INTEGRATED PROCESS TECHNO-ECONOMIC EVALUATION AND FLEXIBLE POWER-TO-DME OPERATION MODE

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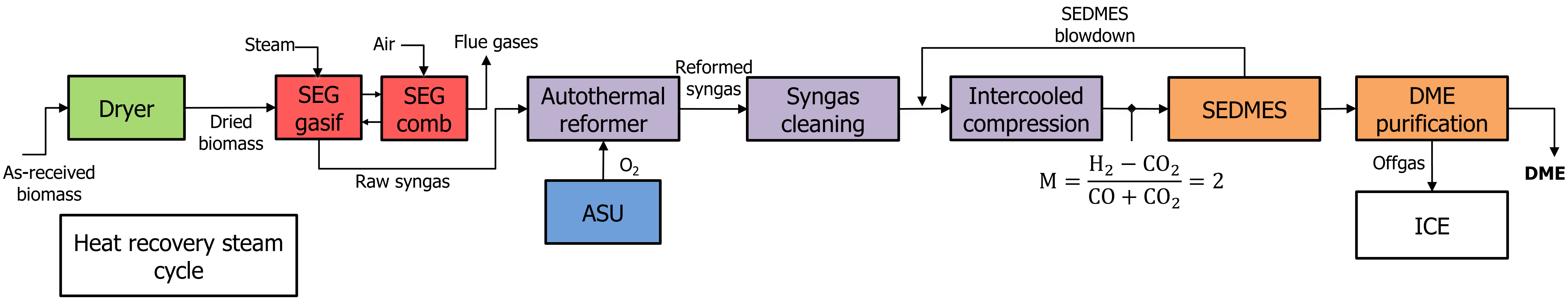
Baseline configuration (F1)



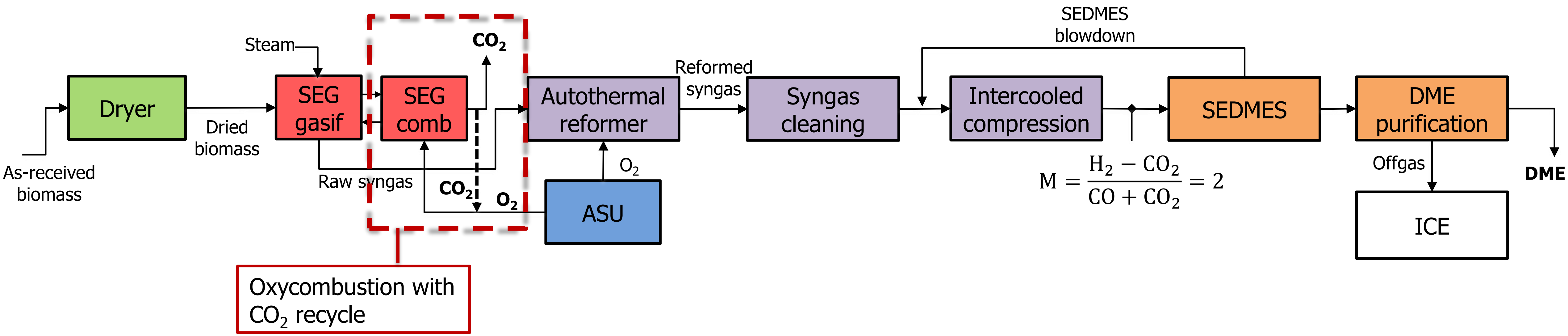
- Woody biomass with 45%$_w$ moisture
- Belt dryer: dried biomass with 15%$_w$ moisture
- Heat recovery steam cycle: designed with rigorous optimization techniques

- SEG temperature: 716°C --> tuned to have M=2 upstream SEDMES
- Steam-to-carbon = 1.5 (molar);
- SEG model validated against: (i) experimental data from University of Stuttgart pilot plant, (ii) 3D simulation results by LUT

- Reformer temperature: 800°C
- Conversion: 90% CH_4, 100% tar
- Raw syngas: H_2 65.6%; CO_2 14.6%; CO 9.0%; **CH_4 8.6%**; C_xH_y 2.1% [%$_{mol}$ dry inert free]
- Reformed syngas: H_2 71.1%; CO_2 14.9%; CO 13.3%; **CH_4 0.68%**; C_xH_y 0.0% [%$_{mol}$ dry inert free]

- SEDMES temperature: ~250°C (PSA system with boiling water reactors)
- SEDMES pressure: 25 bar
- SEDMES modelled by using outputs from TNO rigorous modelling.
- DME purity: 99.9 %$_w$

BECCS configuration: SEG with oxy-combustion (F2)

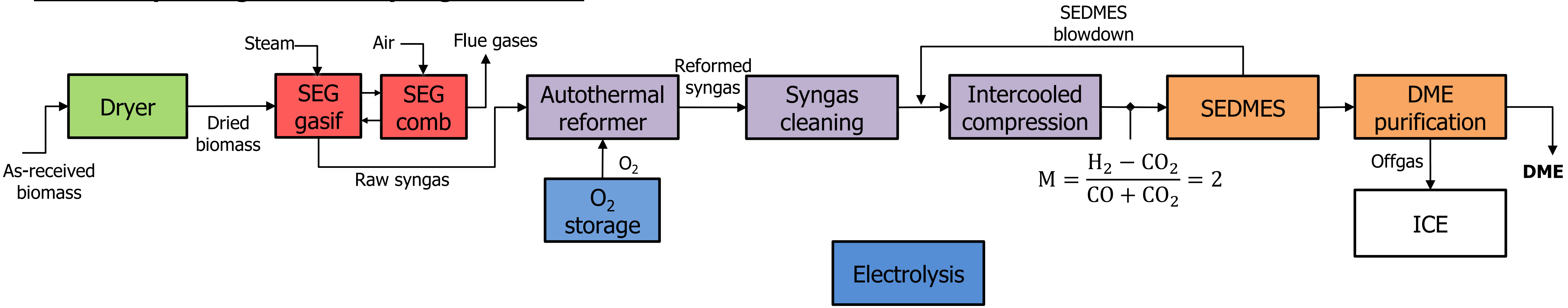


- Oxy-combustion in the combustor -> BECCS leading to <u>negative emissions</u>

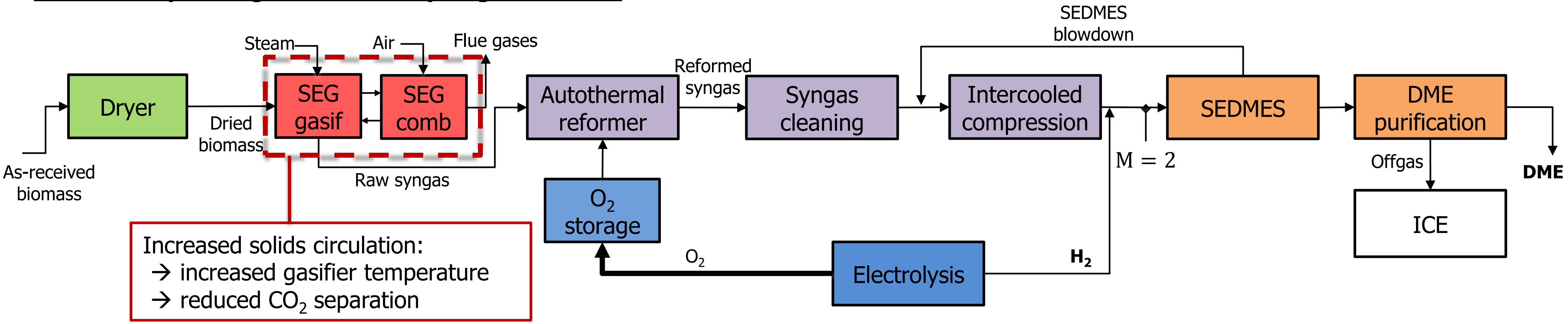
- Calculated as retrofit of the baseline configuration:
  - <u>Same</u> SEG reactors <u>cross-section</u>
  - <u>Exhaust gas recirculation</u> adjusted to maintain the <u>design volumetric flow rate</u> at combustor

Flexibile configuration: power & biomass-to-DME (F3)

Baseline operating mode: no hydrogen addition



Enhanced operating mode: with hydrogen addition

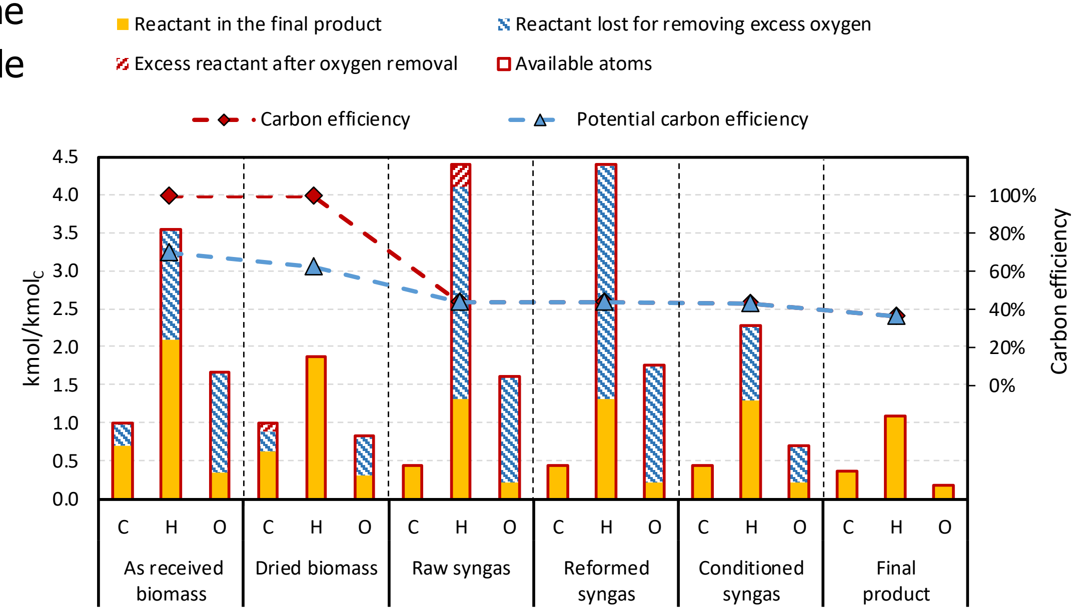


Flexibile configuration: power & biomass-to-DME (F3)

Plant units <u>designed</u> and <u>operated</u> by taking into account an <u>intermittent</u> use of the <u>electrolyzer</u> (-> turned on when electricity price allows an economically viable marginal DME production)

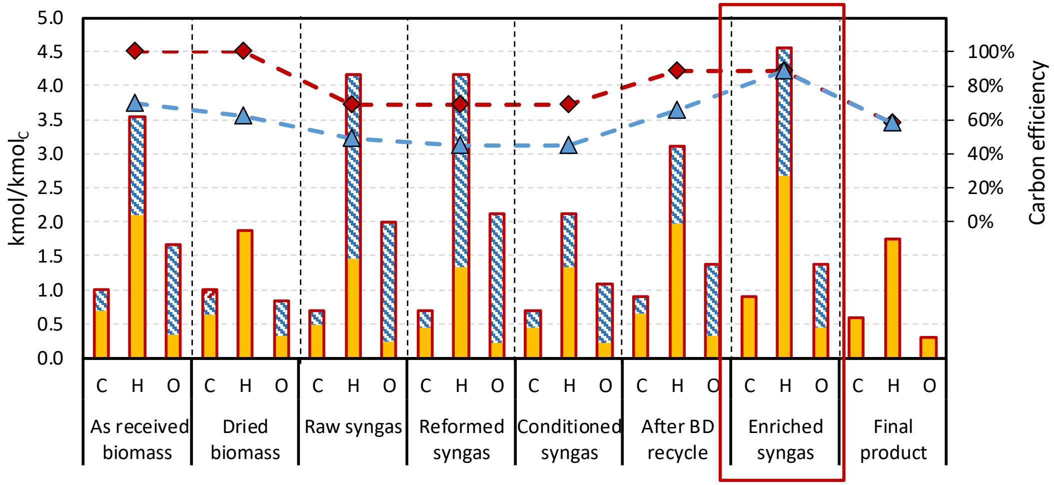
<u>Baseline</u> <u>operating mode:</u>

- SEG temperature: **716°C**
- Raw syngas: H_2 65.6%; **CO_2 14.6%**; CO 9.0%; CH_4 8.6%; C_xH_y 2.1% [$\%_{mol}$ dry inert free]
- Reformed syngas: H_2 71.1%; CO_2 14.9%; CO 13.3%; CH_4 0.68%; C_xH_y 0.0% [$\%_{mol}$ dry inert free]



<u>Enhanced</u> <u>operating mode:</u>

- SEG temperature: **772°C**
- Raw syngas: H_2 52.0%; **CO_2 24.1%**; CO 15.1%; CH_4 7.0 %; C_xH_y 1.8% [$\%_{mol}$ dry inert free]
- Reformed syngas: H_2 59.1%; CO_2 21.7%; CO 18.6%; CH_4 0.58%; C_xH_y 0.0% [$\%_{mol}$ dry inert free]



<u>A. Poluzzi</u>, G. Guandalini, and M. C. Romano, "'Potential carbon efficiency' as a new index to track the performance of biofuels production processes," *Biomass and Bioenergy*, vol. 142, no. November, p. 105618, 2020.

Technical performance

Configuration	Baseline (F1)	BECCS (F2)	Flexible (F3)
Carbon efficiency (CE), %	36.59%	35.37%	58.32%
Biomass-to-DME efficiency ($\eta_{F,global}$), % (LHV basis)	58.52%	56.55%	65.7%
Power-to-DME efficiency (η_{P2F}),%	-	-	53.03%
Net electric power output, MW_{el}	2.59	1.71	-61.90

BECCS:

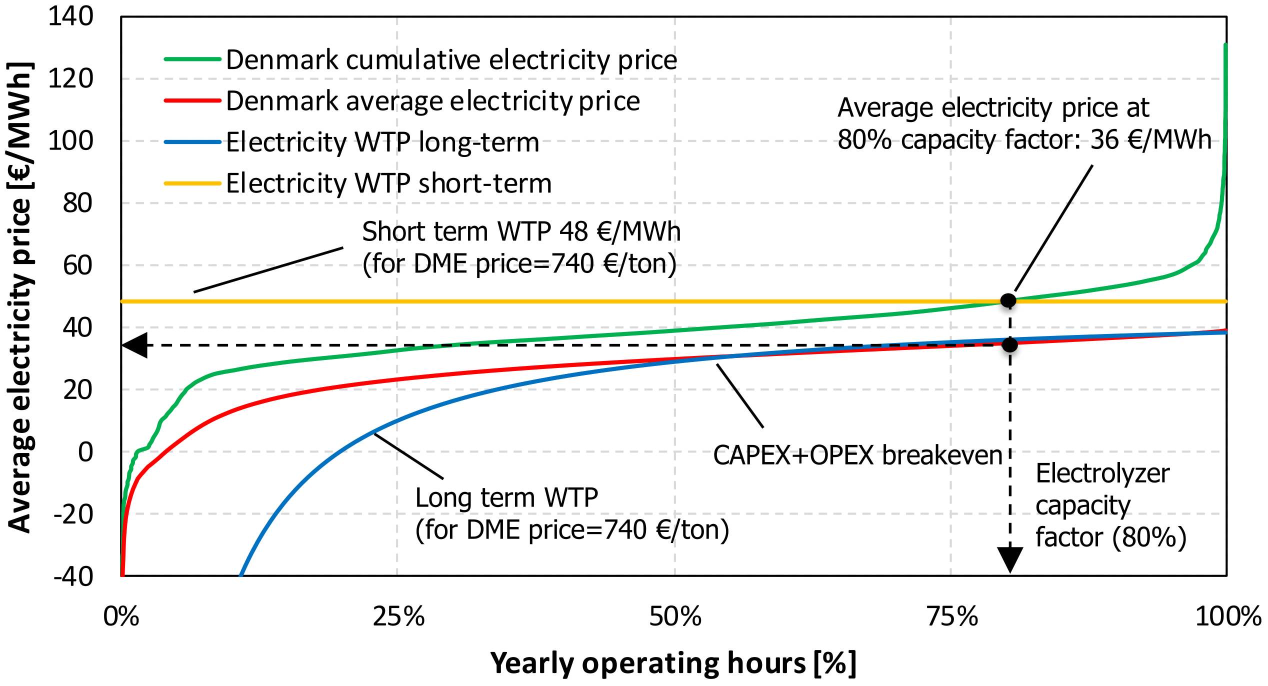
- About 60% of feedstock carbon is captured and permanent stored -> negative emissions.
- Higher oxygen demand (more than 5 times compared to baseline) due to oxy-combustion.

Flexible:

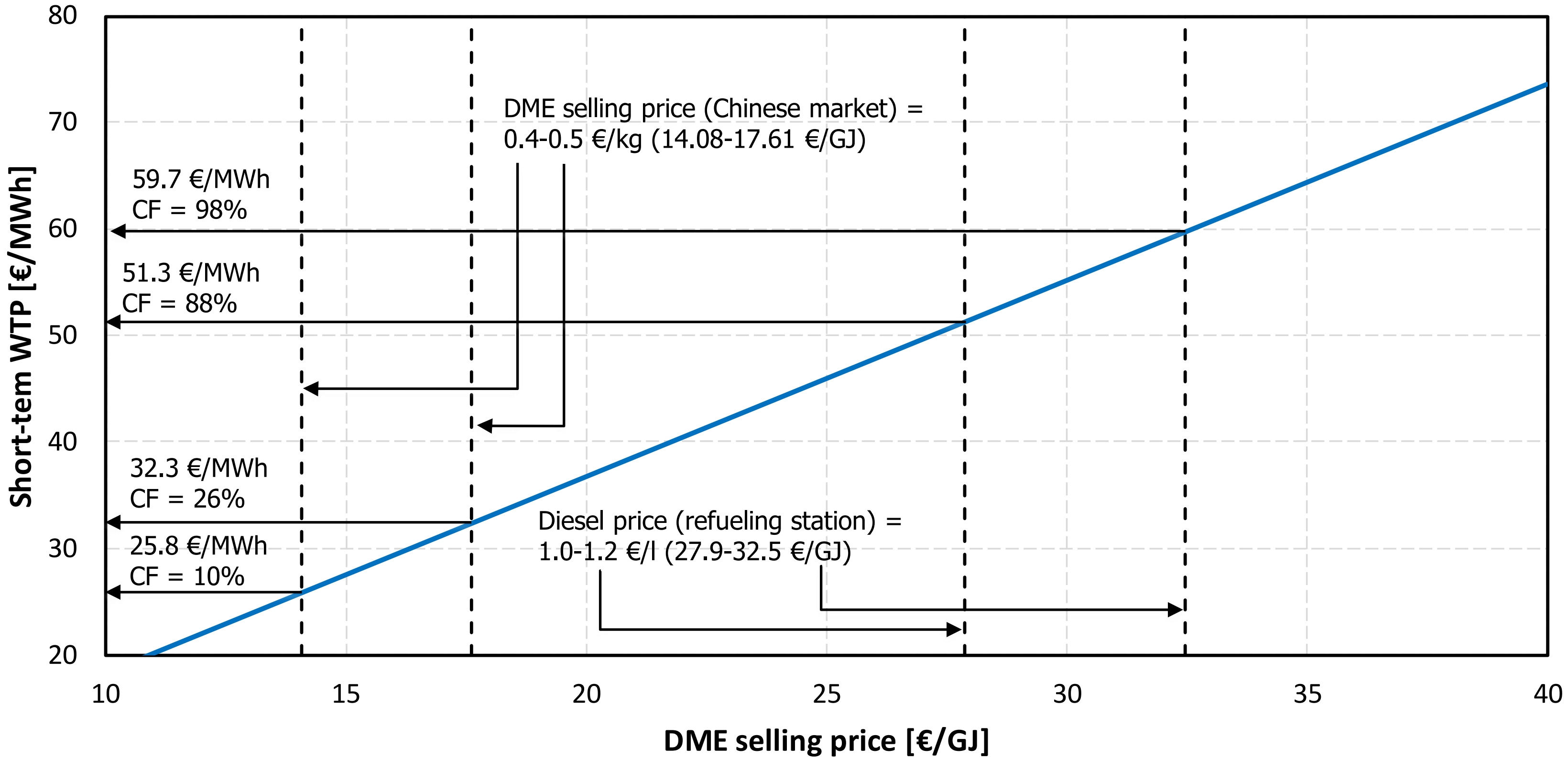
- Hydrogen addition allows to retain the maximum amount of carbon in the syngas (increase CE and $\eta_{F,global}$) and to have higher DME production (+ 47% more than baseline).
- Electricity is converted into DME with η_{P2F}=53% (assumed electrolyzer efficiency: 0.64 MW_{LHV}/MW_{el}).
- Maximum power consumption of the electrolyzer: about 60% of the biomass LHV input.

Economic feasibility of electrolyzer operation and installation

- Cumulative electricity price during the year (green line).
- Average electricity price vs. capacity factor (red line).
- Short term willingness to pay (yellow line). Breakeven OPEX: revenues from DME selling = cost of electricity + cost of water.
- Long term willingness to pay (blue line). Maximum electricity price to breakeven the total costs: revenues from DME selling = electrolyzer CAPEX (assumed 630 €/kW) + OPEX.



Economic feasibility of electrolyzer operation



→ Enhanced operation at high capacity factors if DME selling price is in the range of fuels for mobility.

Economic performance

Biomass cost = 46 €/ton (17 €/MWh)

<u>Baseline</u>:

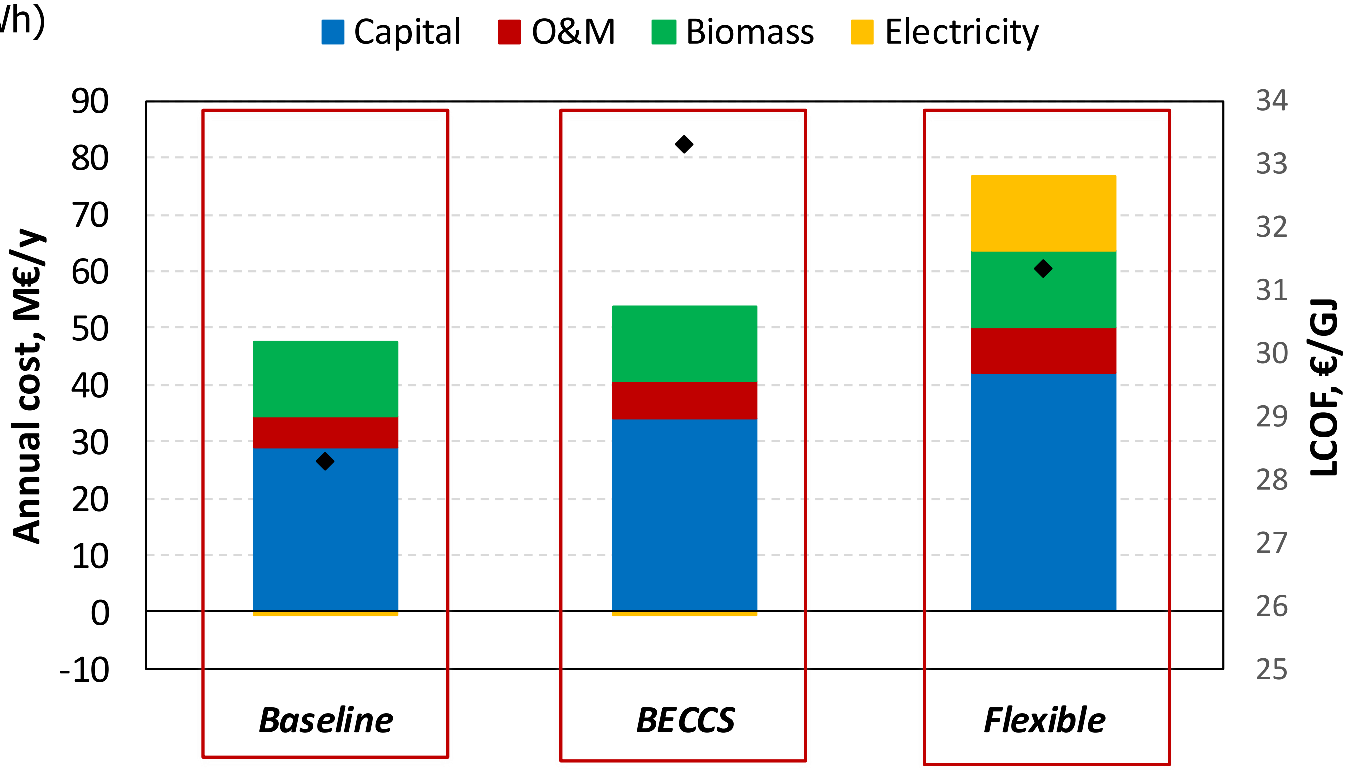
- Total investment = 246.2 M€ *(optimistic N-th plant scenario)*
- Production = 57623 ton/y

<u>BECCS</u>:

- Total investment = **290.8 M€**
- Production = 55691 ton/y

<u>Flexible</u>:

- Total investment = 359.8 M€
- Production = **84993 ton/y**



Denmark day-ahead market:

- Average electricity price = 39.02 €/MWh
- Availability in enhanced operation = 80% h/y
- Average electricity price@80% = 34.82 €/MWh
- Availability in baseline operation = 20% h/y
- Average electricity price@20% = 55.82 €/MWh

- Baseline: most of the annual cost is due to <u>investment capital</u> and <u>biomass costs.</u>
- BECCS: <u>larger ASU and CO_2 compression</u> leads to higher <u>capital cost</u> (-> higher LCOF compared to baseline).
- Flexible: the <u>electrolyzer</u> increases annual capital and <u>electricity costs</u> (-> higher LCOF compared to baseline).

Economic performance: lower the LCOF

A Electrolyzer:

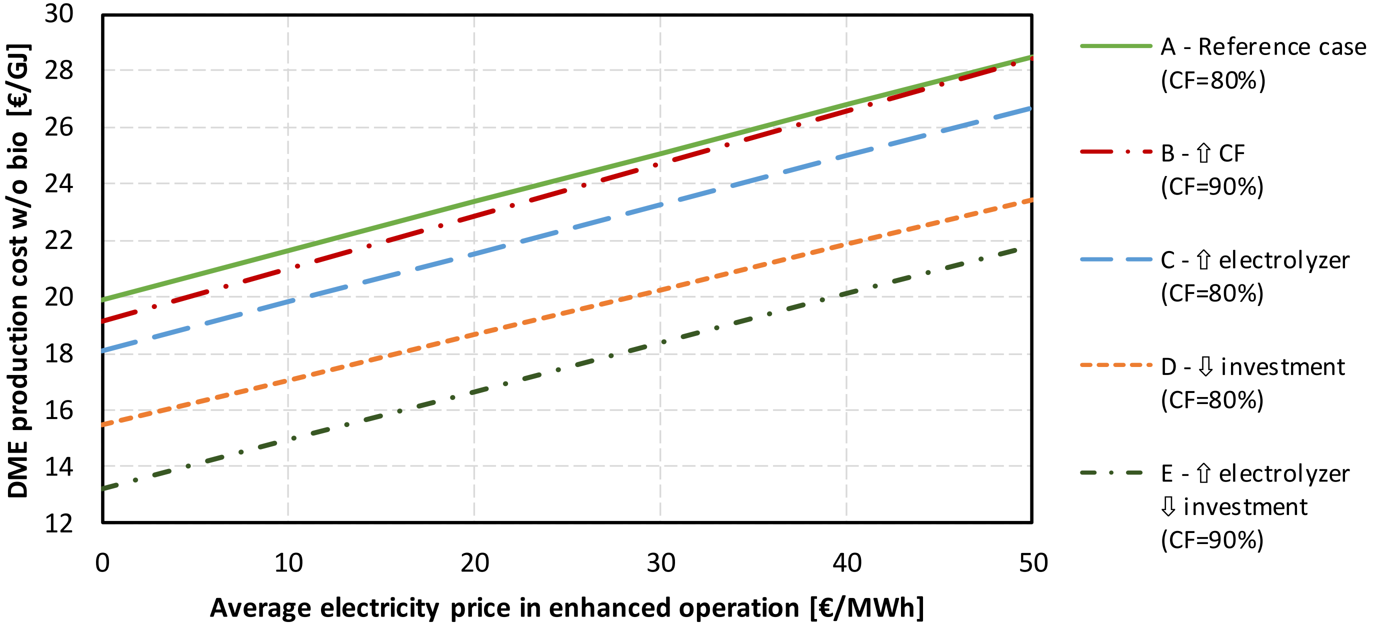
- Capital cost: 630 €/kW_{el}
- Efficiency: 0.64 MW_{LHV}/MW_{el}
- CF: 80%

Other units: 100% CAPEX

B Electrolyzer:

- Capital cost: 630 €/kW_{el}
- Efficiency: 0.64 MW_{LHV}/MW_{el}
- CF: 90%

Other units: 100% CAPEX



C Electrolyzer:

- Capital cost: 400 €/kW_{el}
- Efficiency: 0.71 MW_{LHV}/MW_{el}
- CF: 80%

Other units: 100% CAPEX

D Electrolyzer:

- Capital cost: 630 €/kW_{el}
- Efficiency: 0.64 MW_{LHV}/MW_{el}
- CF: 80%

Other units: 70% CAPEX

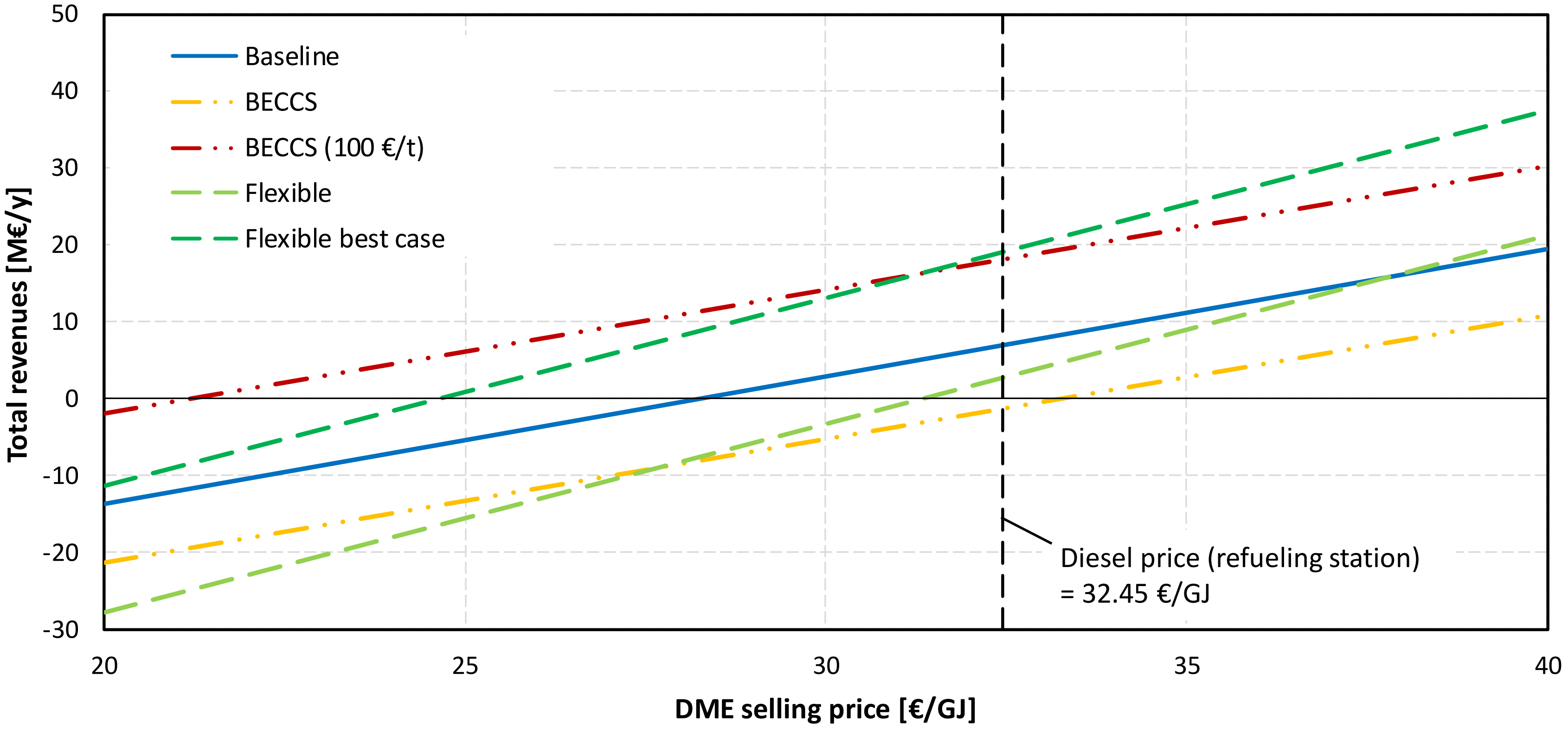
E Electrolyzer:

- Capital cost: 400 €/kW_{el}
- Efficiency: 0.71 MW_{LHV}/MW_{el}
- CF: 90%

Other units: 70% CAPEX

- The improvements in capacity factor (CF) are beneficial, but for CF > 80% the advantages given by a flexible plant are reduced.
- By improving the electrolyzer technology, the DME production cost reduces by about 10%.
- By combining the improvements in the electrolyzer technology and the reduction in CAPEX of the other plant units, the DME production cost decreases by about 7 €/GJ.

Economic performance: total annual revenues



- Plants with CCS need revenues from CO_2 storage.
- The higher the yearly production, the steeper the line → plants with high yearly production benefit more from high selling price.
- High DME selling price, optimistic Capex and high carbon tax (for BECCS case) are needed to make FLEDGED system economically competitive.

Lessons learned

- The flexibility of FLEDGED solutions offer opportunities of improving the economic performance of biomass-to-DME plants.

- The integration with water electrolysis is a key factor to obtain high fuel yield, high carbon efficiency and potentially high revenues for biofuel plants. For fuel selling price in the range of transportation fuels (i.e. properly subsidized), the electrolyzer can operate with high capacity factors (>80%).

- BECCS configuration is interesting just in case of a high carbon tax and as a retrofit option in case of indirect gasification. For new plants, direct oxygen-blown gasification would be economically preferable.

Way forward

- Validate experimentally the SEG-filtration-reforming system, aiming at high carbon conversion, high filtration temperature and low S/C ratio, in order to decrease the O_2 consumption.

- Explore options to reduce the $CaCO_3$ makeup by proper material selection, sorbent pretreatment to improve the mechanical properties and selective sorbent/ash separation for ash-rich feedstocks (e.g. refuse derived fuel).

- Improve the economics of the SEDMES process by optimizing the SEDMES cycle to improve yield and productivity.

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