Thermochemical conversion of biomass

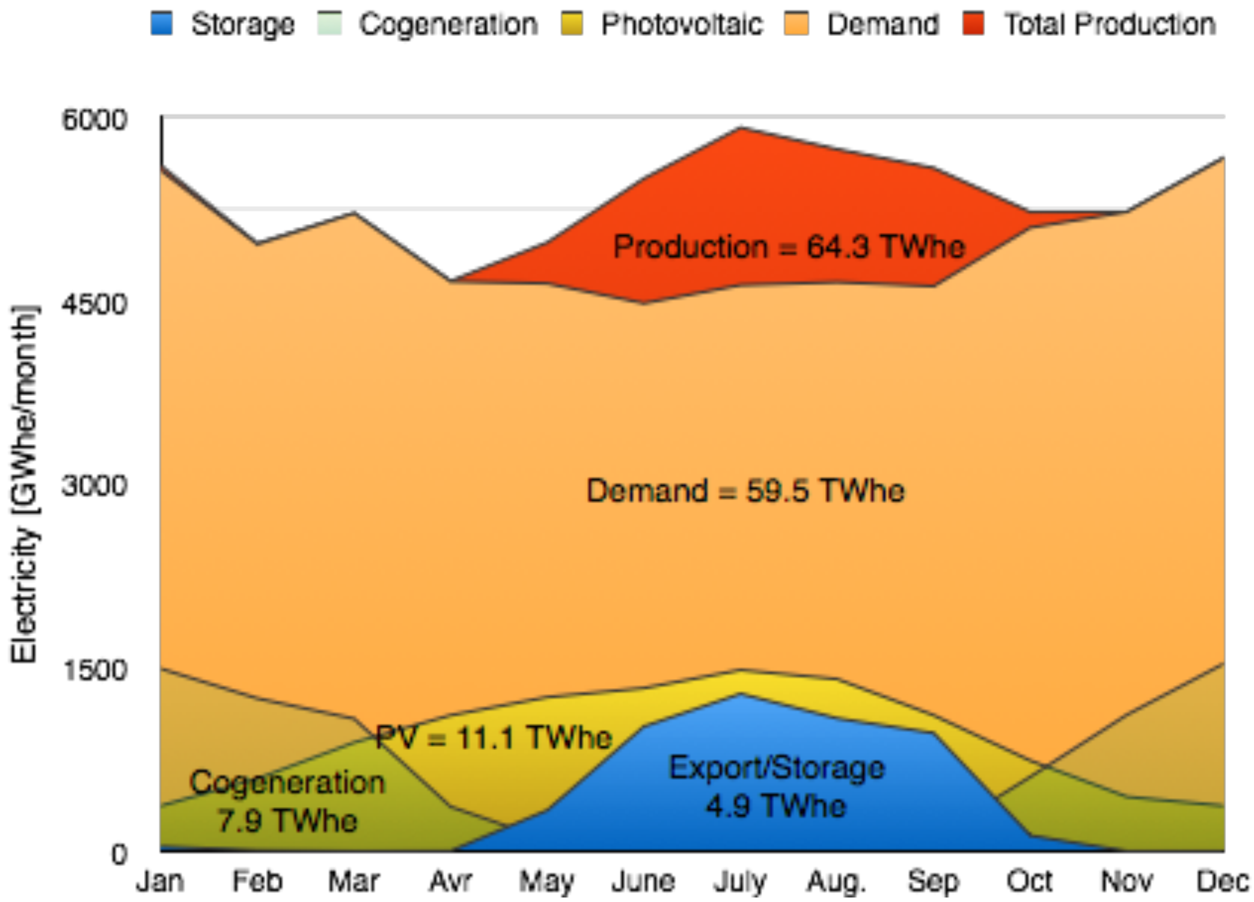
Power to gas

François Maréchal

IPESE
Industrial Process and Energy Systems Engineering
EPFL Valais-Wallis
CH - 1950 Sion

Producing Electricity using renewables

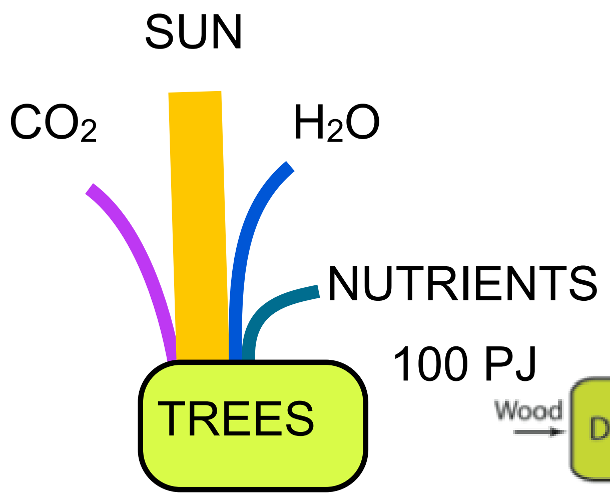
- **Who is going to use the extra amount in the Summer ?**
- **Note : seasonal storage = 45% of PV production**



http://www.energyscope.ch

Scenario 2050 : OFEN / Low

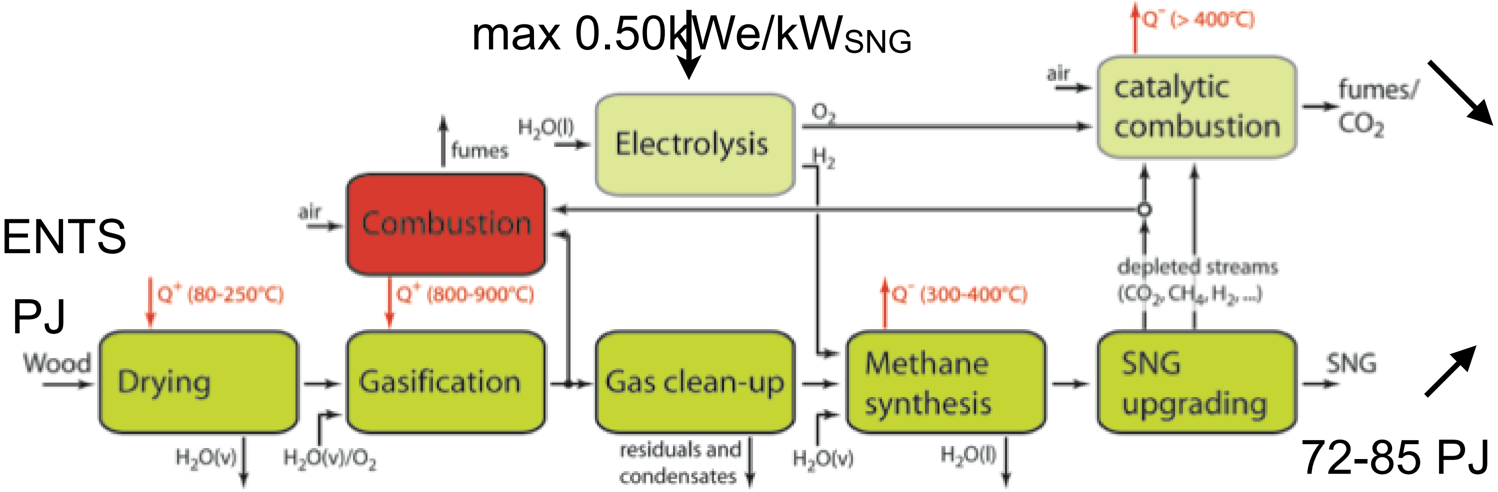
Power to gas concept



100 PJ

Carbon source

Electricity form the grid
4.7 TWhe = 13 PJ_{SNG}
max 0.50 kWe/kW_{SNG}



72-85 PJ
+18%

WOOD | Natural Gas | CO2 (pure)

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

+ 4 H_2 ⟶ + CH_4 - CO_2 + 2 H_2O

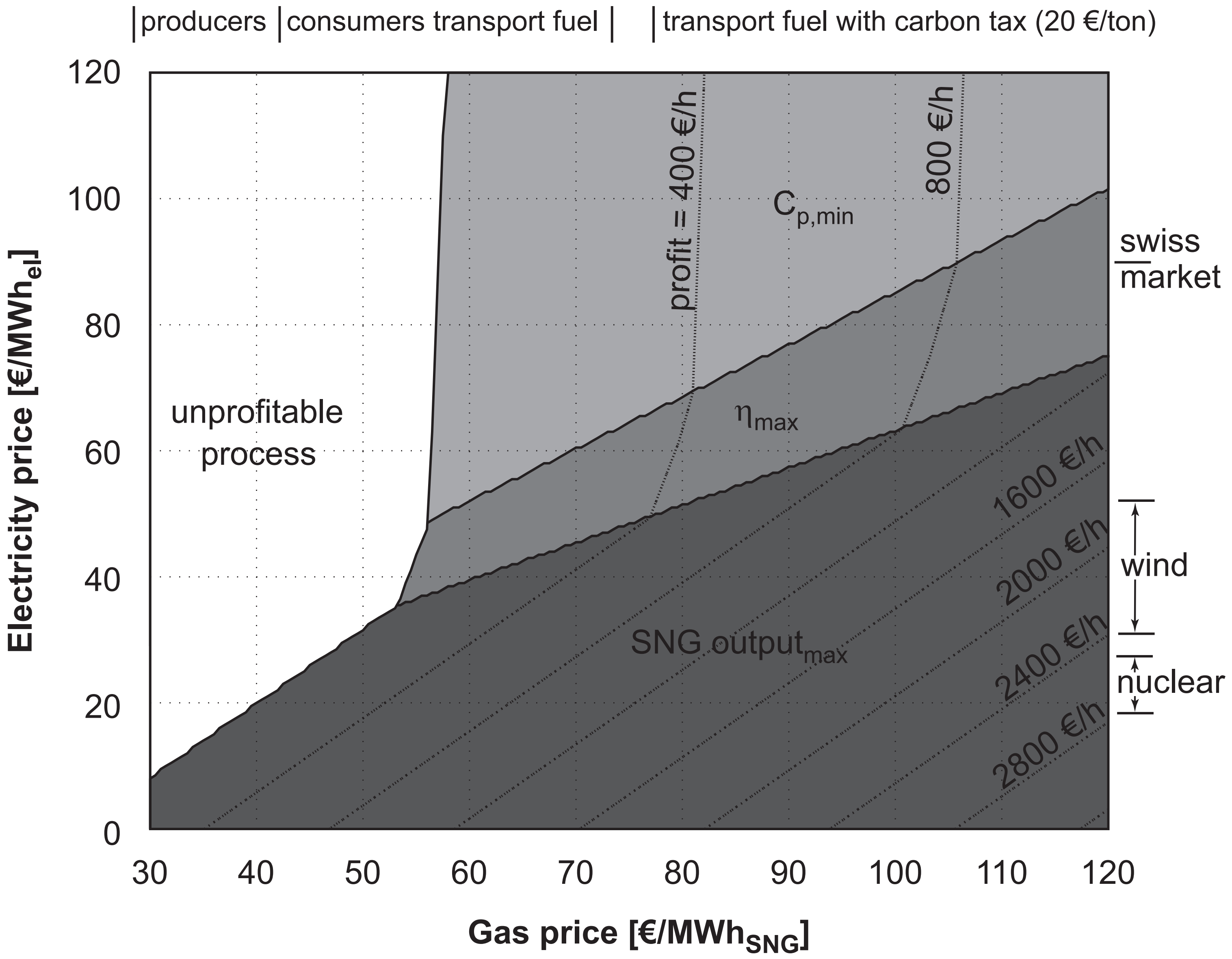
$$\Delta E^+ + 4H_2O \rightarrow$$ + 4 H_2, + 2 O_2

Storage as transportation fuel

$$\eta_c = \frac{\Delta CH4^-_{LHV}}{\Delta E^+} = 85\%$$

Gassner, M., and F. Maréchal. *Energy* 33, no. 2 (2008) 189–198.

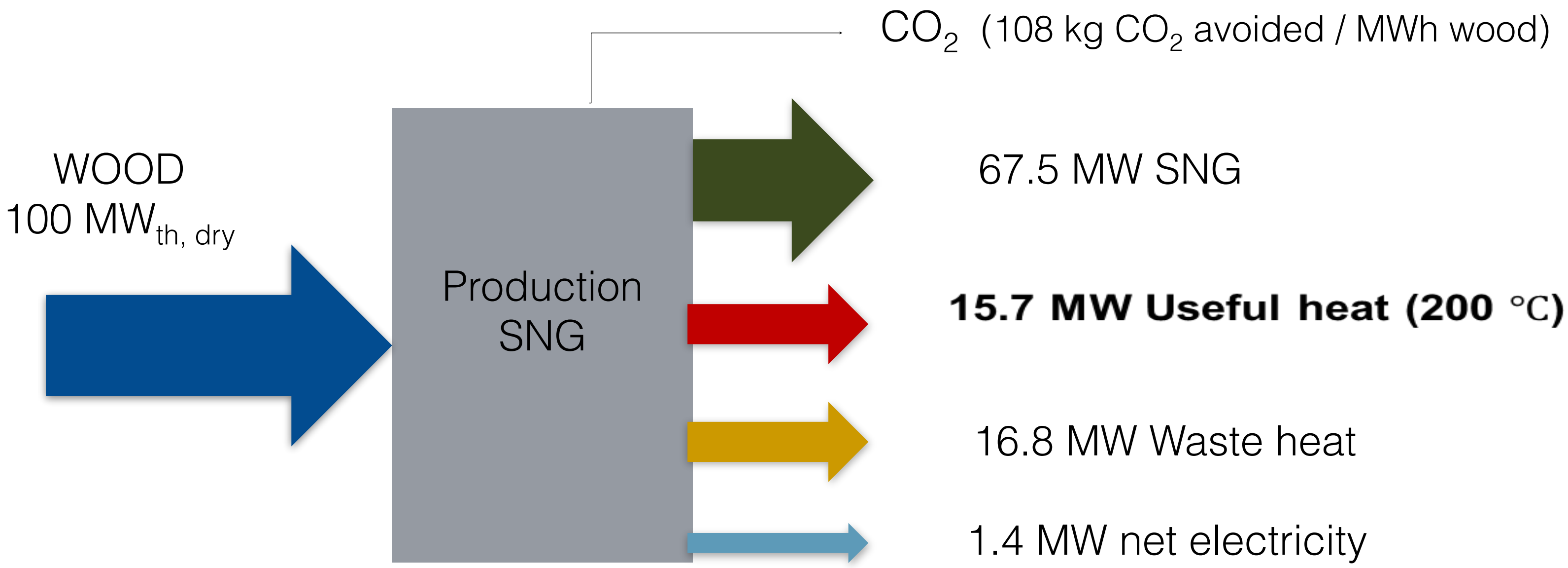
Indirectly heated gasification : electricity storage option



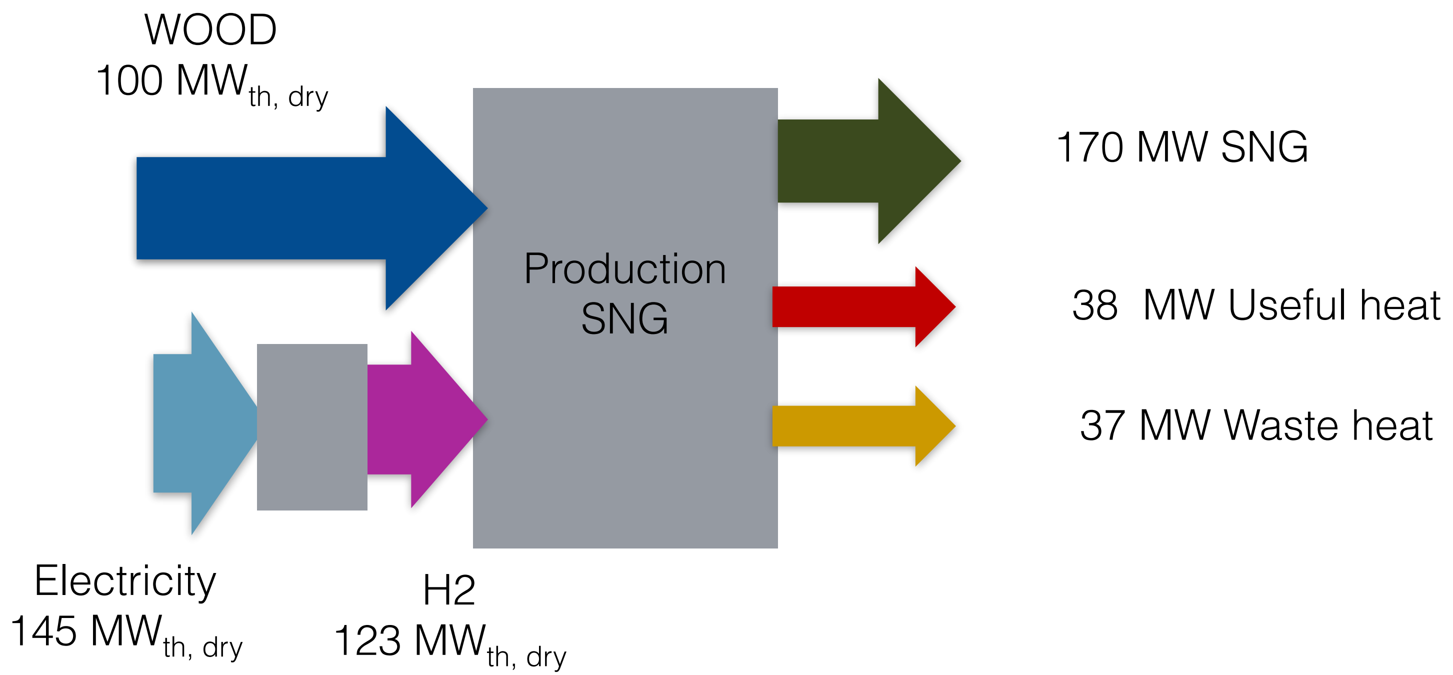
Gassner, M., and F. Maréchal. "Thermo-economic Optimisation of the Integration of Electrolysis in Synthetic Natural Gas Production from Wood." *Energy* 33, no. 2 (February 2008): 189–198. doi:10.1016/j.energy.2007.09.010.

Green boiler and RES storage

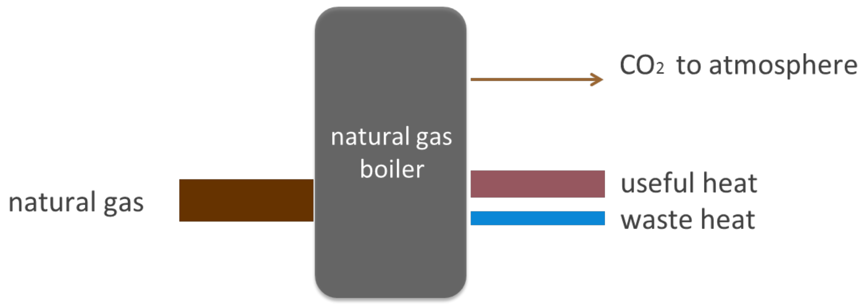
Winter Mode



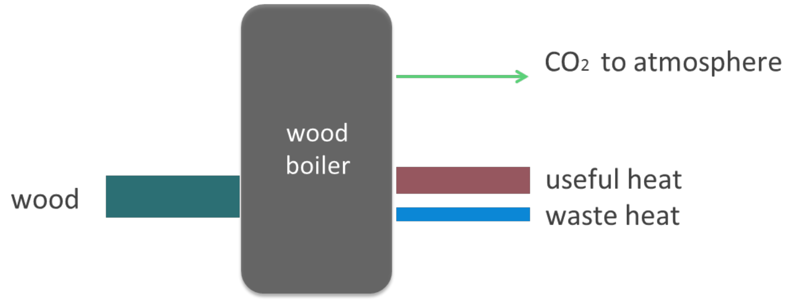
Summer Mode



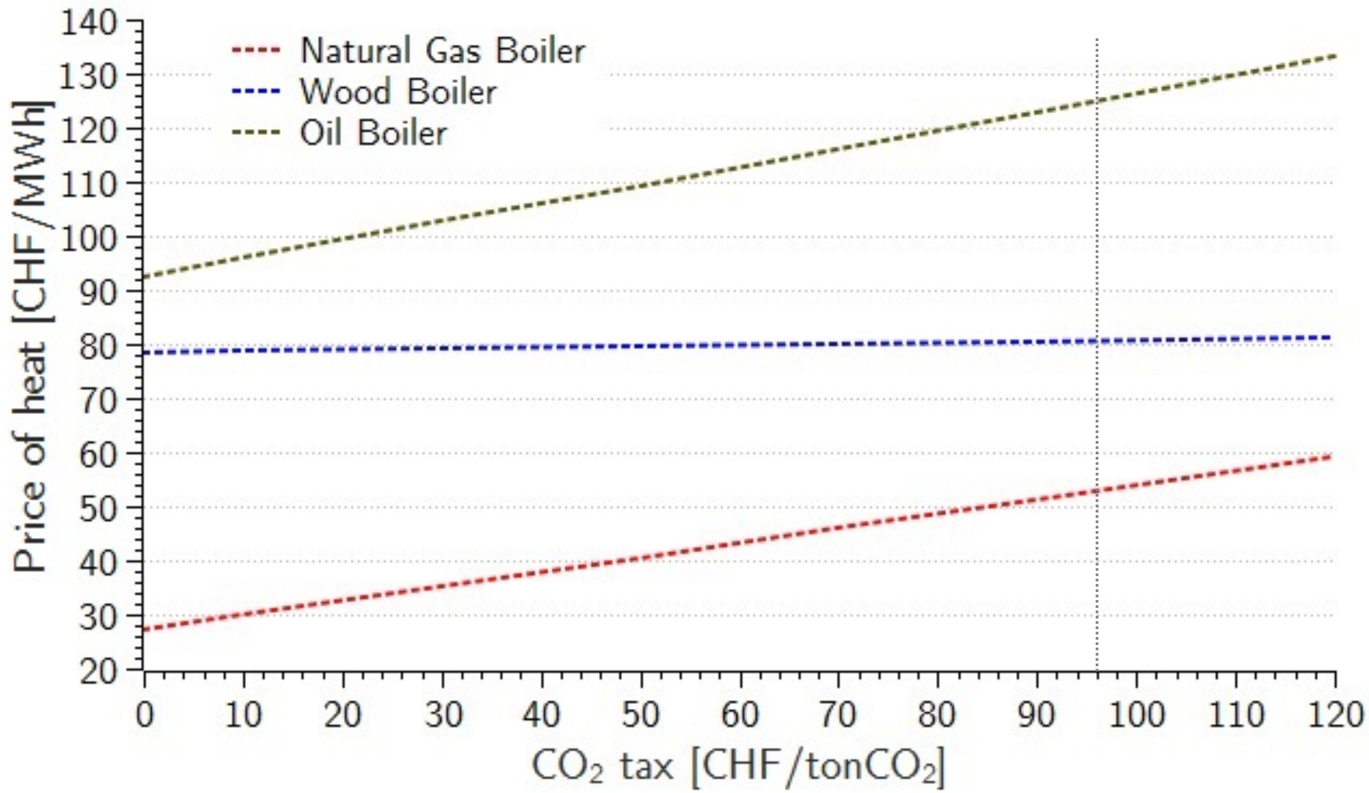
Conventional boilers

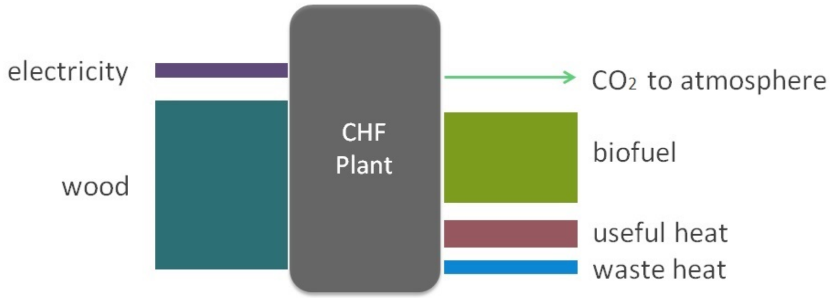


natural gas boiler



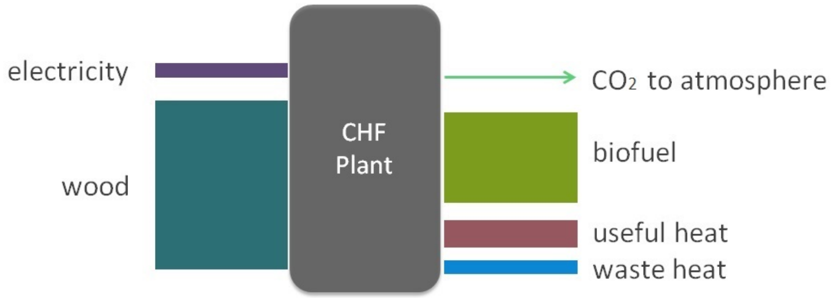
wood boiler




electricity
wood
CHF
Plant
CO_2 to atmosphere
biofuel
useful heat
waste heat

Case I: CHF

Conceptual CHF plant operation schemes



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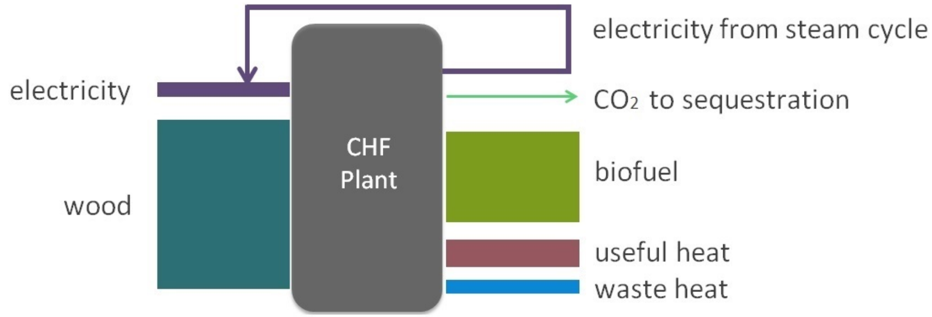
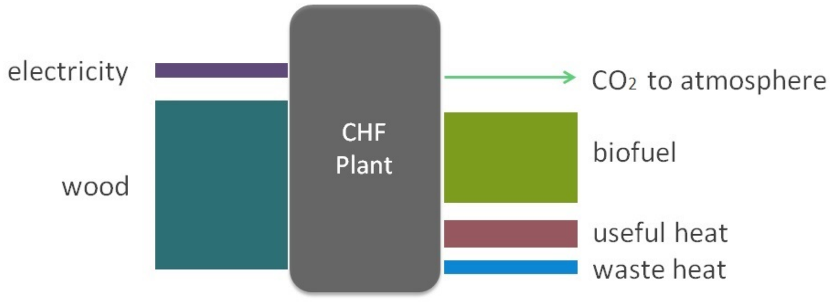


Case II: CHF + CCS

Conceptual CHF plant operation schemes



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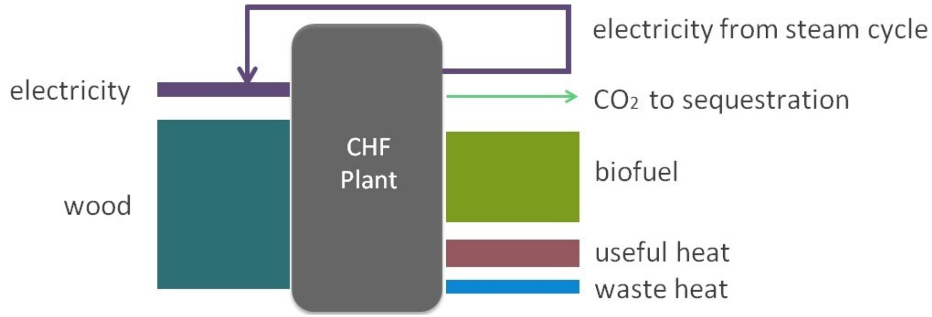

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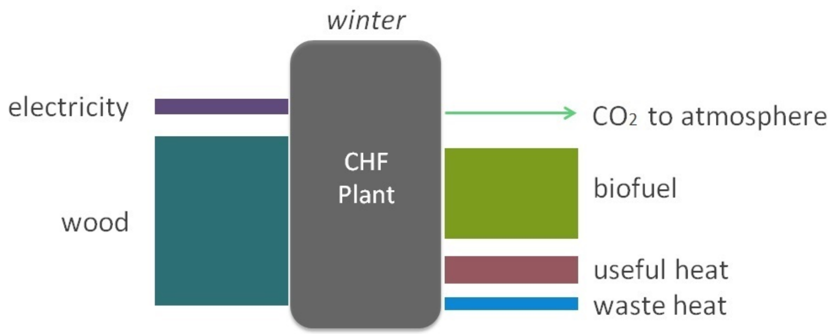
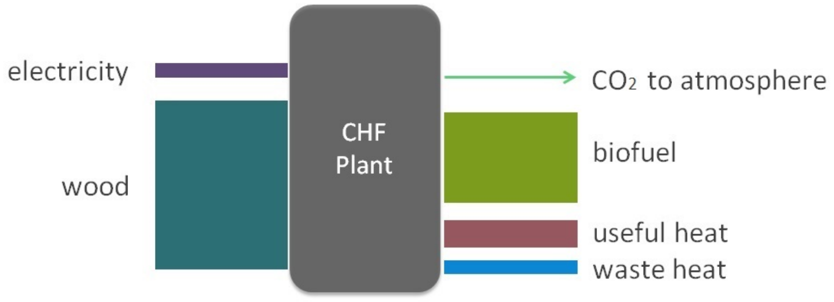


Case III: CHF + P2G

Conceptual CHF plant operation schemes



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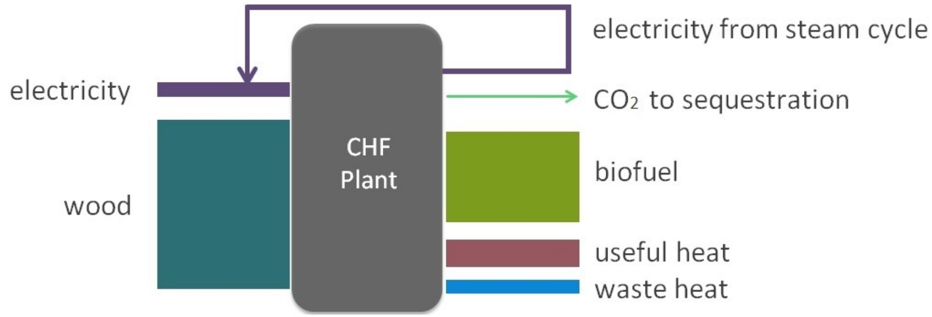
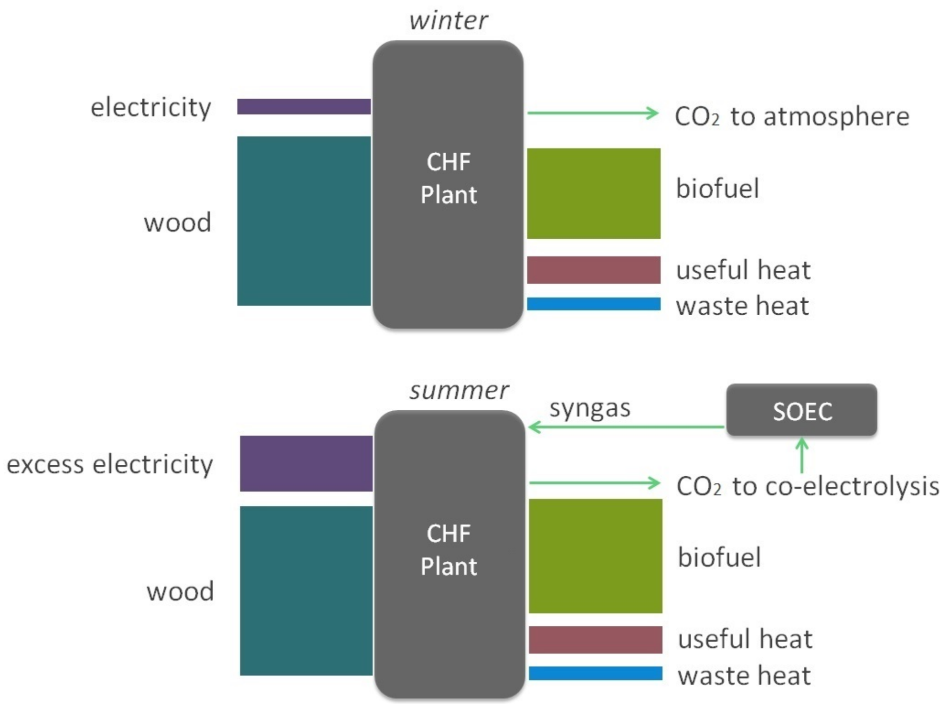


Case II: CHF + CCS



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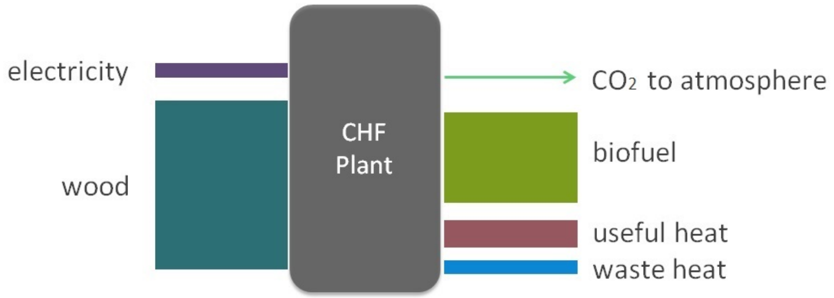

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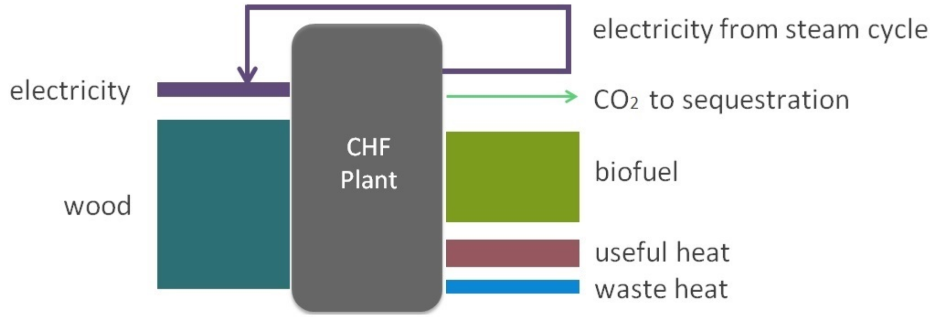

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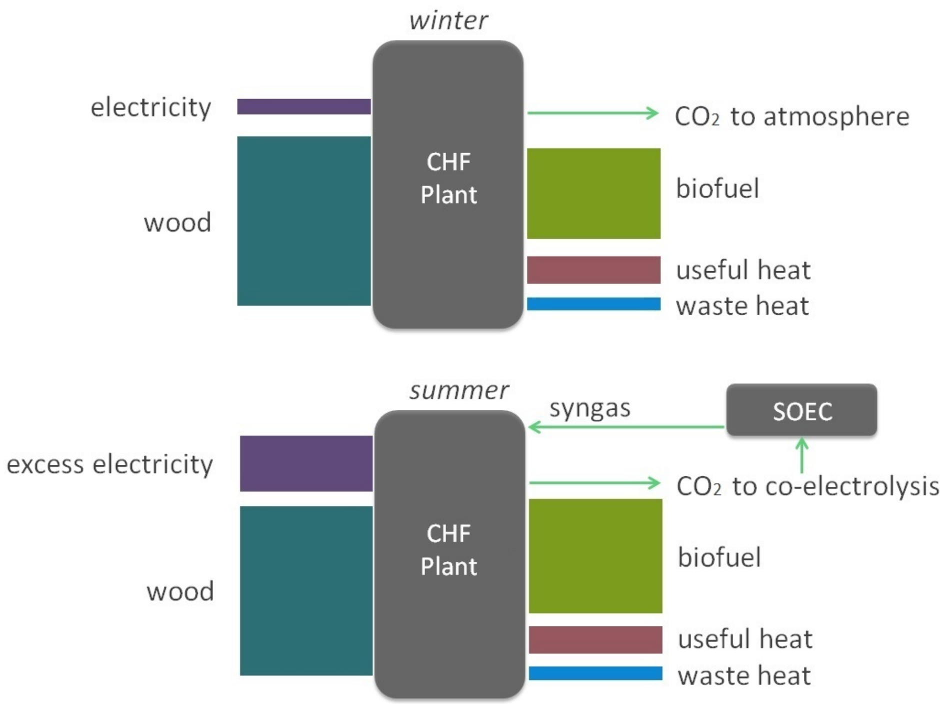

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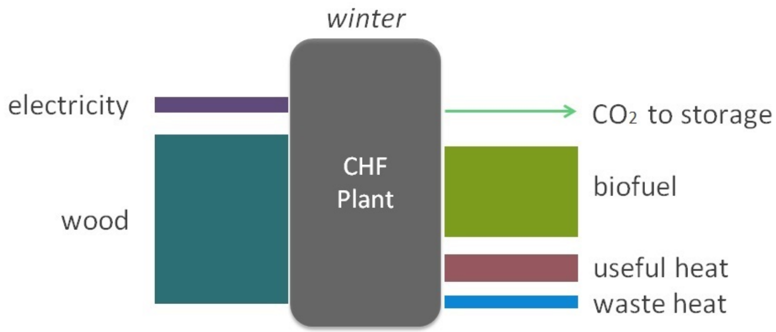
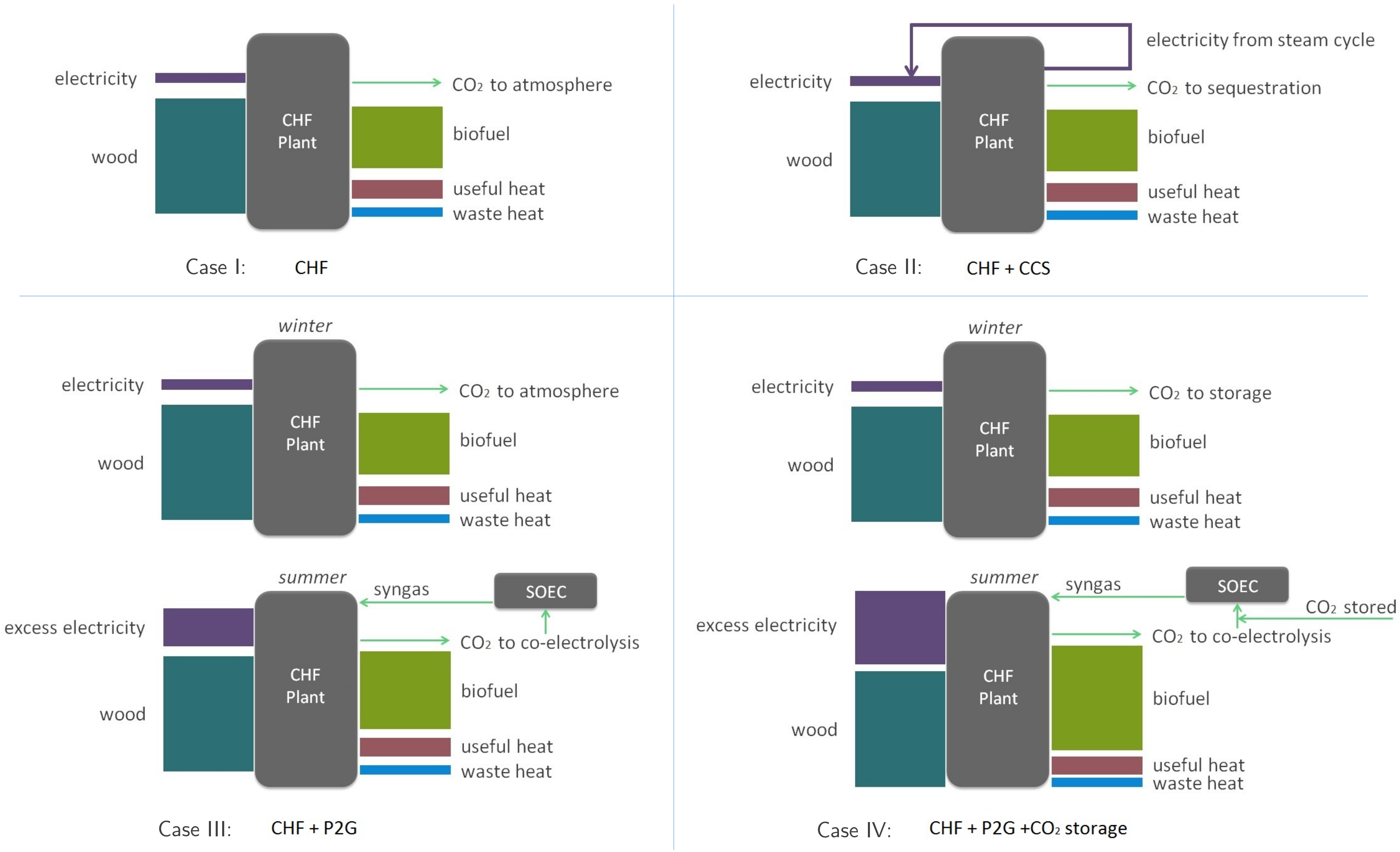


Case IV: CHF + P2G +CO_2 storage


electricity
wood
CHF Plant
CO_2 to atmosphere
biofuel
useful heat
waste heat
Case I: CHF
electricity from steam cycle
electricity
wood
CHF Plant
CO_2 to sequestration
biofuel
useful heat
waste heat
Case II: CHF + CCS
winter
electricity
wood
CHF Plant
CO_2 to atmosphere
biofuel
useful heat
waste heat
summer
syngas
SOEC
excess electricity
wood
CHF Plant
CO_2 to co-electrolysis
biofuel
useful heat
waste heat
Case III: CHF + P2G
winter
electricity
wood
CHF Plant
CO_2 to storage
biofuel
useful heat
waste heat
summer
syngas
SOEC
CO_2 stored
excess electricity
wood
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CO_2 to co-electrolysis
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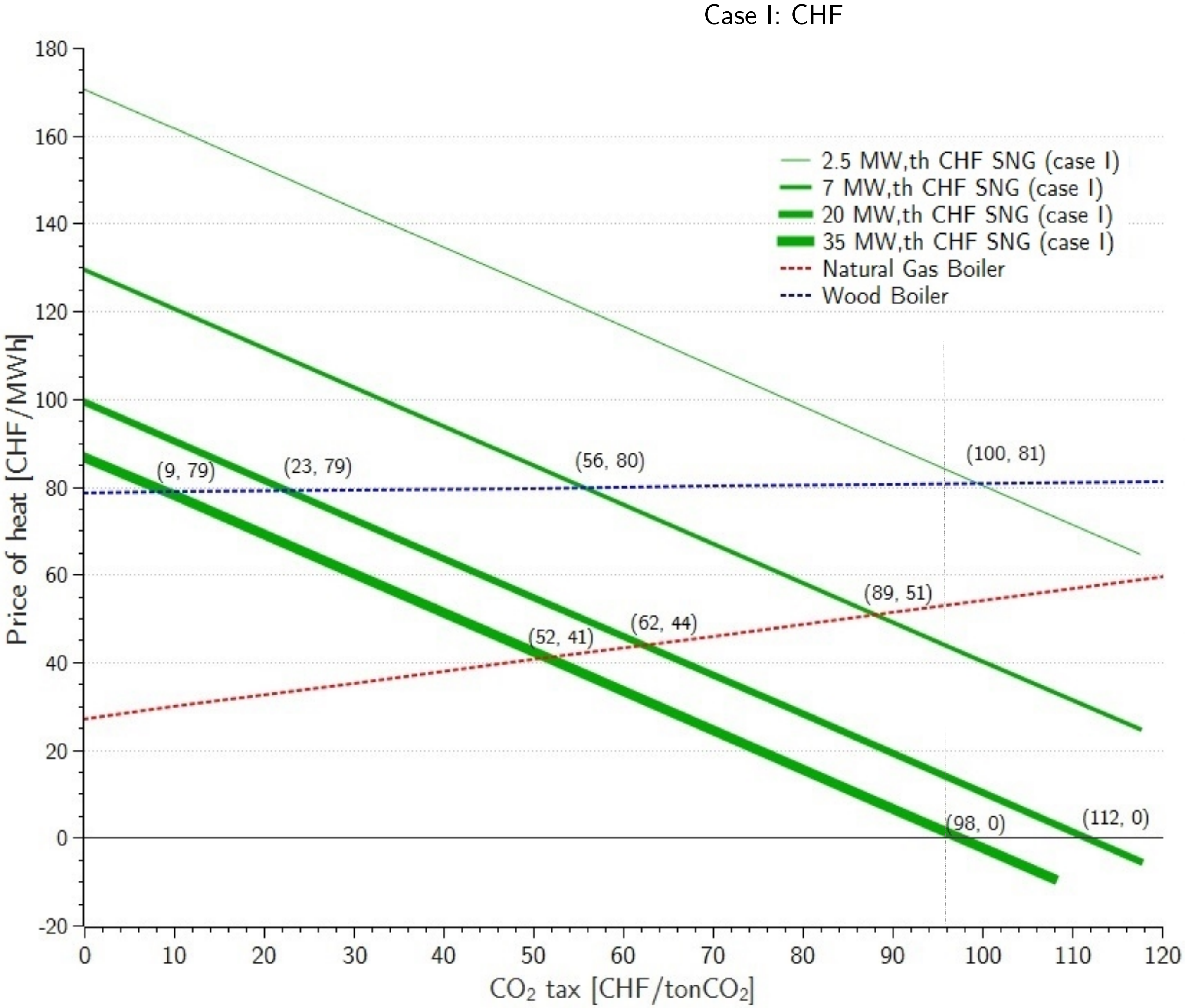
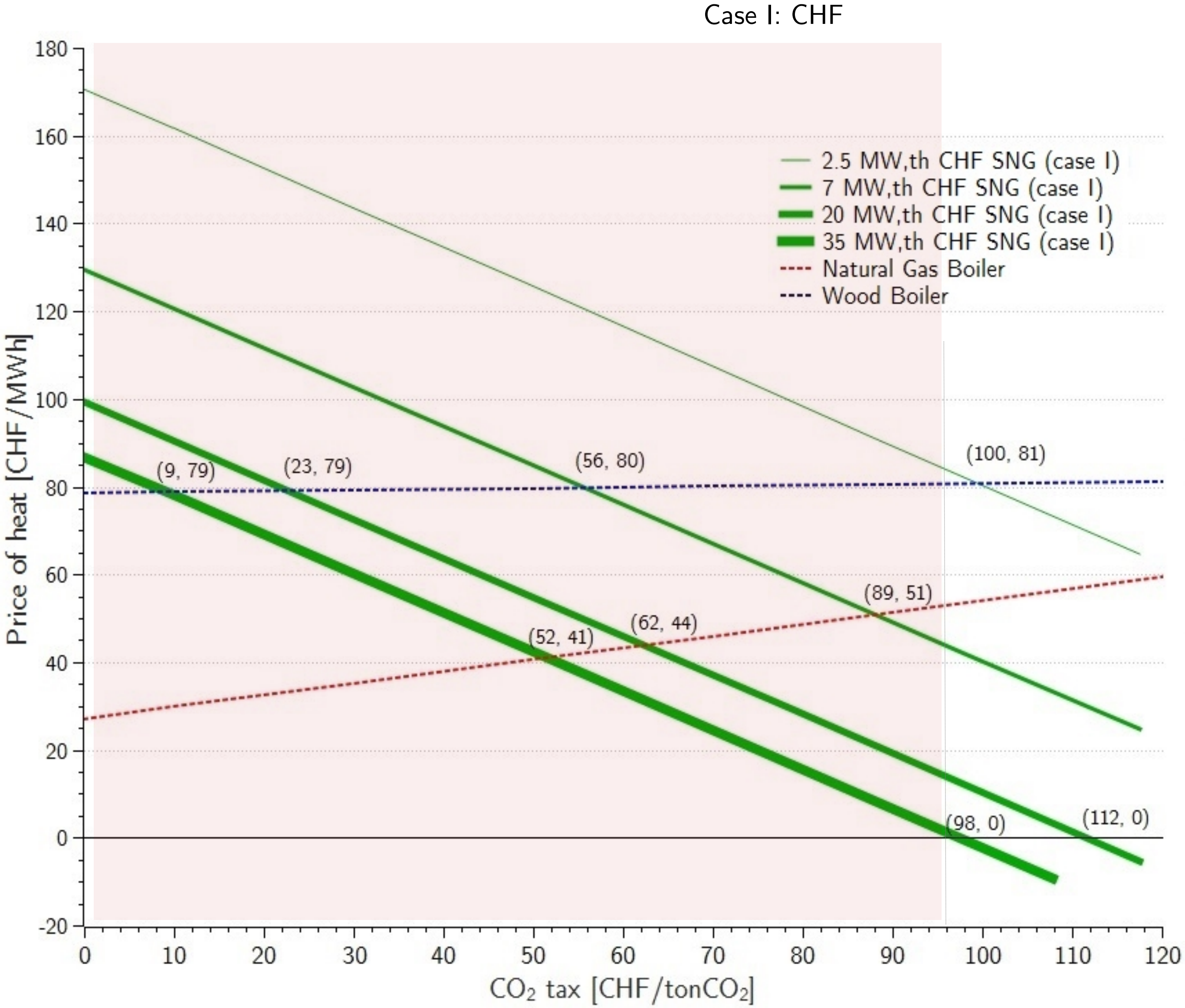


Economic parameters

Wood [CHF/kg]	0.146
Oil [CHF/kWh]	0.087
Natural Gas [CHF/kWh]	0.024



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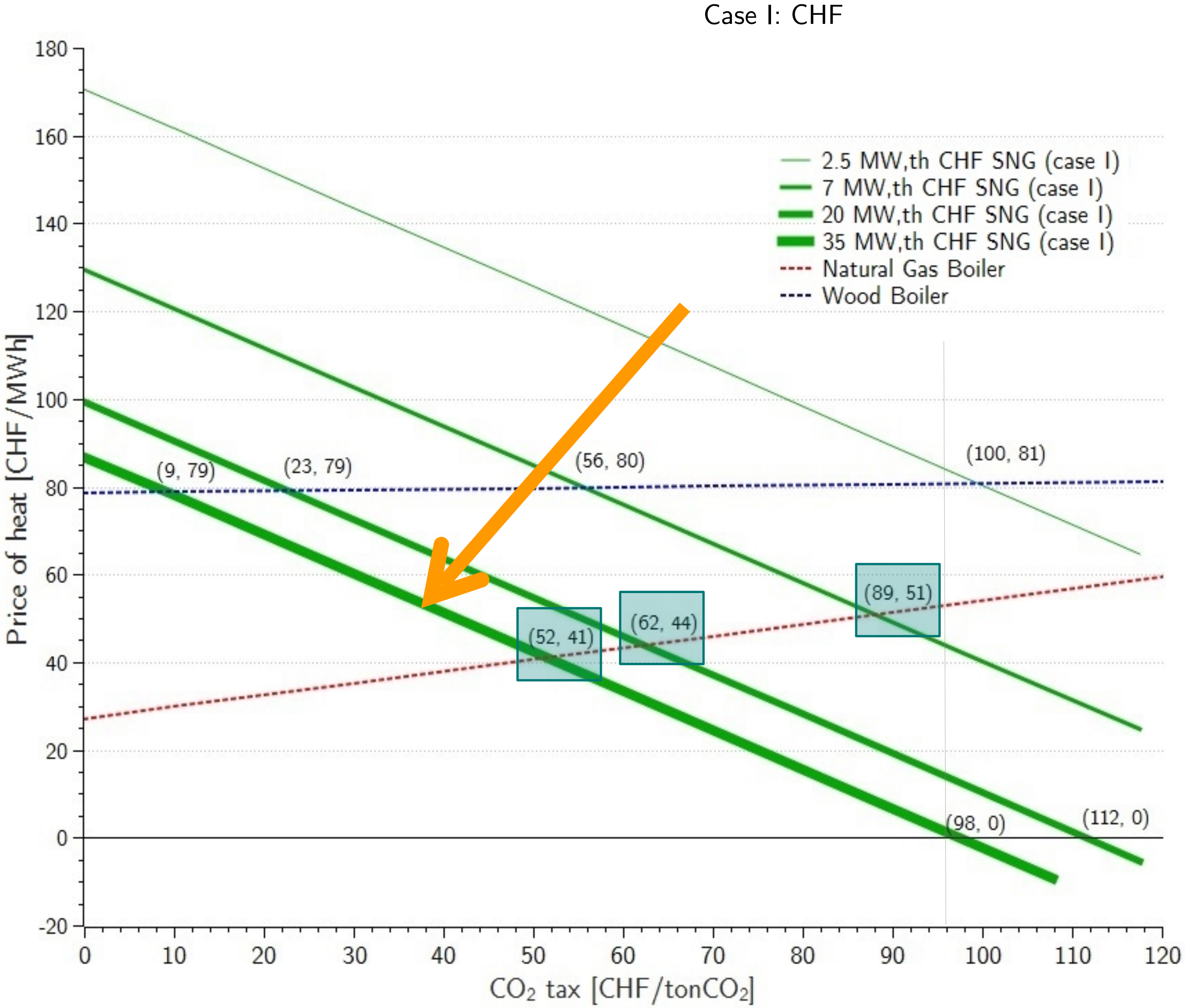

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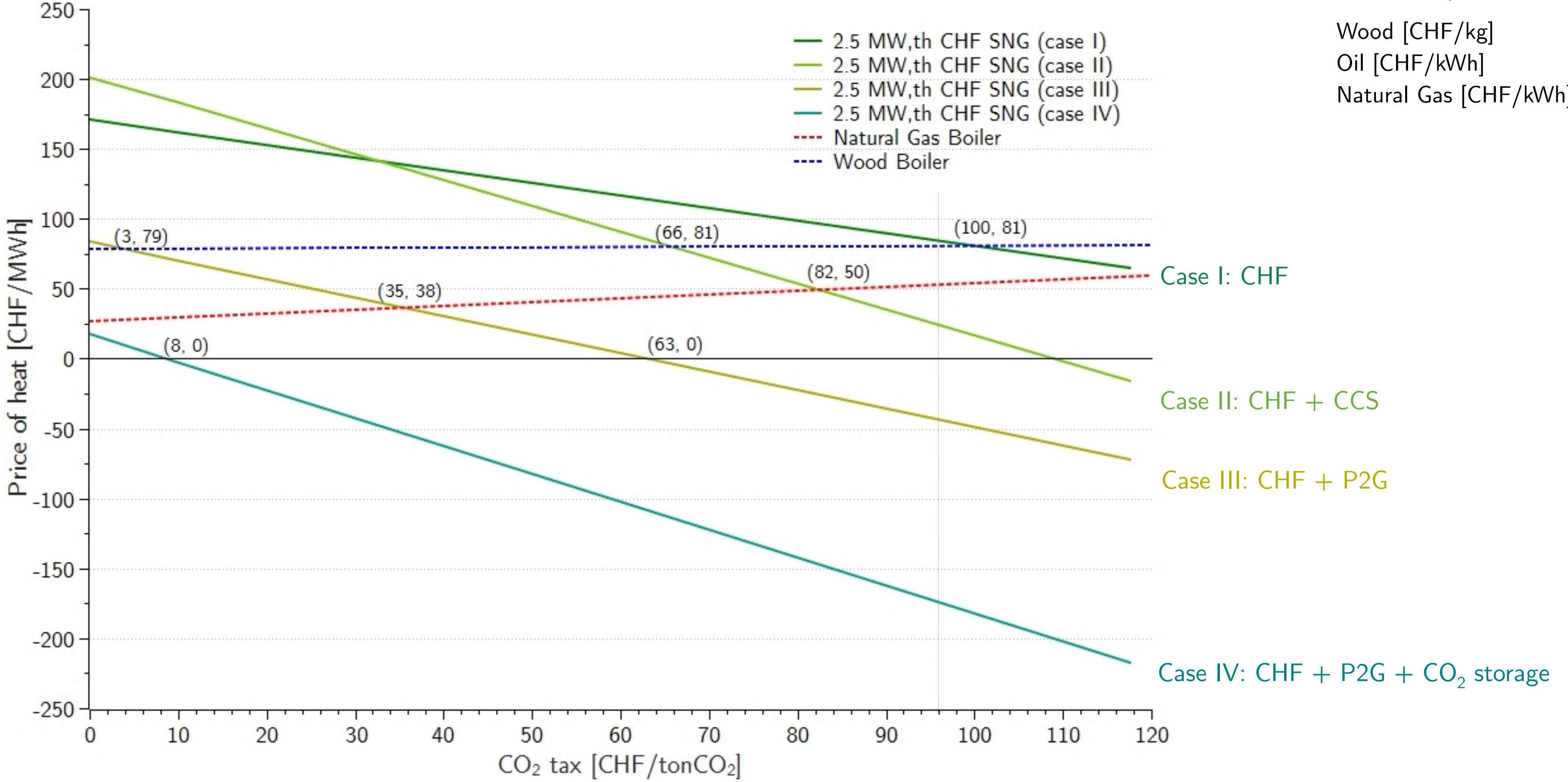
- boiler size ↑, price of heat ↓



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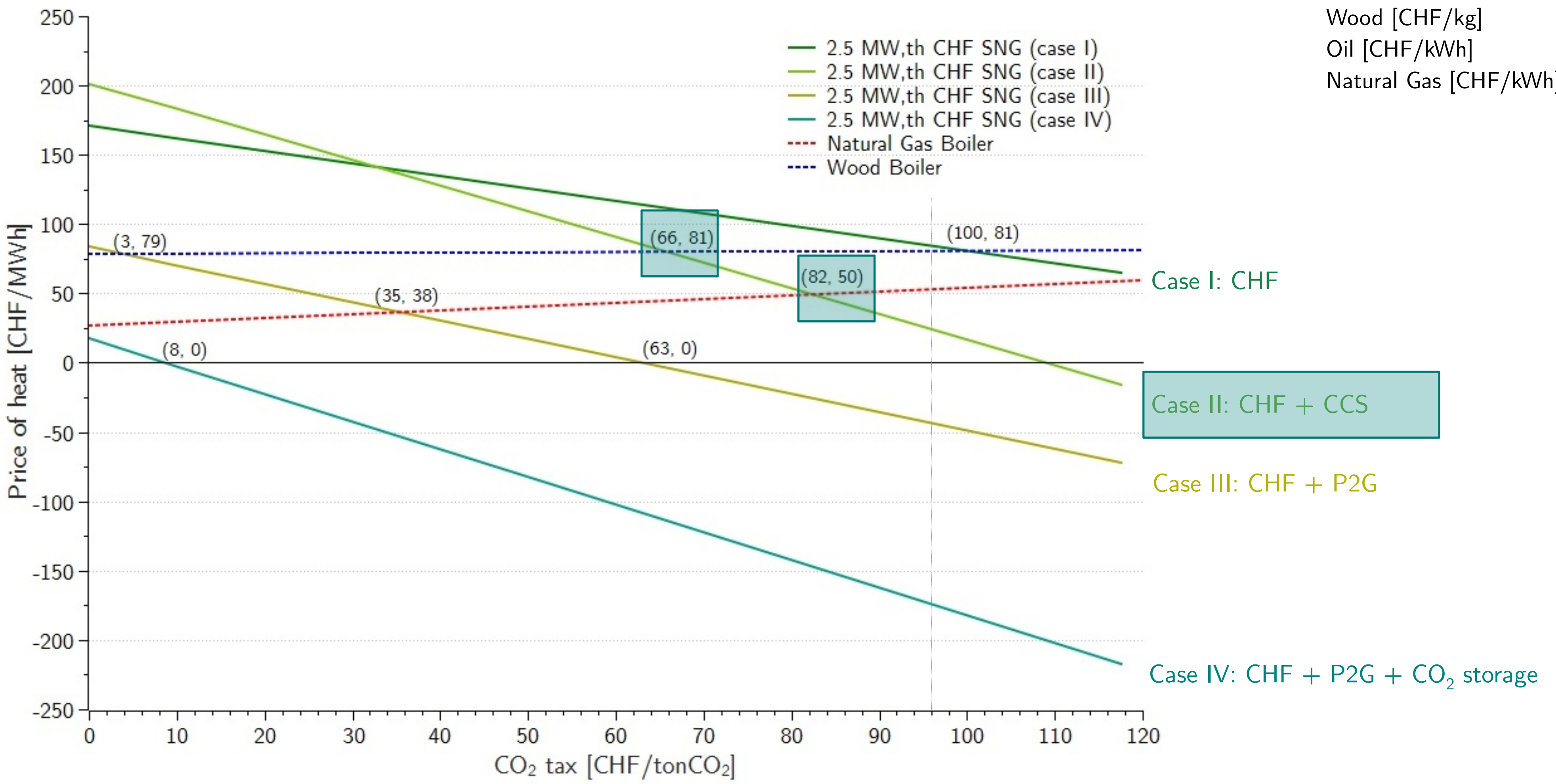
Process performance



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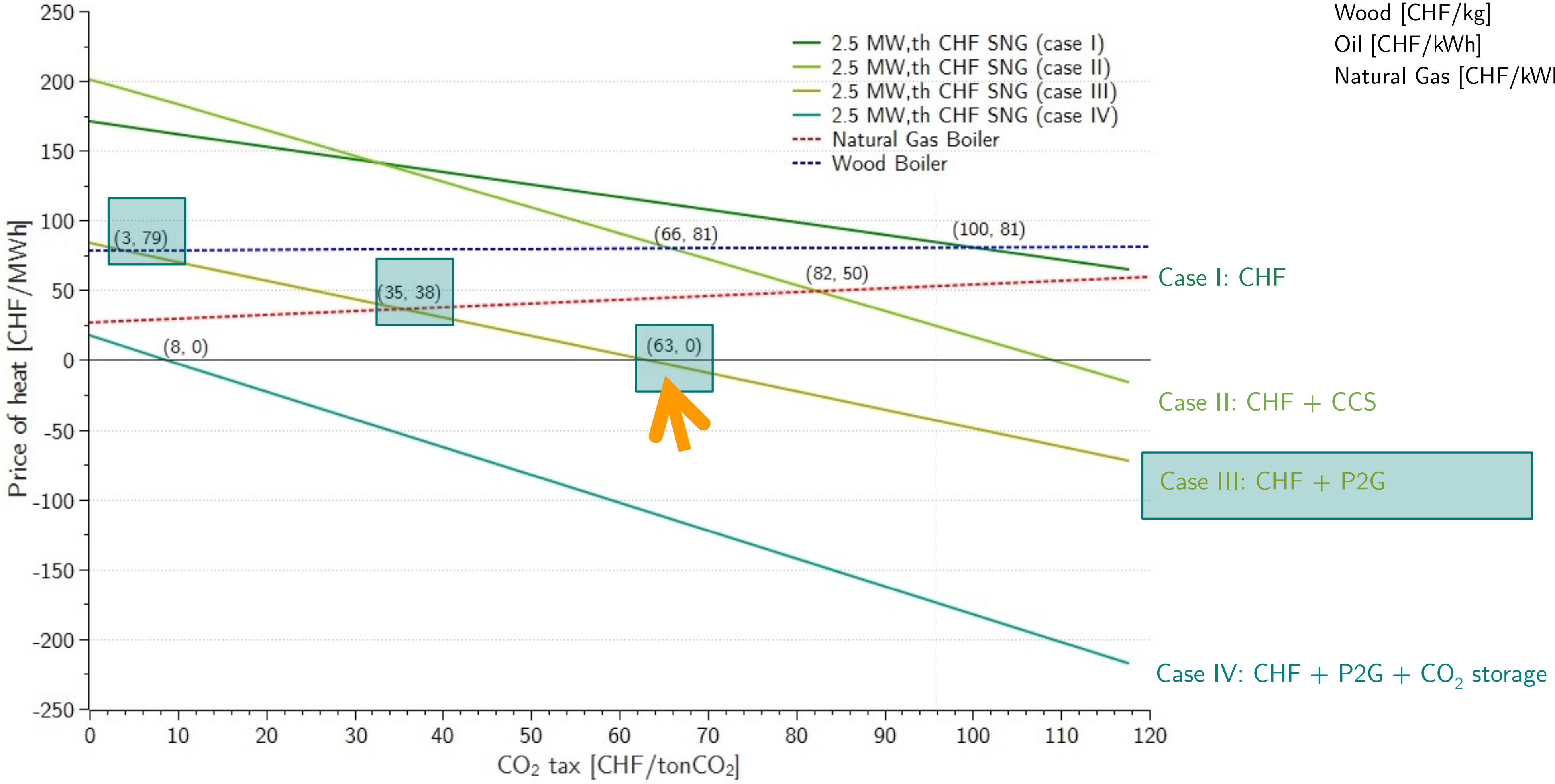

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- integration of co-electrolysis unit lead to a great reduction in heat prices

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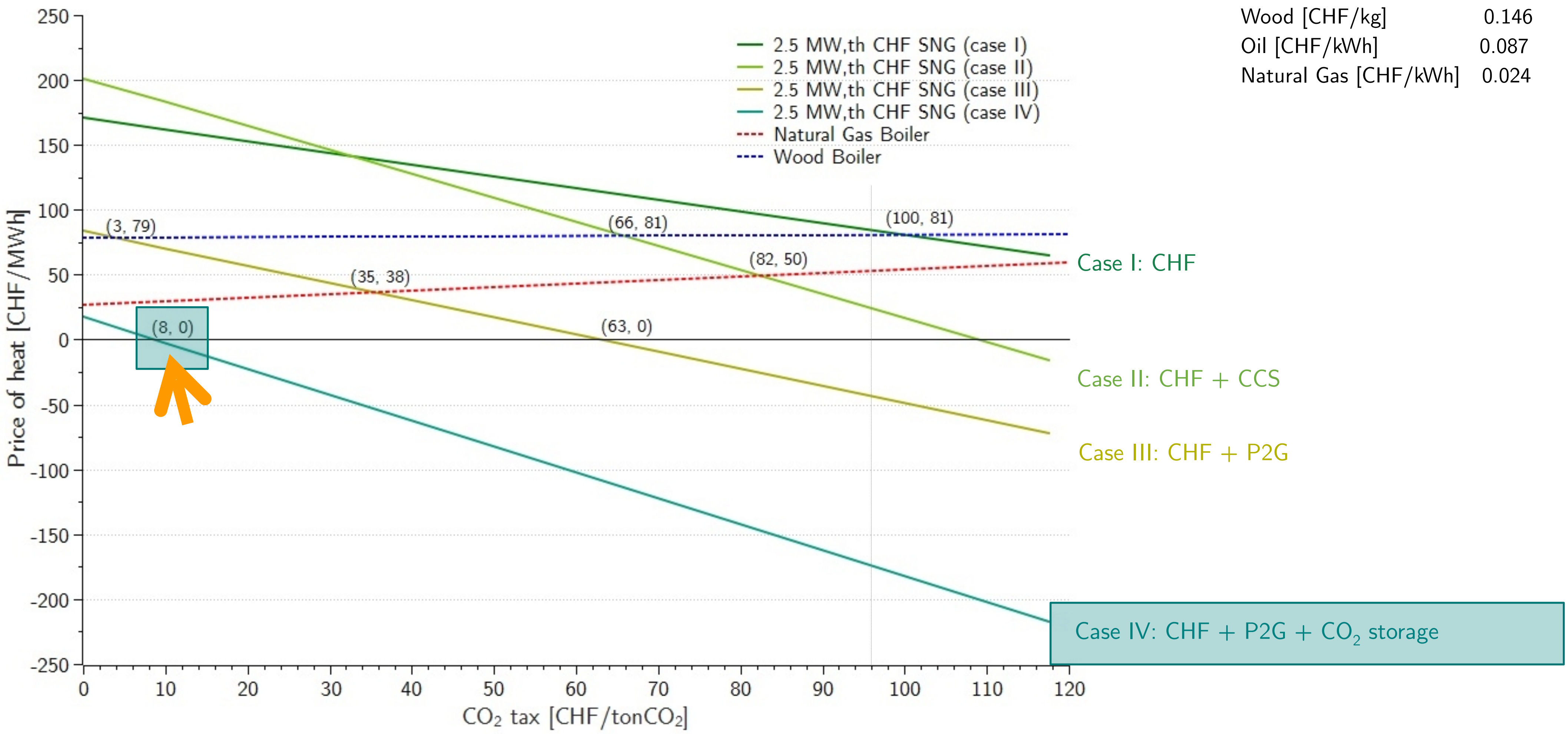

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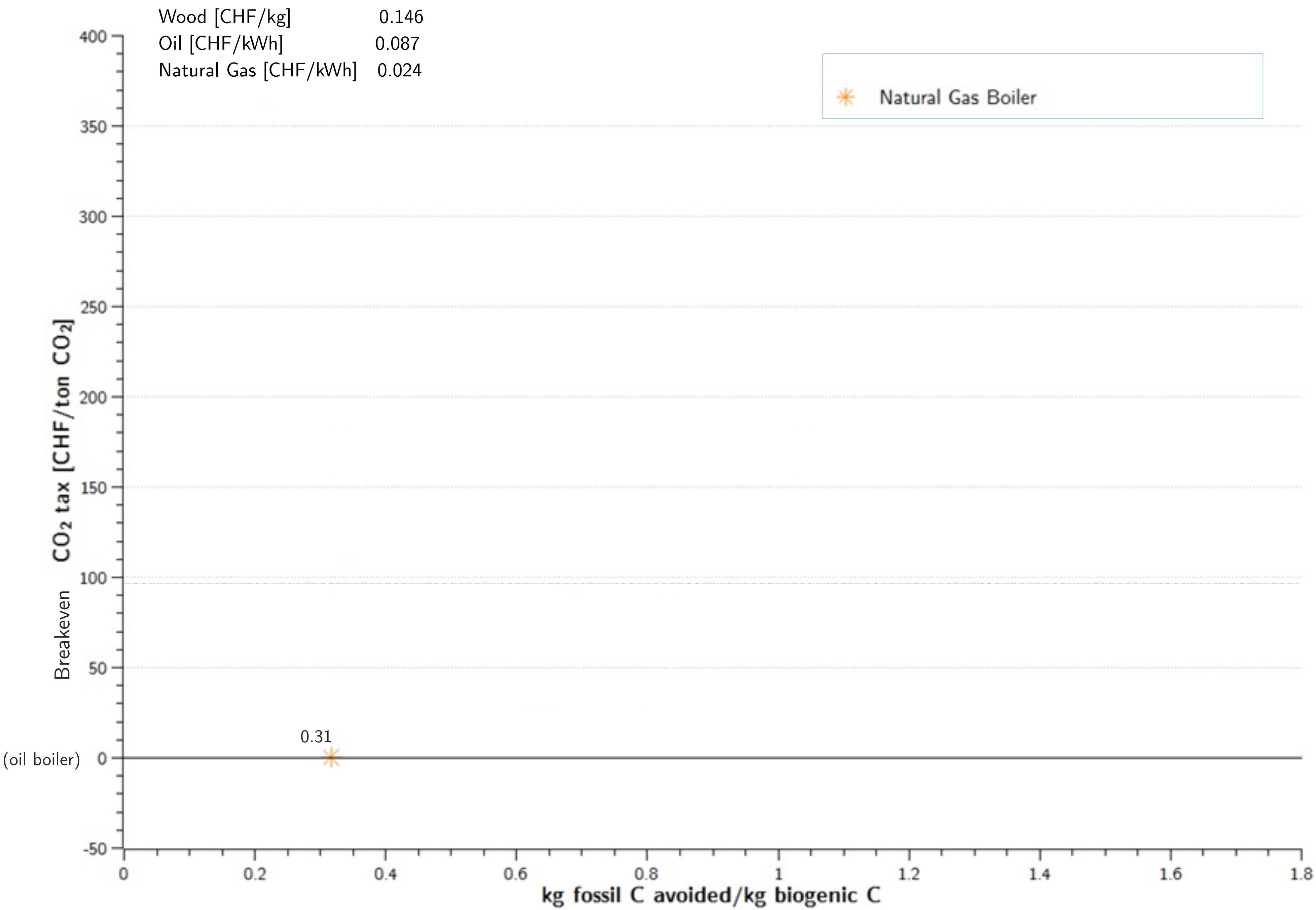
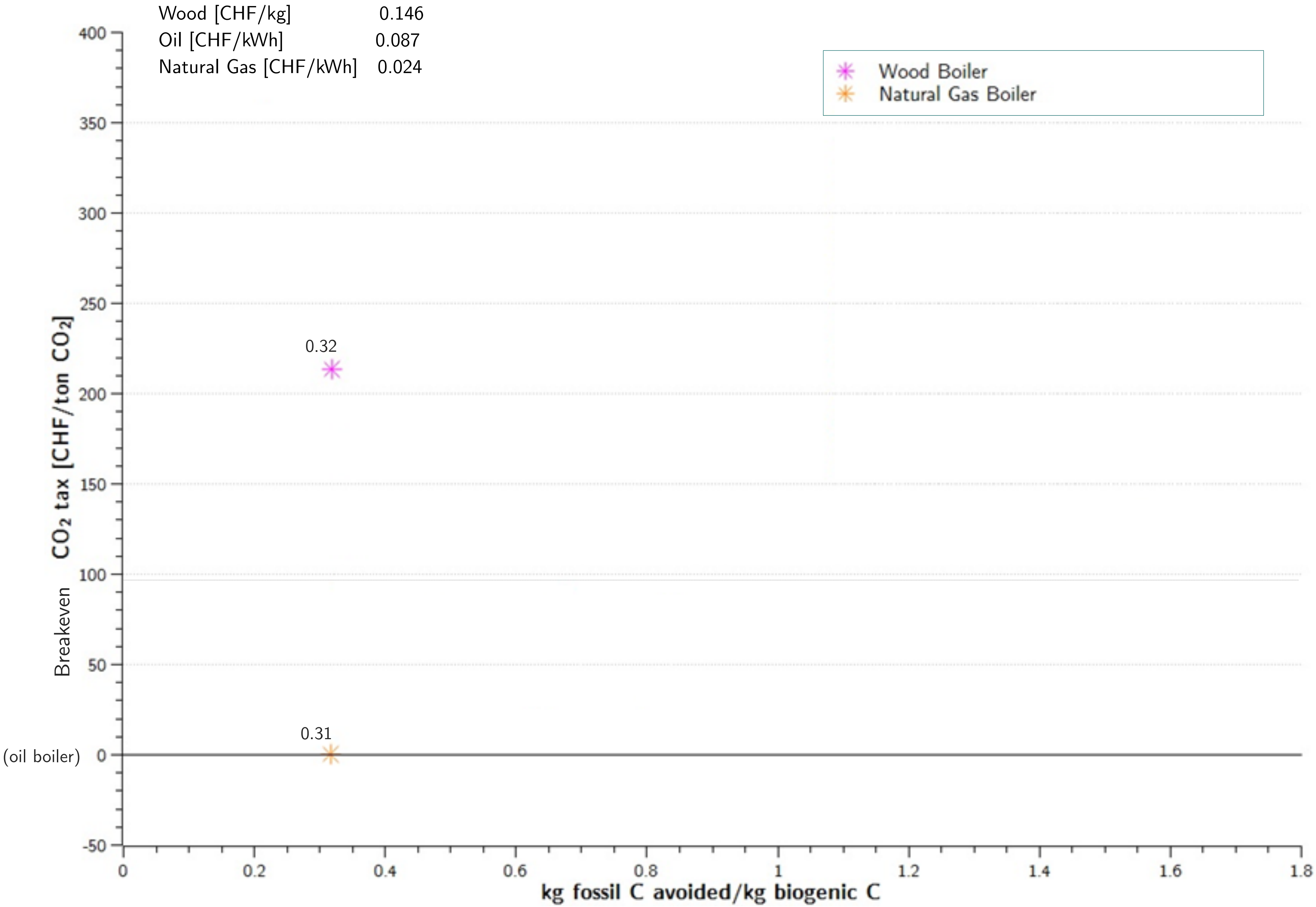
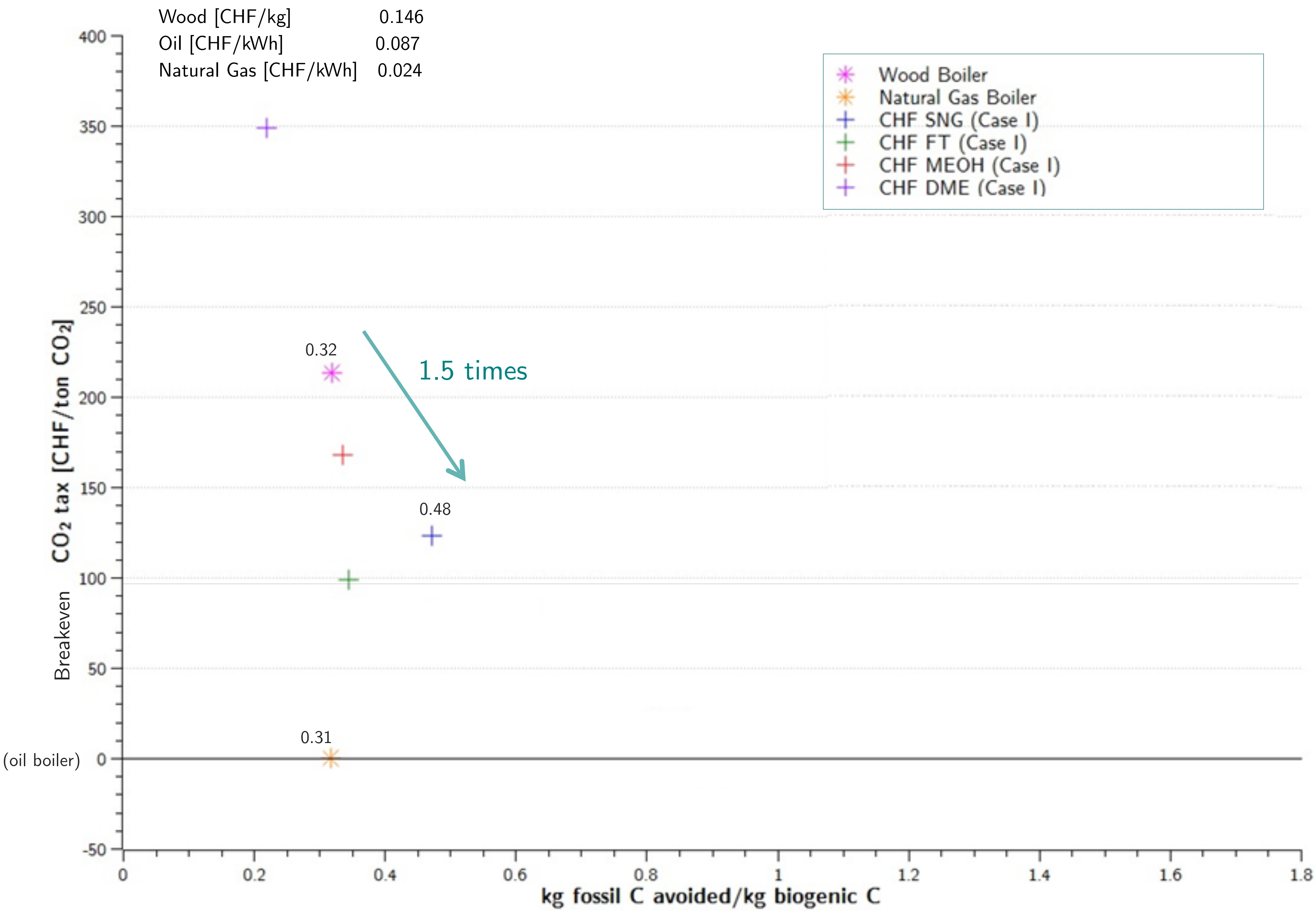
- integration of co-electrolysis unit lead to a great reduction in heat prices
- with CO_2 storage, huge reduction in heat price with negative values for higher CO_2 tax

Carbon savings comparison between technologies




Wood [CHF/kg] 0.146
Oil [CHF/kWh] 0.087
Natural Gas [CHF/kWh] 0.024
Wood Boiler
Natural Gas Boiler
0.32
0.31
CO2 tax [CHF/ton CO2]
Breakeven
(oil boiler)
400
350
300
250
200
150
100
50
0
-50
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
kg fossil C avoided/kg biogenic C

Carbon savings comparison between technologies



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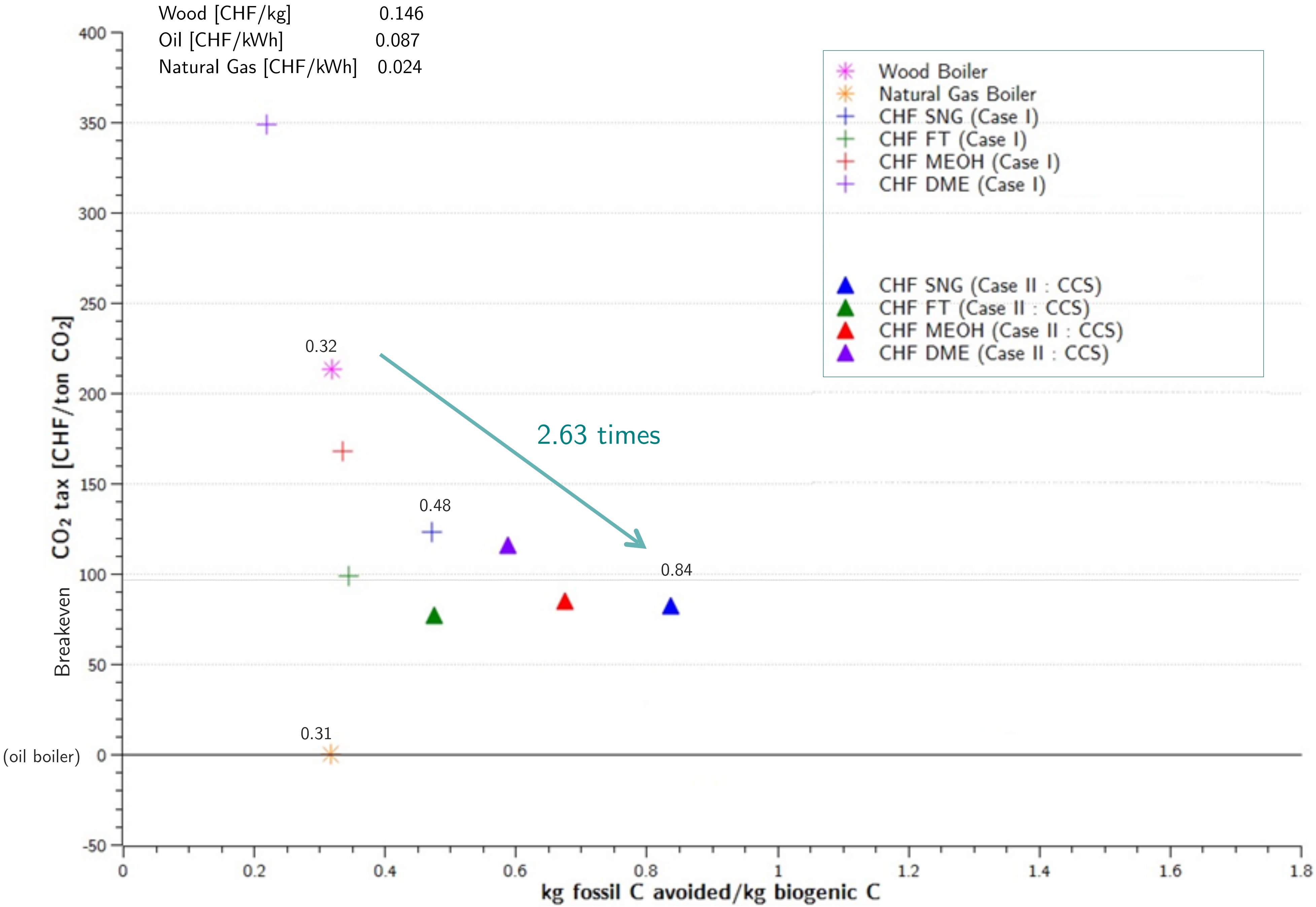

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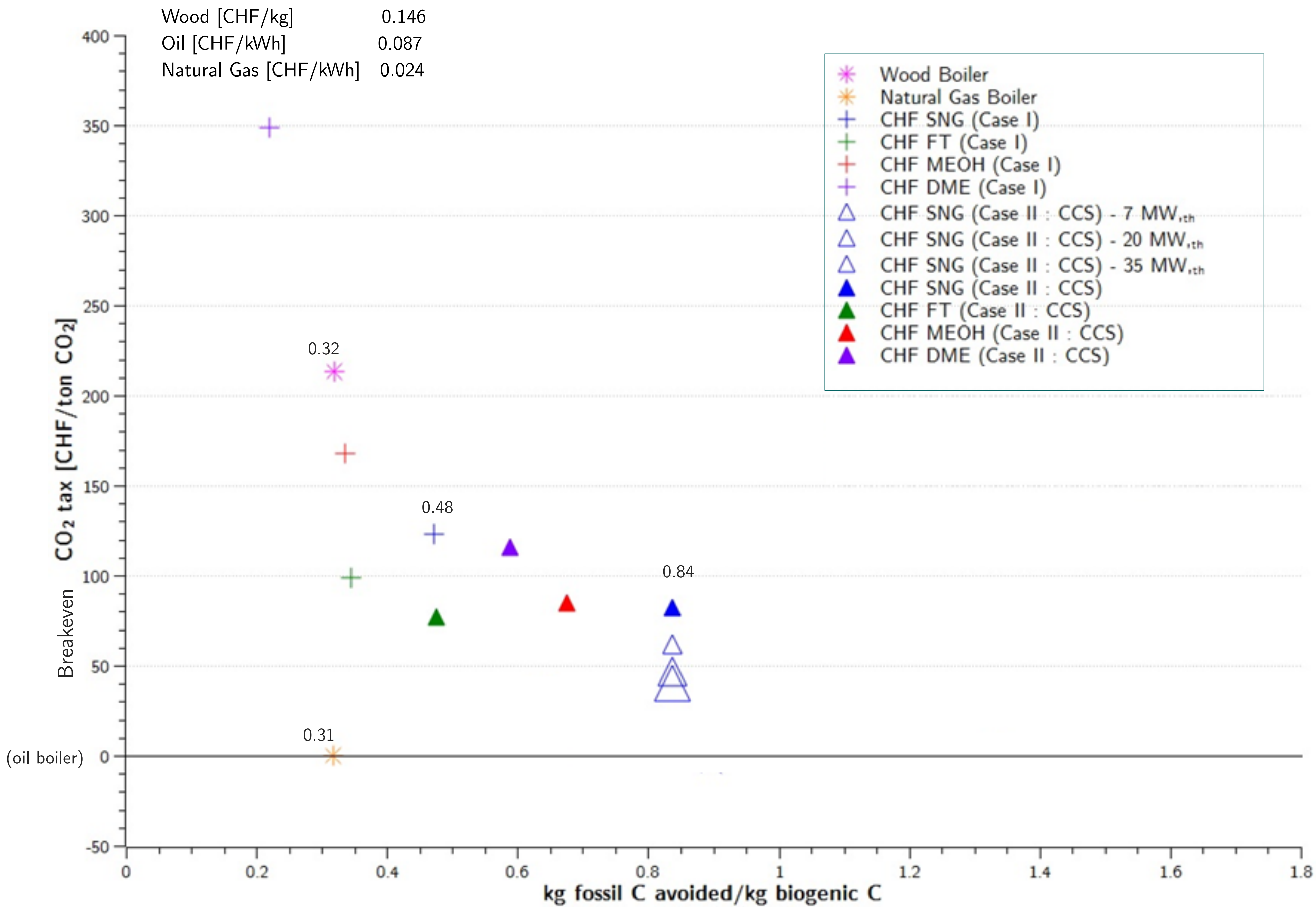

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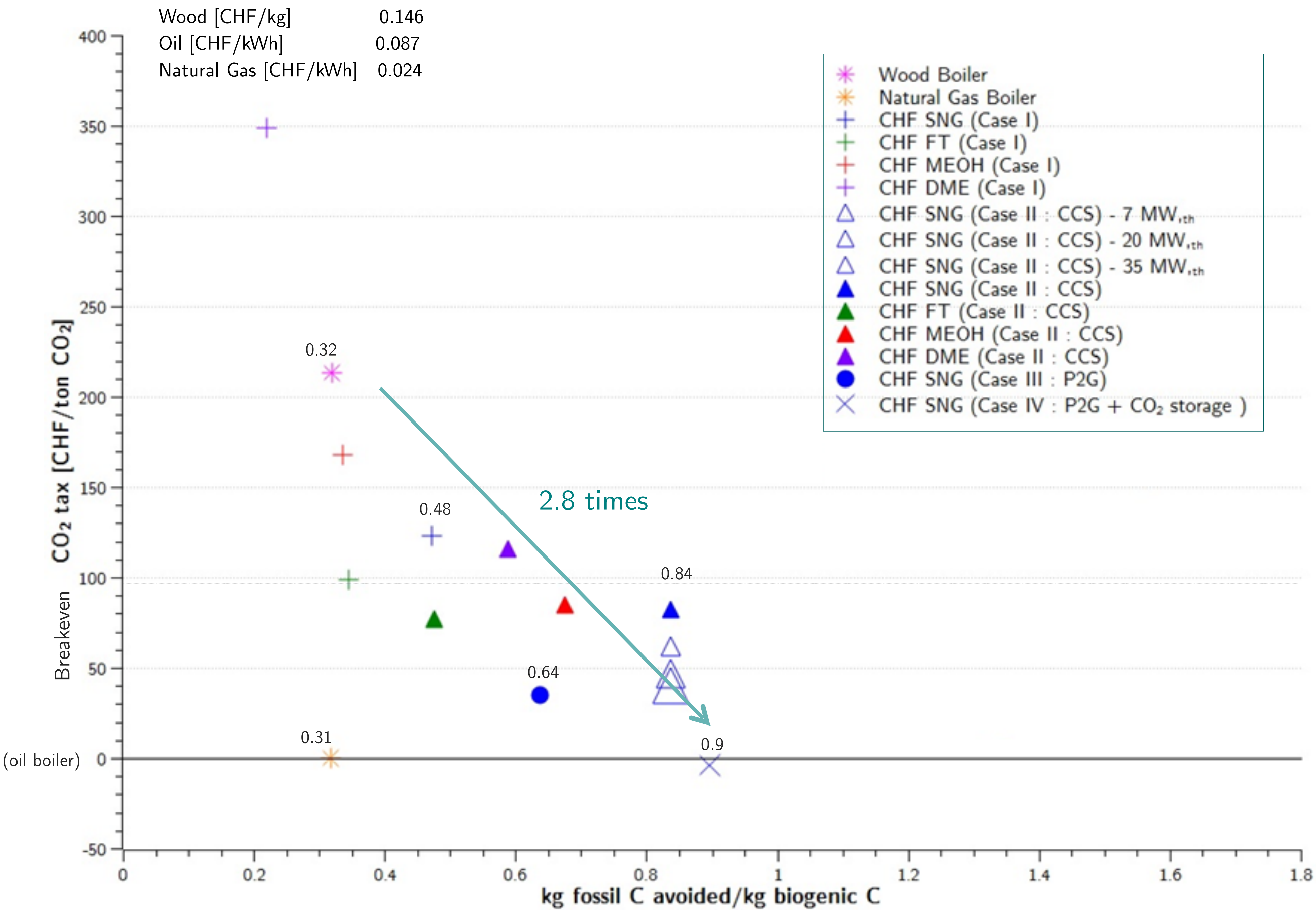


Round trip efficiency of electrcity storage

- **H2 electrolysis integrated in SNG process**
  - CO2 emissions are negative (wood carbon neutral, CO2 is captured)

$$\eta_c = \frac{\Delta CH4^{-}_{LHV}}{\Delta E^{+}} = 85\%$$

- **CH4 conversion NGCC (CO2 = 0 because C biogenic)**

$$\eta_d = \frac{E^{-}}{CH4^{+}_{LHV}} = 60\%$$

- **Roundtrip efficiency**

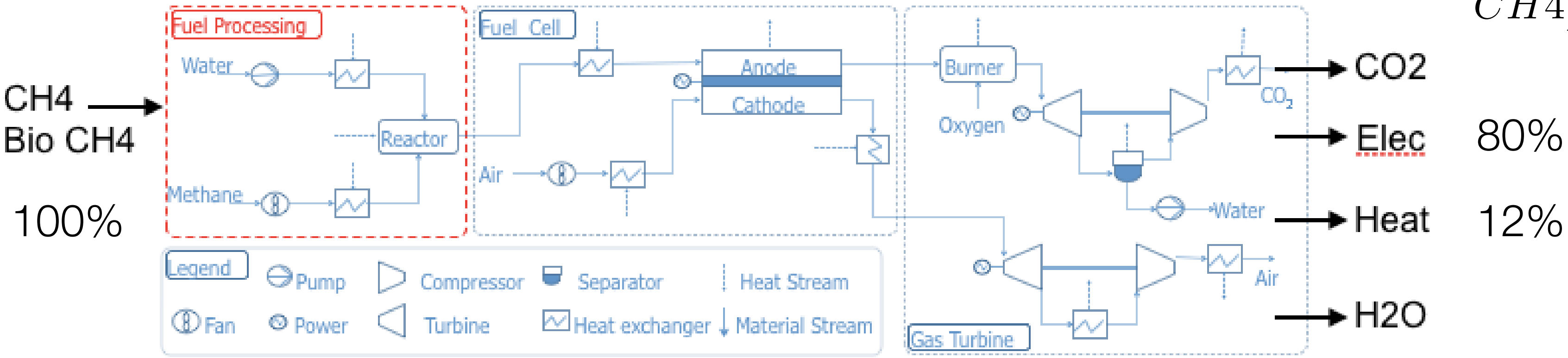
$$\eta = \frac{E^{-}}{E^{+}} = 50\%$$

- **Long term storage on the gas grid !**

If Electricity production efficiency increases

- **Hybrid gas turbine SOFC combined cycle**

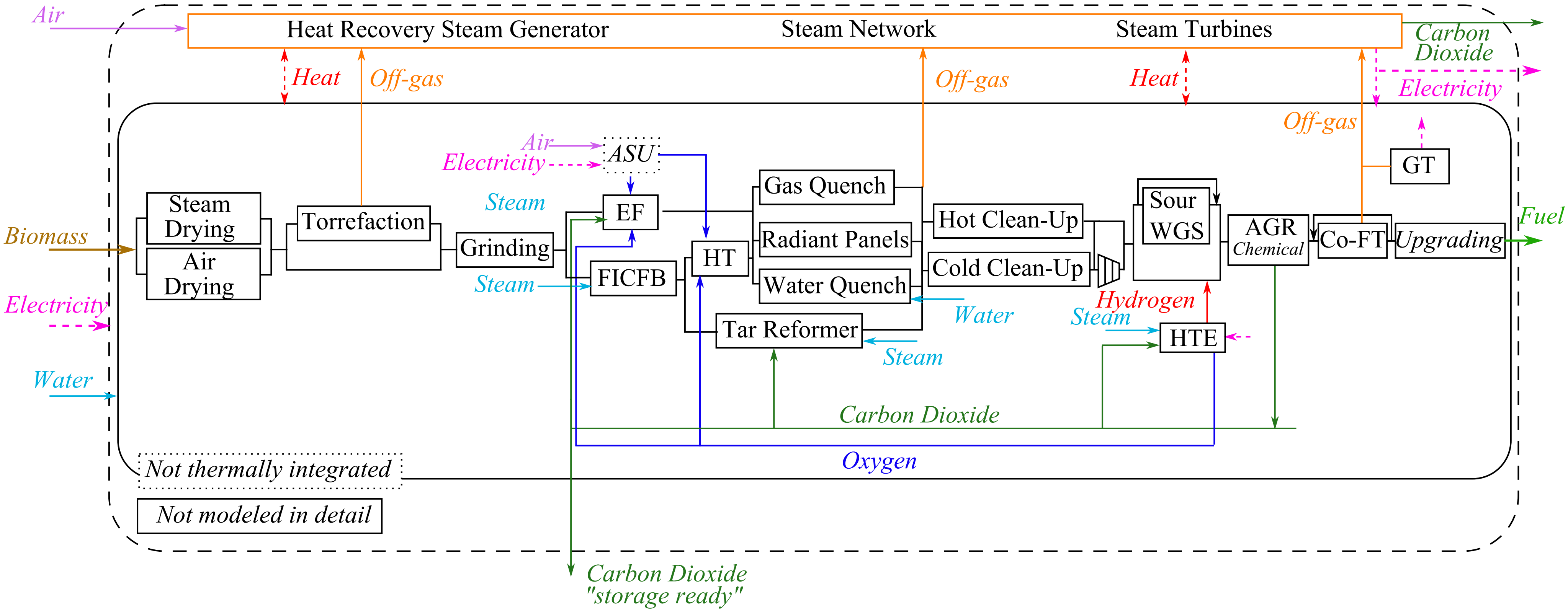
$$\eta_d = \frac{E^-}{CH4^+_{LHV}} = 80\%$$



$$\eta = \frac{E^-}{E^+} = 68\%$$ **A battery is 80%**

- **Round trip with long term storage on gas grid and decentralised production**

Electrolysis integration in the FT production process



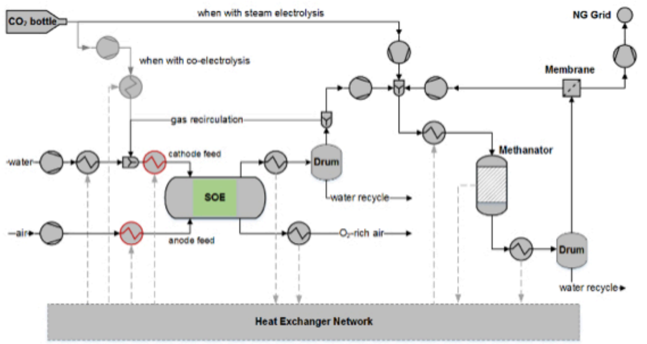
Solid oxide electrolyser

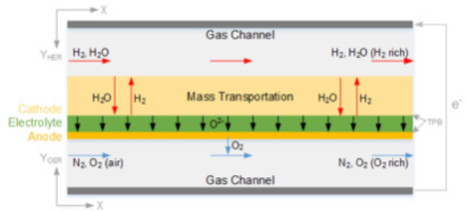
Optimal design of solid-oxide electrolyzer based power-to-methane system

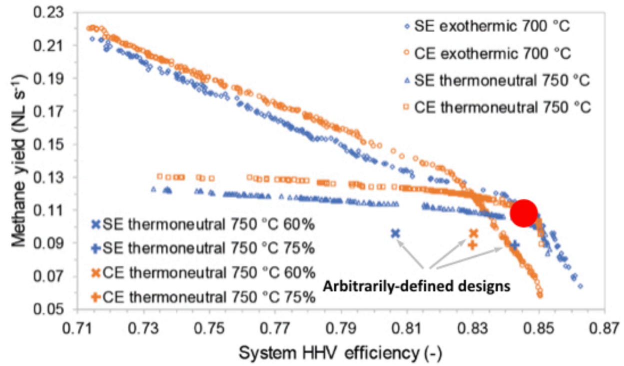
1 System layout

2 Model development & calibration

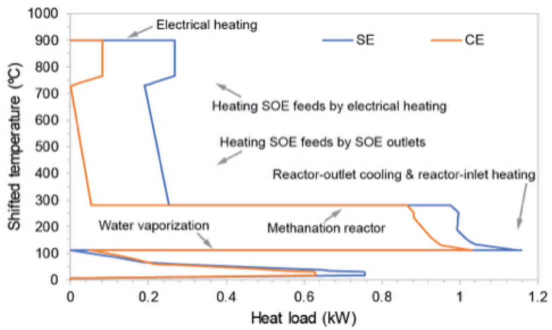
3 Multi-objective optimization







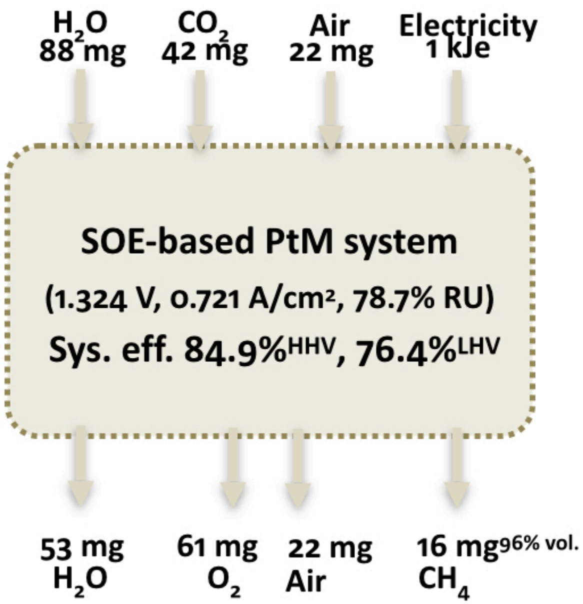
System integration



- SOE (64 * 80 cm² active area)
  - Steam-/co-electrolysis
  - Adiabatic operation
- Methanation reactor
  - Isothermal
- Membrane methane upgrading
  - 1-stage separation
  - Polyamide membrane
- CO_2 sources not included

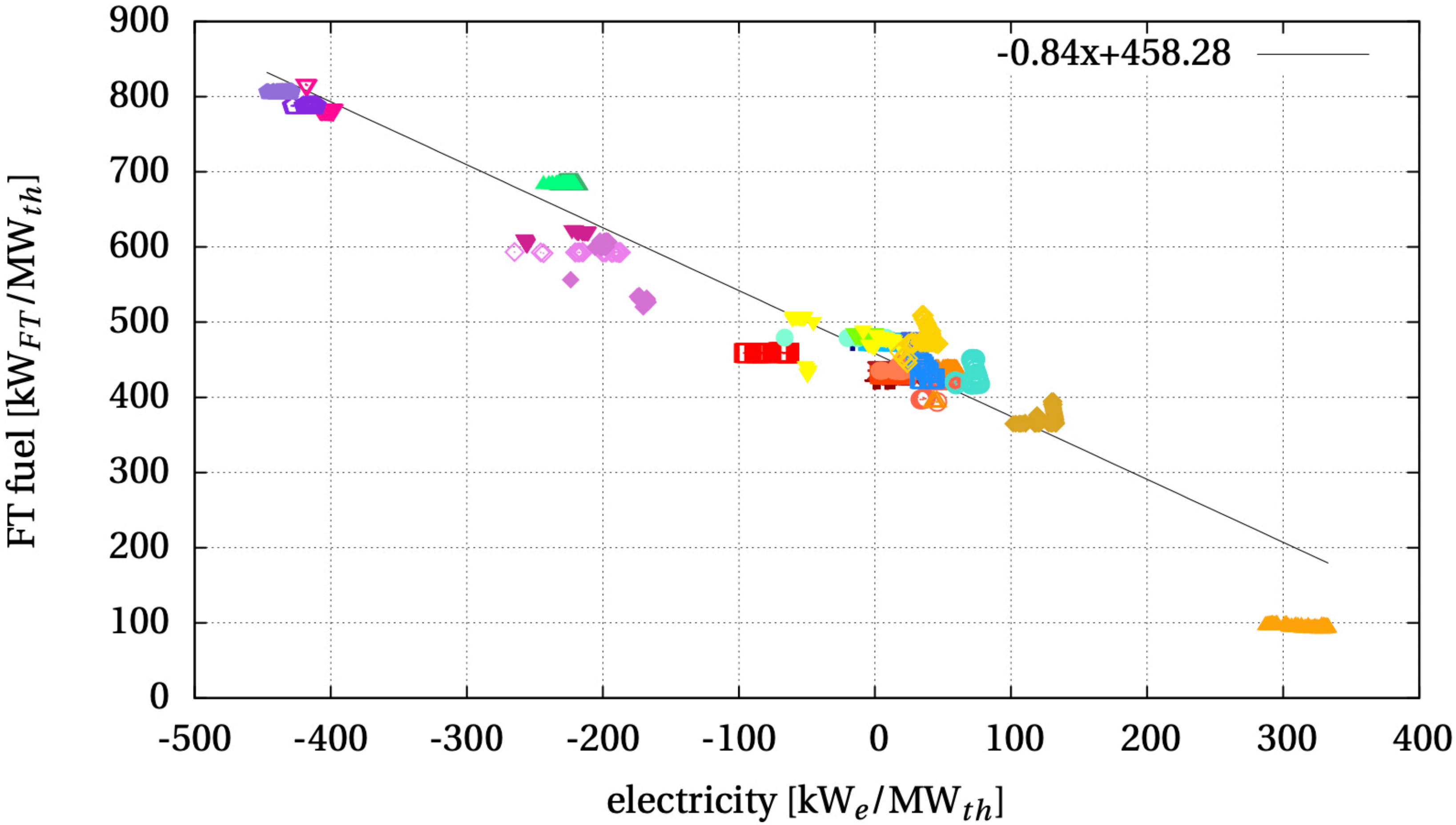
L. Wang, et. al. Optimal design of solid-oxide electrolyzer based power-to-methane systems: A comprehensive comparison between steam electrolysis and co-electrolysis. *Applied Energy* (211), 2018, 1060-1079.

70-80 % efficiency



Integration of the electricity

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



CO2 reuse : Power2Gas concepts

- **Electrolysis : H_2O + E => H_2 +1/2 O_2 (e.g.Proton exchange membrane systems eff ≈ 60%)**
- **+ Methanation (Sabatier Reaction)**
  - Typical Temperature : 250°C-400°C
  - Catalyst : Ni
  - Exothermic

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O + energy \qquad \Delta H = -165.0kJ/mol$$

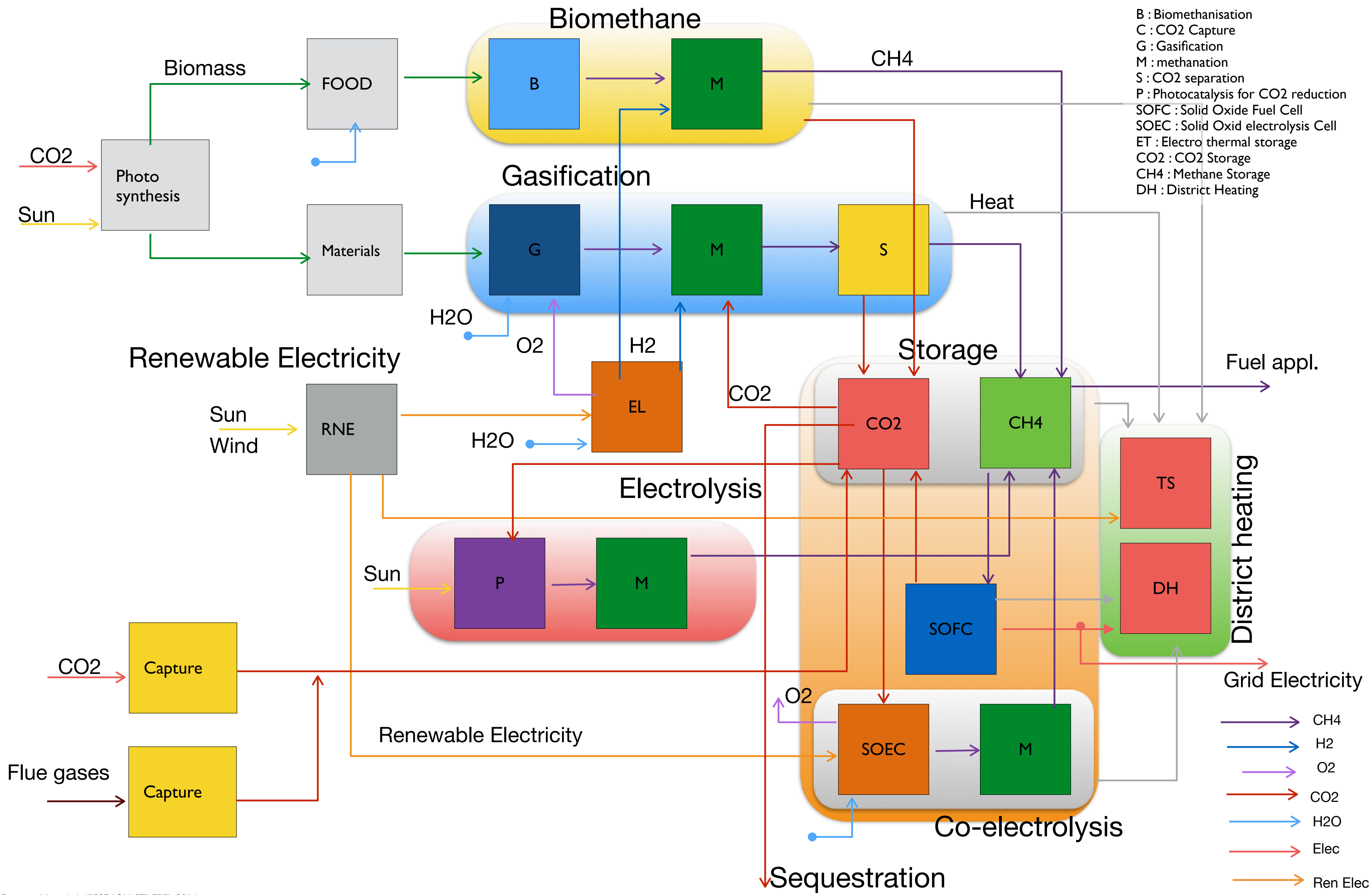
- Biological catalysis[(1)]
  - Typical Temperature : 40-70°C
  - Catalyst : thermophilic methanogen Methanothermobacter thermautotrophicus
  - www.electrochea.com
- Co-Electrolysis (SOEC) + Methanation or Fisher-Tropsh
  - Typical Temperature : 800°C

$$CO_2 + 2H_2O + energy \rightarrow CH_4 + 2O_2$$

(1) Matthew R. Martin, et al. “A Single-Culture Bioprocess of *Methanothermobacter thermautotrophicus* to Upgrade Digester Biogas by CO**2**-to-CH**4** Conversion with H**2**,” *Archaea*, vol. 2013, Article ID 157529, 11 pages, 2013.

(2) Diethelm, S., herle, J. V., Montinaro, D. and Bucheli, O. (2013), Electrolysis and Co-Electrolysis Performance of SOE Short Stacks. Fuel Cells, 13: 631–637. doi: 10.1002/fuce.201200178

CO2 capture and reuse/electricity storage



Conclusion Power to X with biomass

- C(H2O) conversion is a source of Biogenic Carbon for long term electricity storage
- adding renewable H2 to CO2 in the biomass conversion process produces more fuel
  - seasonal storage of electricity as fuel
- CO2 if separated can be sequestrated
- CO2 can be stored as a liquid (70 bar - 25 °C) and be later converted when excess of electricity is available