Thermochemical conversion of biomass

Synthetic Natural Gas

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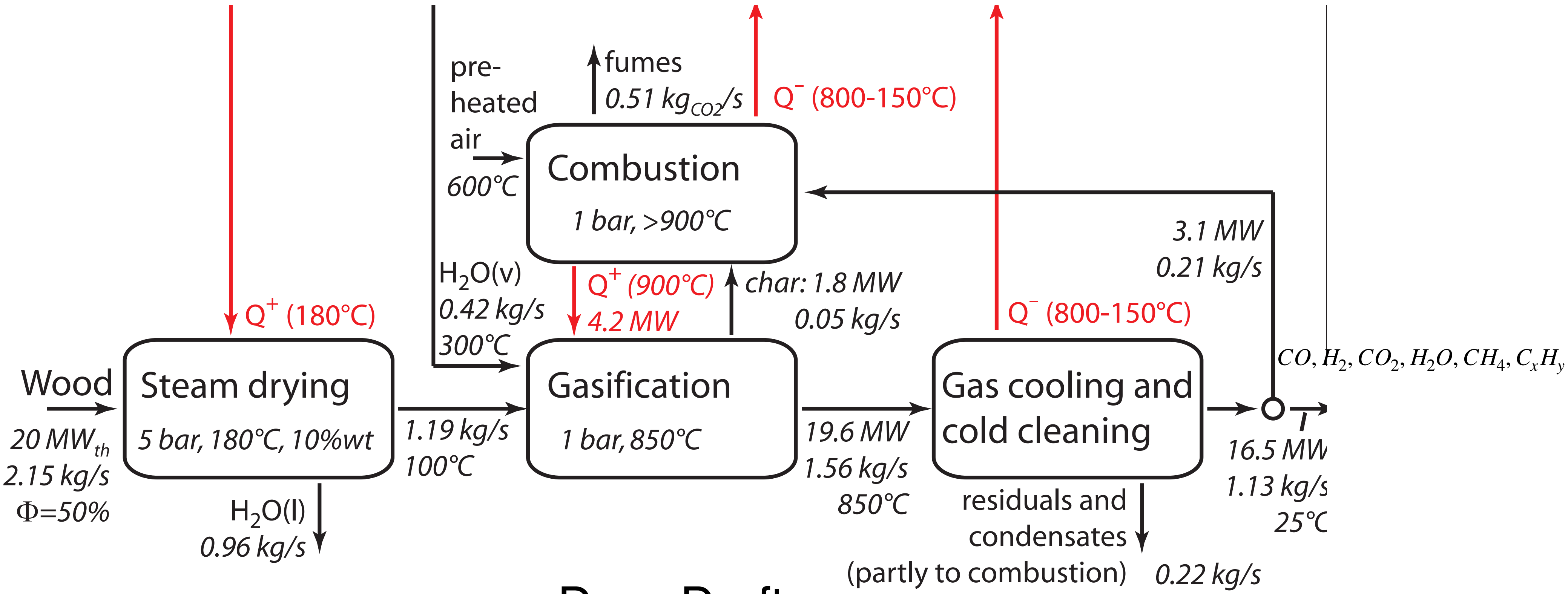
SOLID -> SYNGAS

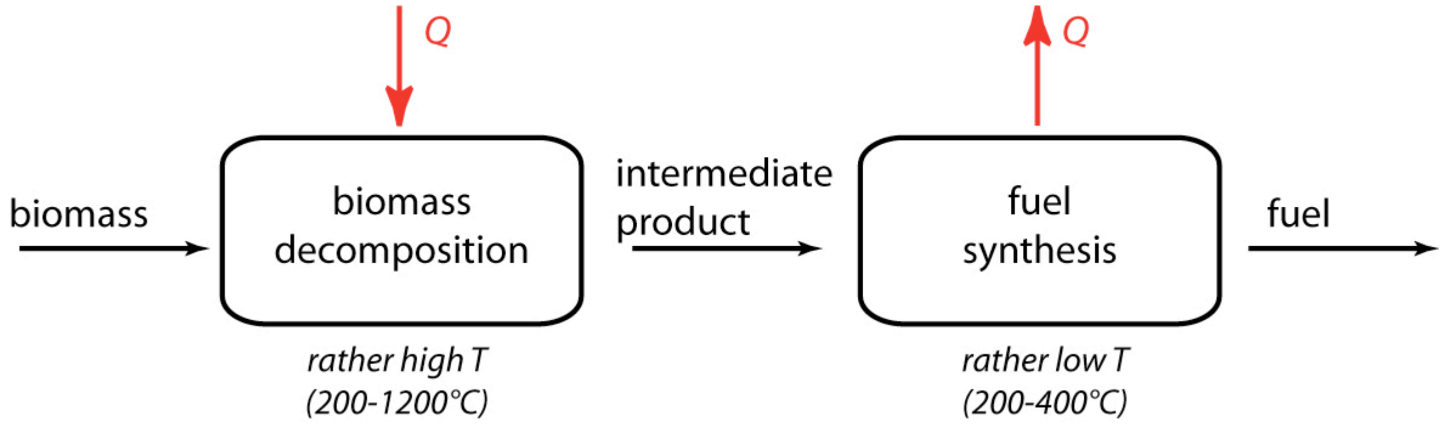


DownDraft
Entrained flow
Indirectly heated
Multi-stage

Thermochemical biomass conversion

Principle of conventional thermochemical routes

Thermochemical biomass to fuel reforming proceeds typically in two (or more) reaction steps:



- gasification
- pyrolysis

non-condensable/ condensable substances (H_2, CO, CO_2, H_2O, CH_4, C_xH_y, char, tars)

- methanation
- FT synthesis
- DME synthesis
- methanol synthesis

Wood to Methane

- Stoechiometry of the methane synthesis reaction from wood

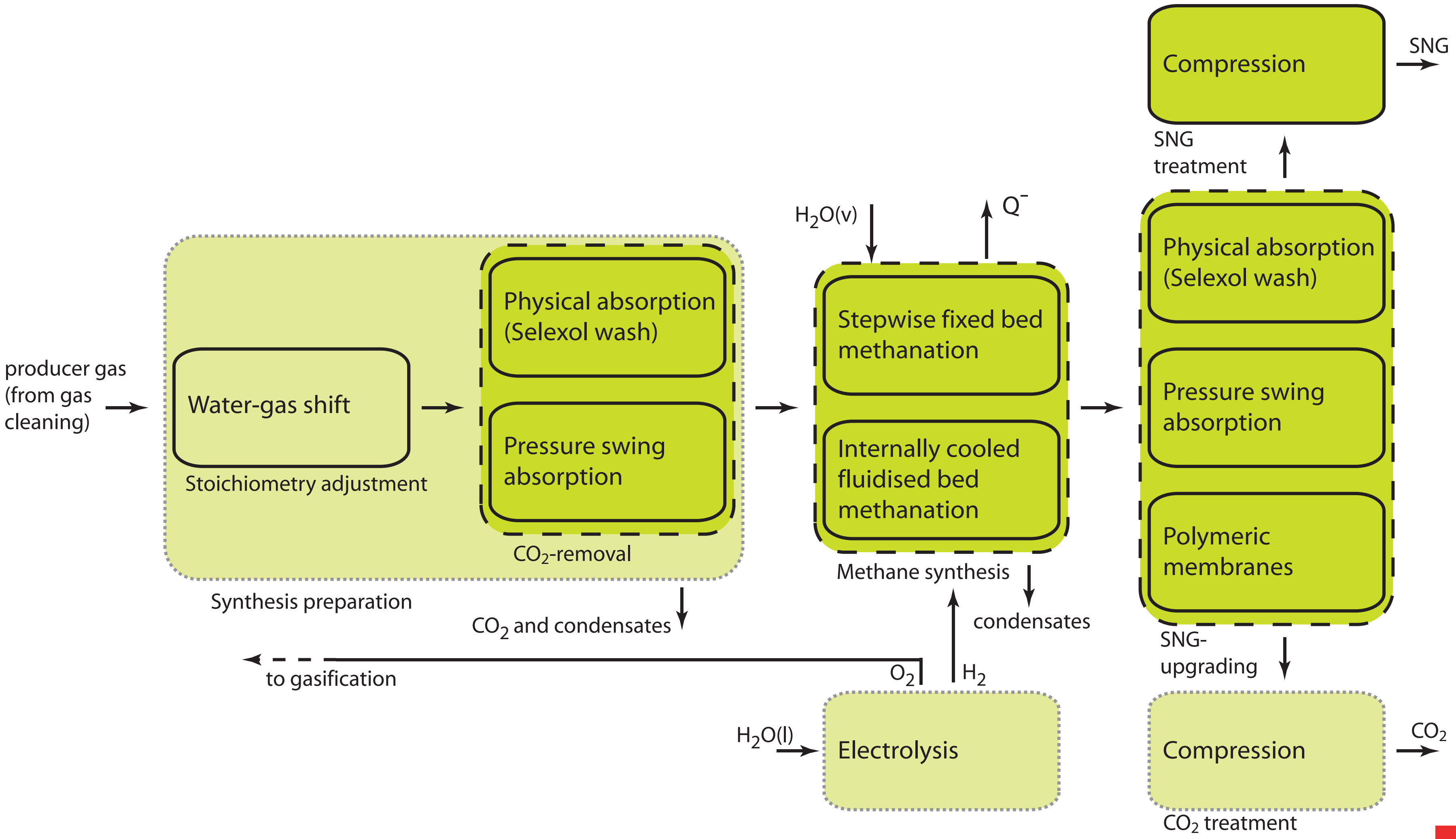
$$CH_{1.35}O_{0.63} + 0.3475H_2O \overset{\Delta H^0 = -10.5\ kJ/mol_{wood}}{\longrightarrow} 0.51125CH_4 + 0.48875CO_2$$

Exothermic

CO2 is a by product

Block flow superstructure

Conventional route (gasification & methanation): synthesis



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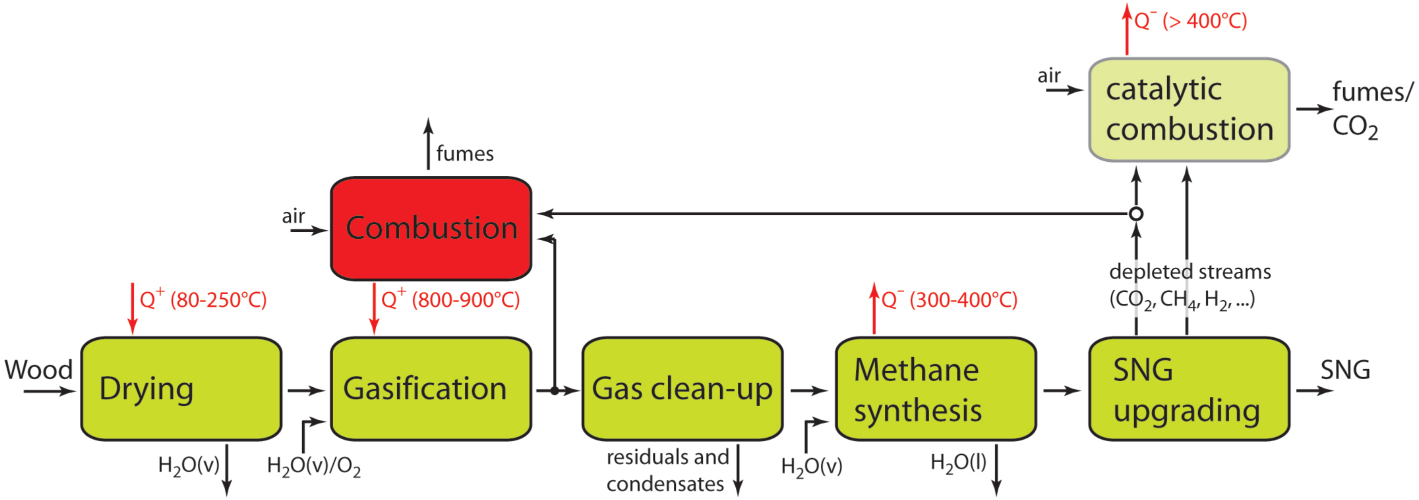
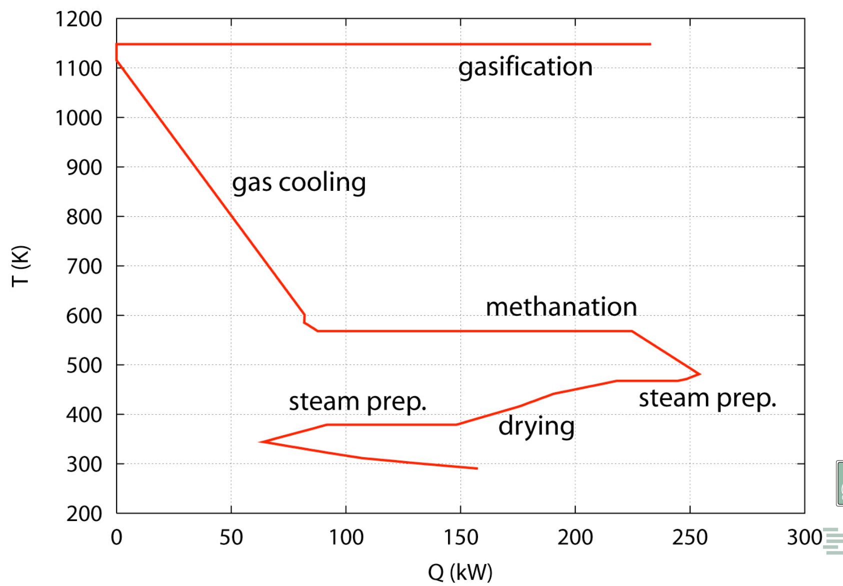
Flowsheet generation (2)
Energy-integration model

Closing the energy balance after heat recovery



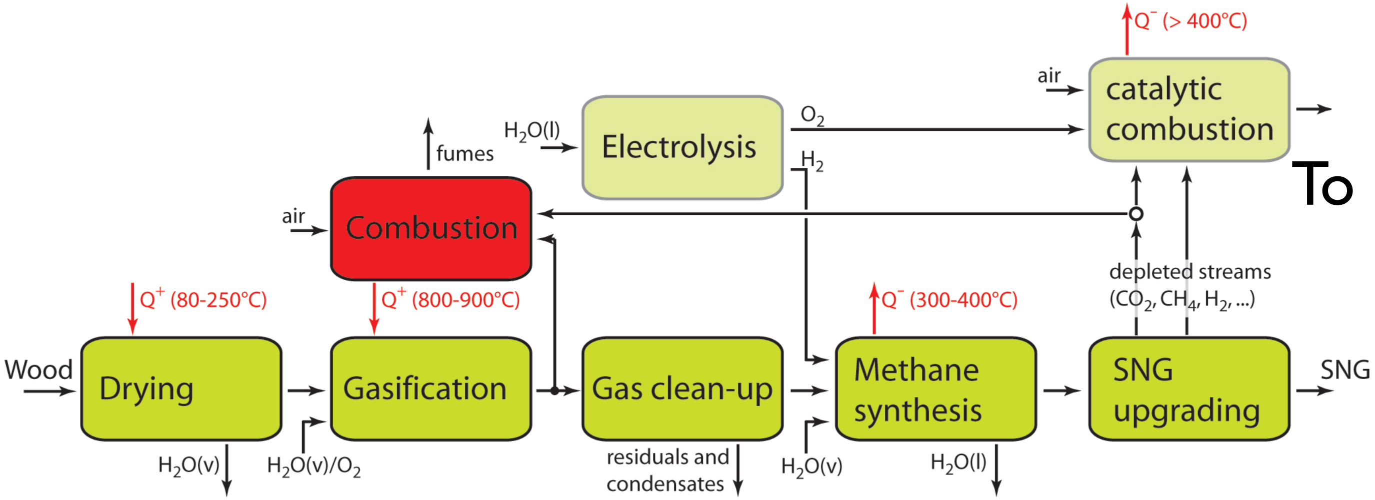
- MER of crude production
- hot utility: combustion
- fuel choice?
    - waste streams
    - intermediate products



Flowsheet generation (2)

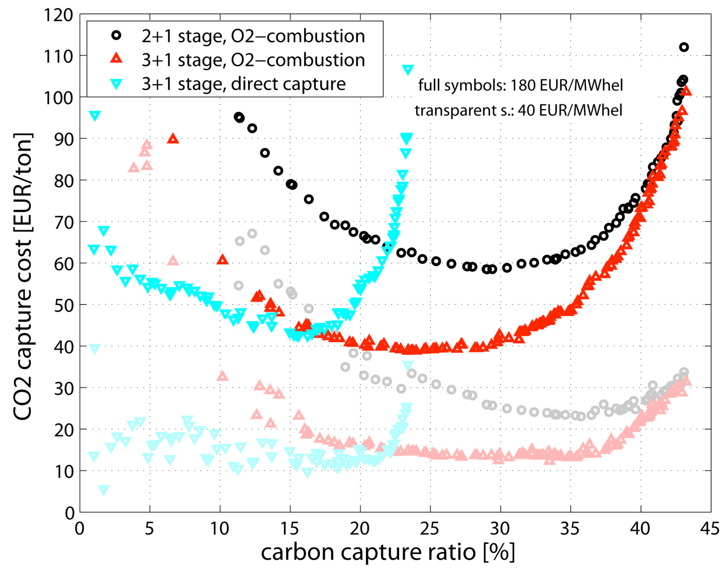
Energy-integration model

Closing the energy balance after heat recovery and produce pure CO2



CO2
To sequestration

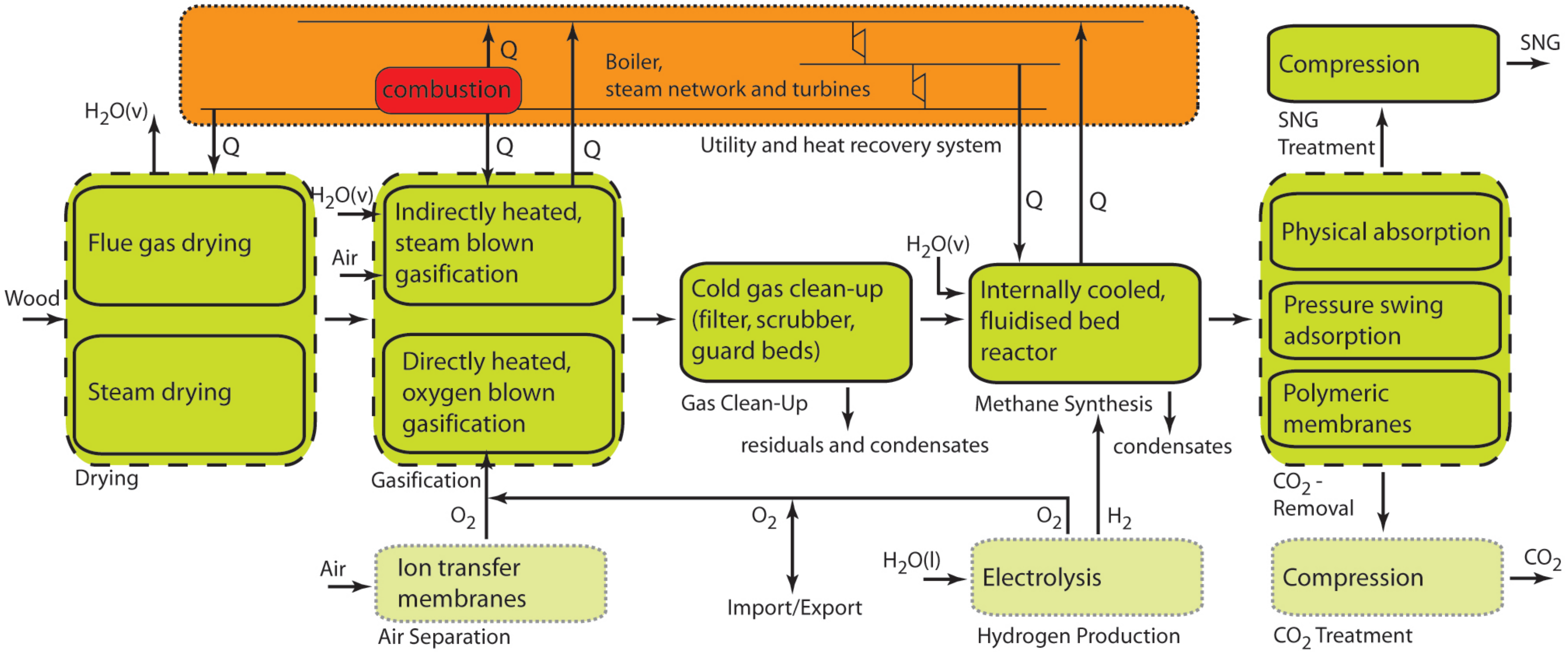
- MER of crude production
- hot utility: combustion
- fuel choice?
- perspective: CCS at < 15 €/t



Flowsheet generation (2)

Energy-integration model

Integrating heat recovery technologies in the superstructure



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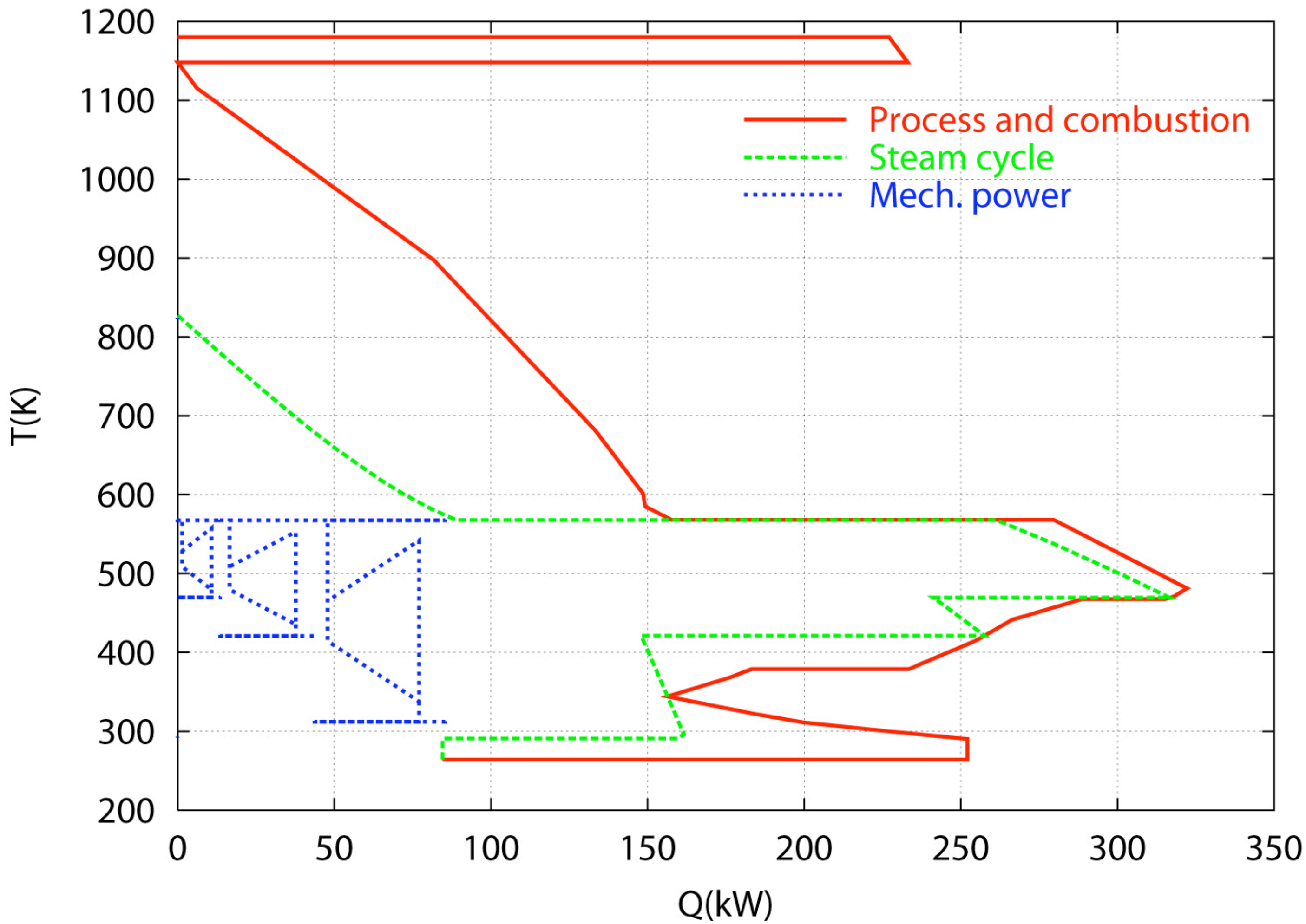
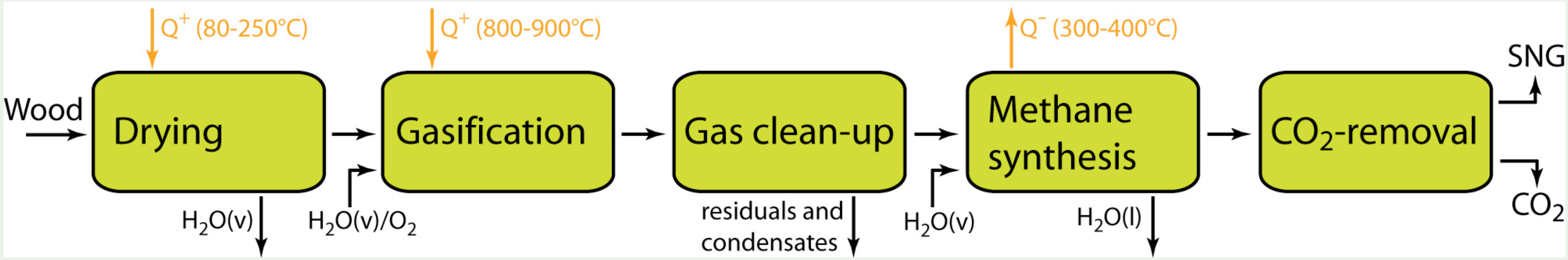
Flowsheet generation (2)
Energy-integration model

MILP resolution: ... to an integrated solution



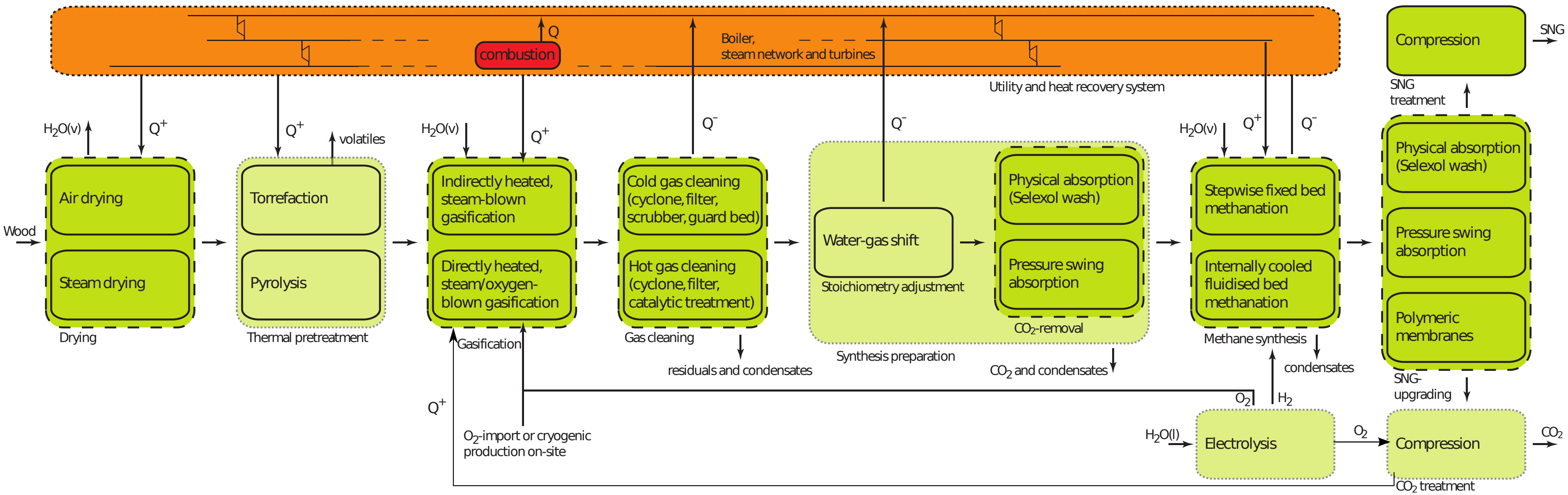
BIOSNG process design

Example: Common wood to SNG route



$$CH_{1.35}O_{0.63} + 0.3475H_2O \xrightarrow{\Delta H^0 = -10.5\ kJ/mol_{wood}} 0.51125CH_4 + 0.48875CO_2$$

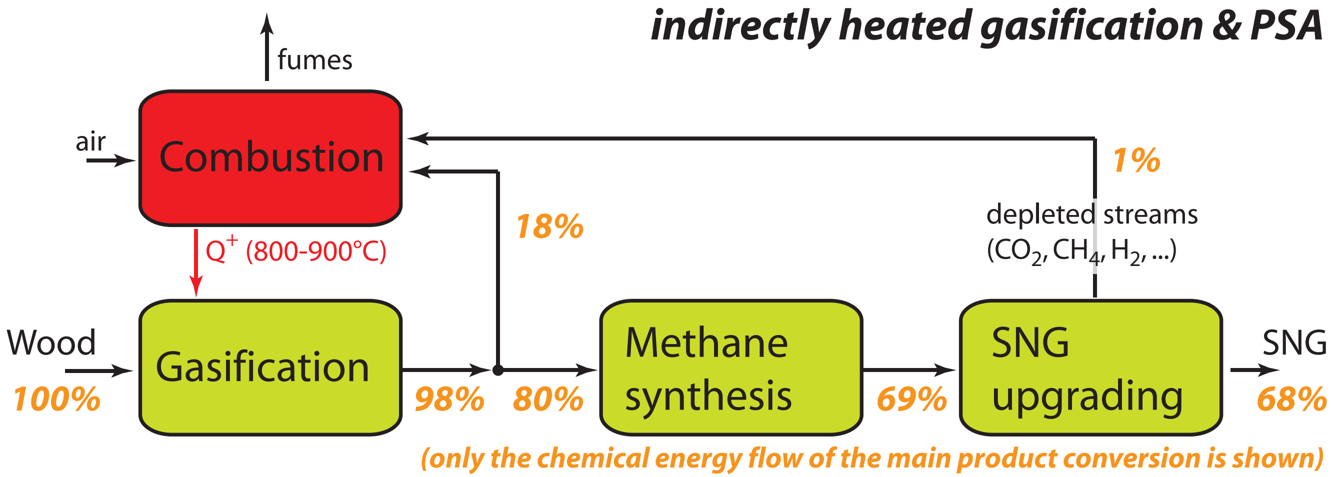
Process superstructure

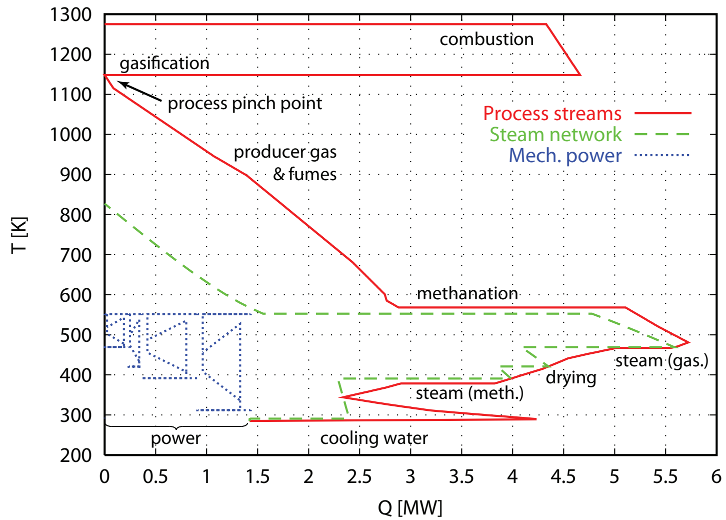


Process performance

conventional SNG

Some (non-optimised) scenarios for conventional SNG production:





input: $20\ MW_{th,wood}$

		FICFB				CFB	
		(base)	(torr)	(pM)	(pM, SA)	(pGM)	(pGM, hot)
Consumption	Wood	100%	100%	100%	100%	100%	100%
	Biodiesel	1.8%	1.6%	1.8%	1.8%	0.1%	-
	Electricity	-	0.5%	-	-	0.9%	-
Production	SNG	67.7%	72.1%	67.5%	67.8%	74.0%	74.0%
	Electricity	2.9%	-	2.6%	3.3%	-	1.6%
Overall efficiency		69.4%	70.7&	68.8%	69.8%	73.2%	75.6%

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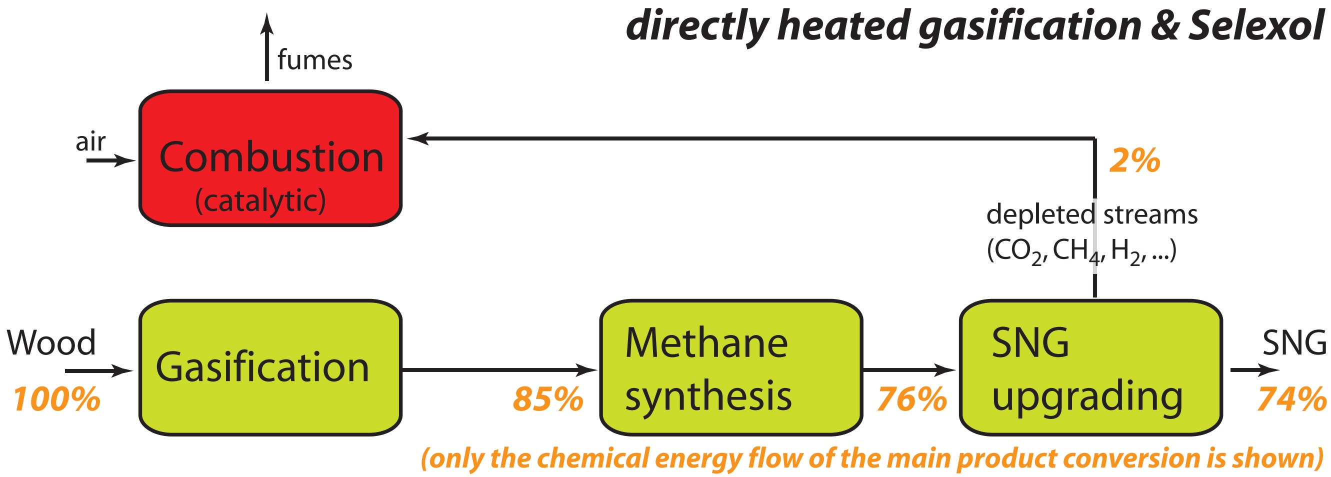

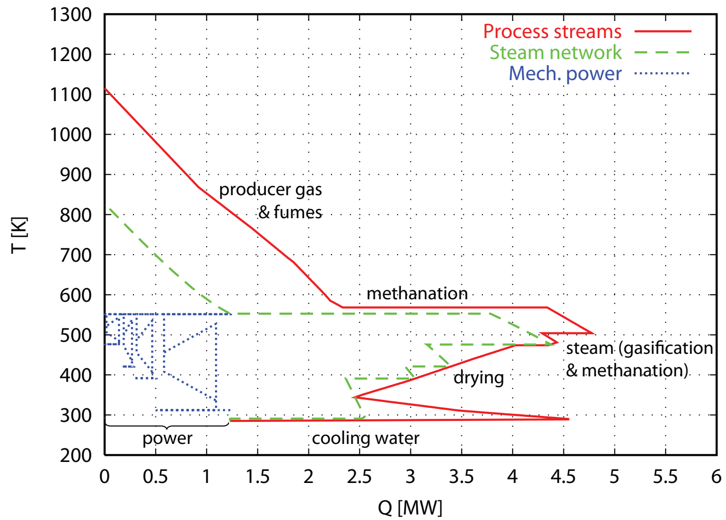

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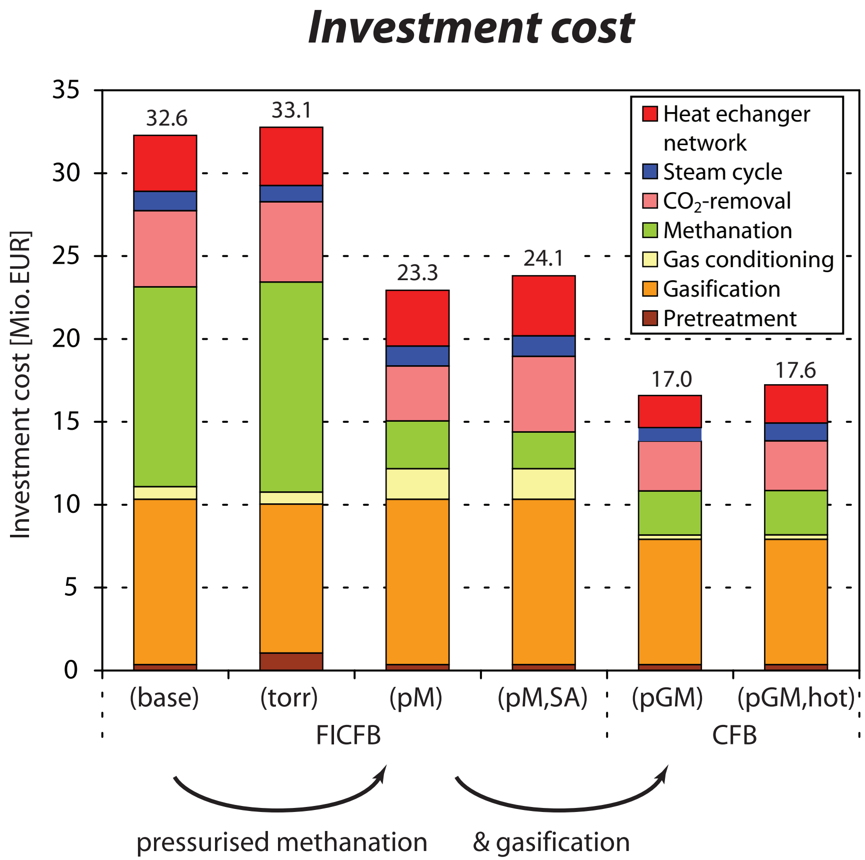
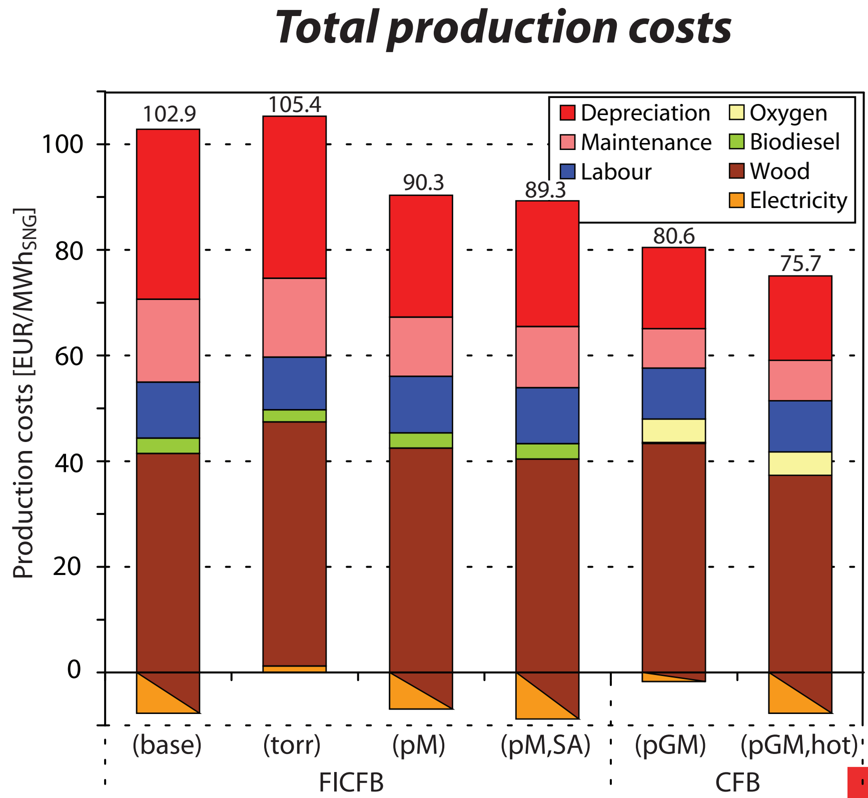
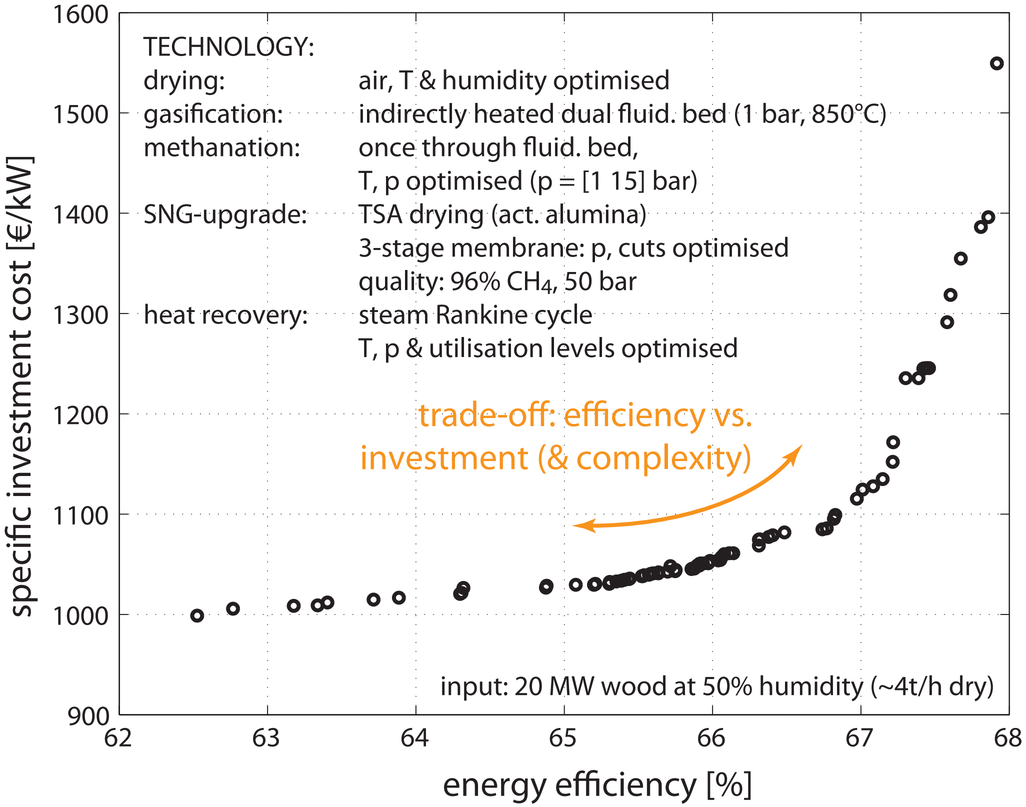




Thermo-economic optimisation

Trade-offs: efficiency and scale vs. investment

Efficiency vs. investment:



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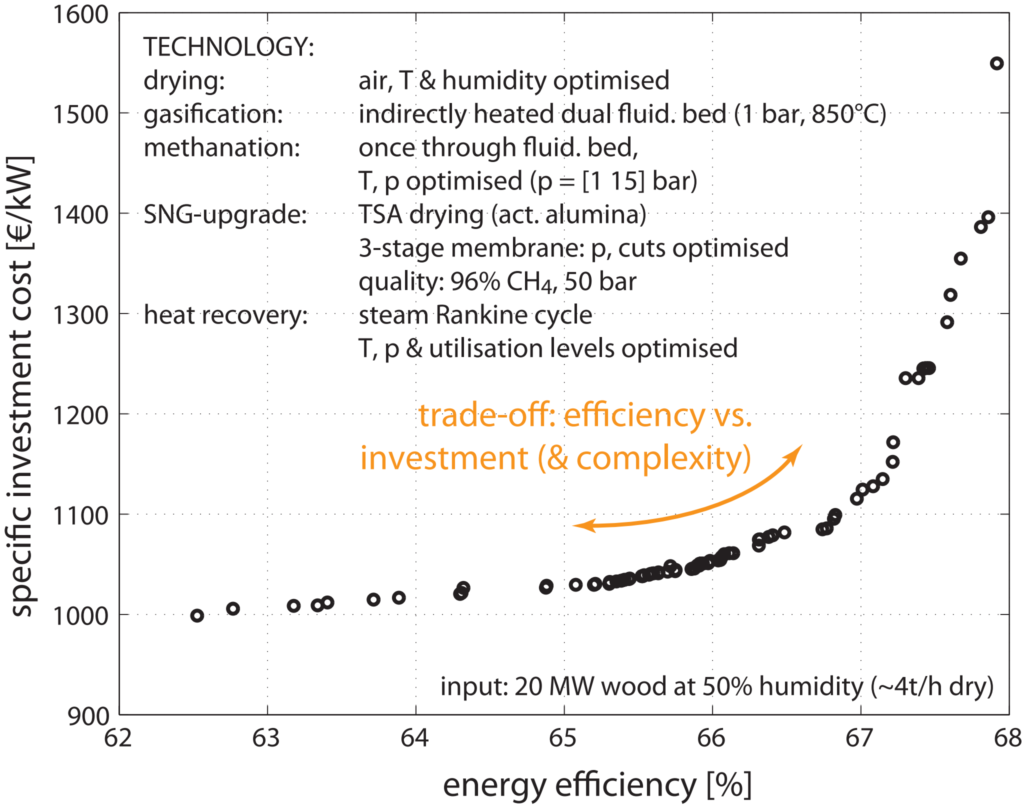
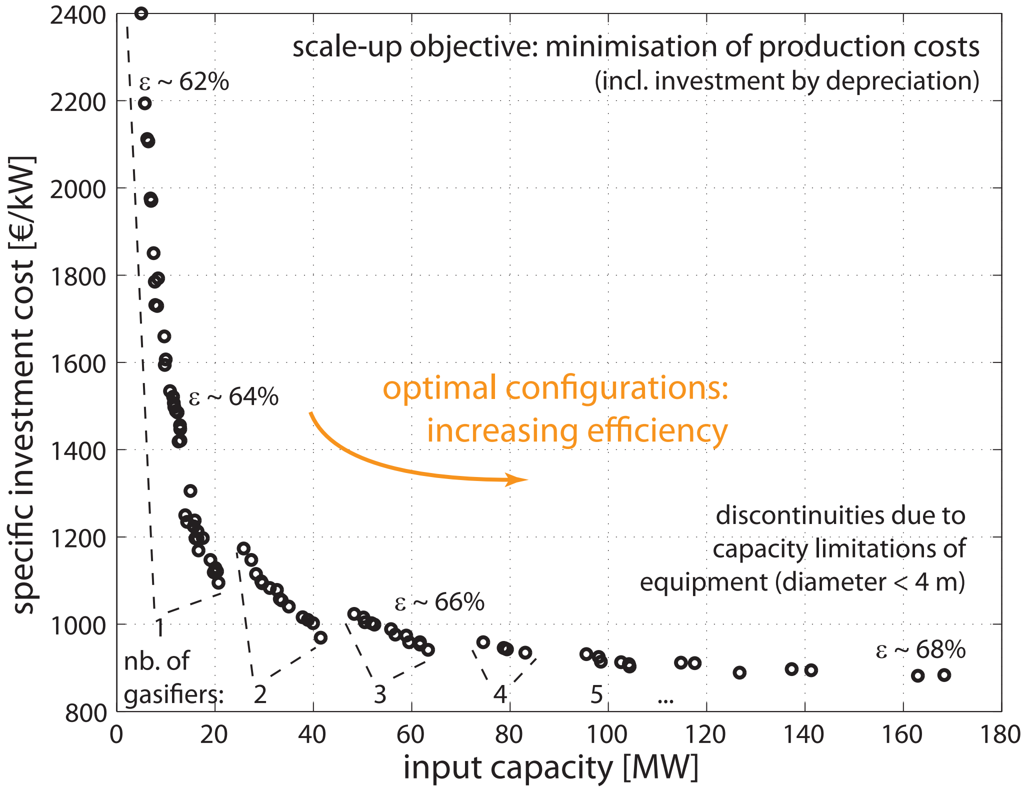
Thermo-economic optimisation

Trade-offs: efficiency and scale vs. investment

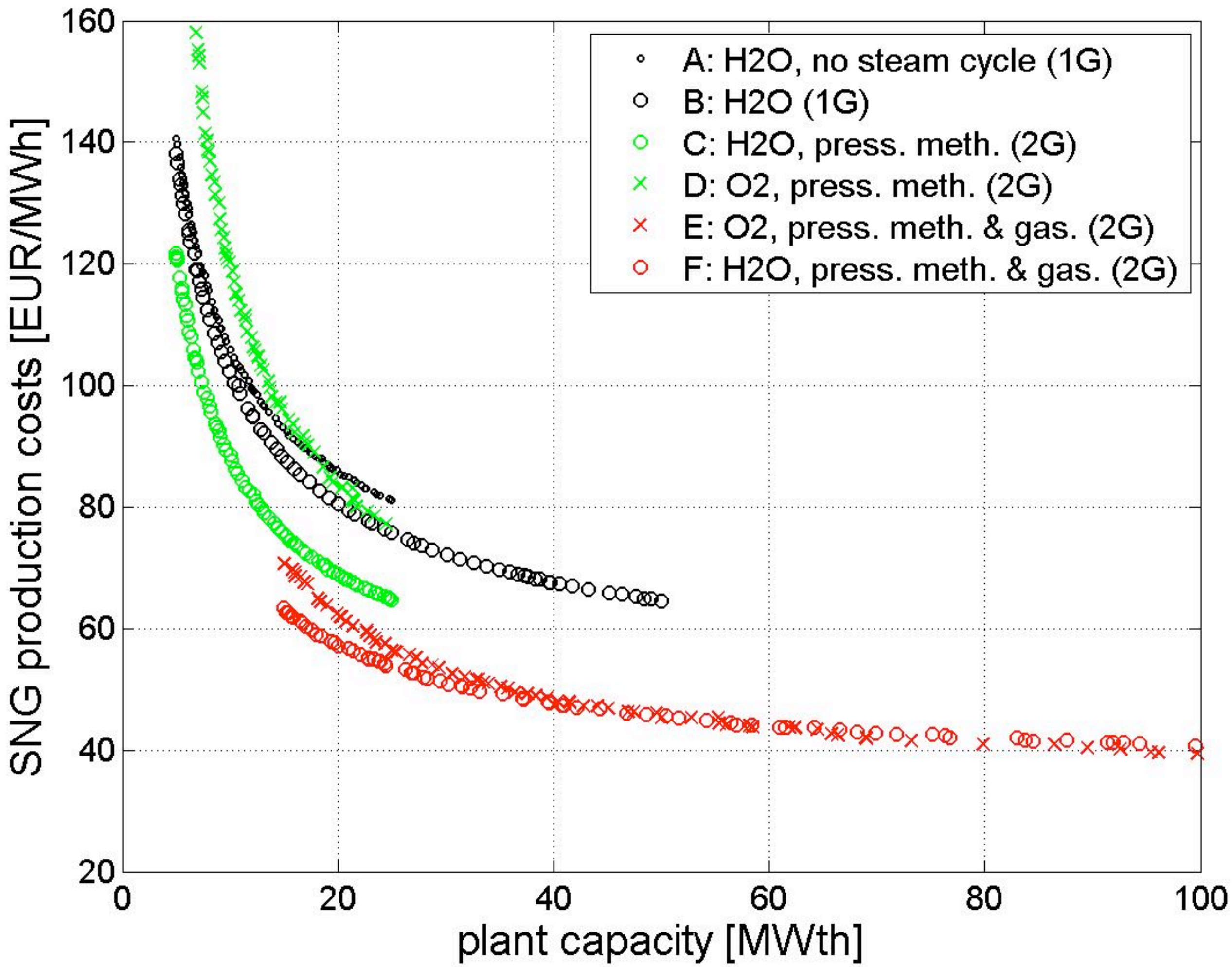
Efficiency vs. investment and optimal scale-up:



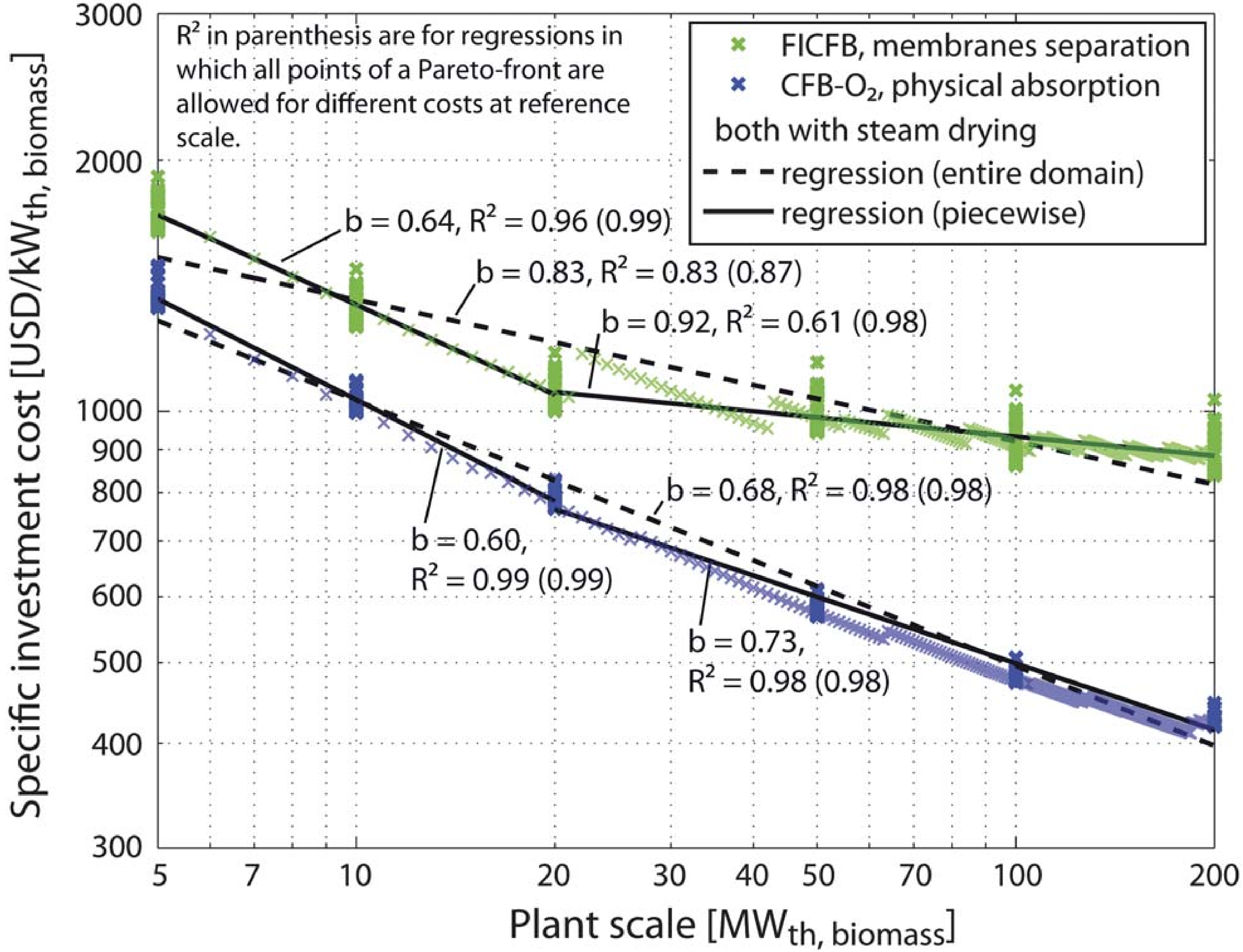


Comparing process configurations
Perspective: comparing process generations

Plant capacity vs. production costs



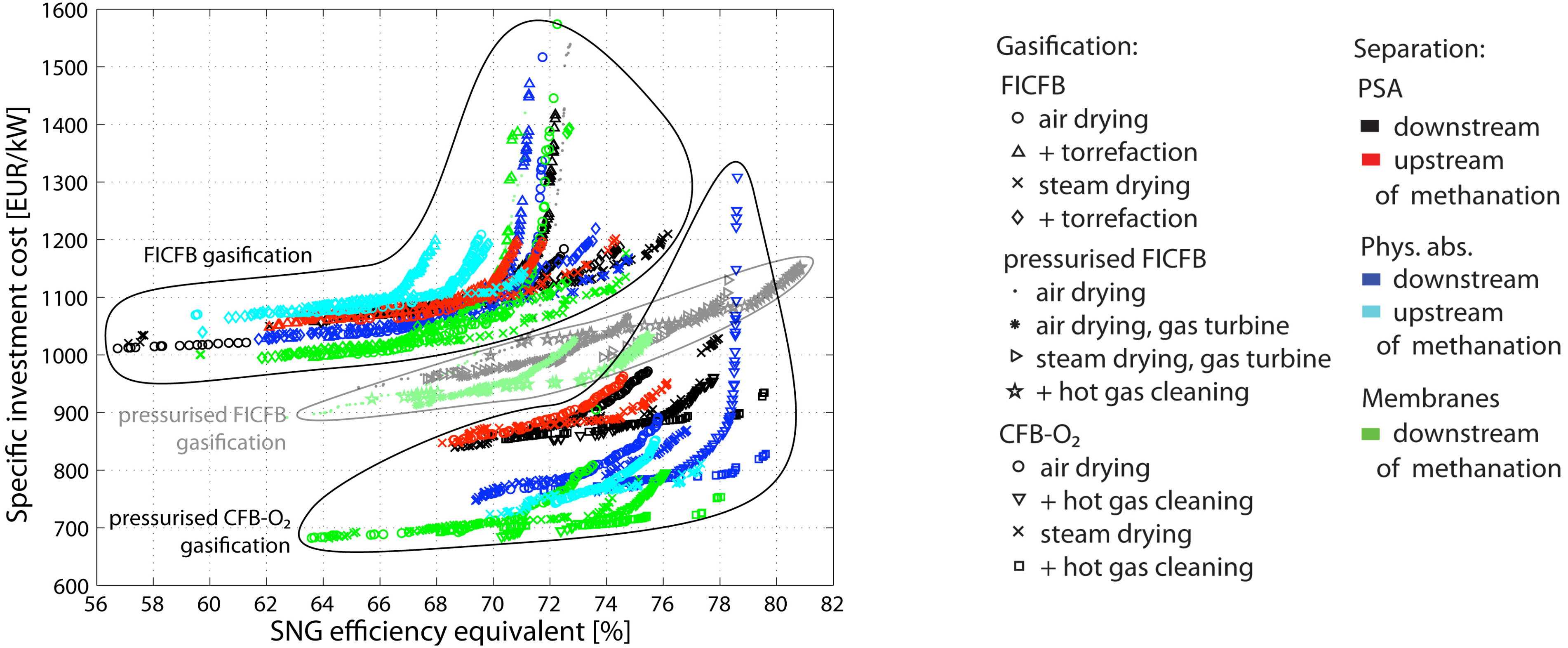
$$Capex(MW_{biomass}) = CAPEX_0 \cdot (MW_{biomass})^b$$



Comparing options

- Each point of the Pareto is a process design

Thermo-economic Pareto front (cost vs efficiency):

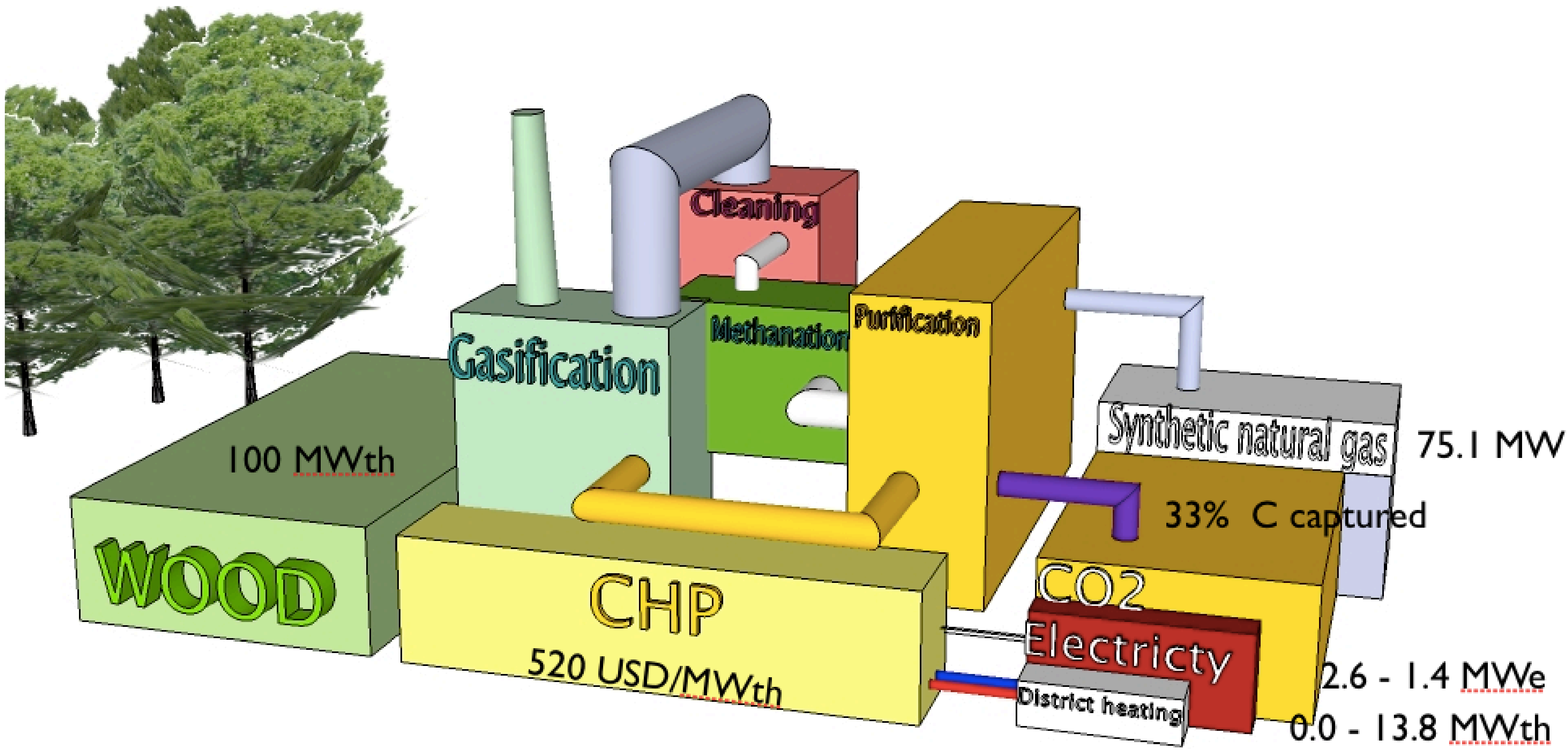


Note : 1.5 years of calculation time !

Gassner, Martin, and François Maréchal. *Energy & Environmental Science* 5, no. 2 (2012): 5768 – 5789.

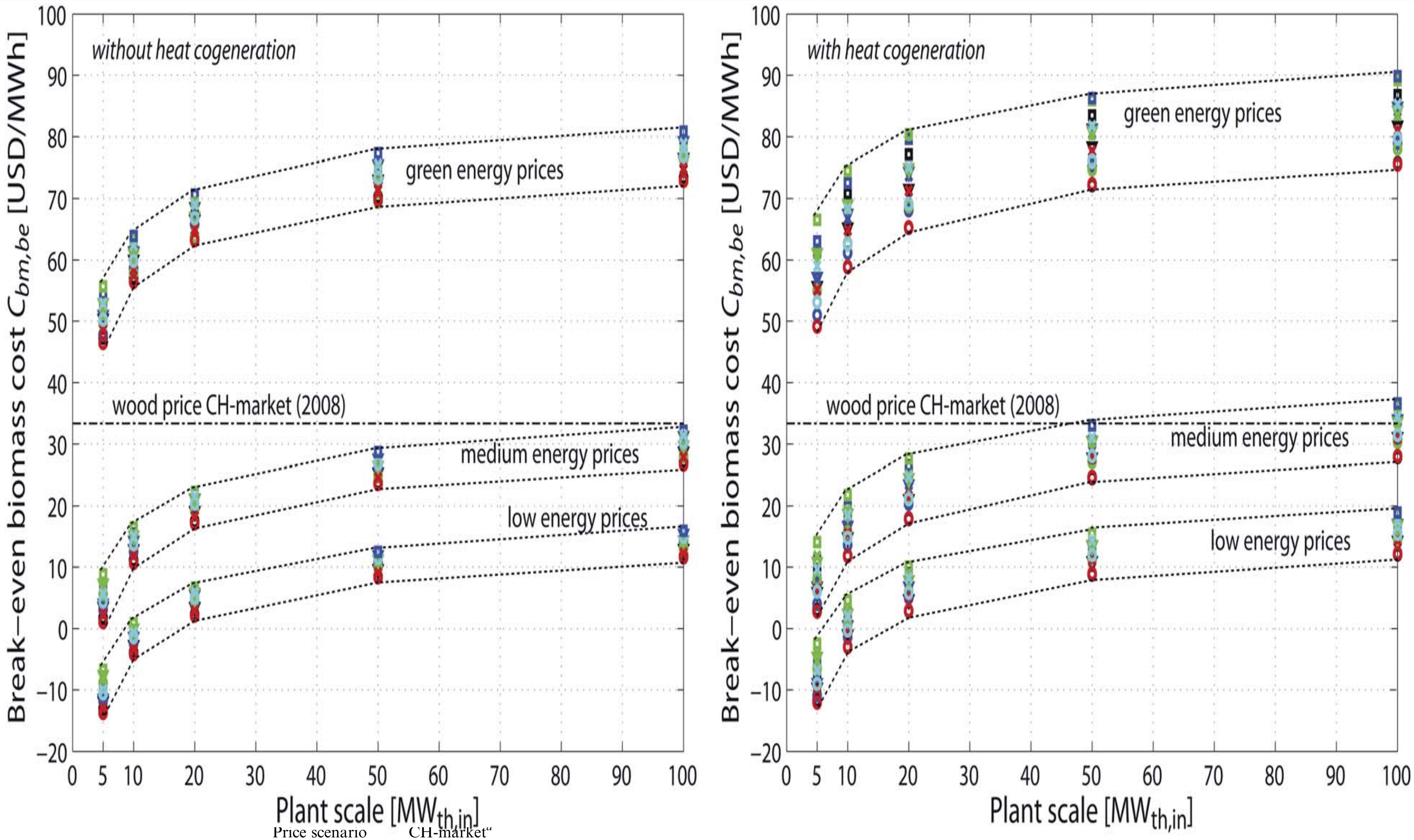
BIOSNG process

- Resource productivity : + 33% per forest m²



From conventional (58%) to optimised (> 75% eff.)

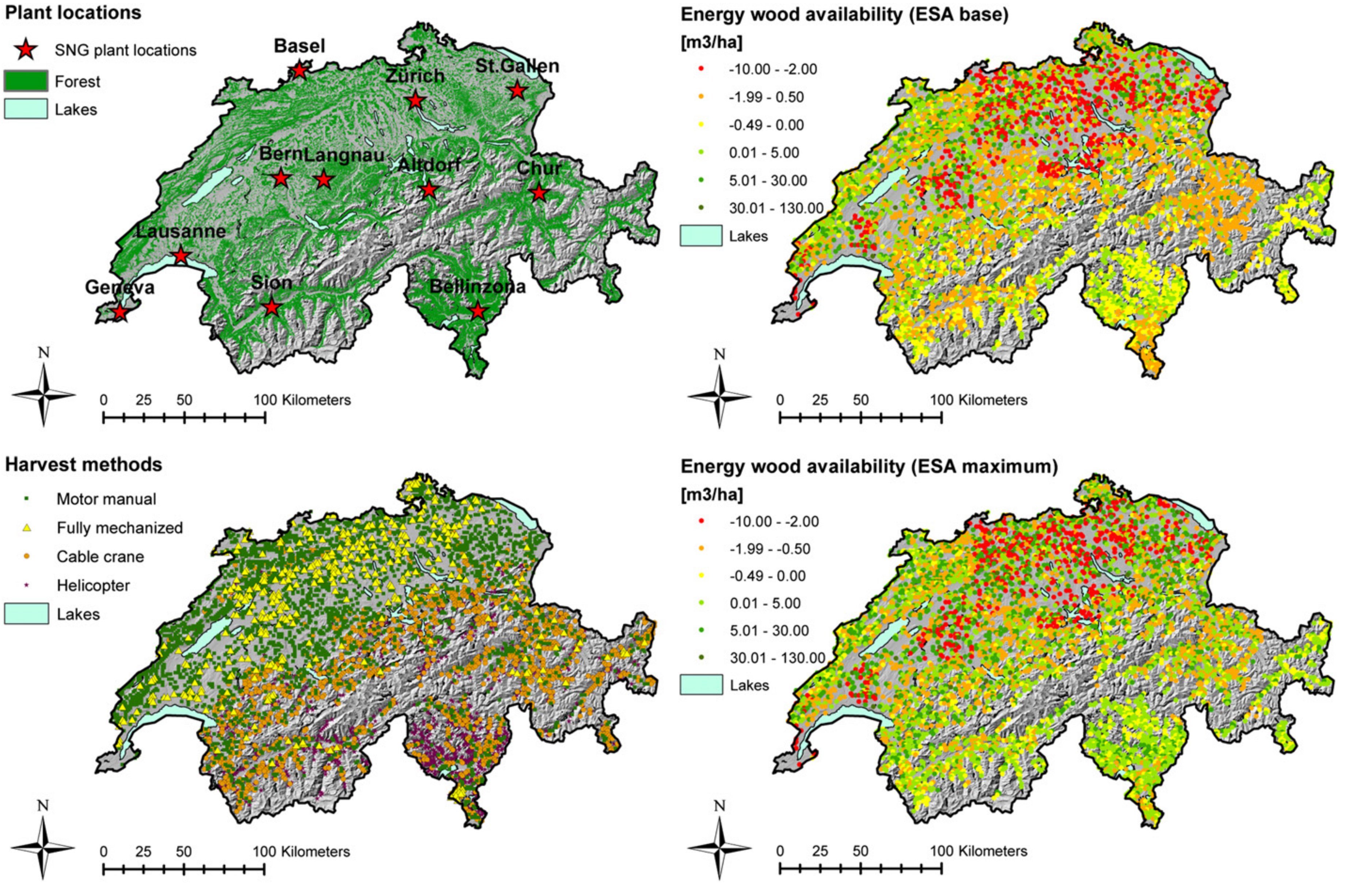
Break-even cost of the resource



			Price scenario			CH-market"	
:nergy vector		Unit	Green	Mid	Low	1999	2008/09
lectricity	C_{el}	\$ MWh^{-1}	180	90	60	90–135	80–160
utomotive uel & SNG	C_{SNG}	\$ MWh^{-1}	120	60	40	80–95	130–140
ndustrial heat	C_q	\$ MWh^{-1}	80	40	26.6	20–35	40–65

Including tax. Figures for 1999 are from Previdoli and Beck,[60] 2008/09 approximate.

Biomass availability



Steubing B, et al., Identifying environmentally and economically optimal bioenergy plant sizes and locations: A spatial model of wood-based SNG value chains, Renewable Energy (2012), http://dx.doi.org/10.1016/j.renene.2012.08.018

Transportation costs

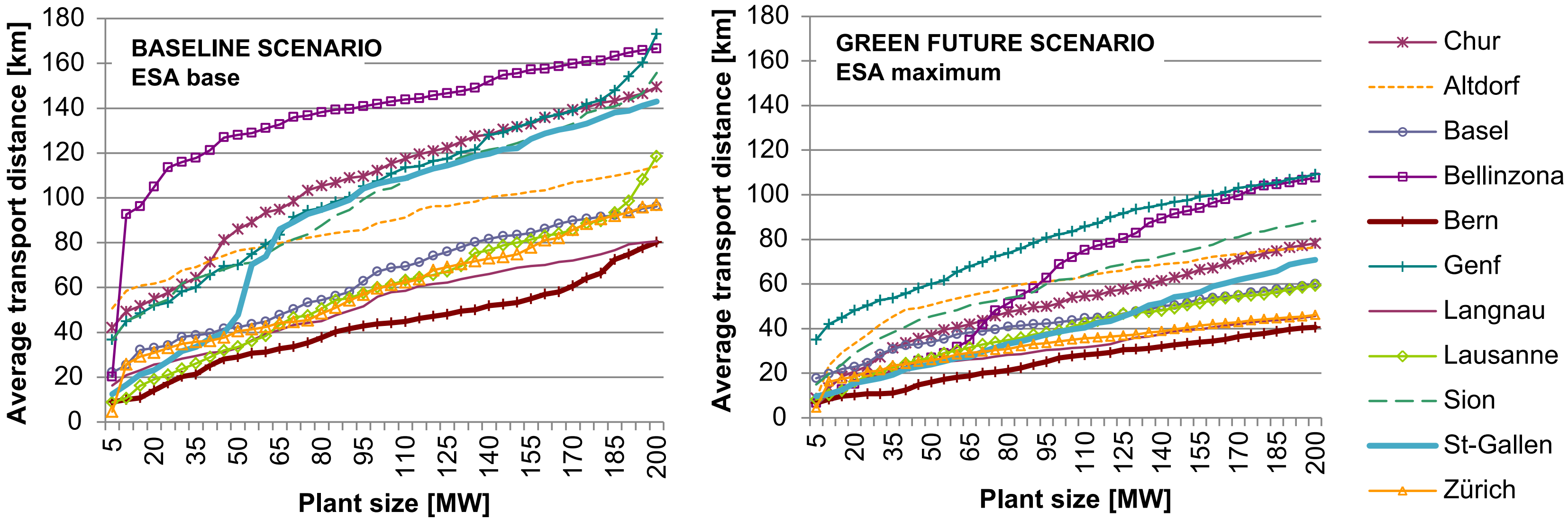
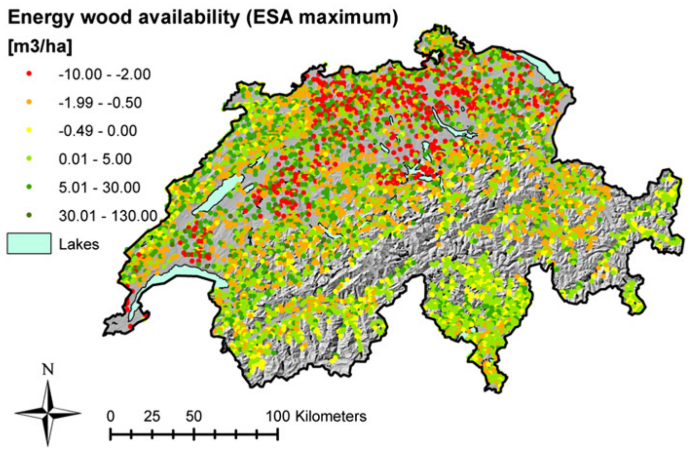


Fig. 6. Transport distances according to plant sizes, locations, and wood availability scenario (left: ESA base, right: ESA maximum).

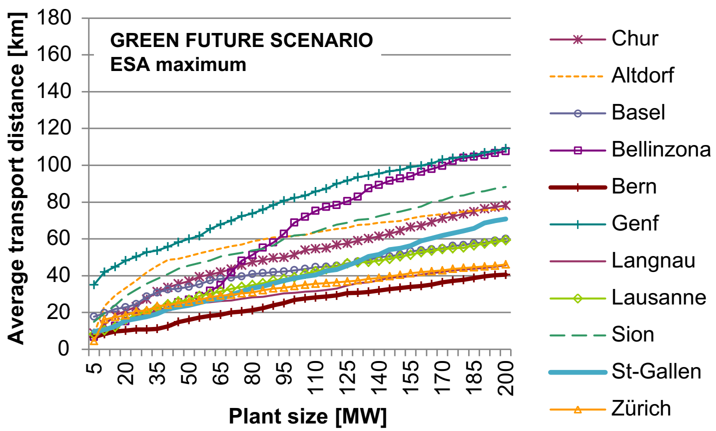
Steubing B, et al., Identifying environmentally and economically optimal bioenergy plant sizes and locations: A spatial model of wood-based SNG value chains, Renewable Energy (2012), http://dx.doi.org/10.1016/j.renene.2012.08.018

Plant location

Area = 40 km2



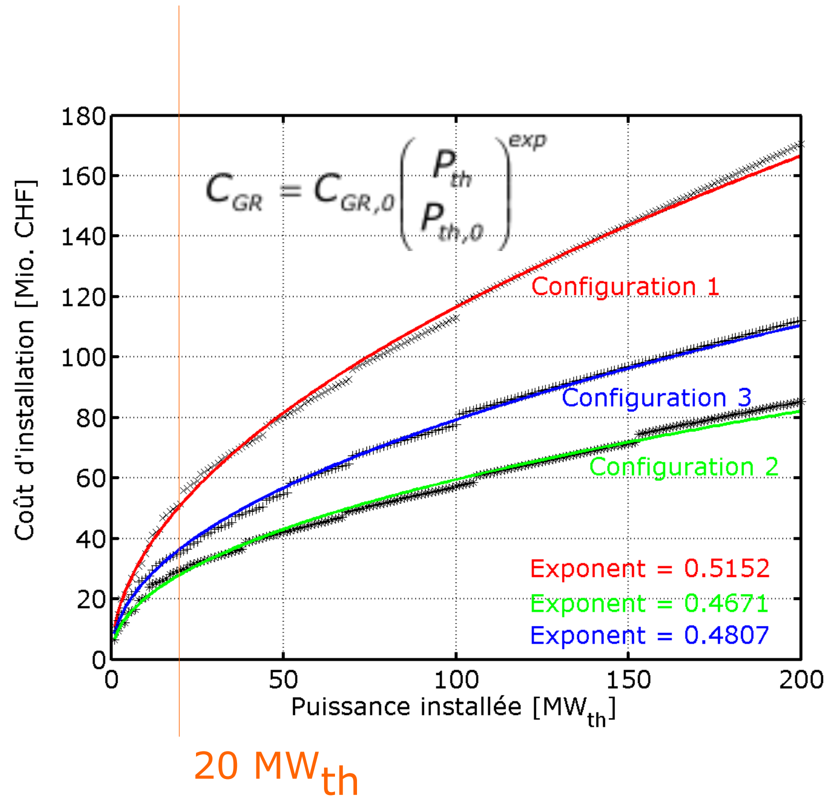
Transport = 10 % of the energy



Process Size => Investment

20 MW_{th}:

- 51.4 Mio. CHF (1)
- 29.5 Mio. CHF (2)
- 35.4 Mio. CHF (3)

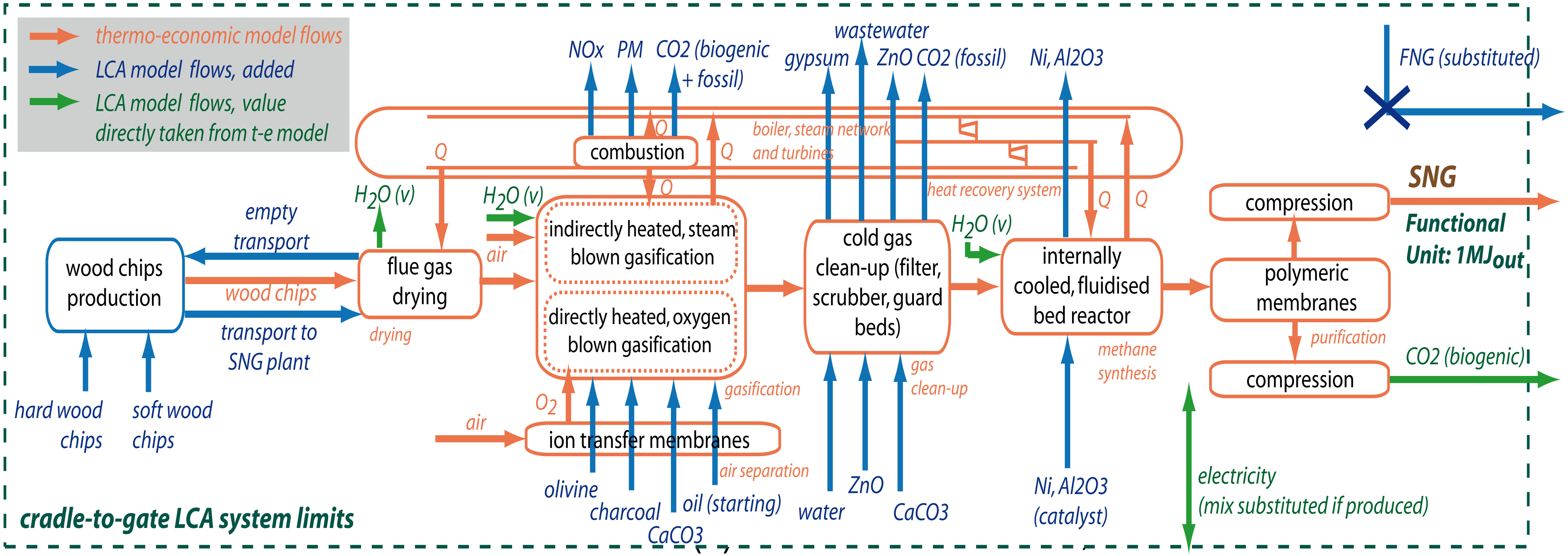


Efficiency : 5000 Wyear/year/ha

Environmental Process performance indicators

Identification of Life Cycle Inventory elements

- Process superstructure, extended with LCI

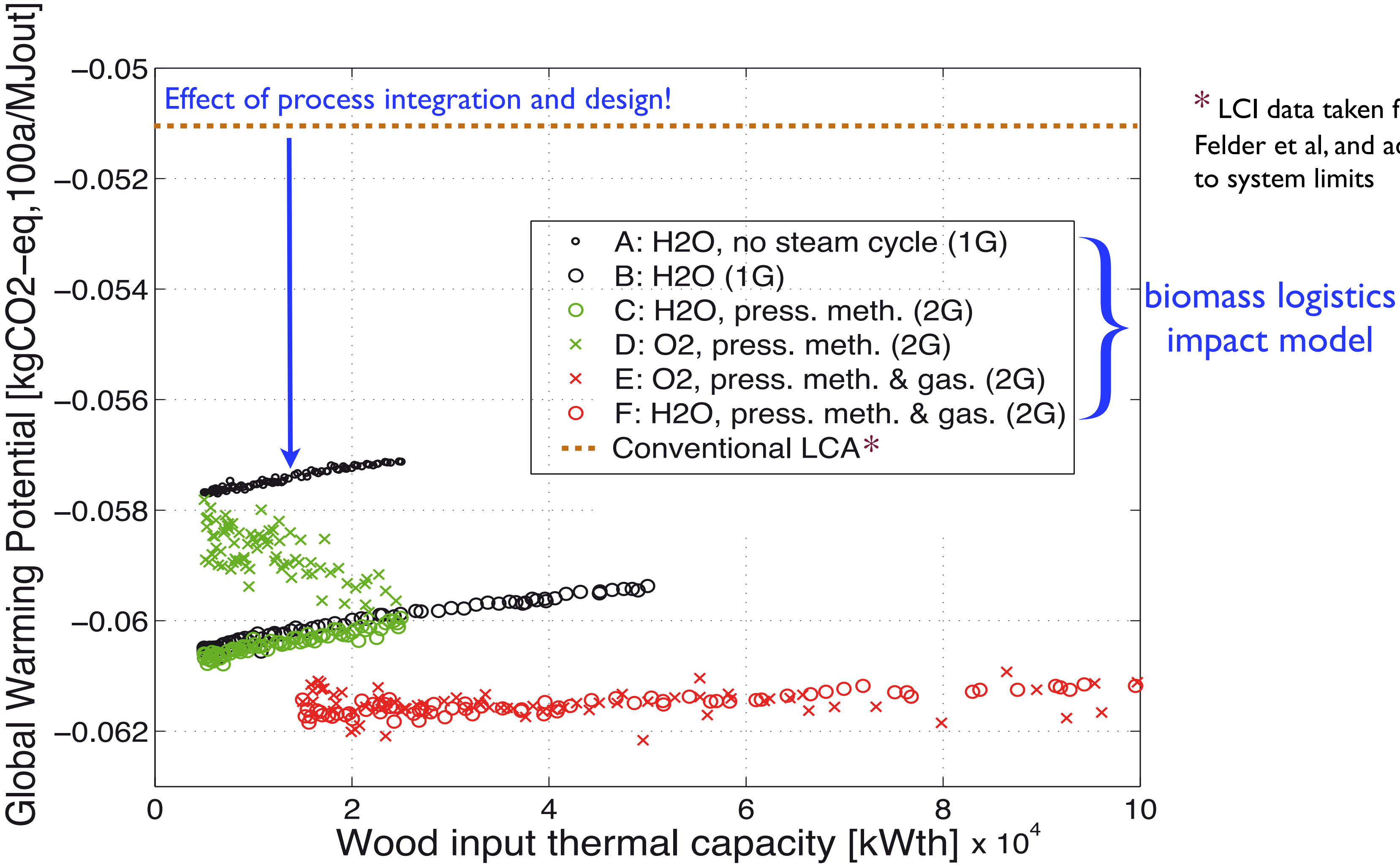


site emissions

(1) http://www.ecoinvent.org

Gerber, L. et al., 2010 Comp & Chem Eng., 1405-1410

The biomass Logistics has an influence on the plant impact

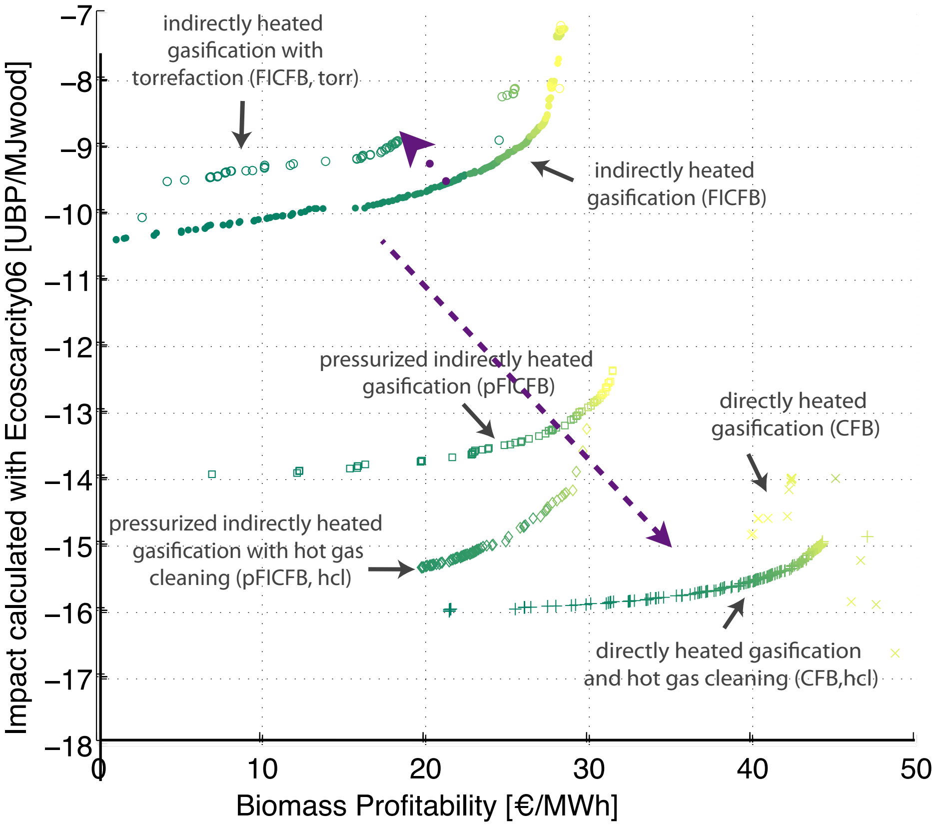


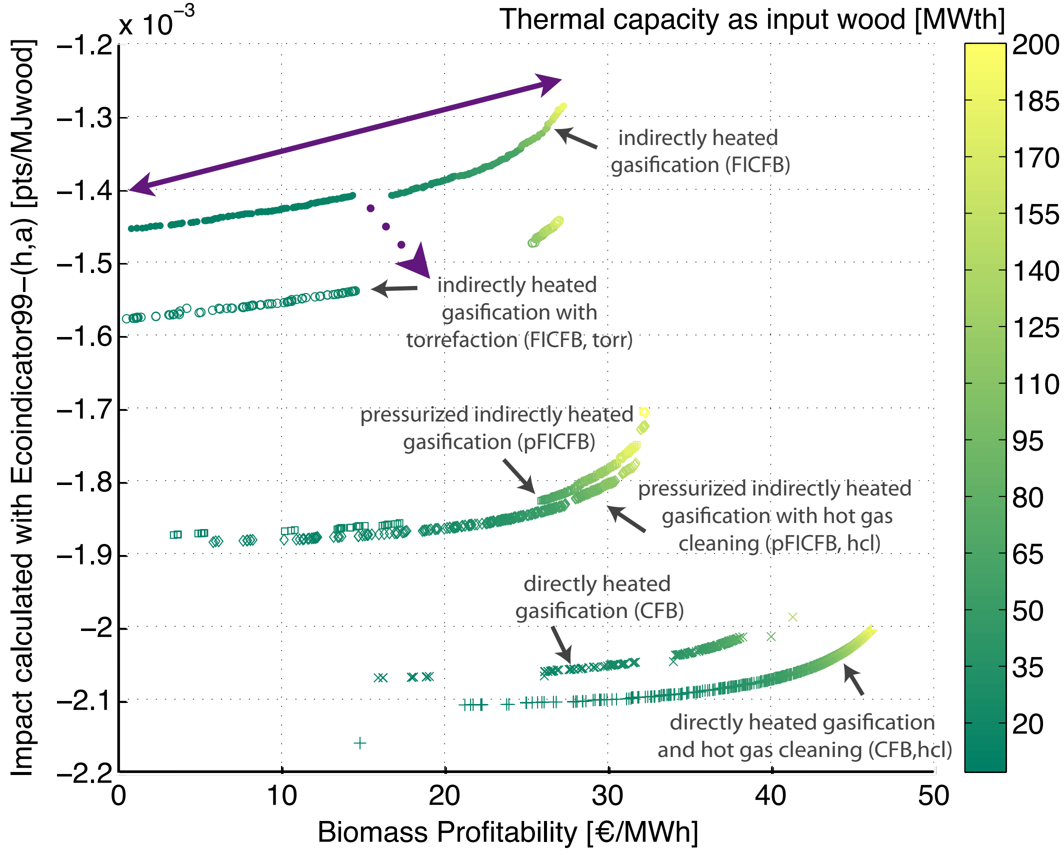
* LCI data taken from Felder et al, and adapted to system limits

→ *Optimal plant size with respect to biomass logistics*

Multi-objective optimization results

- Optimal configurations





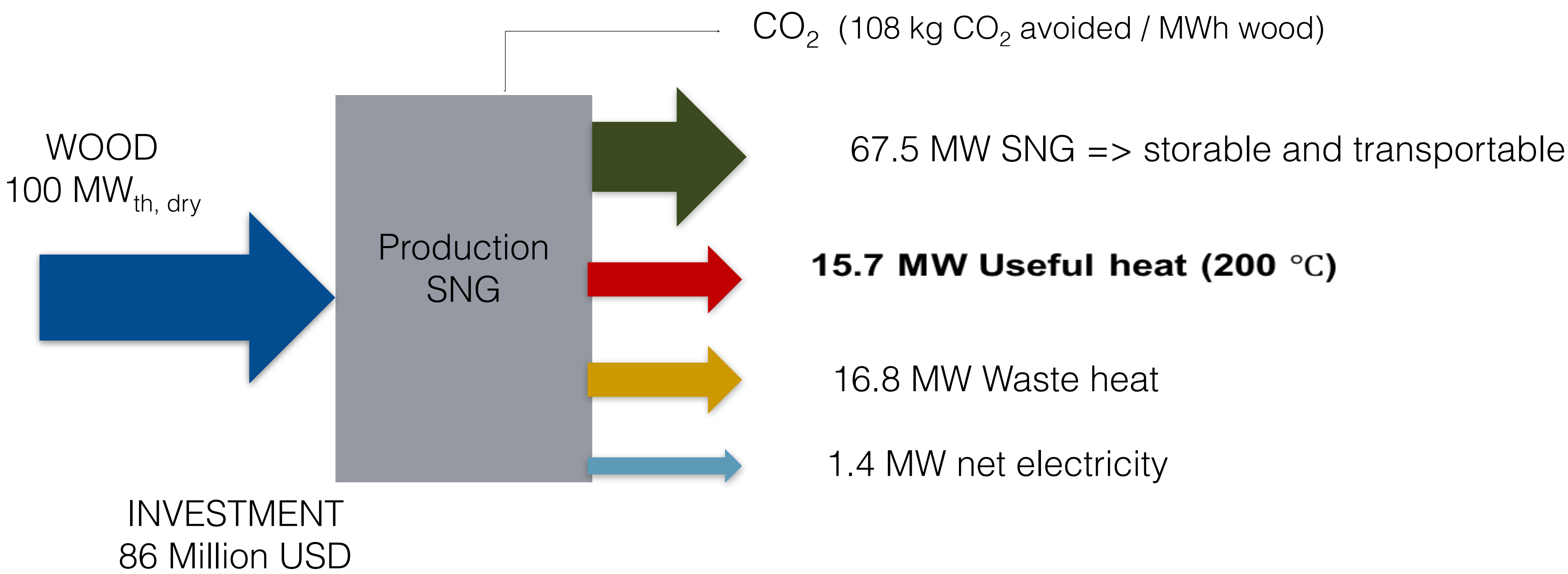
1. *Process scale*

2. *Technology evolution*

3. *Environmental objective function*

Thesis L. Gerber 2012

The green boiler => use of the renewable resource



- Co production of biofuel from wood
  - Synthetic natural gas, methanol, DME, F-T fuels
  - CO2 capture
  - Exothermic => Heat supply
  - Cogeneration of Heat

COST OF HEAT
25 $/MWh (- 47 $/MWh)*

** with CO2 tax*

With market price of WOOD (40$/MWh) and NG (65 $/MWh) and with CO2 taxes (80 CHF/ton), also for capture
8000 hours/year of operation

Synthetic Natural Gas production

- Convert biomass to gas in the grid
  - Efficiency = 70% (LHV Biomass => LHV Gas)
  - Heat can be reused = +15%
  - CO_2 can be separated (negative emissions)