Assessing the performance of future integrated biorefinery concepts based on biomass gasification

Methodology and tools

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iets
Industrial Energy-Related Technologies and Systems
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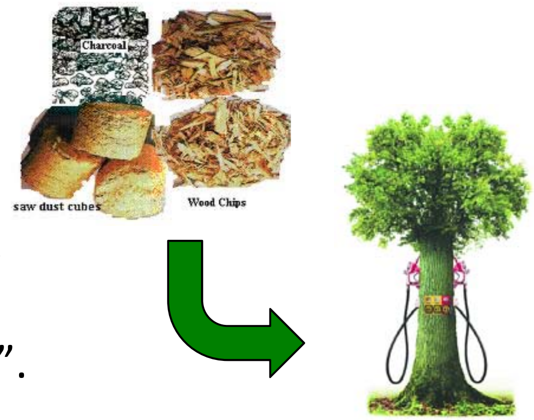
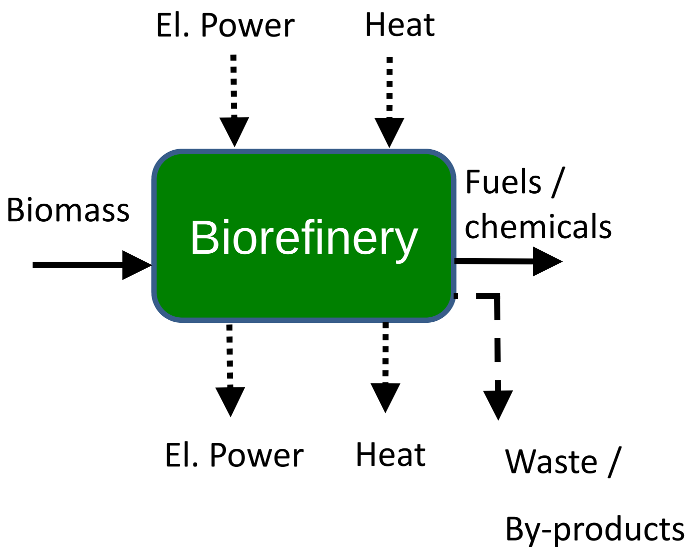
Profu

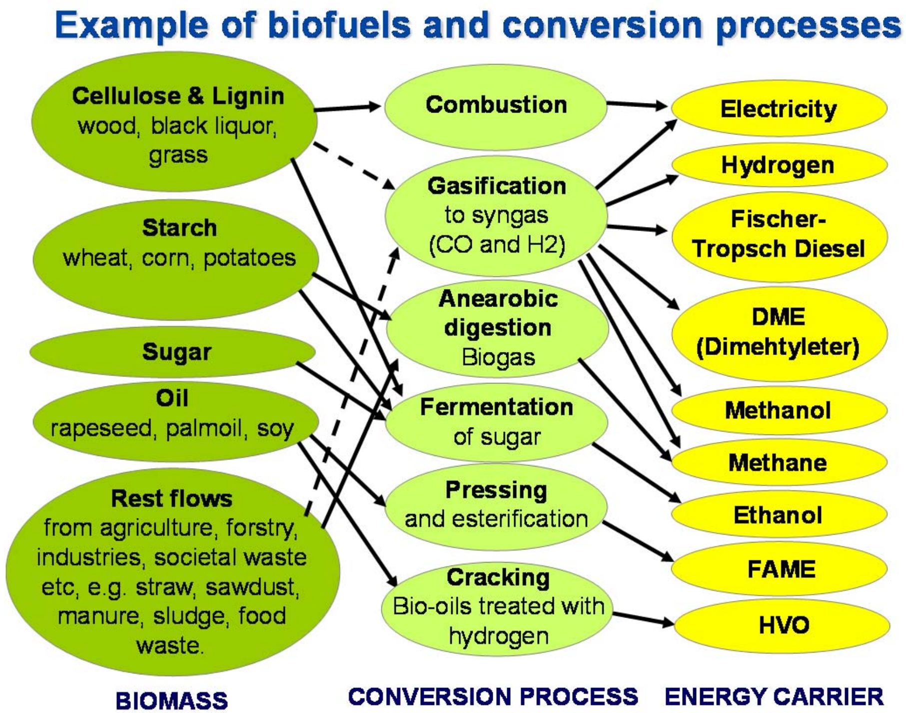
Biorefinery - definition

”A wide range of technologies able to separate biomass resources (wood, grasses, corn, etc.) into their building blocks (carbohydrates, proteins, fats, etc.) which can be converted into value-added products such as biofuels and bio-chemicals”.

F Cherubini and A Strømman, ”Principles of Biorefining”, Elsevier 2011.







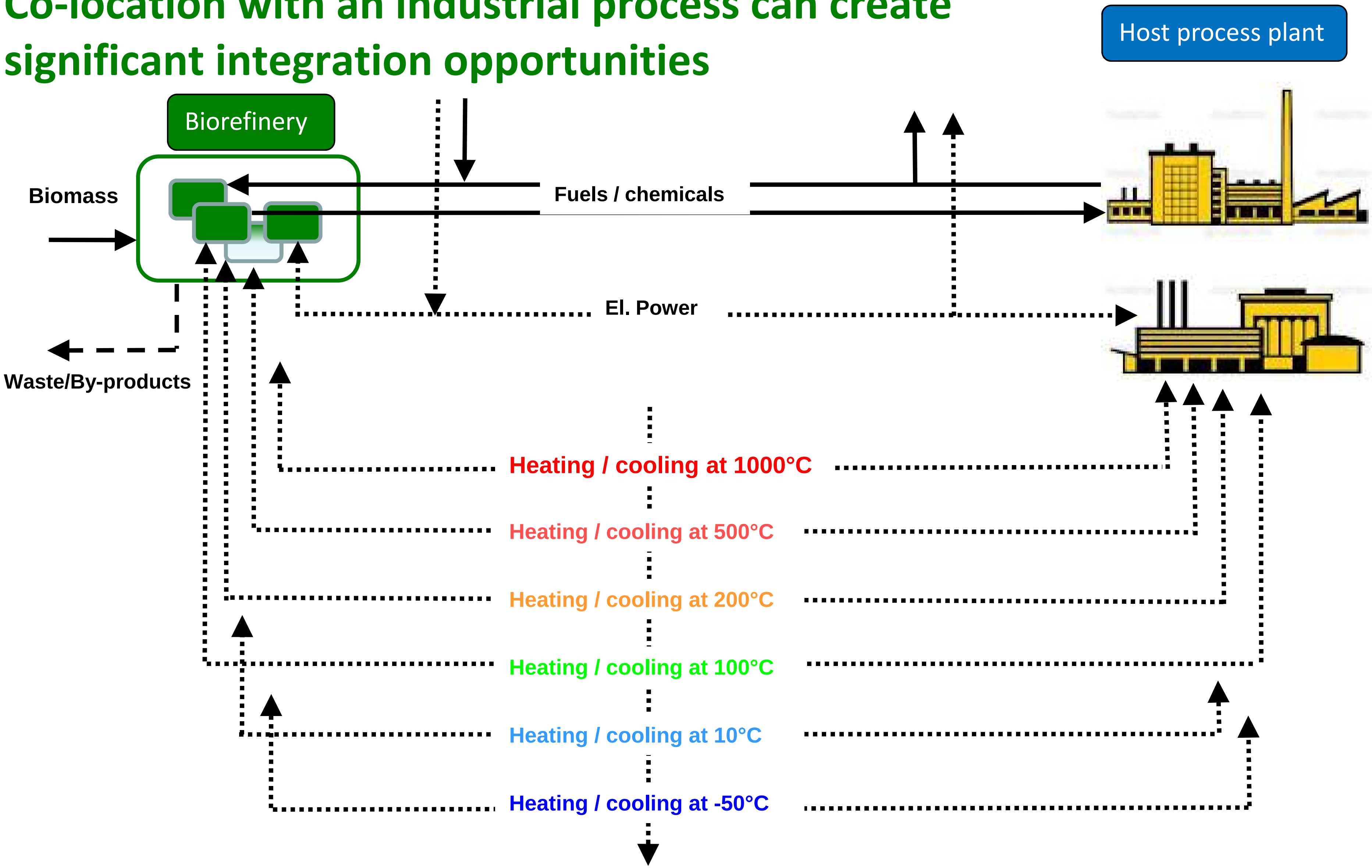
Limited resource

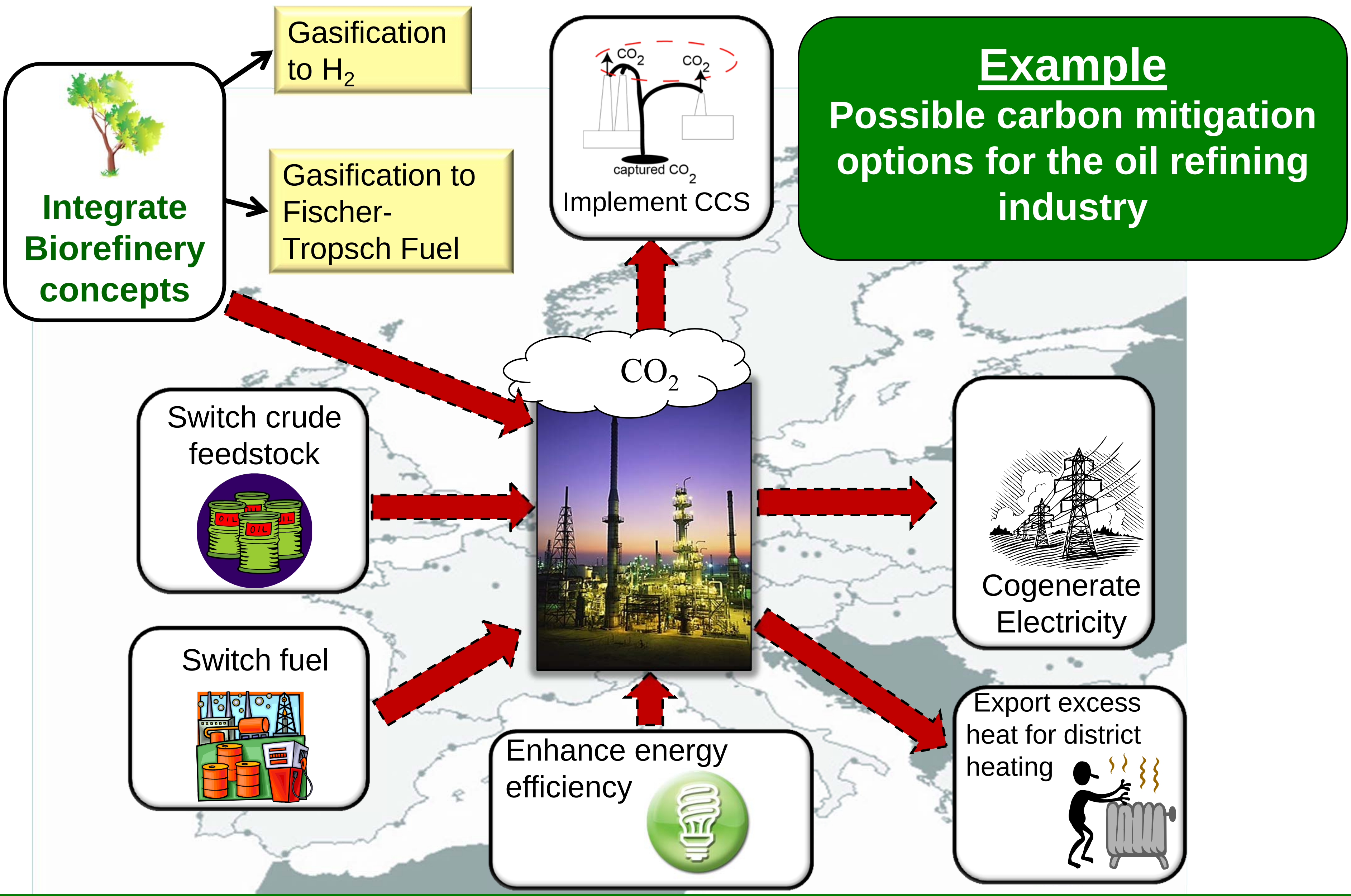
Fast-growing demand

Biorefineries must be as efficient as possible

- Optimal mix of products
- Maximize heat cascading within and between processes

Co-location with an industrial process can create significant integration opportunities




Example
Possible carbon mitigation options for the oil refining industry
Gasification to H2
Integrate Biorefinery concepts
Gasification to Fischer-Tropsch Fuel
CO2
CO2
captured CO2
Implement CCS
CO2
Switch crude feedstock
OIL
OIL
Switch fuel
Enhance energy efficiency
Cogenerate Electricity
Export excess heat for district heating

Drivers behind the current interest in gasification-based biorefineries

Oil refineries, petro-chemical plants, ...

- Handle large volumes of fuels or chemicals
- Consume large quantities of fossil fuels
- Core processes are often based on high temperature synthesis routes
- Are constrained by strict safety regulations regarding chemical hazards and pressurized equipment

Pulp and paper plants:

- Large quantities of by-products than can be converted to high-value products: Black liquor, bark, etc.

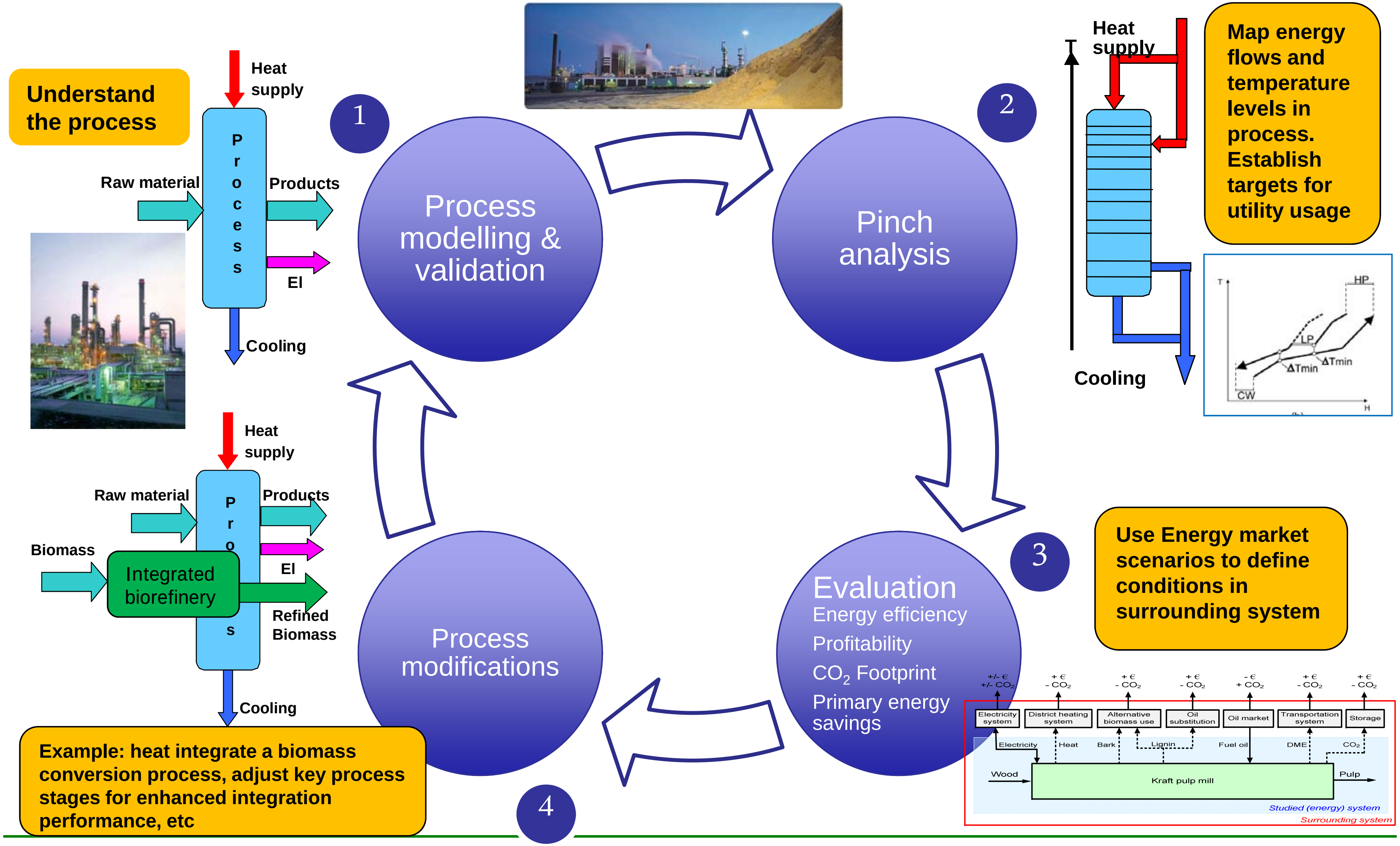
Pulp Mill with stacks of timber in Alberta, Canada

Gasification constitutes an interesting initial common core process path, that can be followed by a multitude of downstream conversion operations

Methodology and tools to support strategic decision-making for future integrated biorefinery concepts

- Systematic screening and optimal synthesis of biorefinery concepts
- Value and supply chain management and evaluation
- LCA-based evaluation of biorefinery concepts
- Future energy market scenarios for evaluation of biorefinery concepts
- Decision-making under uncertainty regarding future market conditions
- Quantifying the benefits of heat integrated vs stand-alone biorefinery concepts

Maximizing biorefinery efficiency using process integration tools



Assessing primary energy savings, profitability and carbon balances of biorefinery investments in industry

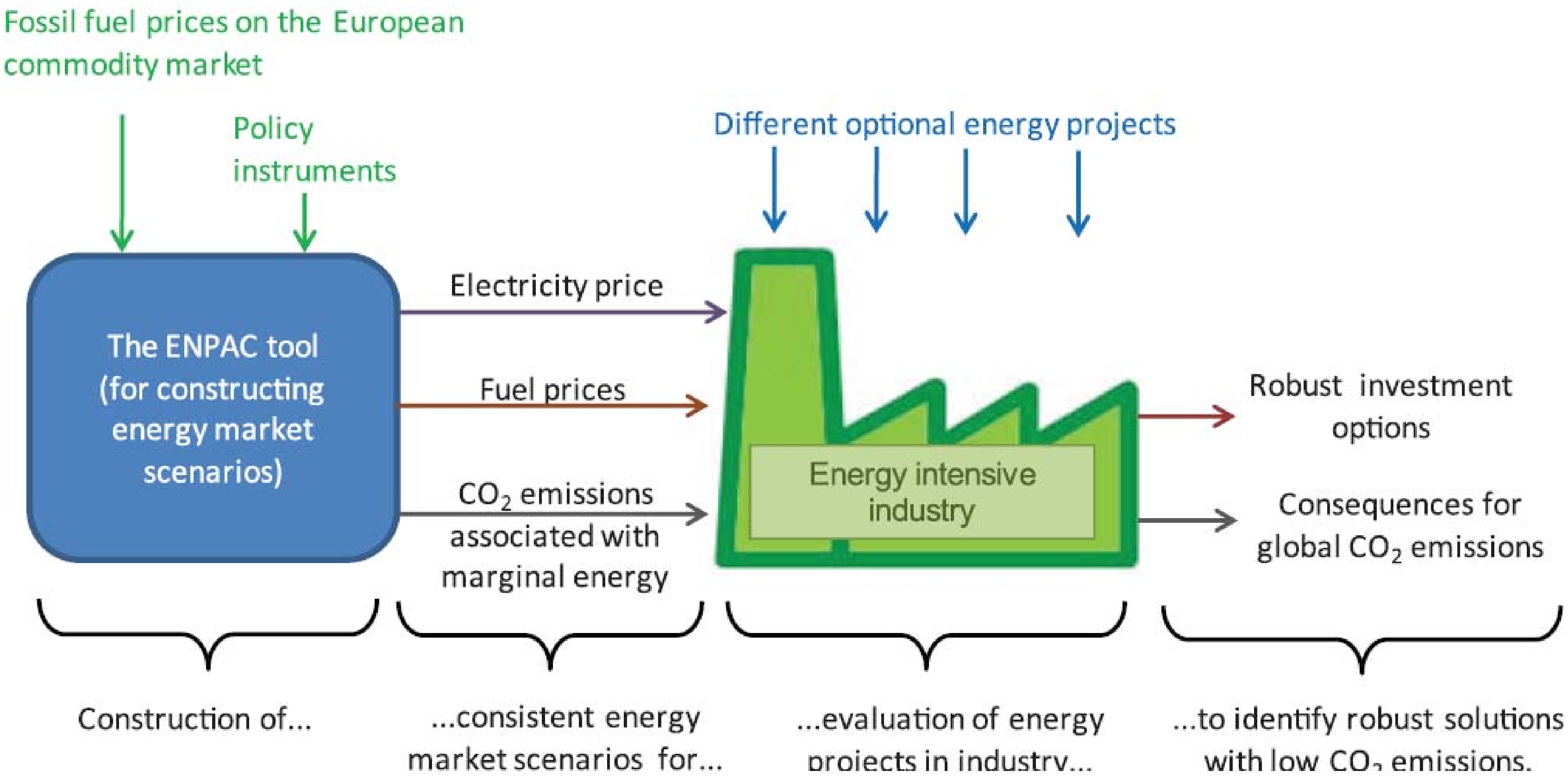


Figure 1: Overview of the purpose of energy market scenarios for evaluation of energy efficiency investments in energy intensive industry where the ENPAC tool is used to construct the scenarios.

Why do we need Energy market scenarios?

Biomass feedstock

Pulp mill

Pulp products

Possible energy export options resulting from implementation of Energy saving measures

Electricity export
126 GWh/year
INV: 28 M€

Biomass fuel export
500 GWh/year
INV: 22 M€

Which option is most profitable and has greatest potential for CO_2 emissions abatement in the medium-term future?

To answer this we need

Future energy prices and description of the future energy market - Not available!

Next best option: Possible future energy prices and energy market description i.e. scenarios

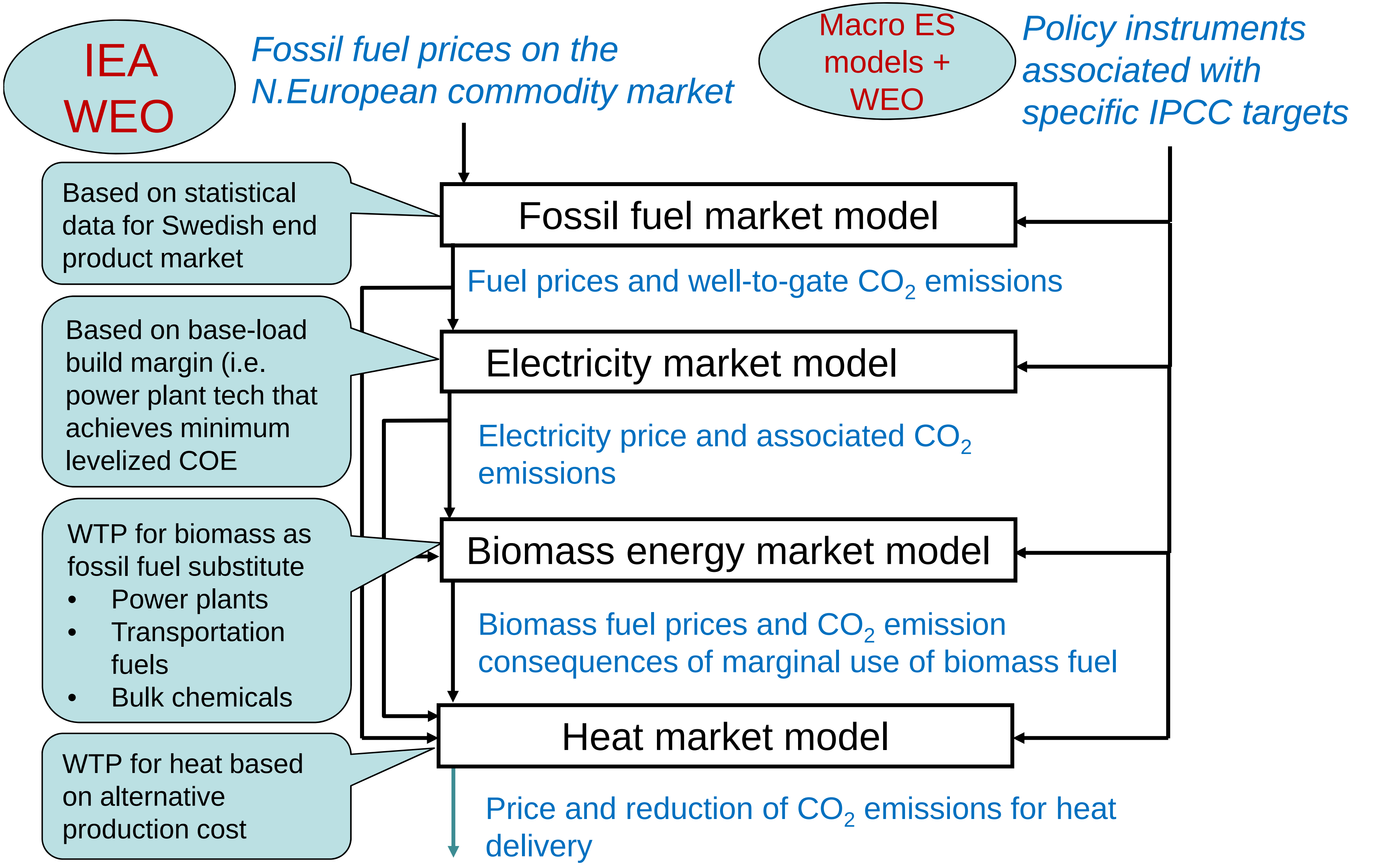
Energy market scenarios

Important: consistency within each scenario

Electricity market	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Base load build margin	NGCC	Coal CCS	Coal	Coal CCS
El. price (€/MWh)	54	[illegible]	57	62
CO_2 (kg/MWh$_{el}$)	374	136	723	136

Biofuel market	1	2	3	4
Marginal biofuel user	Coal power	Coal power	DME Prod.	DME prod.
Biofuel price (€/MWh)	14	20	15	21
CO_2 (kg/MWh$_{biofuel}$)	329	329	122	159

Constructing consistent energy market scenarios with ENPAC tool



Scenario construction in practice

High and low fossil fuel prices are combined with different cost levels for CO_2 emissions and used as input to ENPAC tool. Consistent energy market scenarios are generated.

Fossil fuel prices

CO_2 emission cost

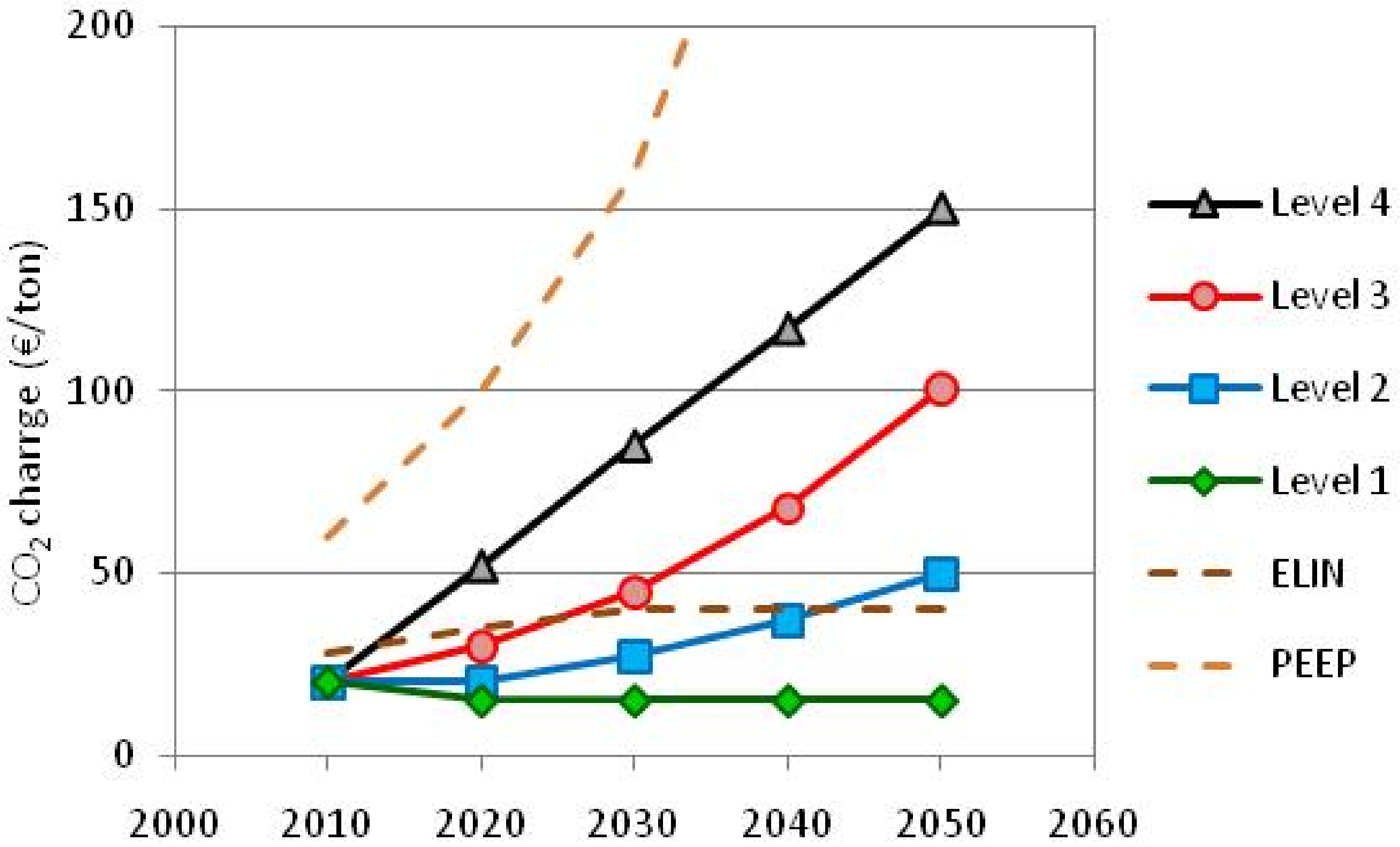
1 2 3 4

High — Sc 1 — Sc 2 — Etc…

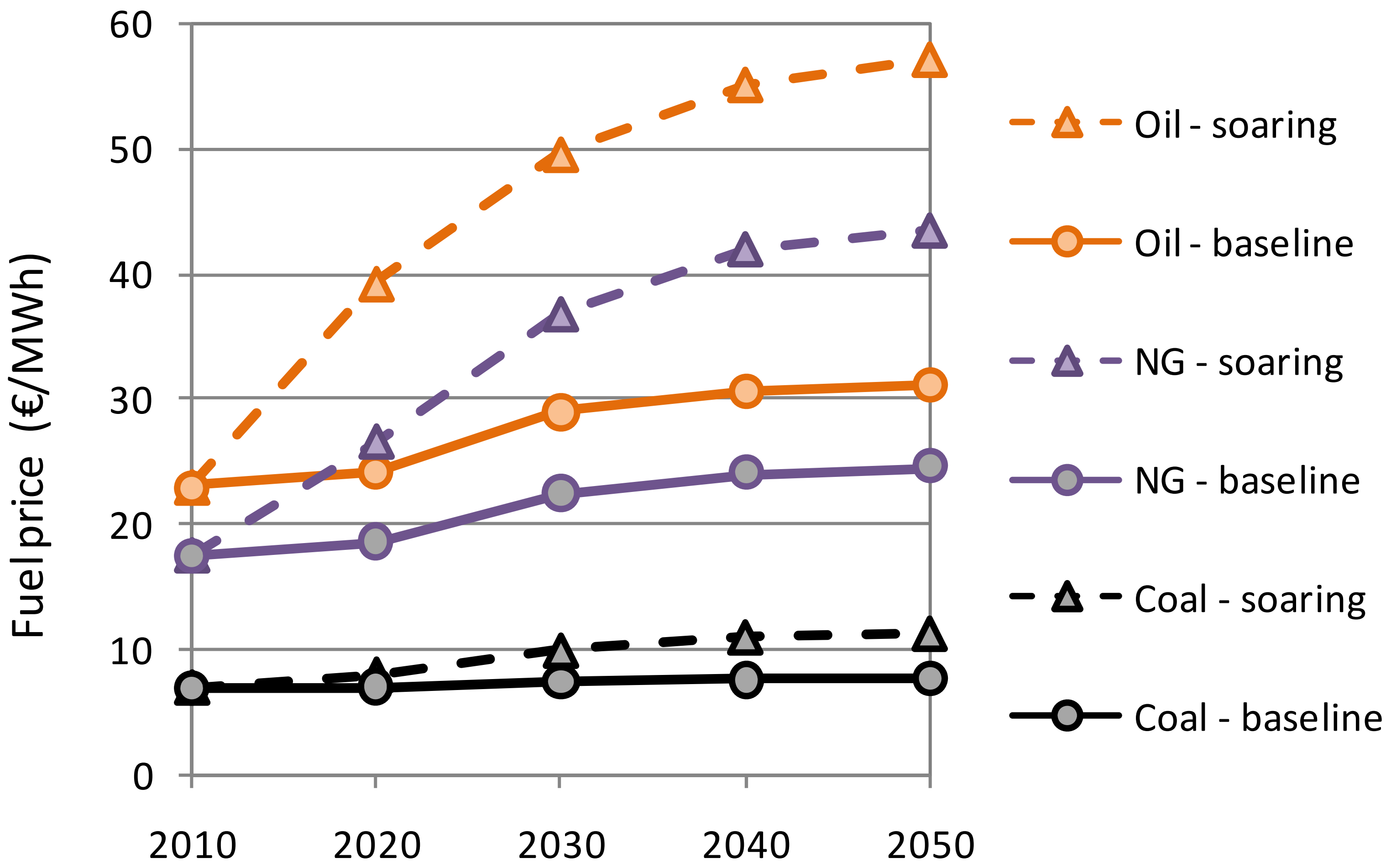
Indicative price levels for el, biomass fuel and excess heat & related CO_2 emissions for Scenario 1

Low

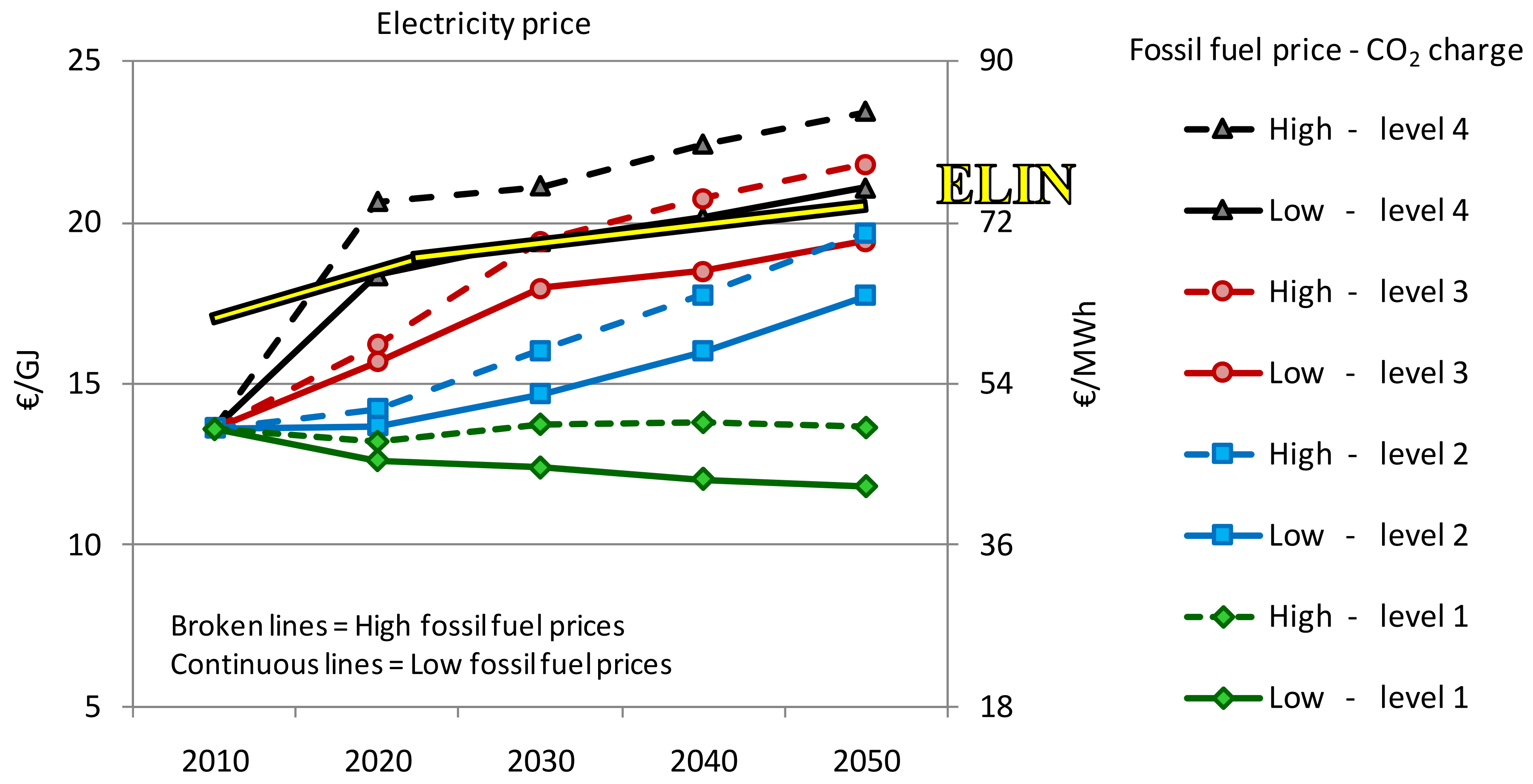
Sample input data: CO_2 emissions costs, €/ton



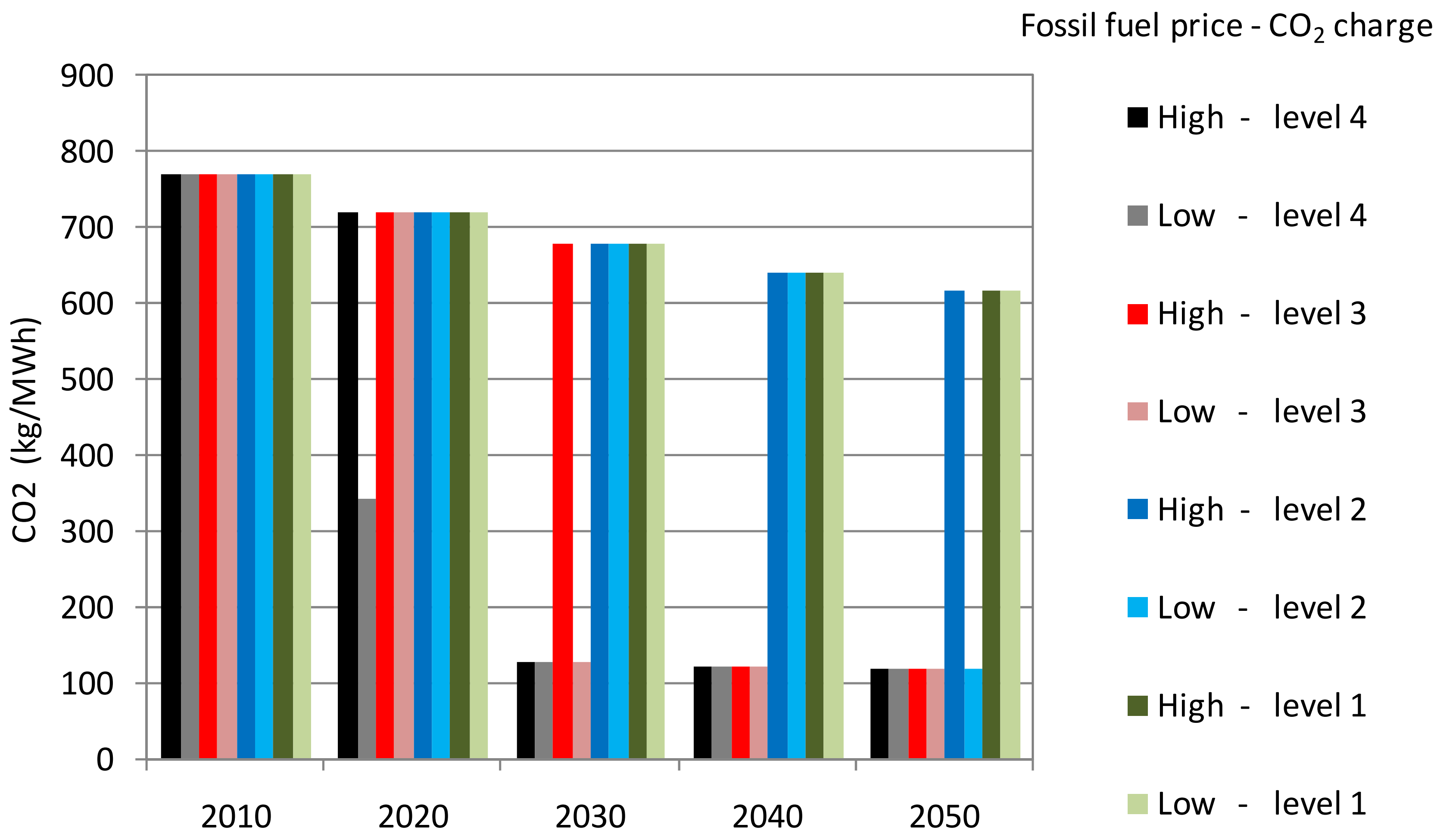
Sample input data: Fossil fuel prices, €/MWh (low/high)
- European Energy and Transport 2006, baseline (low) and soaring prices (high)



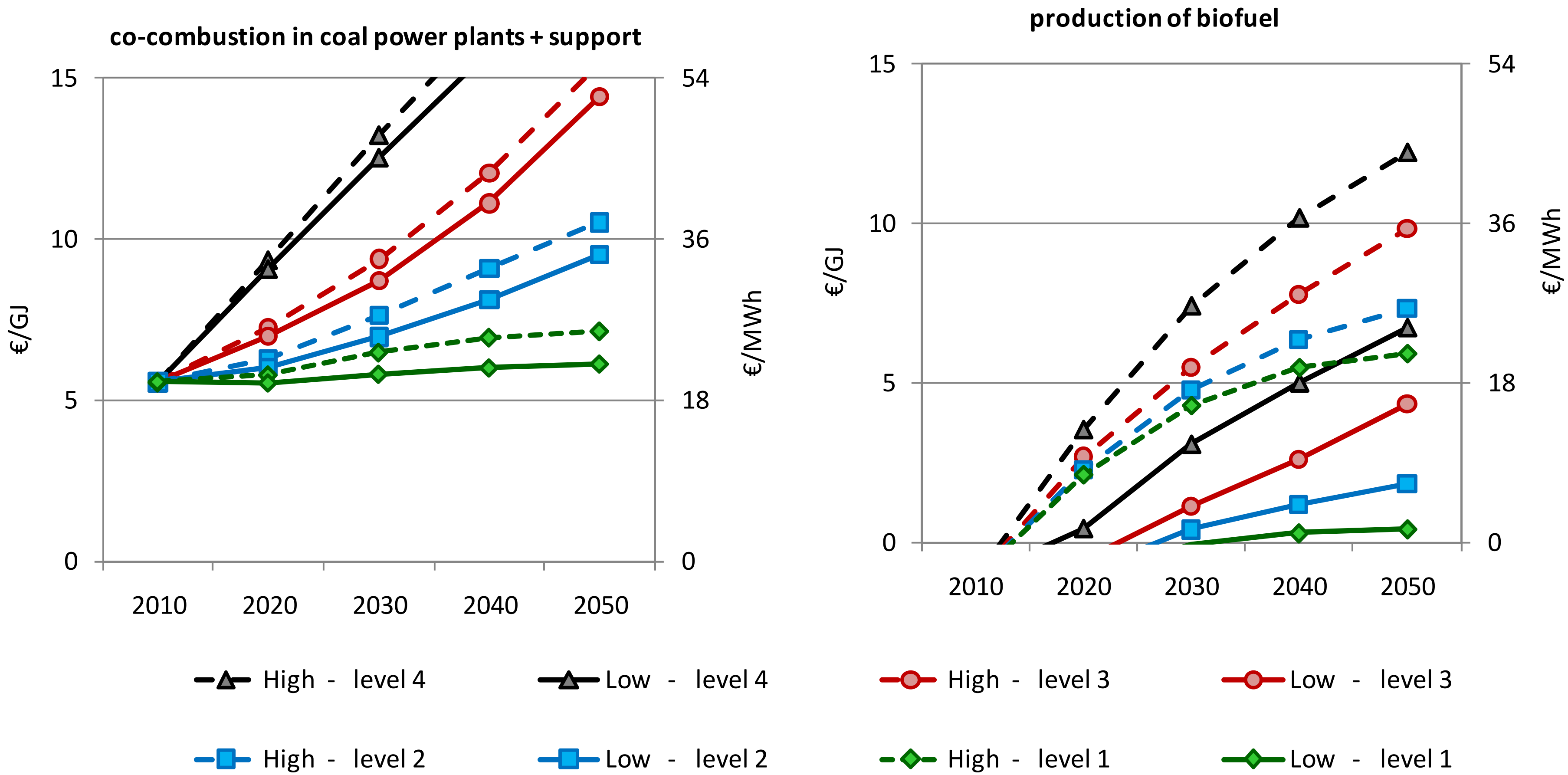
Sample results: base-load electricity price (excl transmission charges and taxes)



CO_2 emissions associated with base load marginal electricity generation (kg/MWh)



Unprocessed wood fuel prices for 2 different assumptions



- CO_2 charge component dominates
- Easy to understand
- Good match with current prices

- Oil price dominates
- Transport sector assumed to have the same CO_2-charge as other sectors, which favours biofuel

Quantifying the benefits of integration of biorefinery concepts in industry – Highlights from recent work at Chalmers

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Contents lists available at ScienceDirect

Energy

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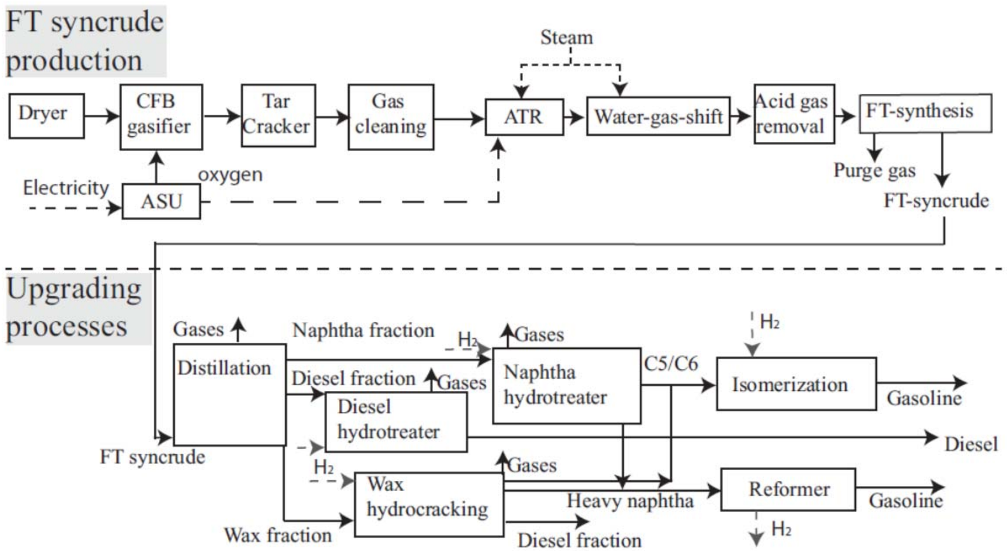
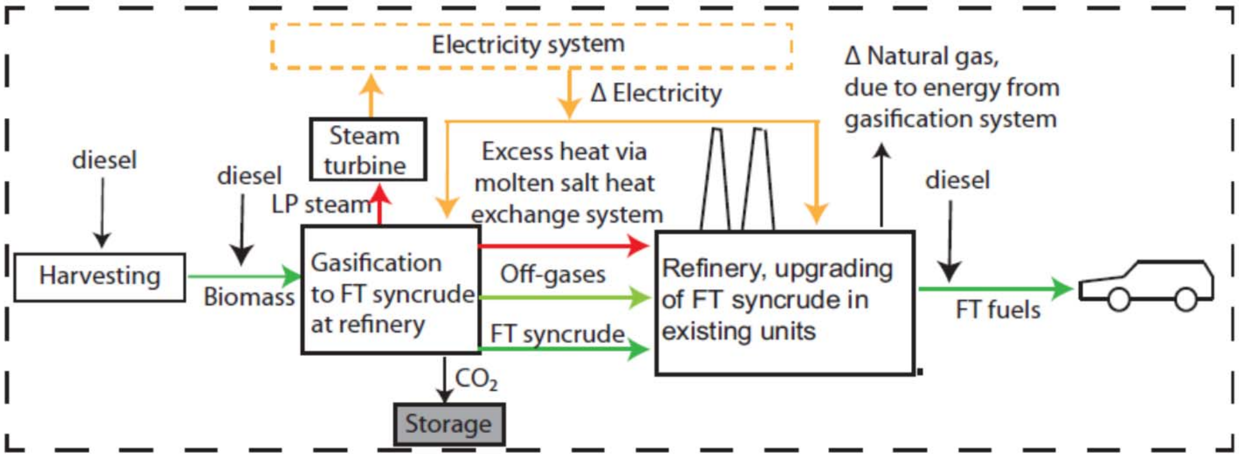
Comparative study of Fischer–Tropsch production and post-combustion CO_2 capture at an oil refinery: Economic evaluation and GHG (greenhouse gas emissions) balances

Daniella Johansson [a,*], Per-Åke Franck [b], Karin Pettersson [a], Thore Berntsson [a]

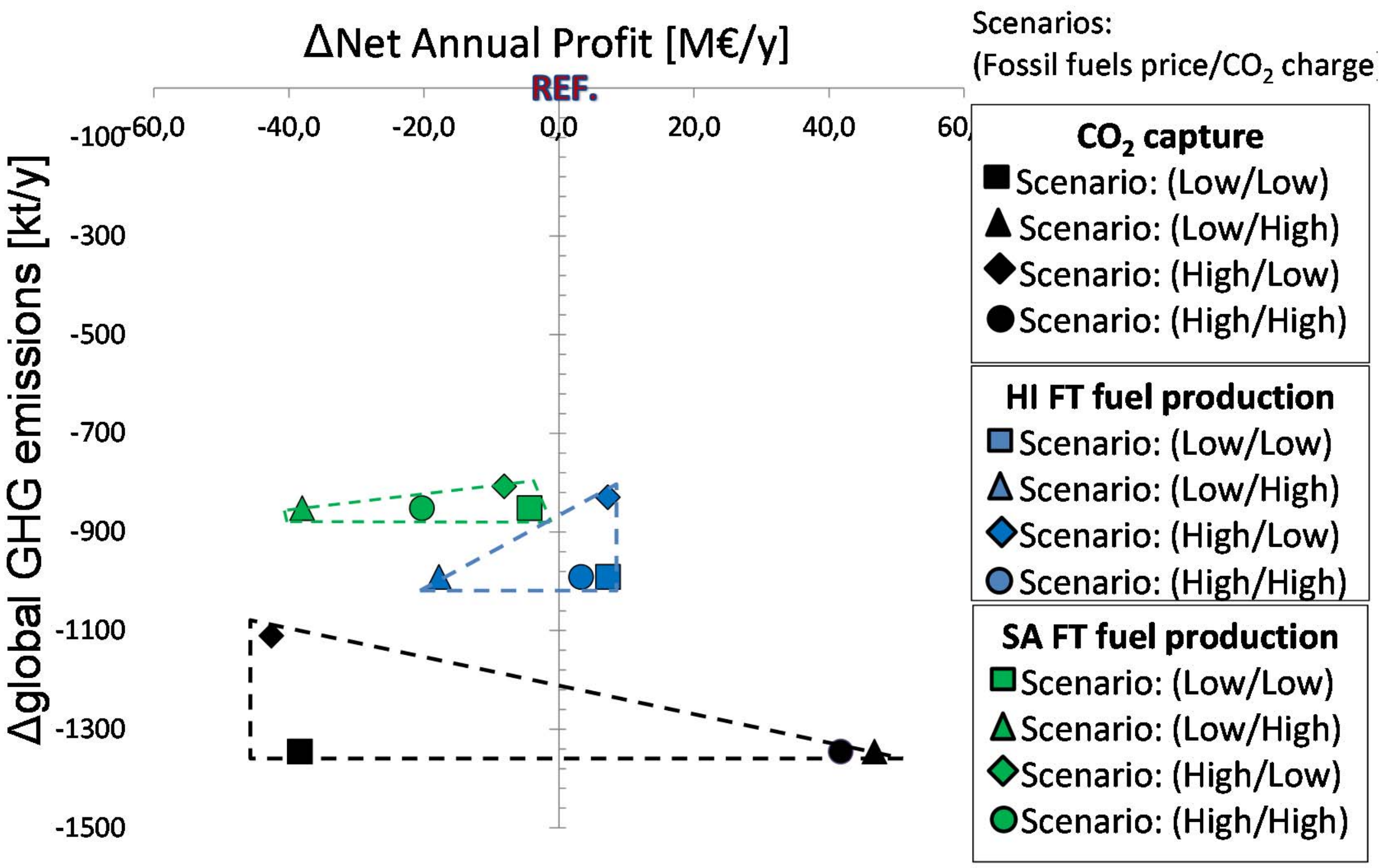
[a] *Division of Heat and Power Technology, Department of Energy and Environment, Chalmers University of Technology, SE-412 96 Göteborg, Sweden*
[b] *CIT Industriell Energi AB, Chalmers teknikpark, SE-412 88 Göteborg, Sweden*

Integration of a biomass-to-FT syncrude unit at an oil refinery site





Profitability and CO_2 balances for Fischer-Tropsch fuels production (integrated and stand-alone) as well as CCS



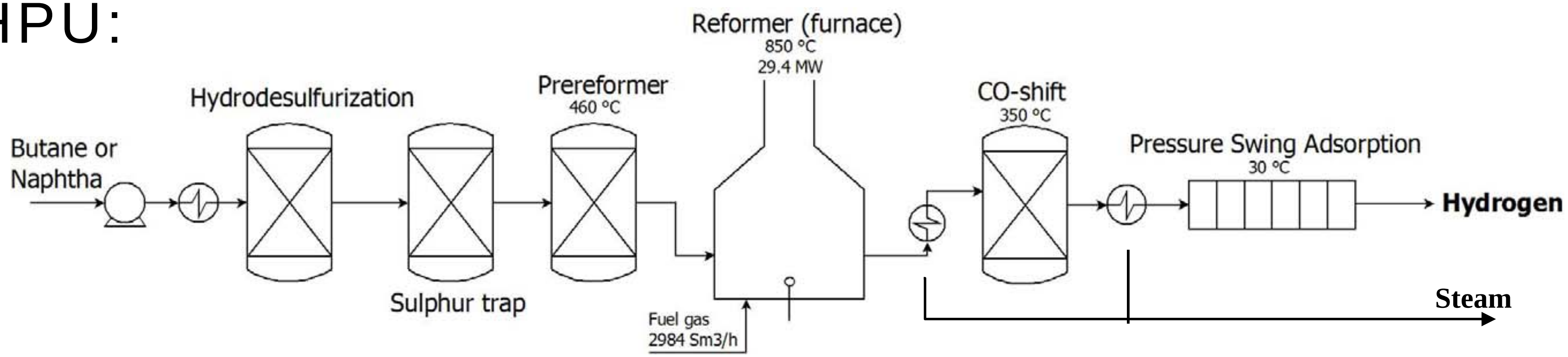
Integration of a biomass-to-hydrogen process in an oil refinery

Jean-Florian Brau*, Matteo Morandin, Thore Berntsson

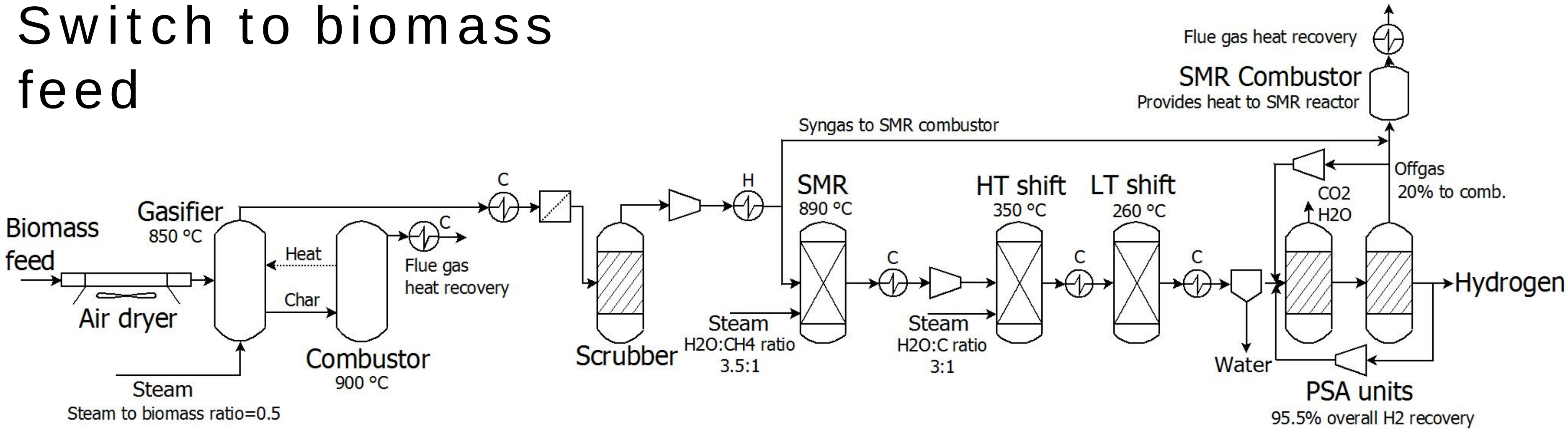
Department of Energy and Environment
Division for Heat and Power Technology

Hydrogen Production Unit

HPU:

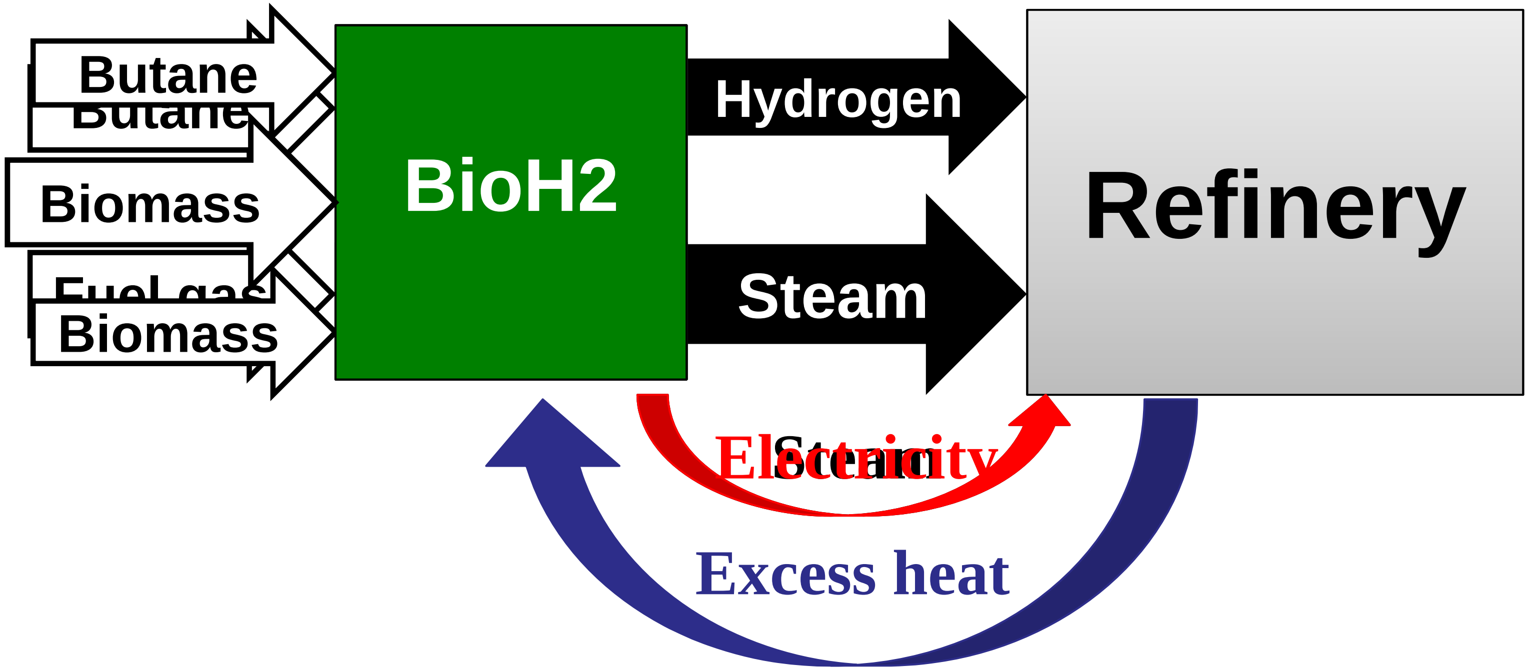


Switch to biomass feed

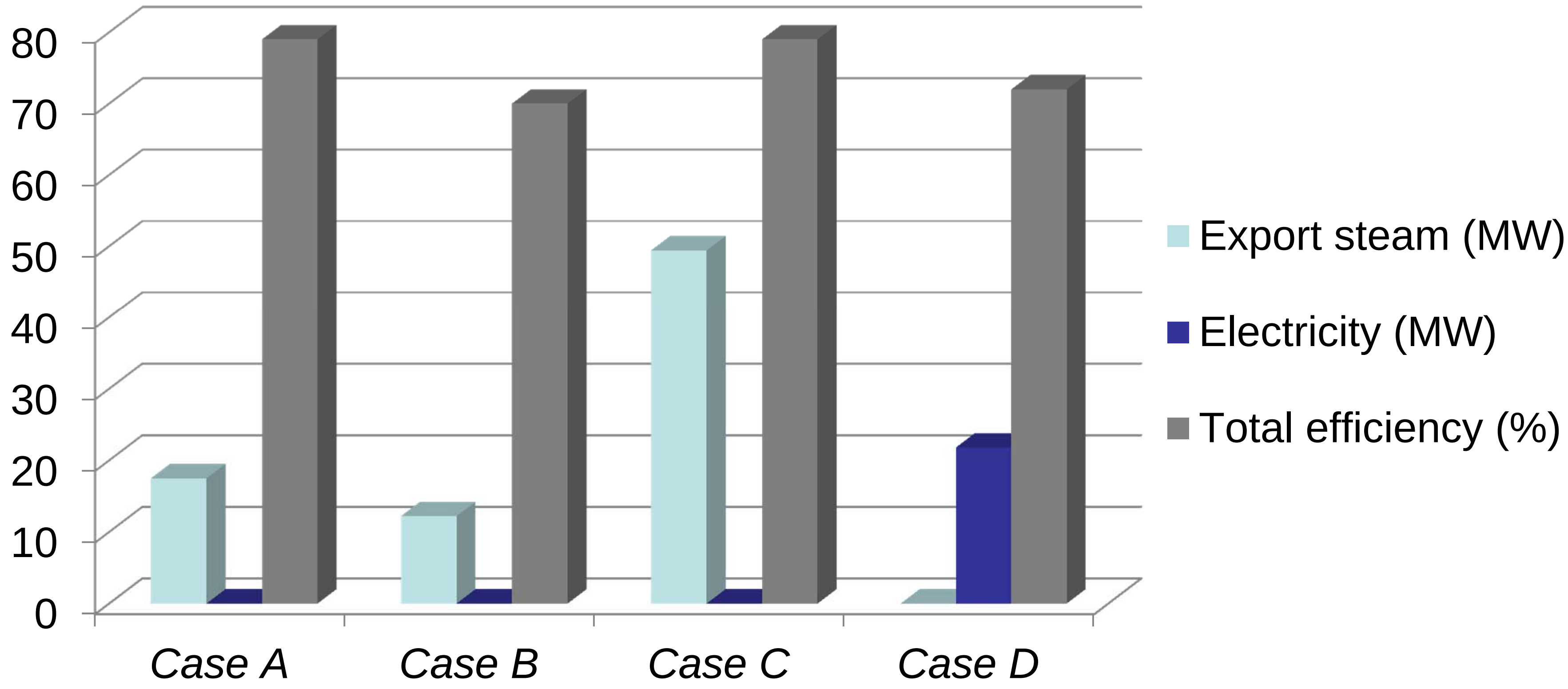


Comparison of 4 different cases:

- **Case A**. 35 % substitution, internal drying, HP steam export
- **Case B**. 100 % substitution, internal drying, HP steam export
- **Case C**. 100 % substitution, external drying, HP steam export
- **Case D**. 100 % substitution, external drying, electricity production



Results: excess energy export and efficiency



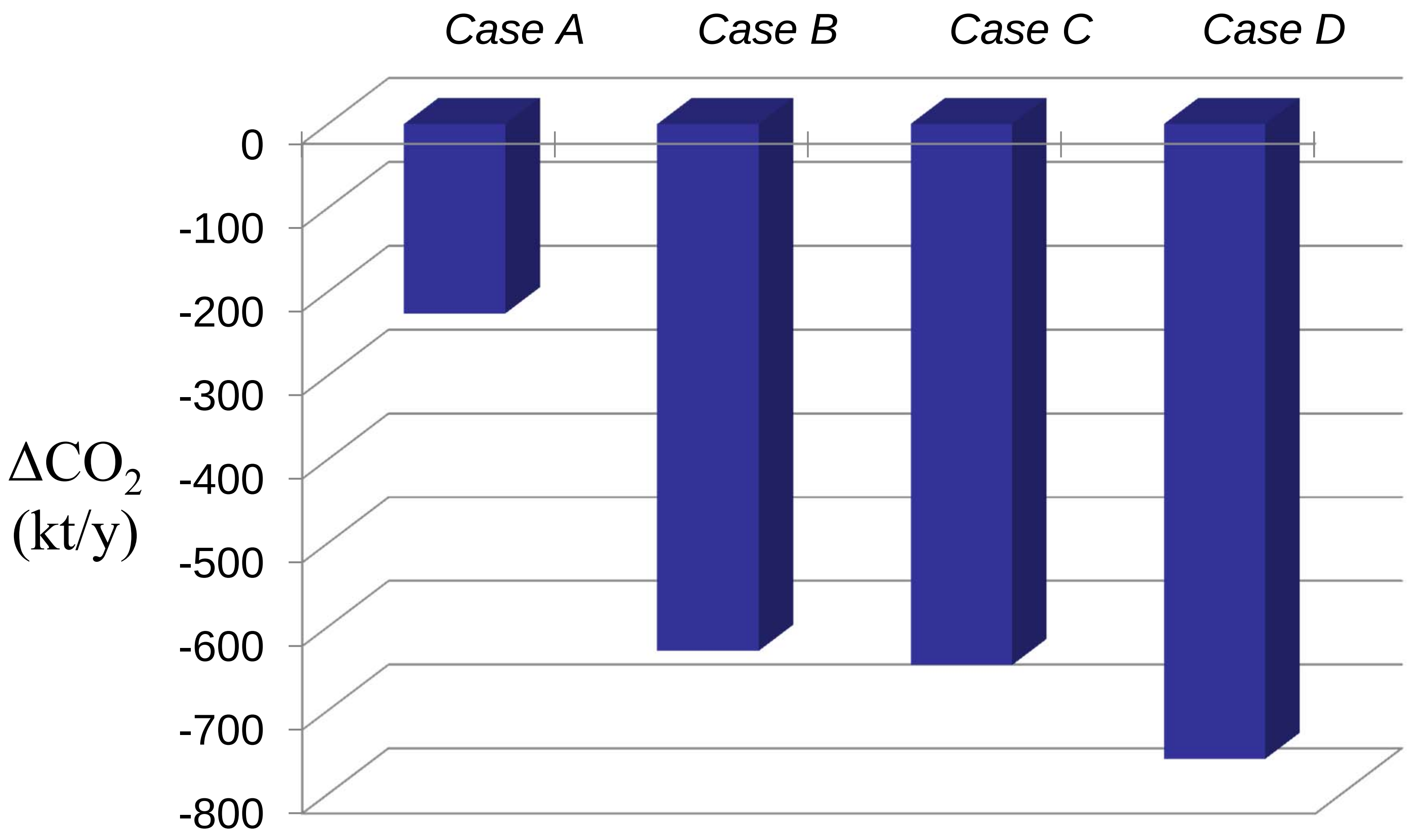
A: energy demand drying = excess heat from HPU

B: internal drying = penalty on efficiency

C: external drying = gain of 9 p.p. in efficiency

D: 21,8 MW electricity produced

Results: reduction of carbon footprint



Refinery's total CO_2 emissions: 1,67 Mt in 2010

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Integration of biomass gasification with a Scandinavian mechanical pulp and paper mill – Consequences for mass and energy balances and global CO_2 emissions

Johan Isaksson [a,*], Karin Pettersson [a], Maryam Mahmoudkhani [a], Anders Åsblad [b], Thore Berntsson [a]

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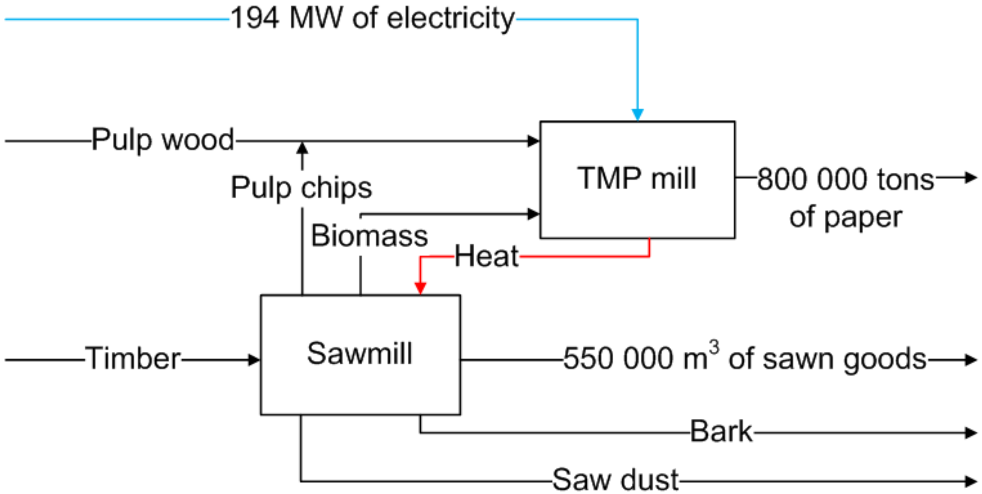
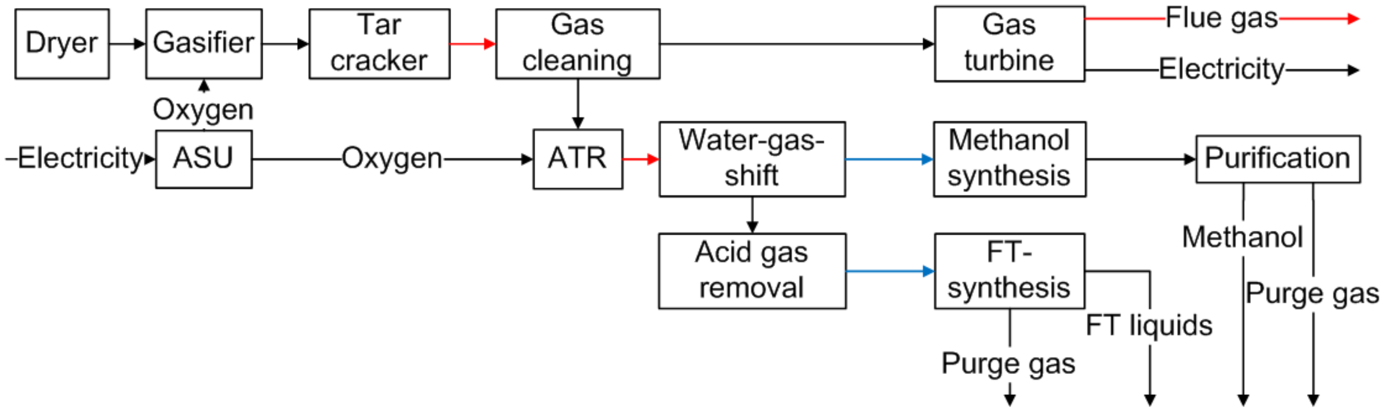
[b] CIT Industriell Energi, Chalmers Teknikpark, SE-412 88 Gothenburg, Sweden

Host site: TMP mill and co-located Sawmill

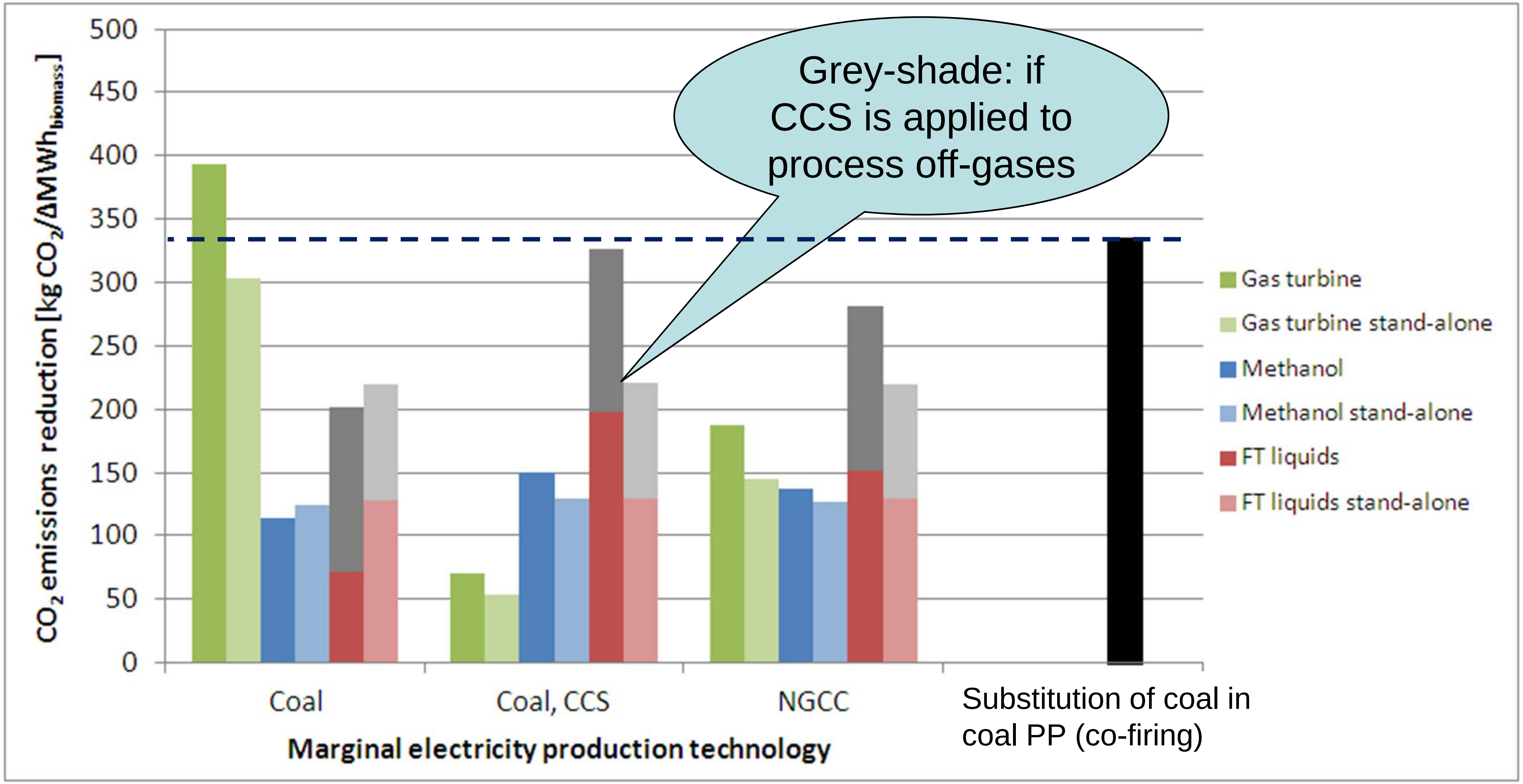


- Biomass residues corresponding to 94 MW_{LHV}
- In addition, about 1.55 TWh (177 MW_{LHV}) of forest residues is available within a 100 km radius.

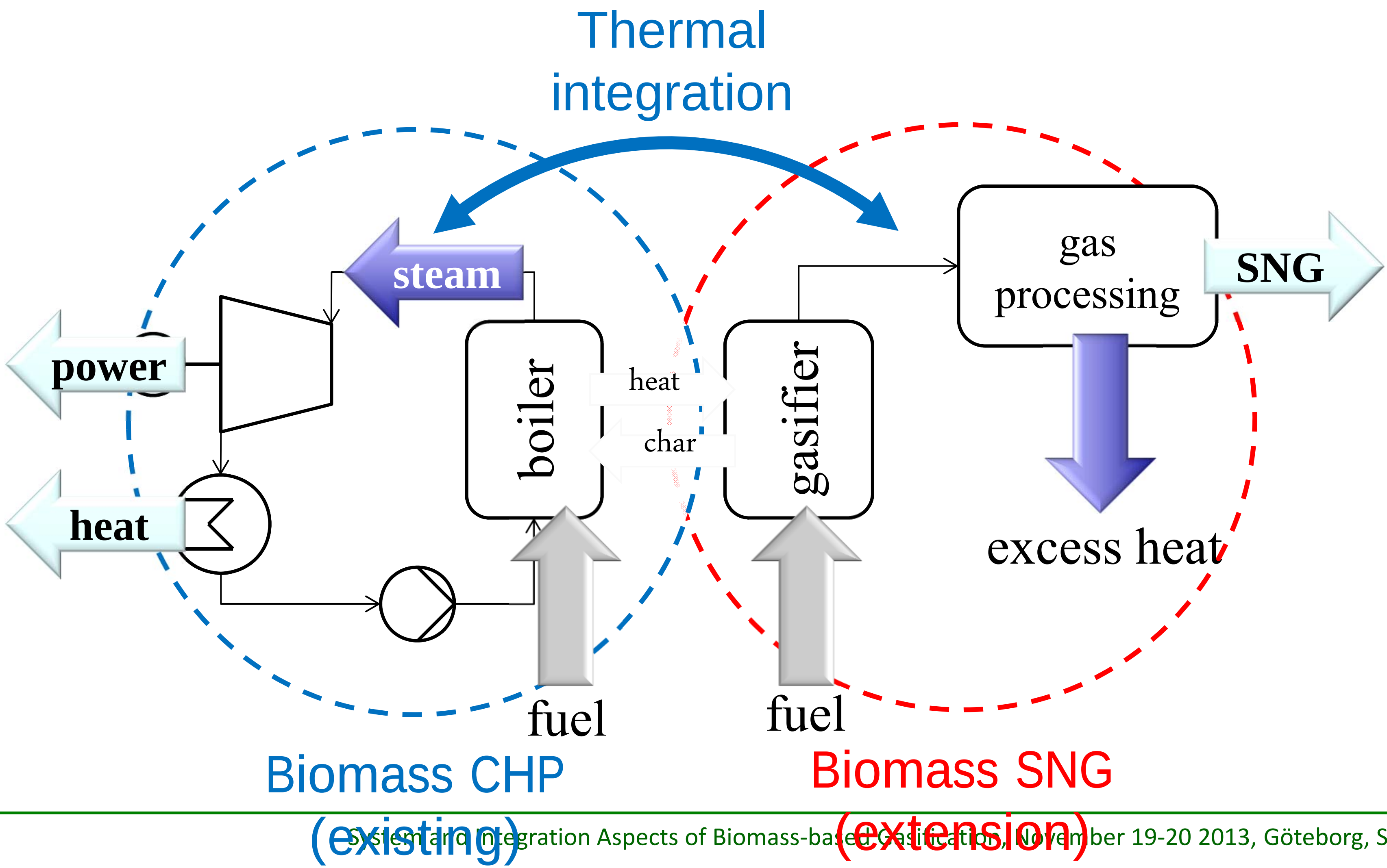
3 gasification based biorefinery concepts were considered



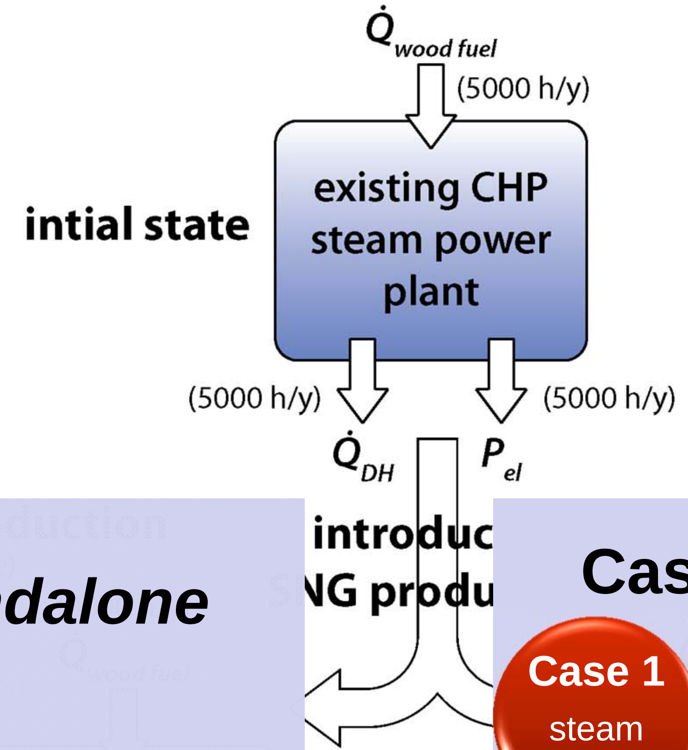
Carbon balances incl comparison with stand-alone concepts



SNG production process integrated with Bio-CHP plant



Case study – SNG production



Case SNG standalone

existing CHP plant

&

Stand-alone SNG process with steam dryer

Cases SNG integrated

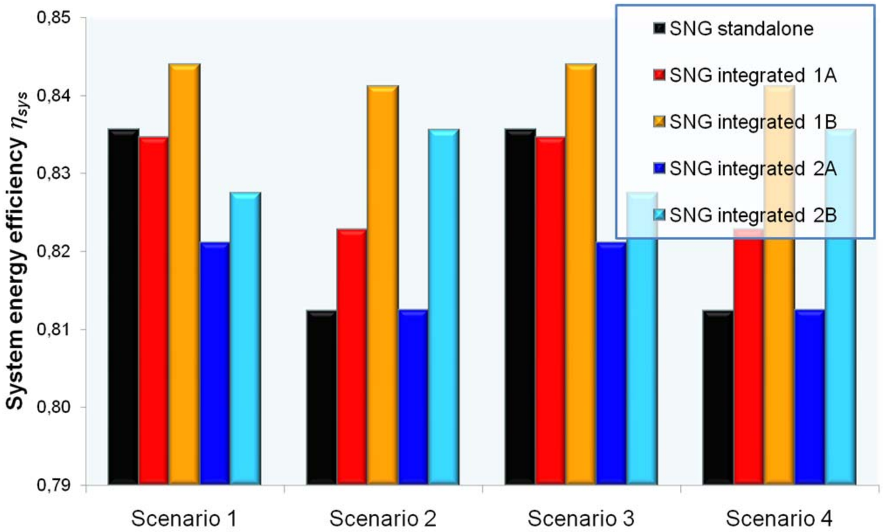
Case 1 steam drying

- **1A** balancing integration
- **1B** maximum integration

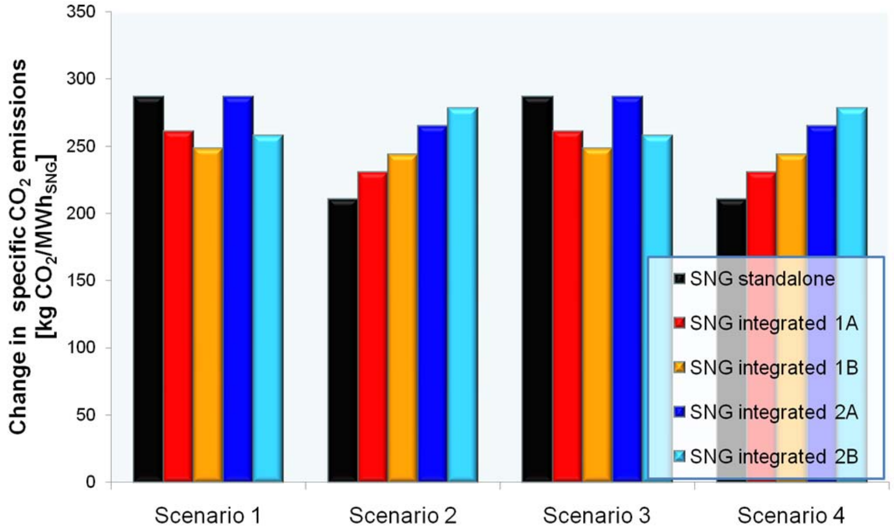
Case 2 low T air drying

- **2A** balancing integration
- **2B** maximum integration

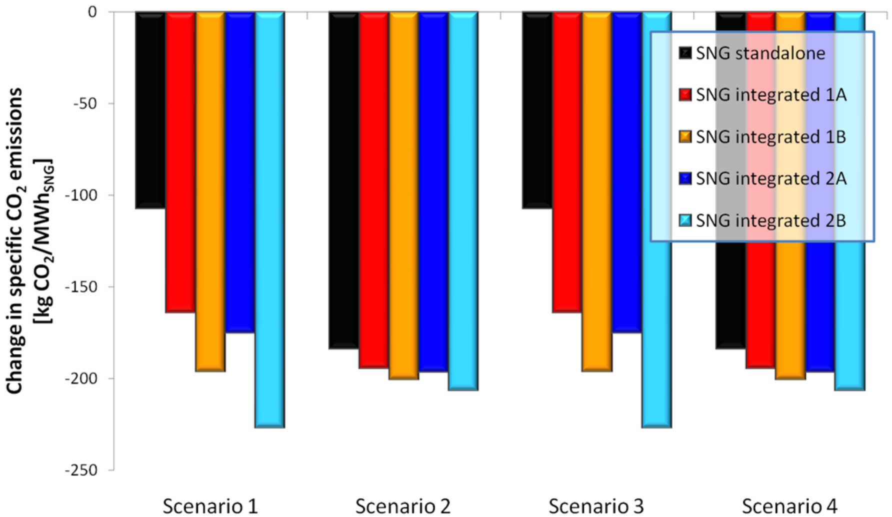
Results - η_{sys}



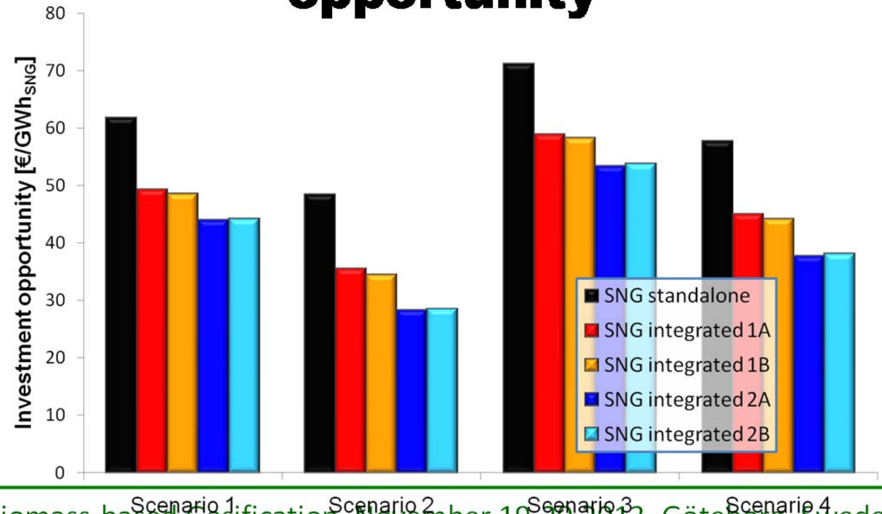
Results – ΔCO_2



Results – biomass use CO_2 neutral



Results – Investment opportunity



Integration of biomass gasification to incumbent industry – energy balances and greenhouse gas emission consequences

Kristina Holmgren, PhD student, *IVL Swedish Environmental Research Institute Ltd /Chalmers, Div. Heat & Power Technology*
Thore Berntsson, Supervisor; Professor, *Chalmers; Div. Energy & Environment, Dep. Heat & Power Technology*
Eva Andersson, Co-supervisor; PhD, *CIT Industriell Energi AB*
Tomas Rydberg, Co-supervisor, PhD, *IVL Swedish Environmental Research Institute Ltd*

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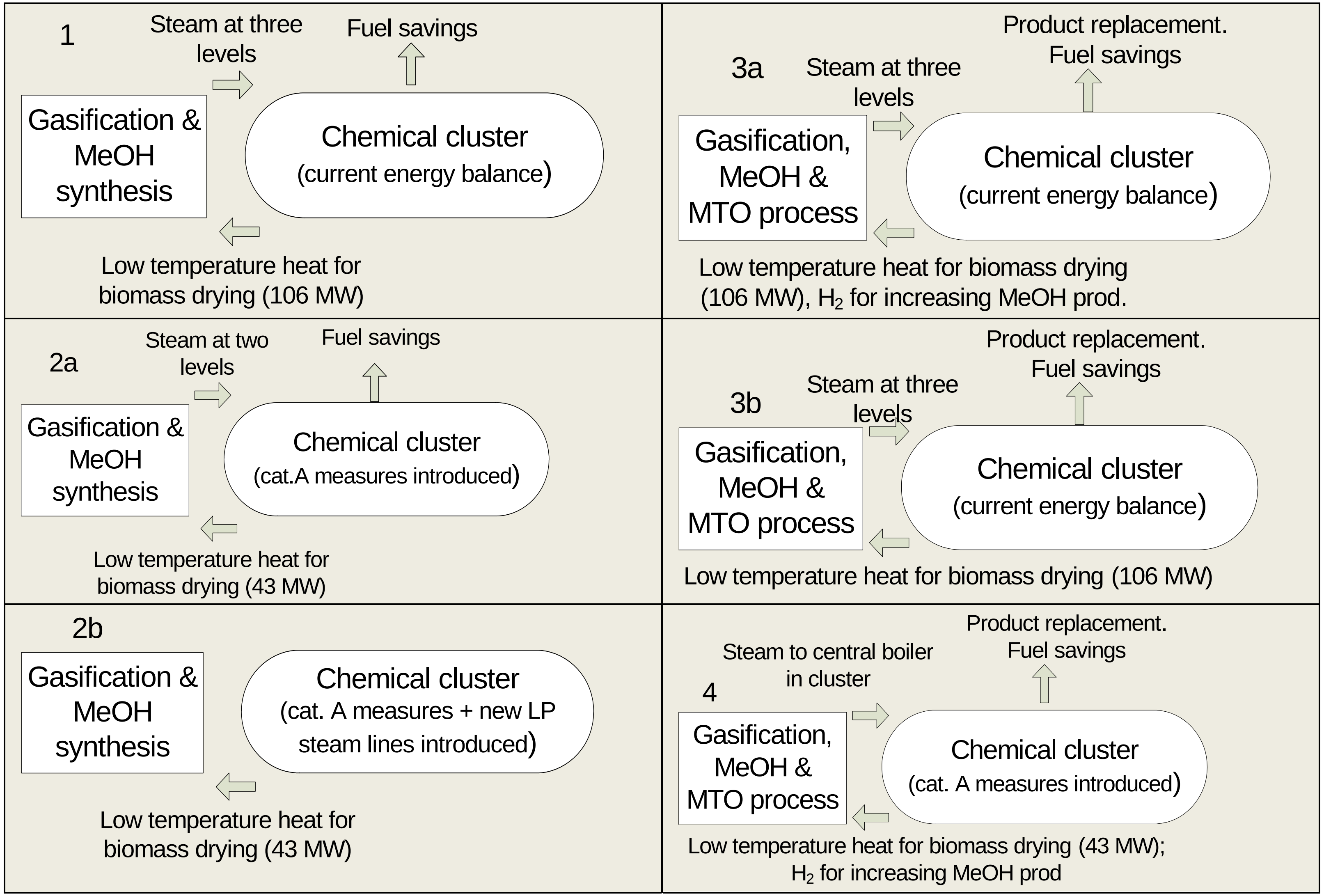
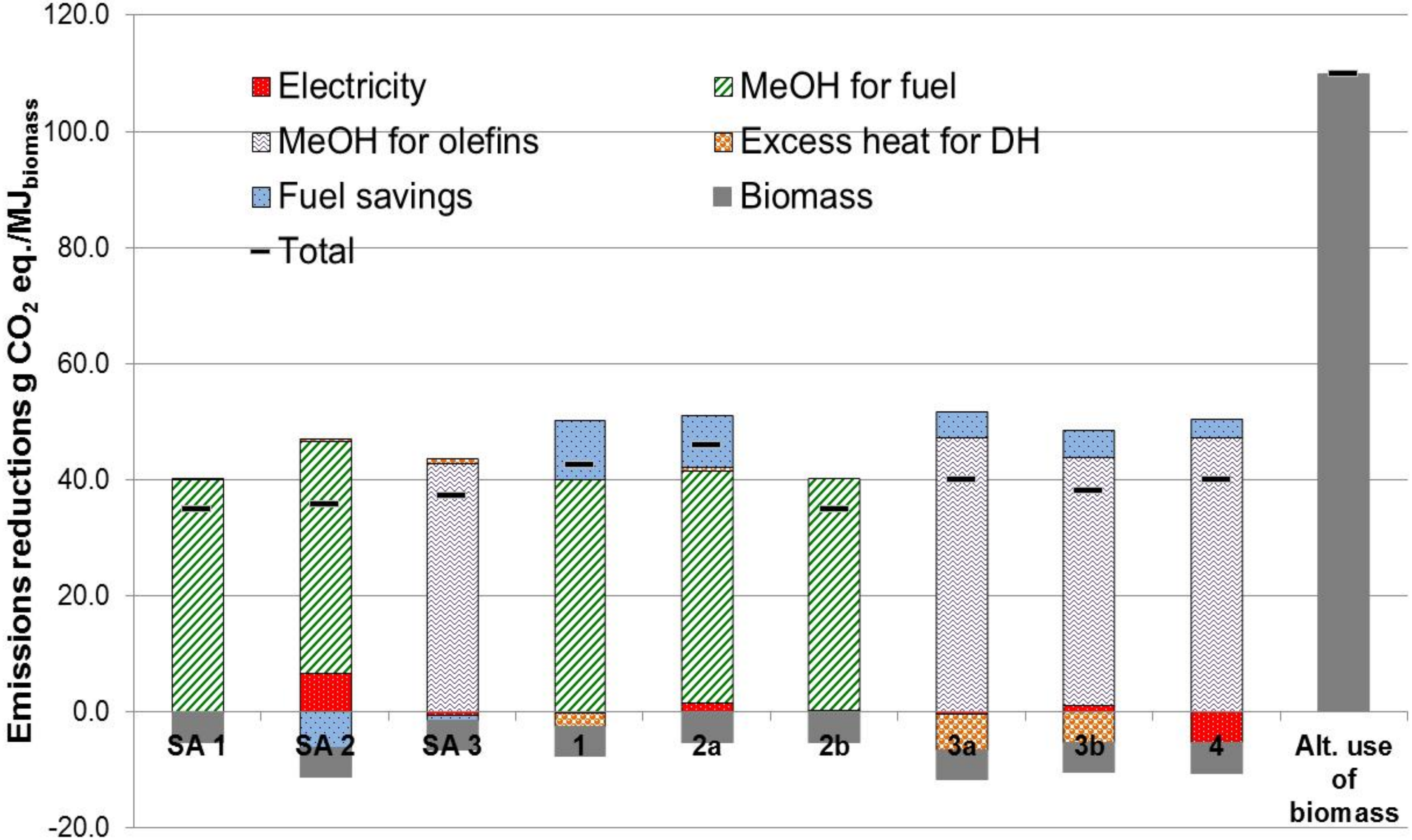
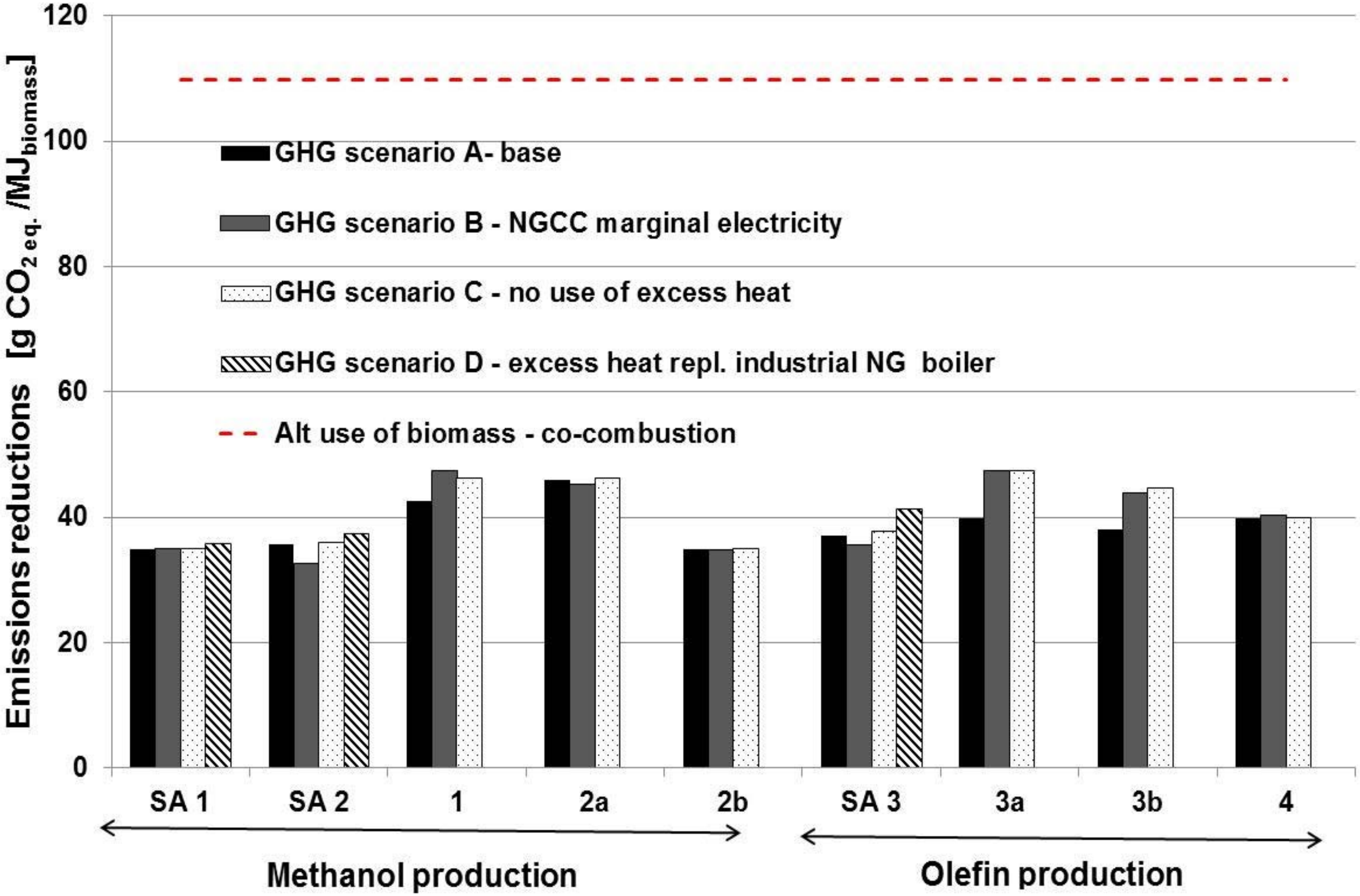
Process integrated cases analysed




Electricity
MeOH for fuel
MeOH for olefins
Excess heat for DH
Fuel savings
Biomass
Total
Emissions reductions g CO2 eq./MJbiomass
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
SA 1
SA 2
SA 3
1
2a
2b
3a
3b
4
Alt. use of biomass


120
100
80
60
40
20
0
Emissions reductions [g CO2 eq. /MJbiomass]
GHG scenario A- base
GHG scenario B - NGCC marginal electricity
GHG scenario C - no use of excess heat
GHG scenario D - excess heat repl. industrial NG boiler
Alt use of biomass - co-combustion
SA 1
SA 2
1
2a
2b
SA 3
3a
3b
4
Methanol production
Olefin production

Conclusions

- Process integrated cases have higher GHG reduction potential than SA cases
- The GHG impact of replacing DH can be negative or positive
- The use of excess H_2 increase GHG emission reductions
- Production of olefins and biofuels result in GHG emissions reductions of similar magnitude
- Directly replacing coal is still better than all the investigated cases

General conclusions from recent studies in our group

- Hard to compete with coal substitution if climate change mitigation is the main objective for biomass usage…
- Electric power generation in high-efficiency biomass-fired power plants is a climate-friendly option, as long as coal power plants are the marginal power generation technology
- For future power grid generation mixes, the situation is significantly different. Use of biomass as feedstock for production of vehicle fuels, materials and chemicals is most attractive from a climate-change perspective
- Integration of biomass gasification biorefinery concepts at an industrial process plant site can kan achieve significant synergy effects compared to stand-alone operation
- Carbon atoms are not strictly necessary for energy purposes whereas they are necessary for production of ”green” materials and chemicals