Optimal process design for thermochemical biofuel production plants

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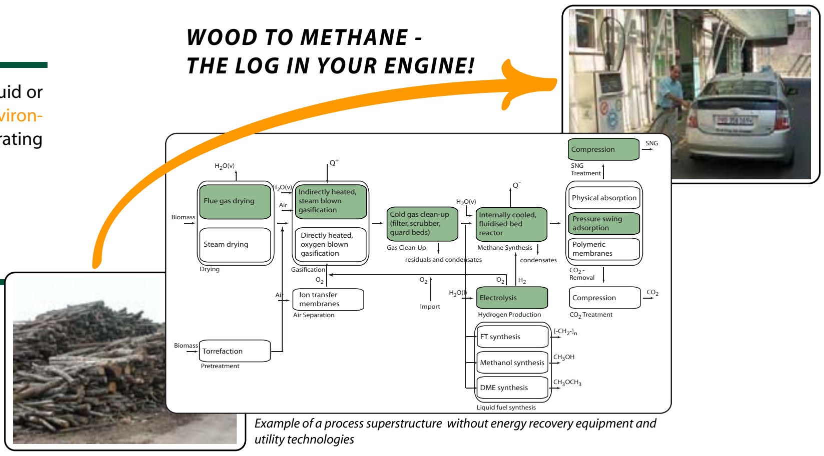
Goals

Design of optimal processes for the thermochemical conversion of biomass to (liquid or gaseous) fuels, heat and power with respect to its energy efficiency, cost and environmental impact. Identification of most promising technologies and optimal operating conditions.



Example of a process superstructure without energy recovery equipment and utility technologies

Design methodology

SUPERSTRUCTURE DEFINITION

Determination of framework and feasible production pathways

- Investigation of product specifications, raw materials and energy resources
- Identification of suitable technology for the conversion to be assembled it in a process superstructure

THERMO-ECONOMIC MODELLING

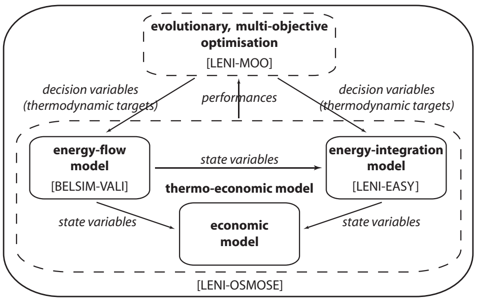
Flowsheet generation

Energy-flow model: calculation of the operation of the process units

- application of thermodynamic conservation principles
- modelling the physical and chemical conversions
  - → heat and power requirements
  - → hot and cold streams

Energy-integration model: determination of the material and energy flows

- formulation of the heat cascade
- targeting the minimum energy requirements
- integration of useful energy conversion equipment
- maximisation of combined fuel, heat and power production
  - → material and energy flows
  - → overall thermodynamic process performance



Methodology for the conceptual design of optimal process flowsheets

Equipment sizing and costing

Meeting the thermodynamic design target for the flowsheet

- dimensionning of process equipment to meet the flowsheet results with design heuristics and pilot plant data
- assessment of equipment cost considering the specific operating conditions

MULTI-OBJECTIVE OPTIMISATION

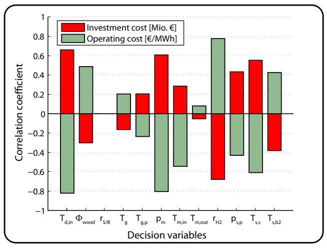
Generation of optimal flowsheets

Identification of the best feasible solutions preserving multiple aspects of the design problem

- definition of energetic, economic and/or environmental performance indicators to be used as objectives
- choice of decision variables among technology choice and operating conditions
- generation of a set of optimal designs using and evolutionary, multi-objective optimisation algorithm

Results analysis

Analysis of the numerically generated configurations with regard to multiple criteria



Correlation coefficients between the decision variables and the objectives

Example: SNG production from wood

THERMOCHEMICAL PRINCIPLE

$$CH_{1.35}O_{0.63} + 0.35\, H_2O(l) \xrightarrow{\Delta H = -10.5\ kJ/mol_{wood}} 0.51\, CH_4 + 0.49\, CO_2$$

OPTIMISATION PROBLEM DEFINITION

Reforming technology

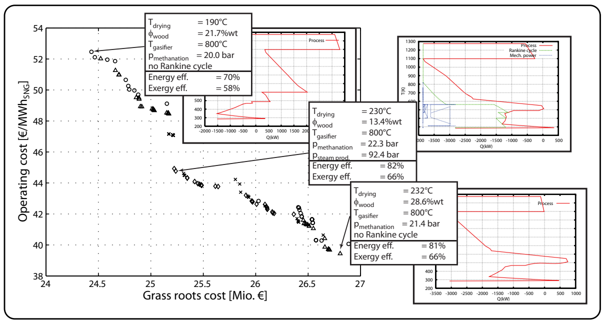
- flue gas drying of wood
- indirectly heated fluidised bed gasification
- conventional cold gas cleaning
- internally cooled fluidised bed methanation
- CO_2-removal with pressure swing adsorption

Decision variables

drying	temperature	[160; 240]	°C
	wood outlet humidity	[5; 35]	%
gasification	steam to biomass ratio	[0.4; 0.8]	-
	temperature	[800; 900]	°C
	steam preheat temperature	[300; 600]	°C
methane synthesis	pressure	[1; 50]	bar
	reactor inlet temperature	[300; 400]	°C
	reactor outlet temperature	[300; 400]	°C
	additional hydrogen	[0: 3]	%wt
Rankine cycle (optional)	steam production pressure	[40; 100]	bar
	superheat temperature	[350; 550]	°C
	additional bleeding level	[50; 250]	°C

Principal parameters

plant capacity	20 $MW_{th,wood}$
wood humidity	50 %wt
wood costs	16.7 €/MWh
electricity costs (export)	26.4 €/MWh
electricity costs (import)	88.9 €/MWh
Wobbe Index	>13.3 kWh/Nm^3



Pareto trade-off between operating and investment costs with some detailed solutions.

RESULTS SUMMARY

energy efficiency	70-82 %
exergy efficiency	58-70 %
production costs	60-74 $€/MWh_{SNG}$
avoided CO_2 due to NG substitution	150-200 kg/MWh_{wood}
avoided CO_2 with sequestration at plant	400-450 kg/MWh_{wood}

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