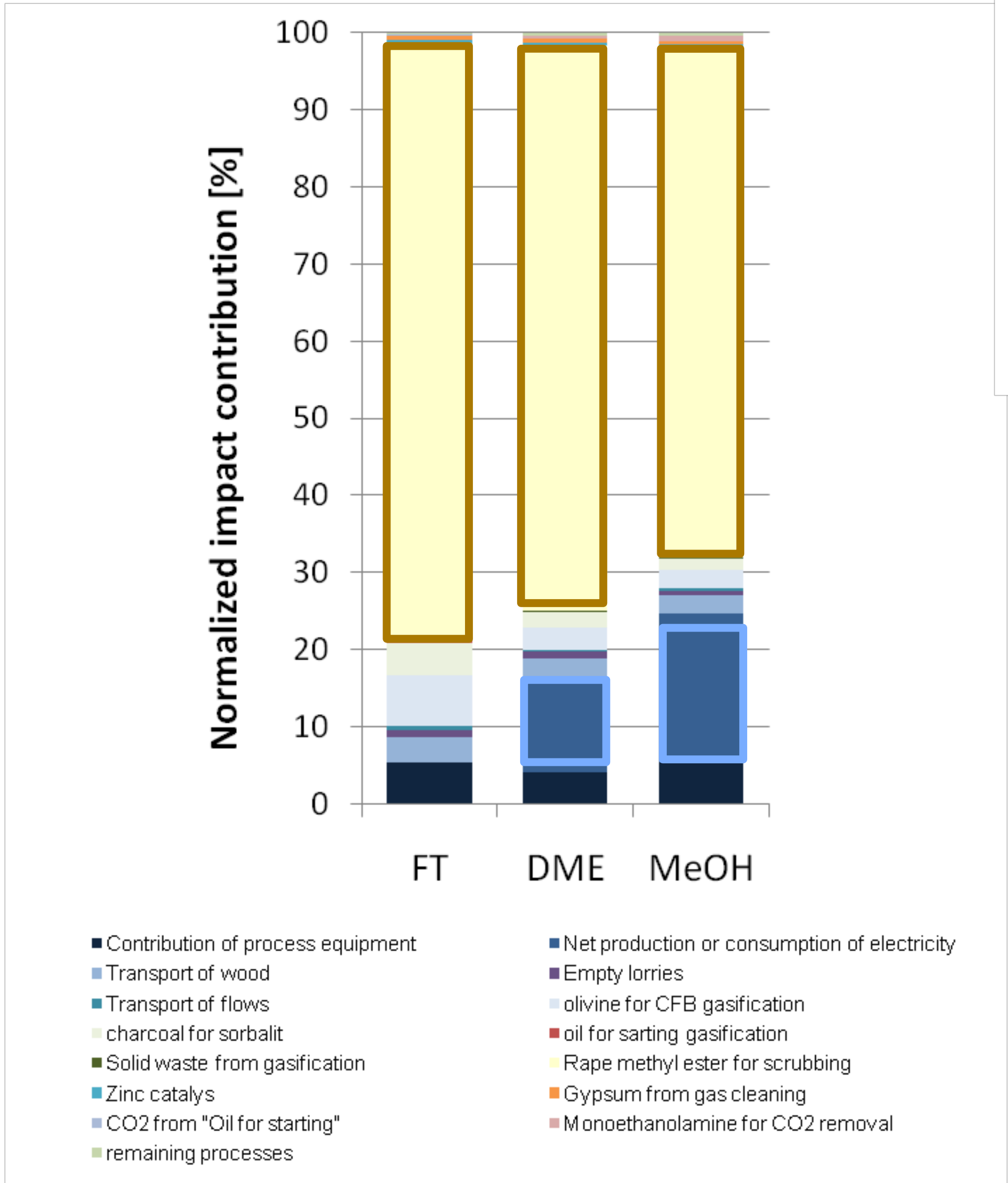
- ***P_{syn}***: *FT 25bar, MeOH 85bar, DME 50bar*
- *CO_2 capture: chemical absorption with MEA*

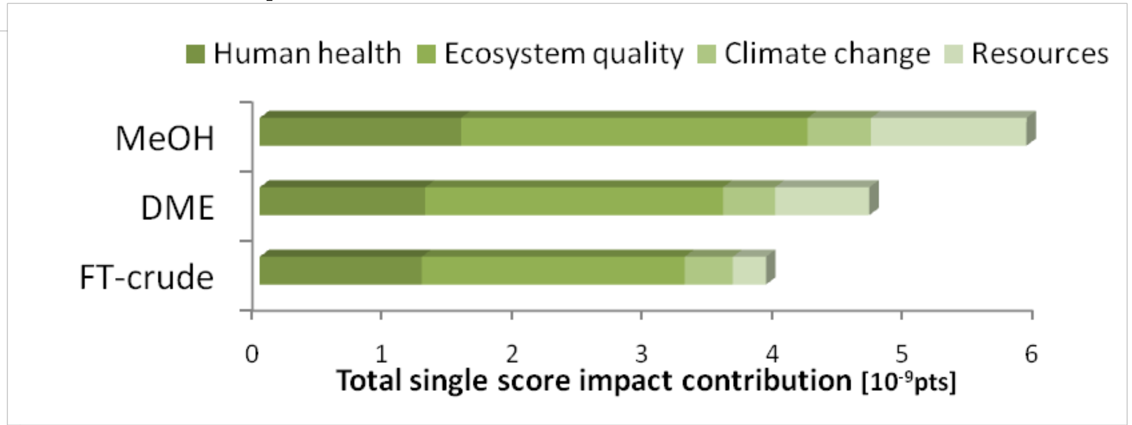
➡ ***Power production***

- ***FT***: *Electricity output !*

Process Performance - Comparison

- Competitiveness: Environmental impacts





➡ ***Major differences***
- ***Electricity consumption***
(Swiss mix for medium voltage electricity production at grid)

➡ ***Largest impact***
- *Gas cleaning:*
Rape methyl ester (RME) from rape cultivated with pesticides !

➡ ***Process improvements:***
Alternative gas cleaning technologies

Conclusion

- Liquid fuel => energy density up to 40 MJ/kg/32 MJ/l
- Biomass 2 Liquid => 50- 60%
  - including co-production of electricity
- Liquid fuels
  - *** FT fuels => integration to refining
  - ** Methanol => fuel or product
  - * DME => green substitute fuel/additive
- Stoichiometry => production of H2 by electrolysis
  - marginal efficiency is 84% Electricity to LHV