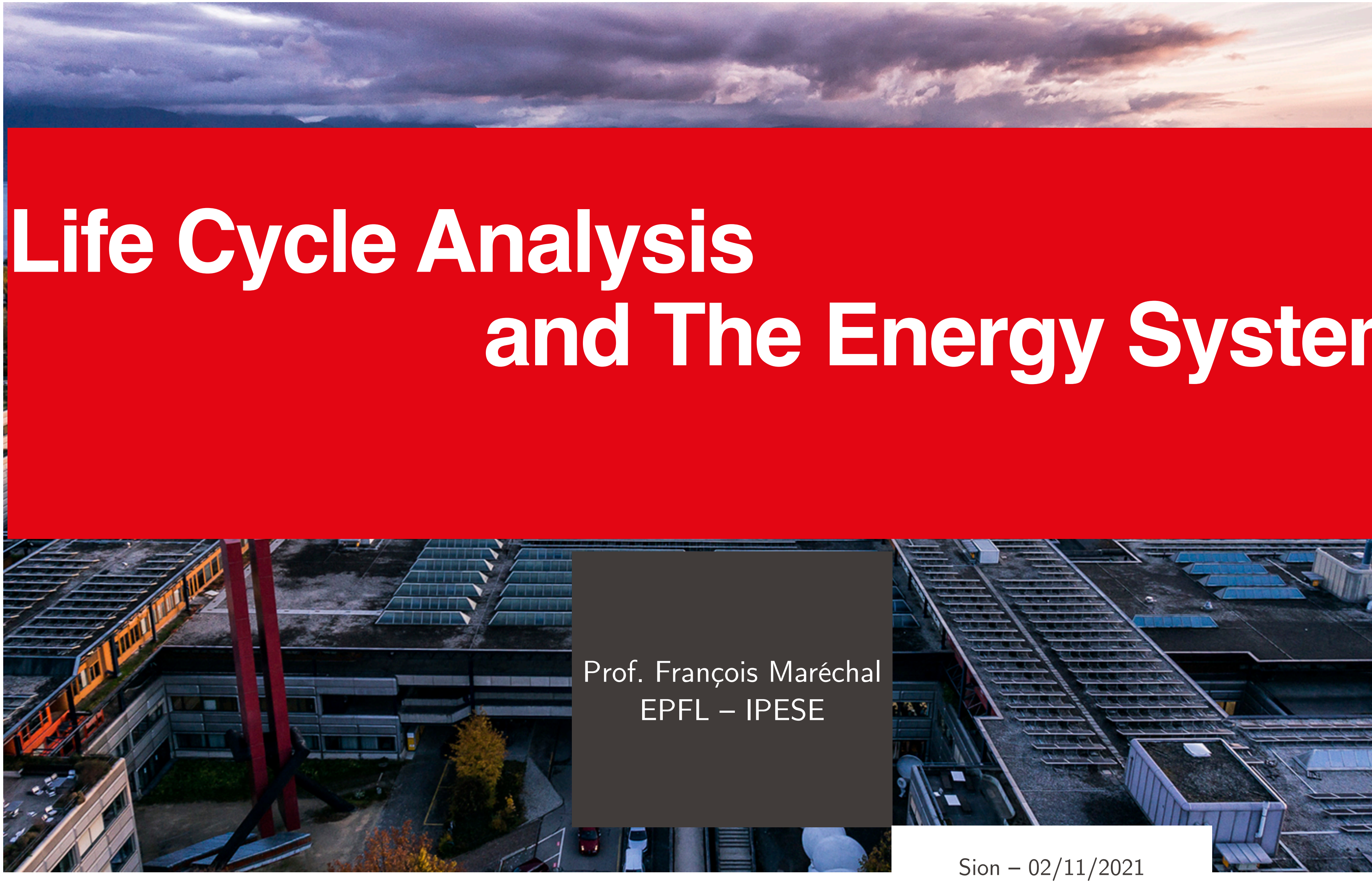
EPFL



Life Cycle Analysis and The Energy Syster

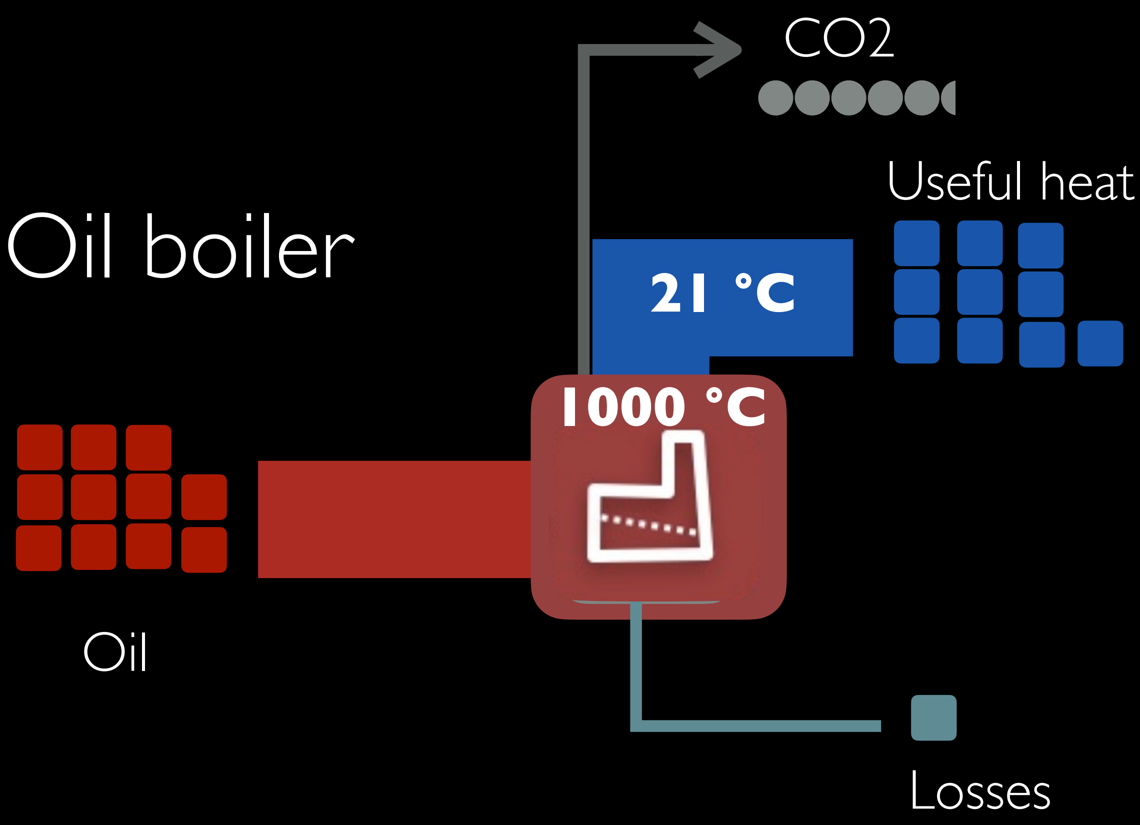
Prof. François Maréchal
EPFL – IPESE

Sion – 02/11/2021

École polytechnique fédérale de Lausanne

HOW DO WE SATISFY THE ENERGY NEEDS IN A BUILDING ?

"Good" Oil boiler



EPFL

ENERGY NEEDS OF A BUILDING

170

CHF/month/100 m^2

Energy (Oil)

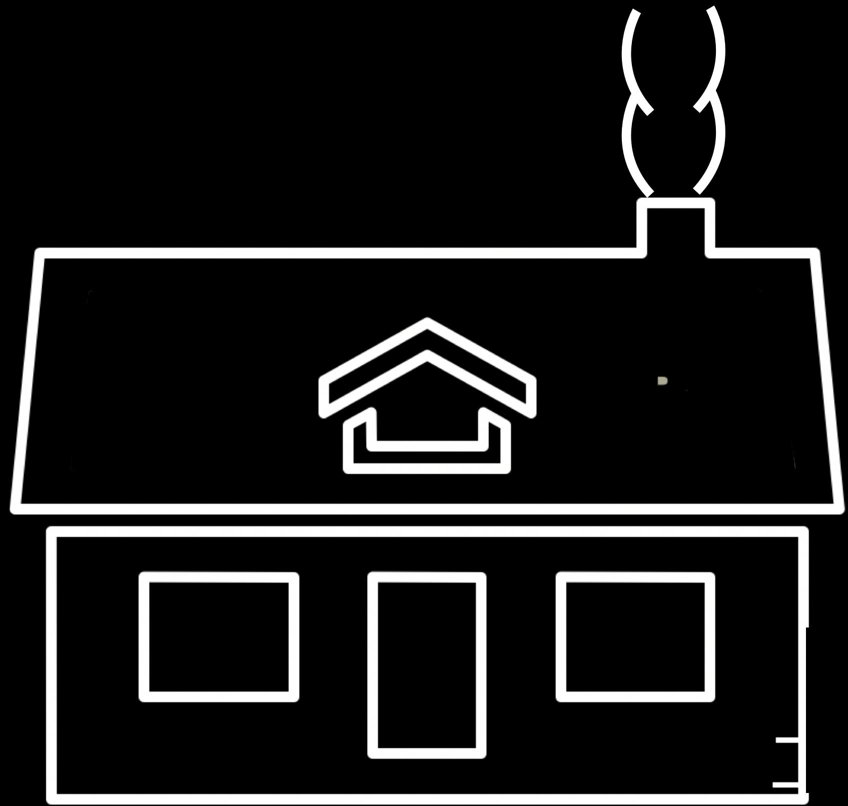
140 CHF/month/100 m^2

in which 105 CHF/month/100 m^2

achat

Boiler

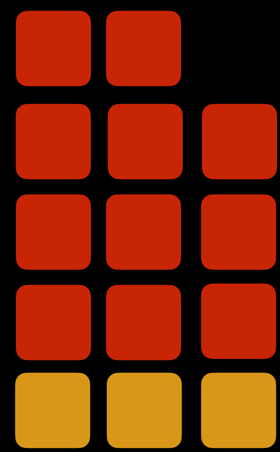
30 CHF/month/100 m^2



3.8

tons **CO_2** /year/100 m^2

35 CHF/month/100 m^2



EPFL

Life cycle assessment : emissions before the use

15 to 40% of the CO2 emissions have been made to prepare the fossil fuels

		Natural gas	**Wood**	**Gasoline**	**Diesel**
	kg/Nm3	0.7	240	0.8	0.8
LHV	MJ/kg	50	17.8	44.4	43.4
	GJ/Nm3	0.0359	5.3-9.6	35.5	34.7
CO2	g CO2/MJ	49.3	0	67	72
supply eq CO2	g CO2/MJ	11.6	1.4-1.8 (production) 0.19 (20 MW) -1.1(320 MW) 1.6 - 2.9	16.7	13.4
	g CO2/MJ	60.9	1.6-2.9	83.7	85.4
		19%	-	20%	16%
Cost	cts/kWh	10	3 - 7.5	18.6	19.2
industry	cts/kWh	3.4			

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Environmental impact of the use of combustion

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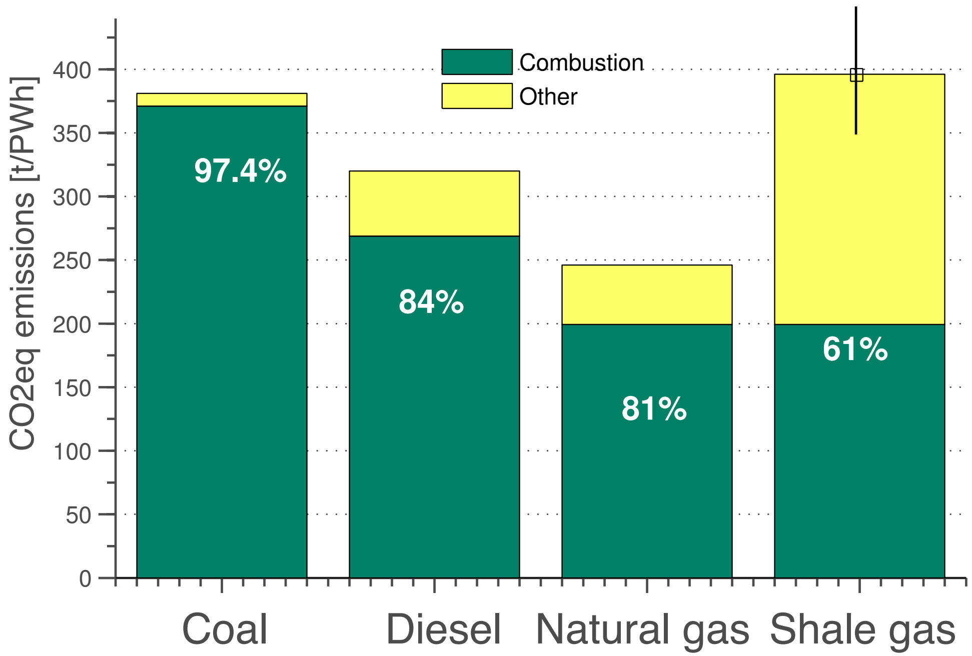
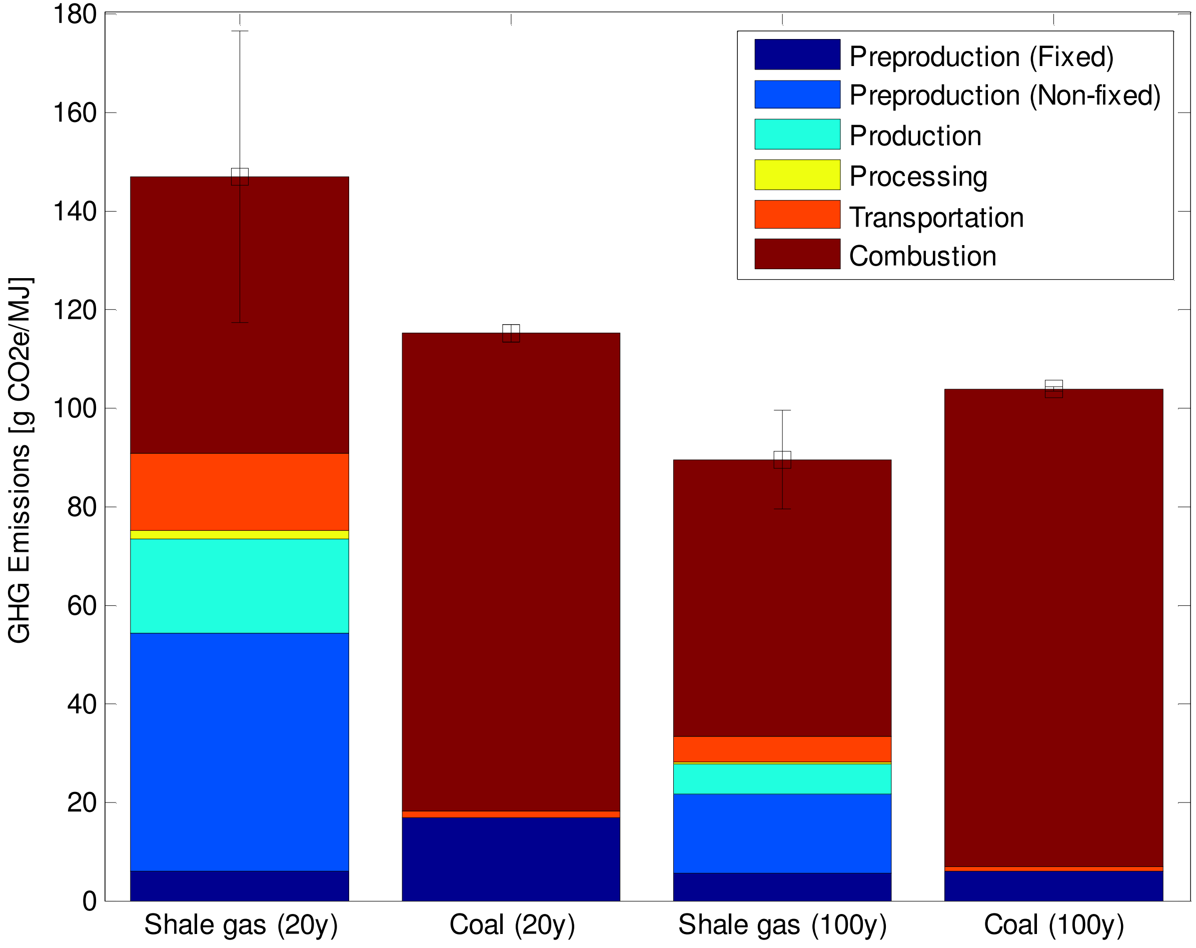
- Importance of the life cycle
  - Extraction
  - Conditioning
  - Transport
  - Refining
  - Distribution
  - Combustion



CO2 eq : is a measure of the global warming potential of the emissions over the overall conversion chain up to combustion. The global warming potential is considering not only the C
also other emissions like CH4 (that has a GWP of 20 CO2 eq), NOx and other gases in the complete life cycle chain.

Shale gas vs coal for heat production



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Uncertainty in the evaluation of the impact

François Maréchal – francois.marechal@epfl.ch

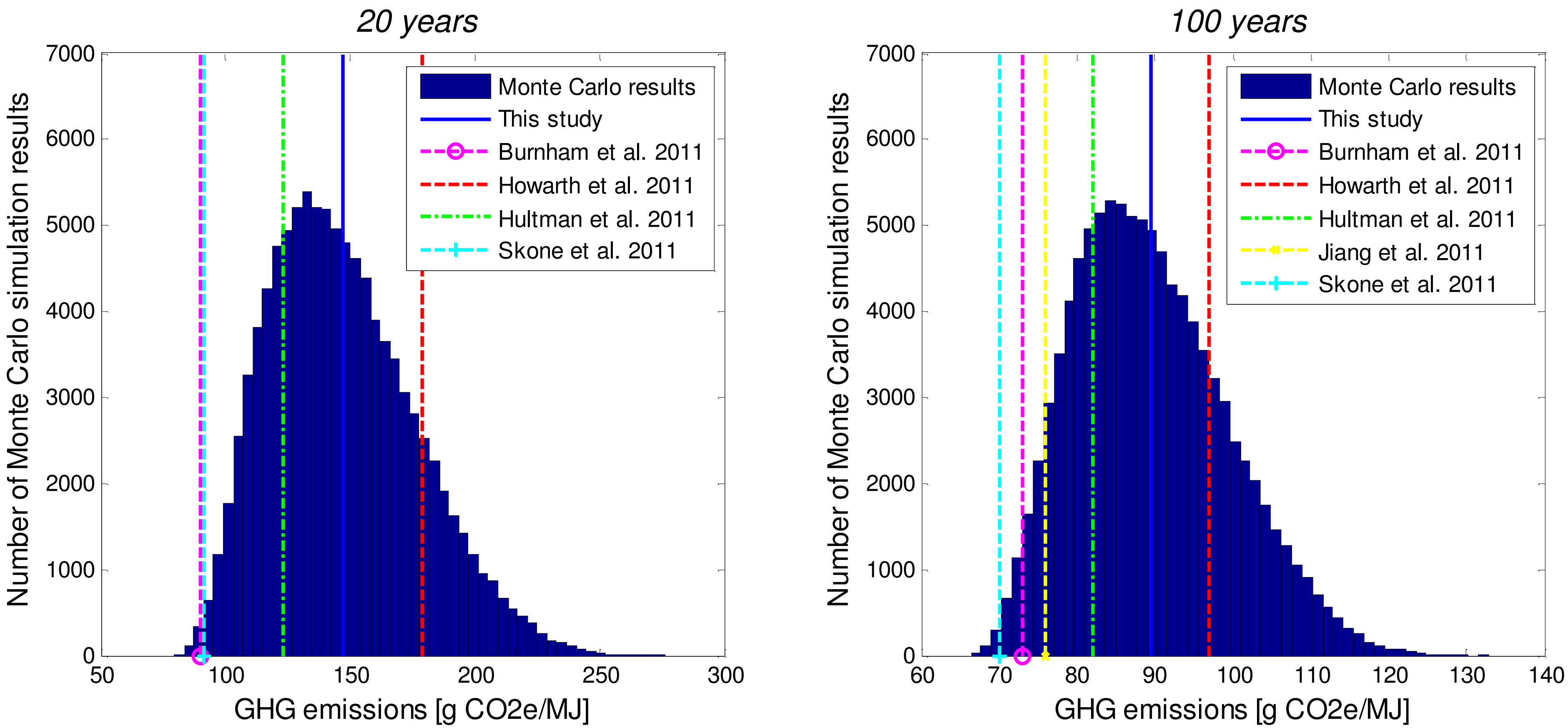

Figure 27 Comparison with other studies considering heat production

Shale gas vs coal for electricity production

- Efficiency of conversion
  - Natural gas : 60%
  - Coal : 38%

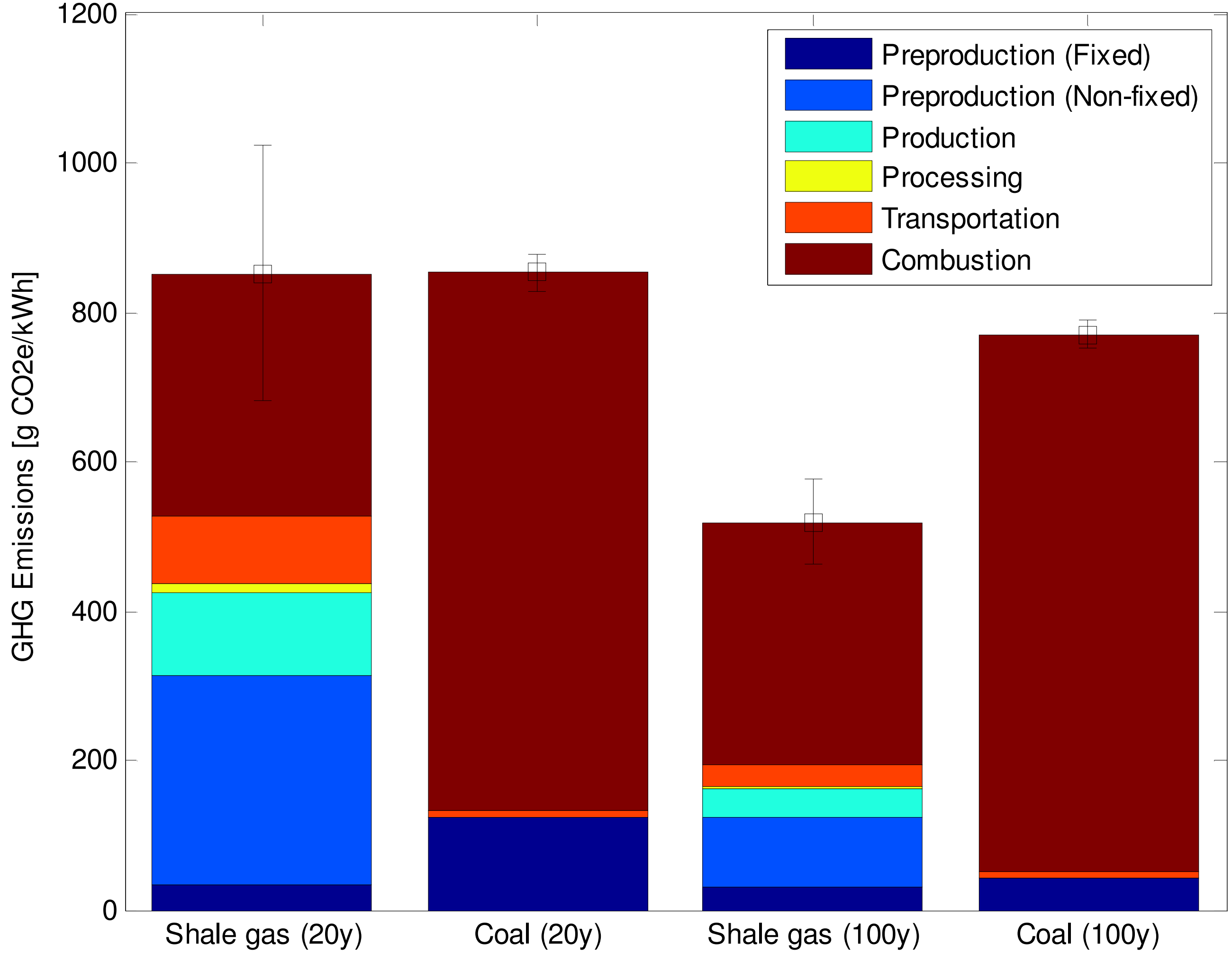

Figure 26 GHG emissions of the different phases of shale gas and coal life cycles

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LCA shows actions to mitigate emissions

- Measure 1
  - Flaring of off gases
- Measure 2
  - Green completion : send back
- Measure 3
  - Tracking fugitive emissions

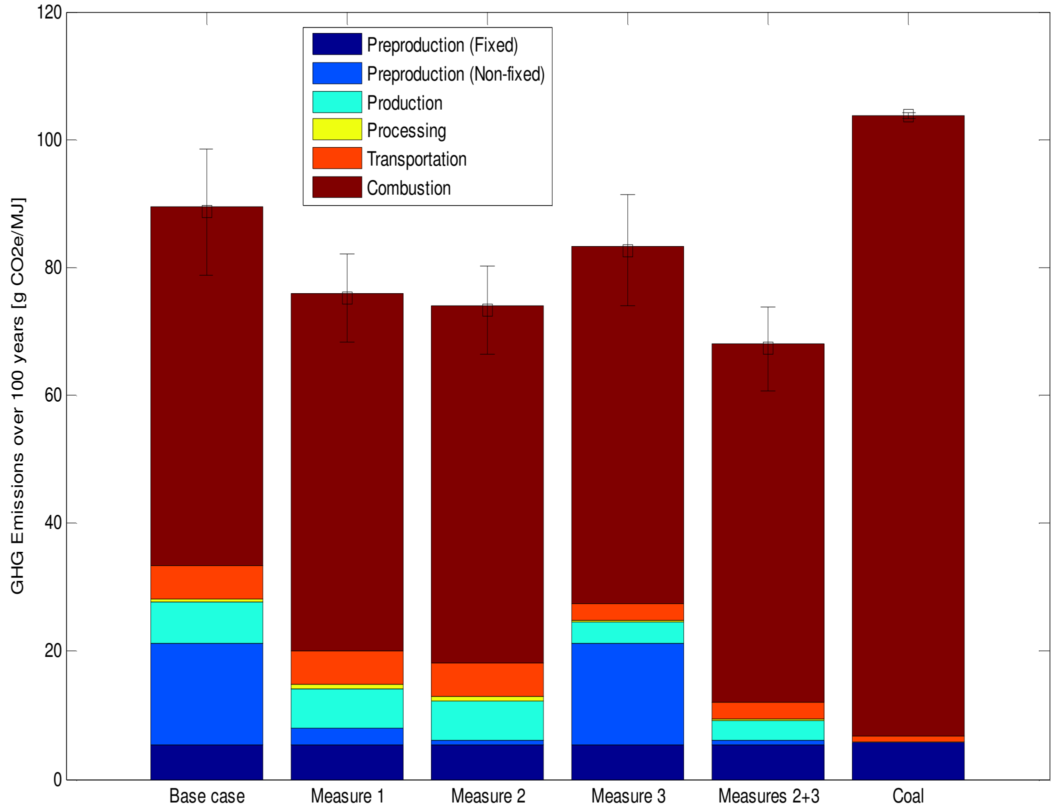
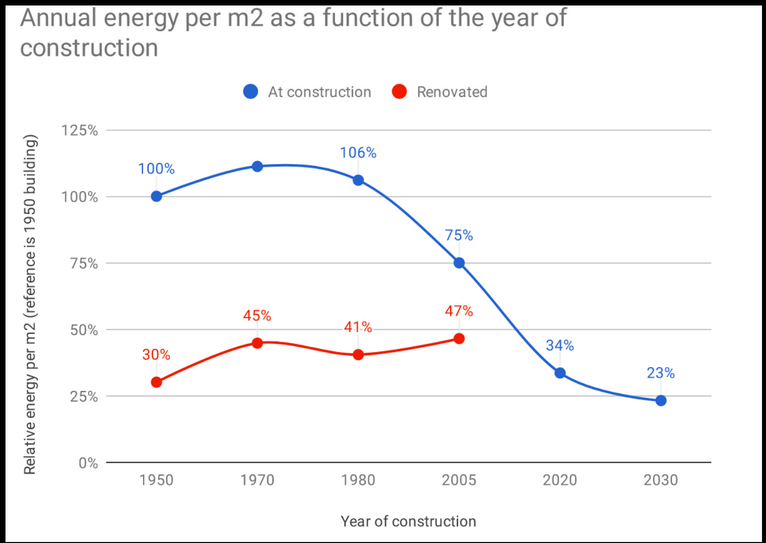


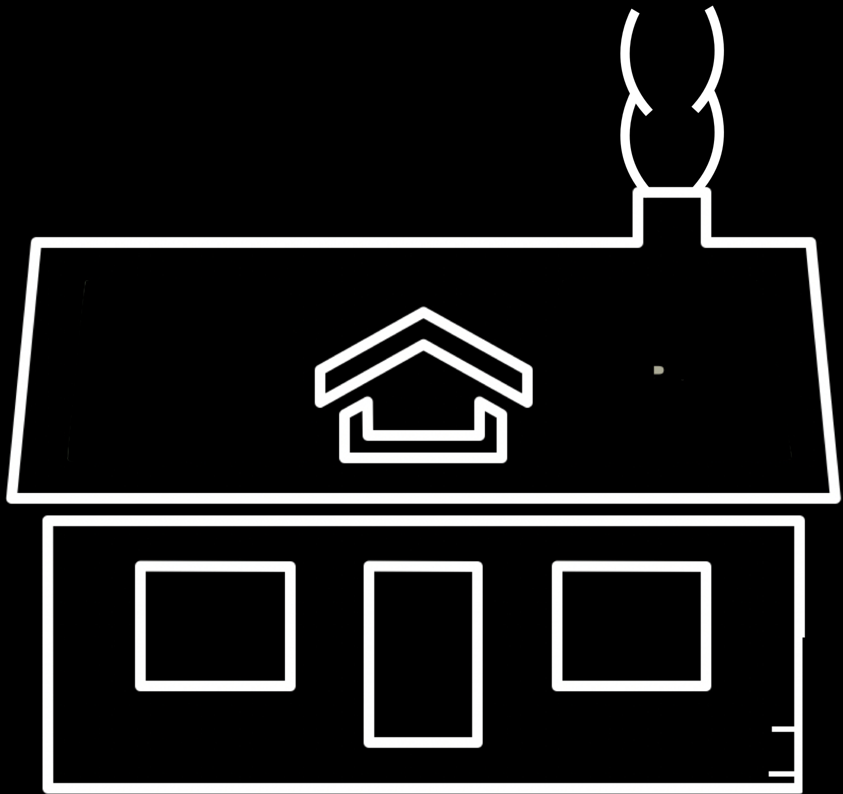
Figure 33 hale gas life cycle GHG emissions according to different potential mitigation measures over the 100 year timeframe

Nicolas Fuelleman, Master thesis, 2012

François Maréchal – francois.marechal@epfl.ch

RENOVATING BUILDINGS

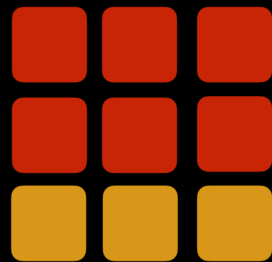




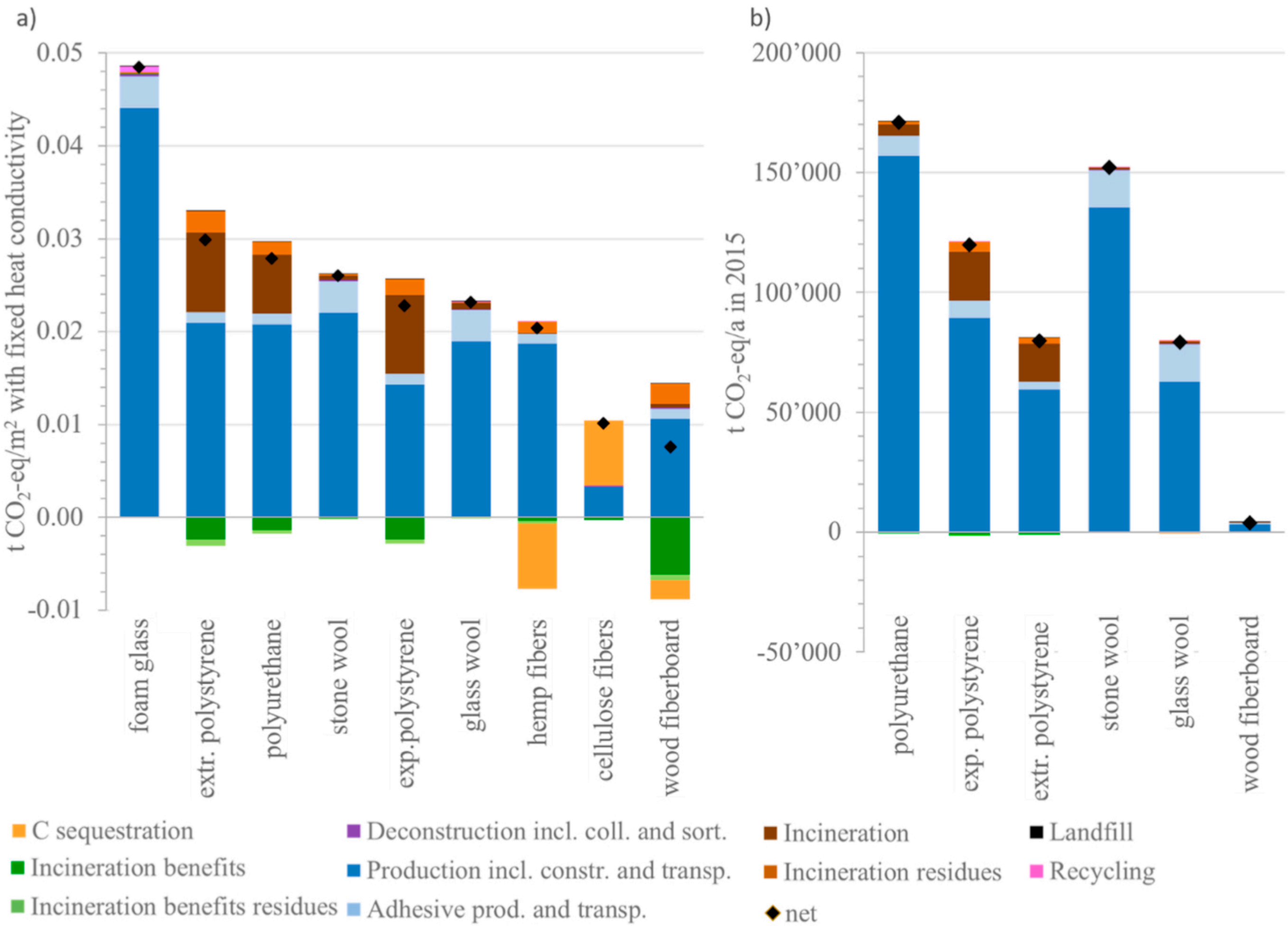
3.8

tons **CO_2** /year/100 m²

35 CHF/month/100 m²



LCA of insulating materials



Life cycle for the insulation materials

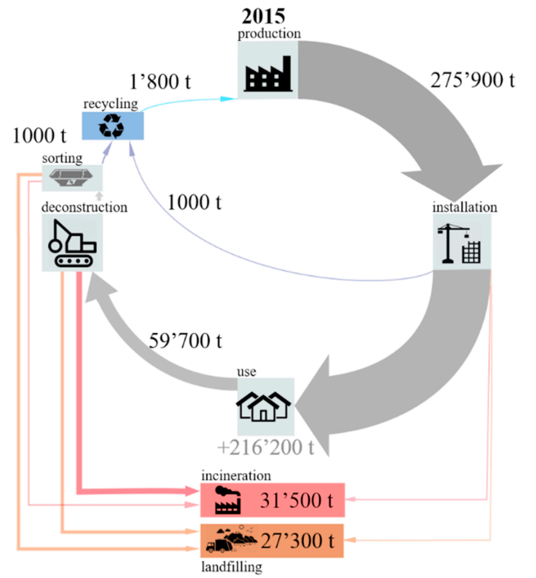


Fig. 2. Material flows of thermal insulation materials, without contaminants or residues, added to, and deconstructed from, Swiss residential buildings in 2015.

Fig. 3. Impacts on climate change (a) for different insulation materials per m^2 with fixed heat conductivity and (b) for the total thermal insulation system, added to, and deconstructed from, Swiss residential buildings in 2015. Insulation material added to, and deconstructed from Swiss residential buildings in 2015. exp. = expanded, extr. = extruded.

M. Wiprächtiger, et al. Resources, Conservation & Recycling 154 (2020) 104631

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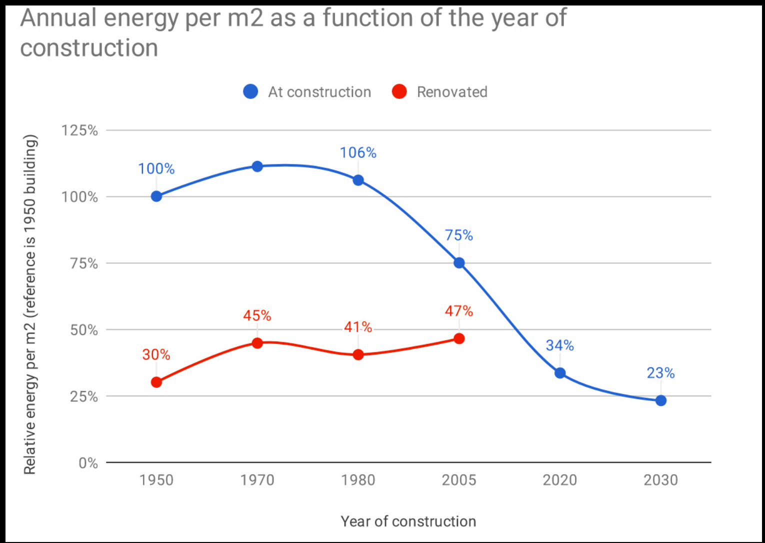
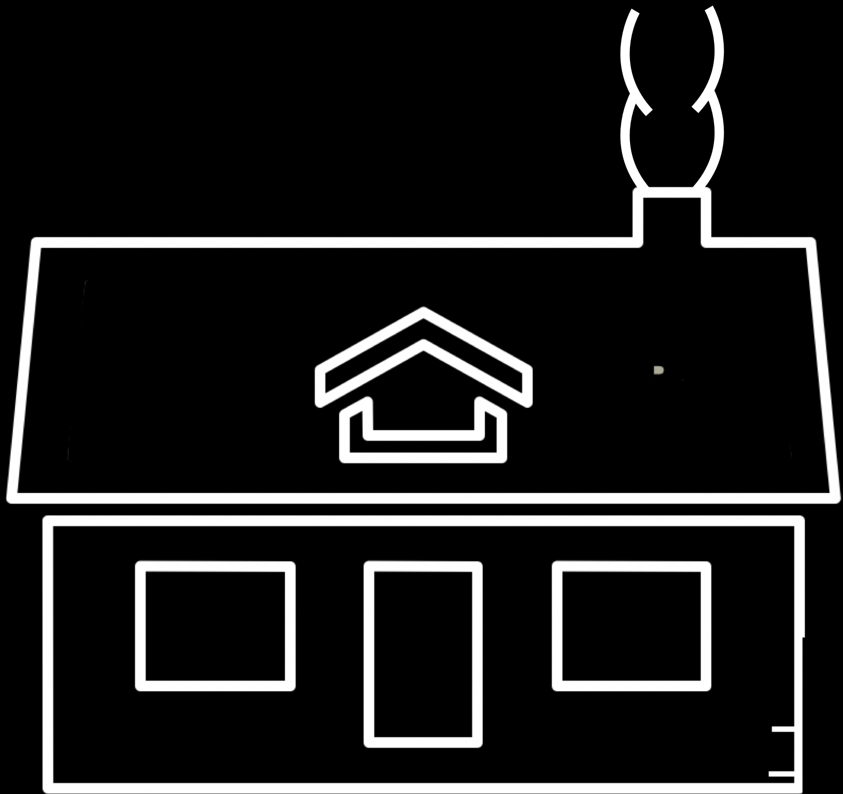
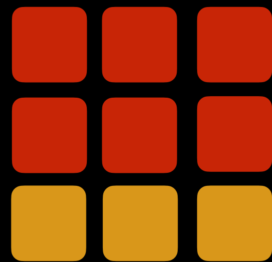
RENOVATING BUILDINGS





2.0

tons **CO_2** /year/100 m^2
35 CHF/month/100 m^2

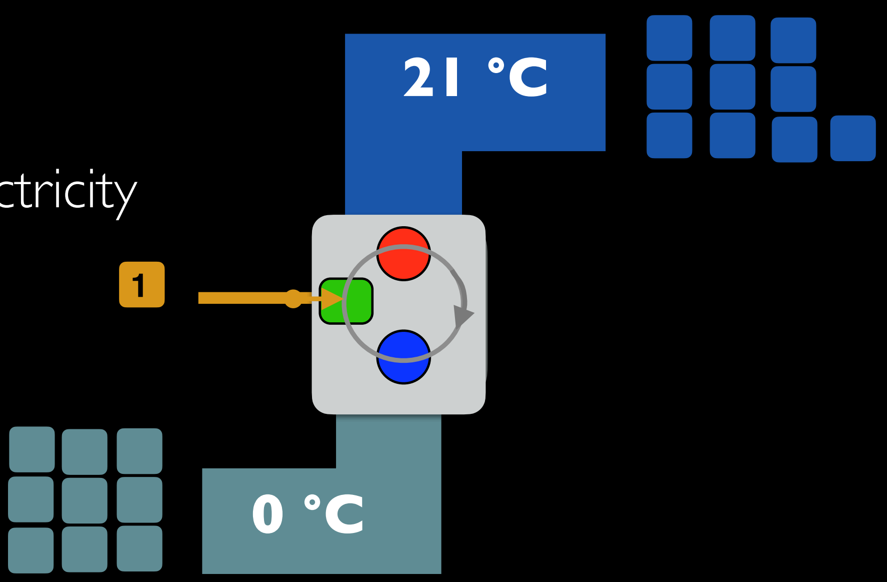


HOW DO WE SUPPLY HEAT TO A BUILDING
ASK THERMODYNAMICS

I units of electricity supplies 10 units of heat with 9 units of the environment

Nicolas Léonard Sadi CARNOT (F)
1796 - 1832

$$\dot{E} = \dot{Q}(1 - \frac{T_{cold}}{T_{hot}})$$



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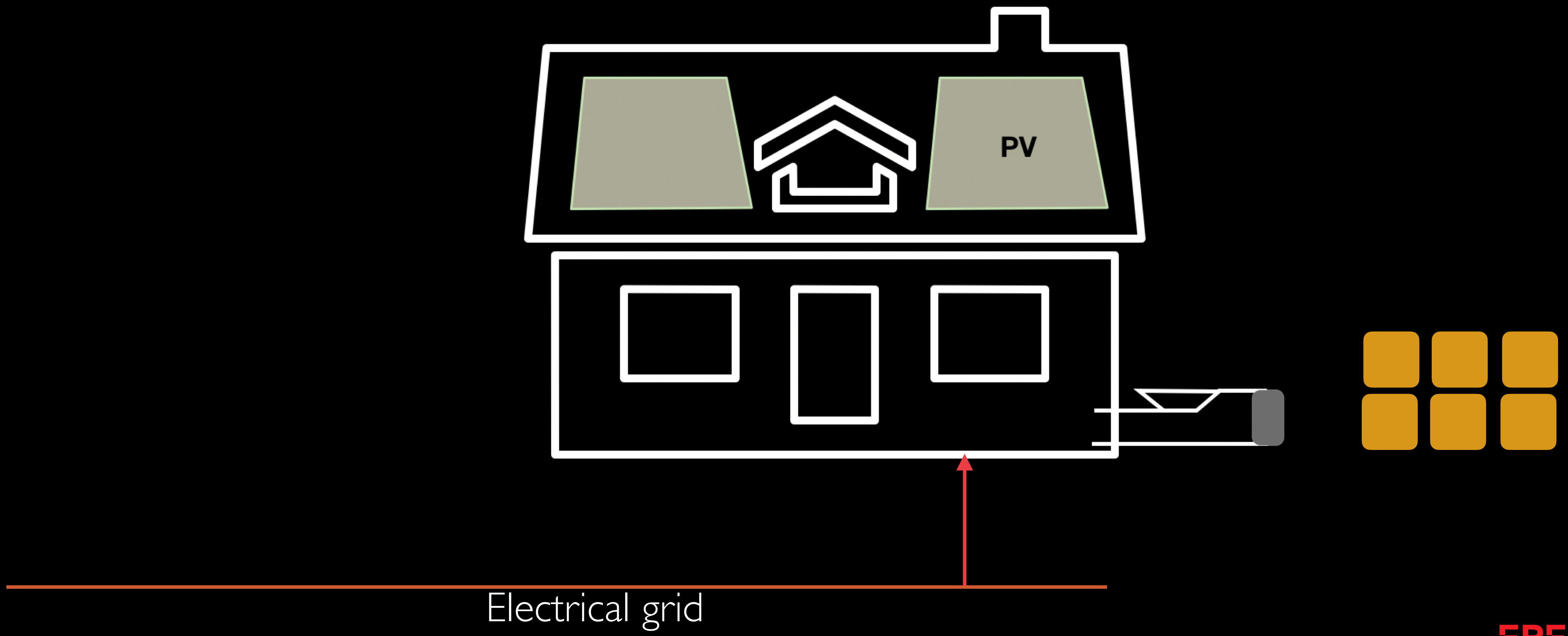
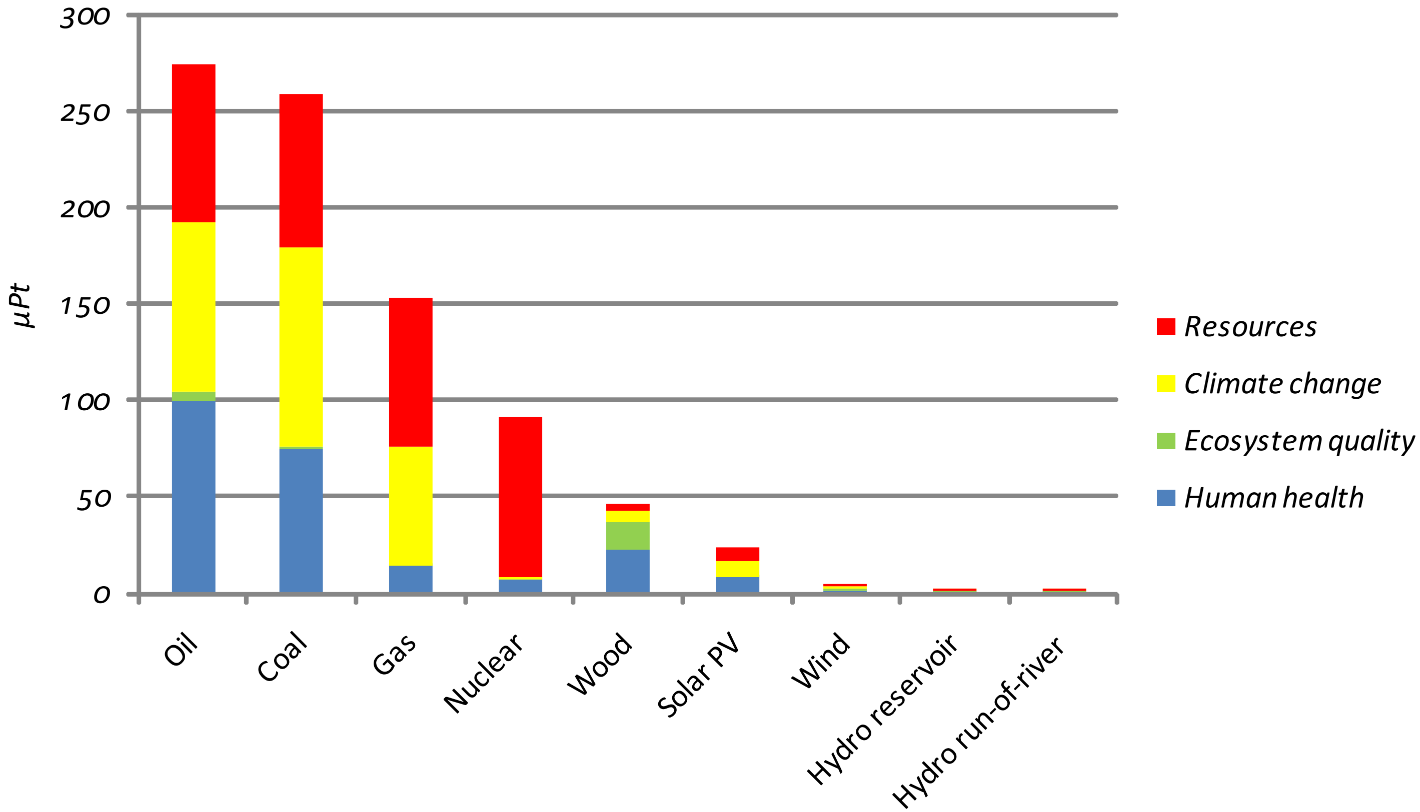
HEAT PUMP INTEGRATION IN A BUILDING



The potential impacts of electricity generation



Inventory : ecoinvent 2.2 (European averages)
LCIA method : IMPACT 2002+ (single score)

CIRAIG[MC]

EU electricity mix

IPESE
Industrial Process
and Energy Systems
Engineering

Current electricity mix

Coal	Oil	Gas	Nuclear	Wind	Solar	Hydro	Geothermal	Biomass	Other fossils	Other renewables
17%	0.7%	21%	29%	14%	4.4%	9.4%	0.2%	3.8%	0.3%	0.2%
772*	32*	953*	1317*	636*	200*	423*	9*	173*	14*	9*

* Values in TWh

VS

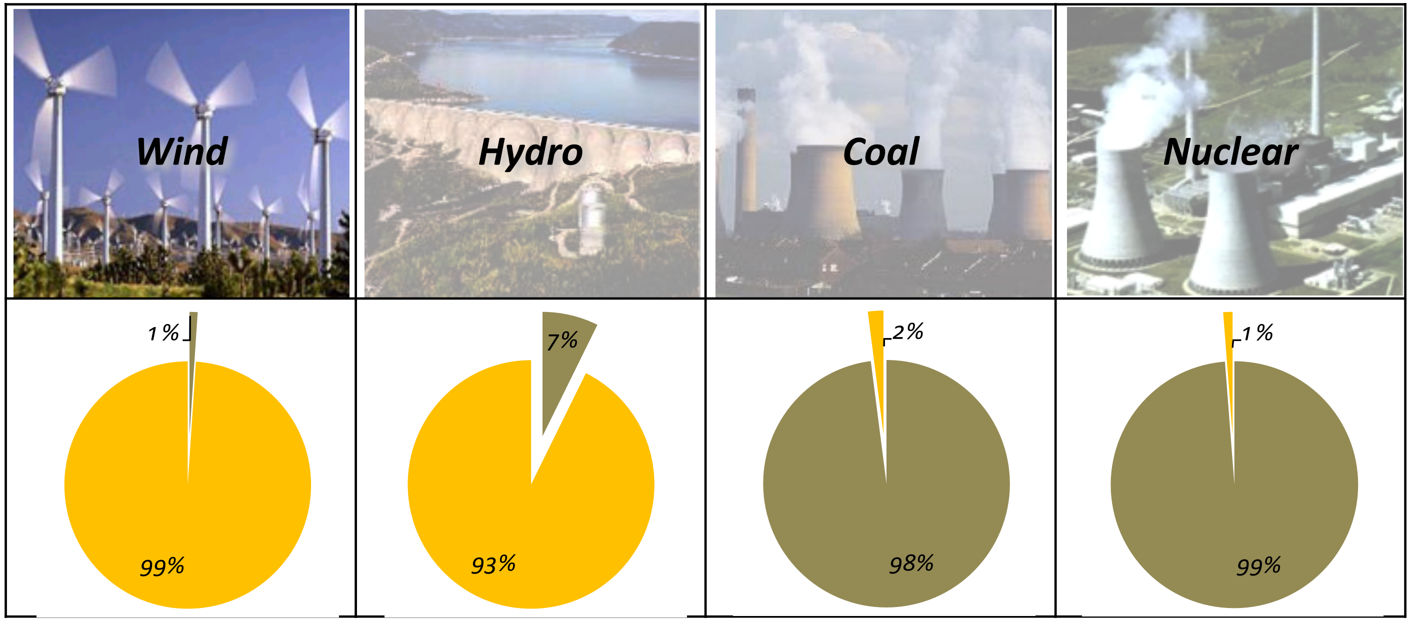
Renewable electricity mix

WInd onshore	Wind offshore	Solar	Hydro run-of-river
51%	4%	17%	28%
2547*	200*	849*	1398*

* Values in TWh

Total yearly electricity generation with deep electrification: 4540 TWh (current mix) and 4994 (renewable mix)

The relative importance of the Infrastructure



Infrastructure

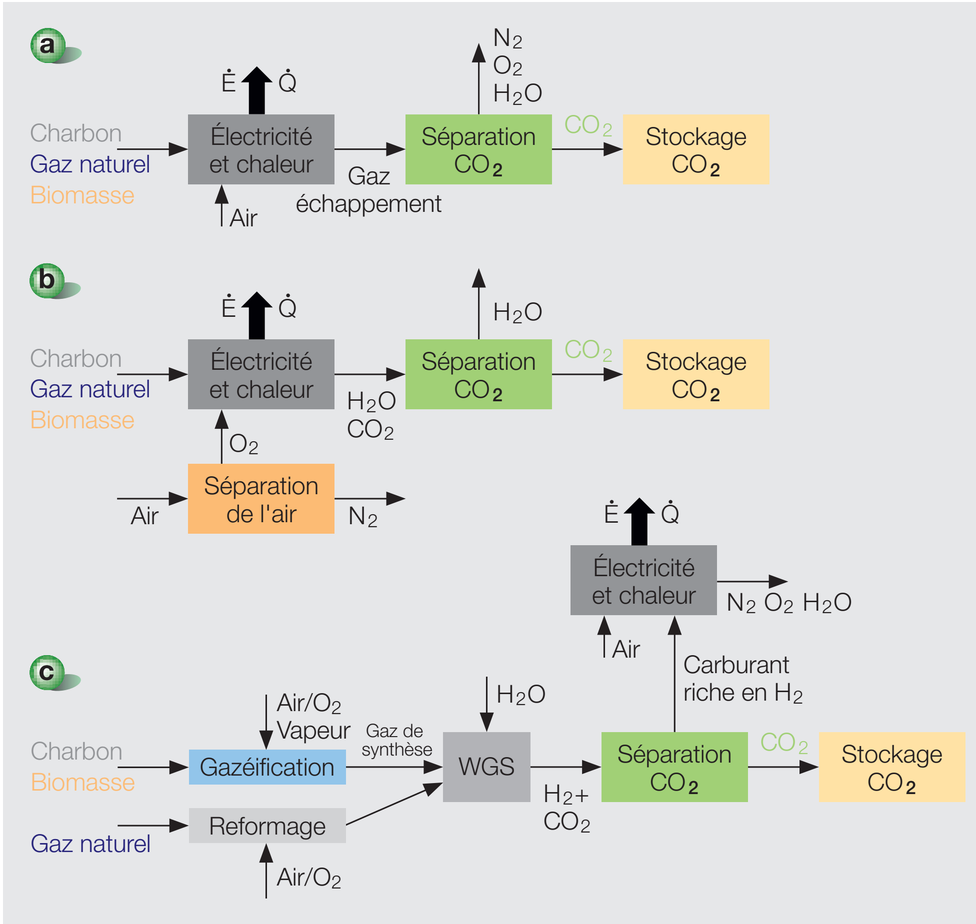
Process

Inventory : ecoinvent 2.2 (European averages)
LCIA method : IMPACT 2002+ (single score)

CIRAIG

CO2 Capture

- Energy Penalty
  - Compression
    - 2% (LHV)
  - Capture :
    - 4-7% (LHV)
  - Total
    - 6 à 9% (LHV)
- Investment
  - + 30%

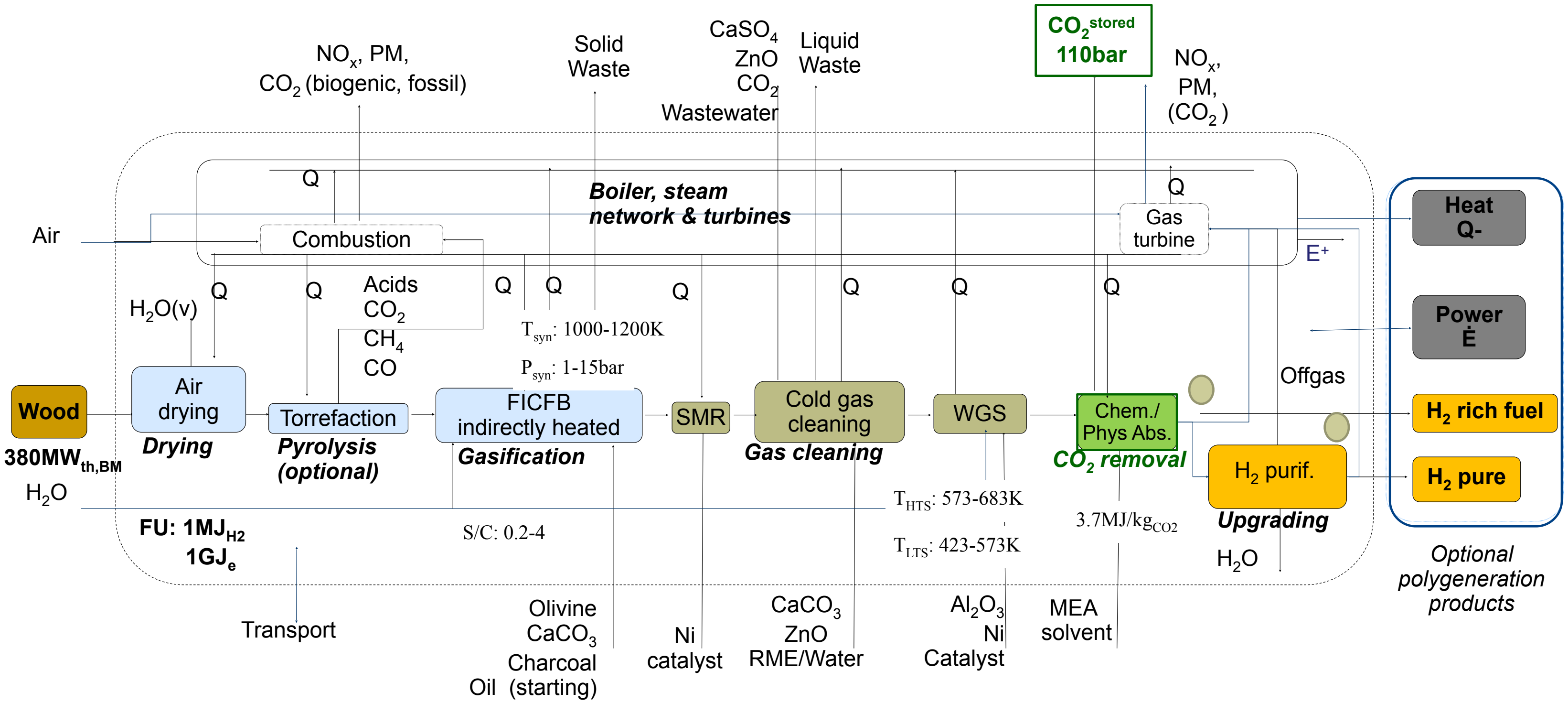


Post combustion

Oxi combustion

Pre-combustion

Electricity production with CO2 capture from biomass

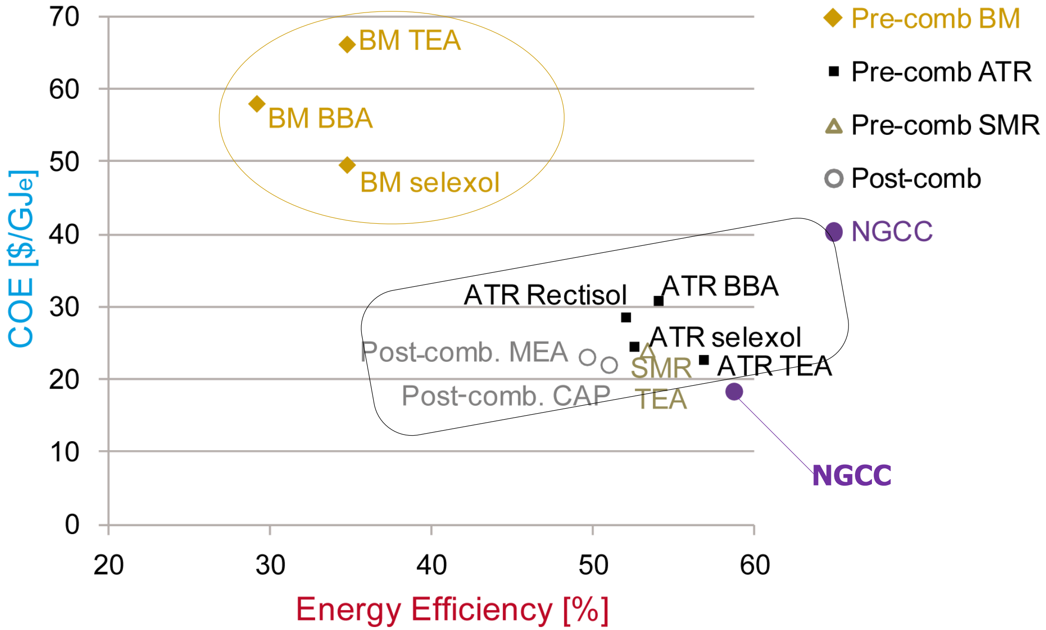


➢ Configurations (380MW$_{th,BM}$)

- Without/with CO_2 capture (compression to 110bar)
- H_2 process with Ė import or self-sufficient or Ė generation

CO_2 capture options comparison

- CO_2 capture energy and cost penalty
  - Different process configurations
    - Natural gas fed processes 90% CO_2 capture, biomass 60%

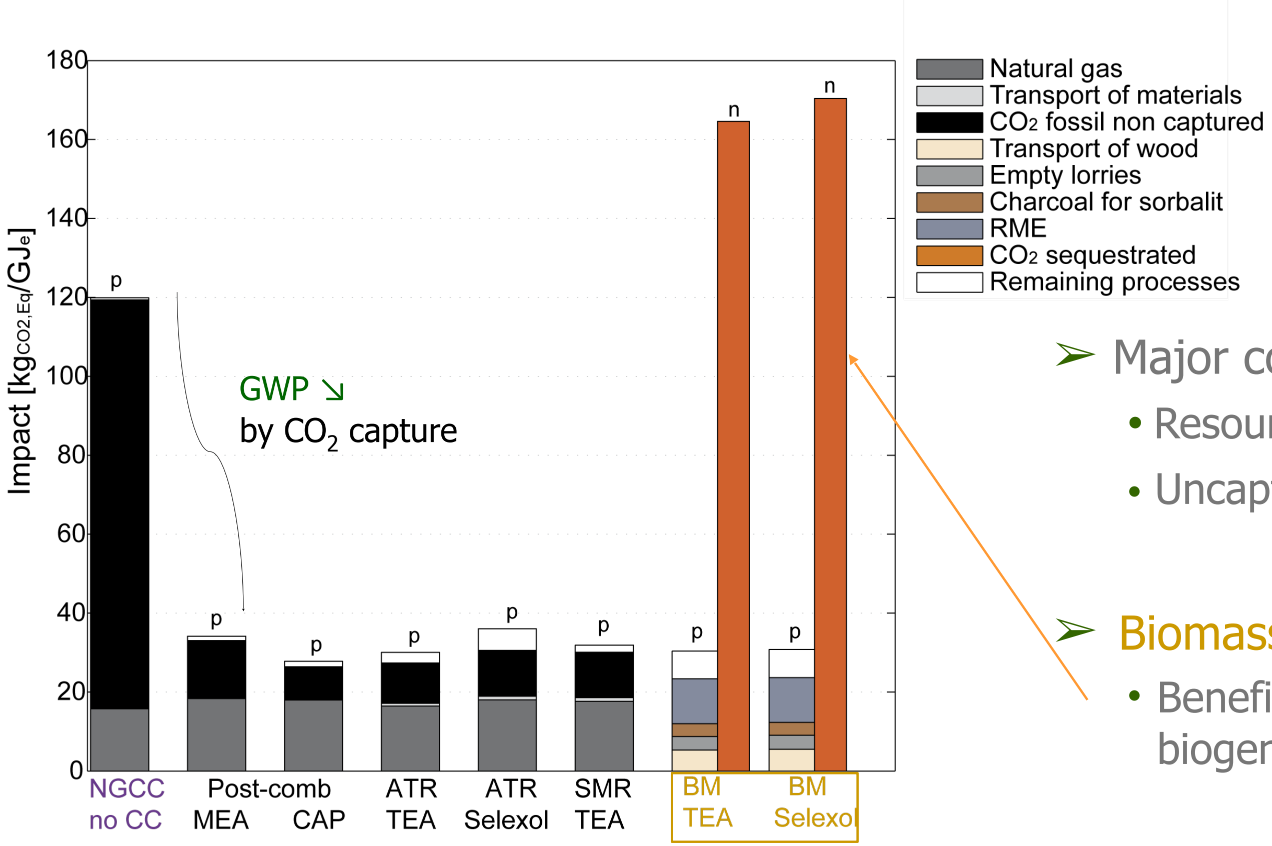


  - Competition between post- and pre-combustion

Economic scenario base: 9.7$/GJ$_{res}$, 7500h/y, 25y, 6%ir

CO_2 capture options comparison

- CO_2 capture environmental performance
  - IPCC 07: Global warming potential (FU=1GJe)



➢ Major contributions
- Resource extraction
- Uncaptured CO_2

➢ Biomass fed process
- Benefit of capturing biogenic CO_2 !

Decision-making

◆ Most economically competitive process configurations

System	NGCC	Post-comb	ATR	BM
Performance	**no CC**	**MEA**	**Selexol**	**Selexol**
Feed [MW_{th}]	559	582	725	380
CO_2 capture [%]	0	82.9	78.6	69.9
ε_{tot} [%]	58.75	50.6	53.5	35.4
Net electricity [MW_e]	328	295	383	135
[$kg_{CO2,\ local}/GJ_e$]	105	13.9	22.2	-198.1
COE incl. tax[$/$GJ_e$]	18.2-28.8	9-40	12.8-42	15-69
Avoid. Costs incl. tax [$/$t_{CO2,avoided}$]	-	-63-121	-49-127	0-253

➢ CO_2 capture penalty

- *Efficiency ↘: 6-10%-pts (CO$_2$ compression ~2%-pts)*
- *COE ↗: 20-25%*

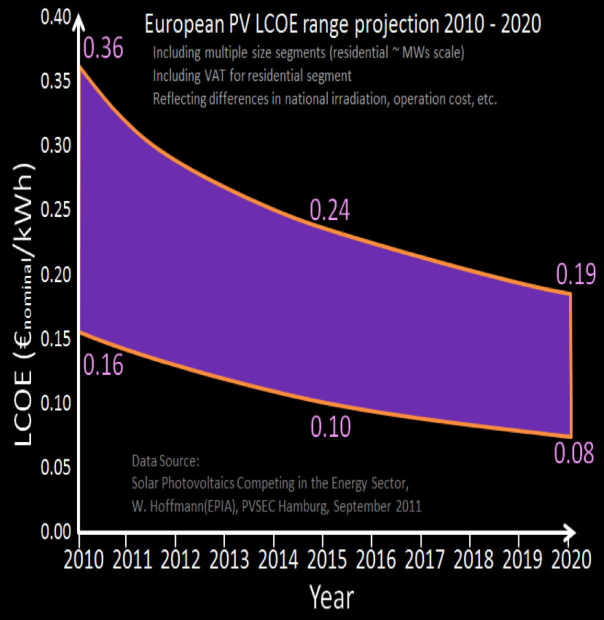
➢ Best performing process

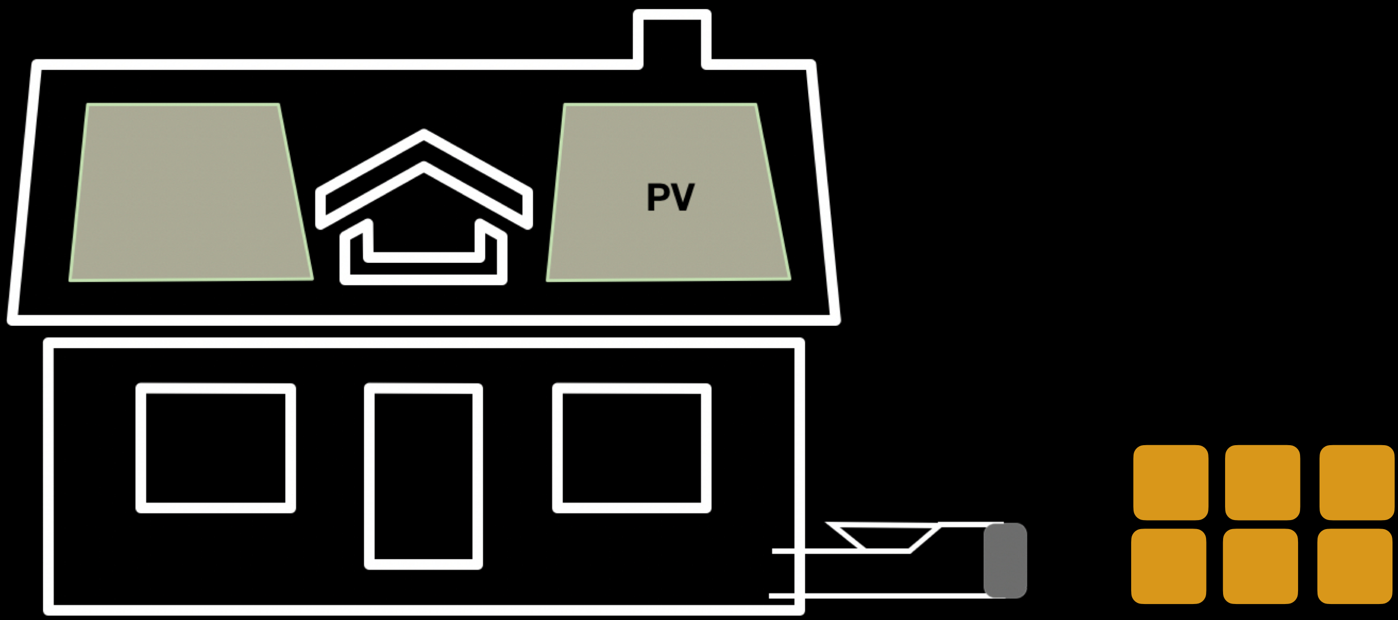
- *Efficiency: Nat gas. pre-comb.*
- *Economic: Nat gas. post-comb.*
- *Environmental: Biomass pre-comb.*

➢ Competition between processes and objectives!

HEAT PUMP INTEGRATION IN A BUILDING

PV costs projections

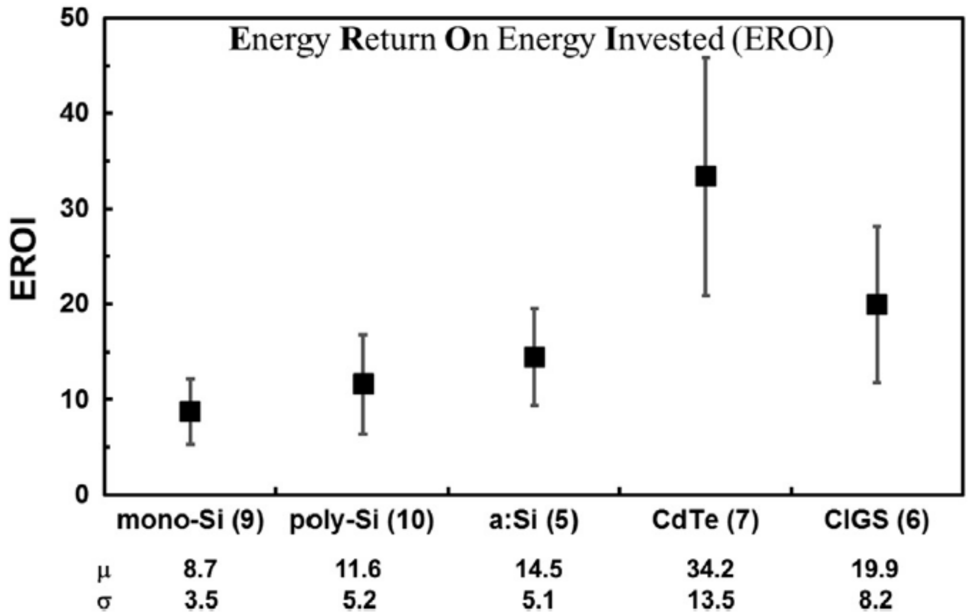




http://www.toitsolaire.ch

EPFL

Energy return on energy invested



$$EROI = \frac{\text{Electricity produced}}{\text{Energy for panel production}}$$

« variation in embedded energy was greater than the variation in efficiency … suggesting that the relative ranking of the EPBT of different PV technology today and in the future depends primarily on the embedded energy and not the efficiency »

(Bhandari, et.a.. (2015).. Renewable and Sustainable Energy Reviews, 47 133-141)

CIRAIG[MC]

Energy pay-back time of Photovoltaics systems (meta-analysis)

Photovoltaic pannel (# studies)	Median (years)	Standard deviation
Mono-SI (9)	4.1	2.0
Poly-SI (10)	3.1	1.3
a:SI (5)	2.3	0.7
CIGS (4)	1.7	0.7
CdTe (7)	1.0	0.4

(Bhandari, K. P., Collier, J. M., Ellingson, R. J., & Apul, D. S. (2015). Energy payback time (EPBT) and energy return on energy invested (EROI) of solar photovoltaic systems: A systematic review and meta-analysis. Renewable and Sustainable Energy Reviews, 47 133-141.)

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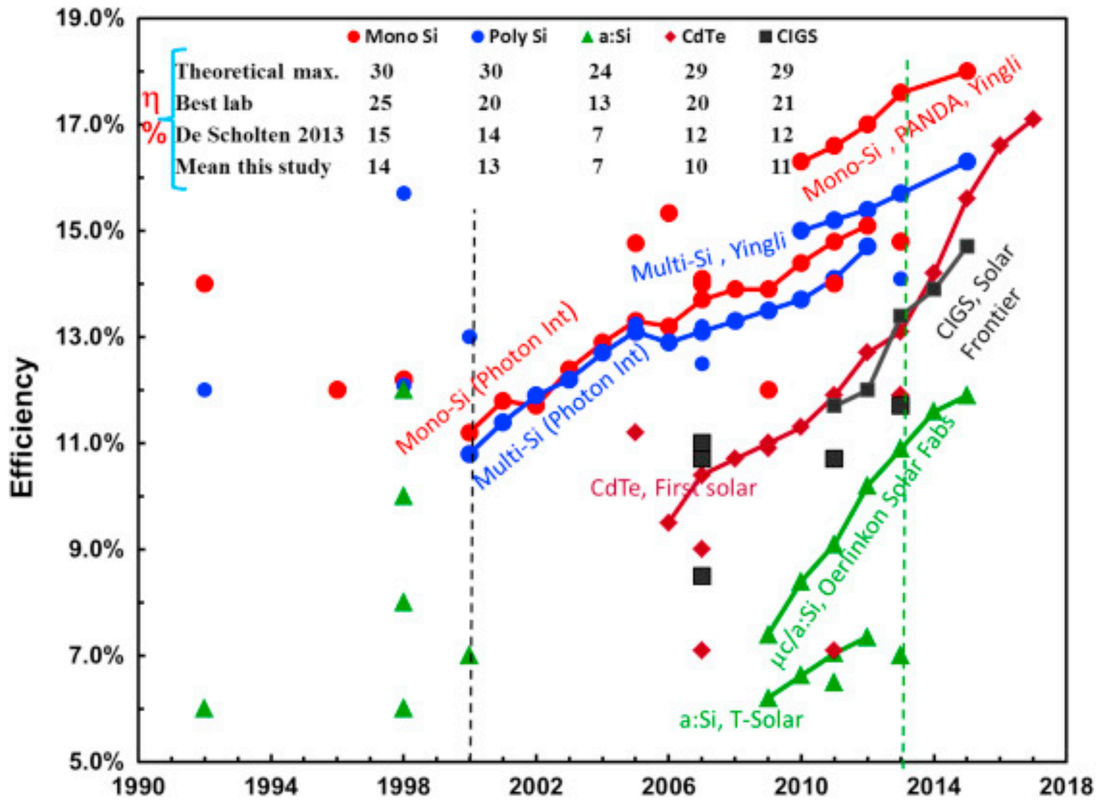
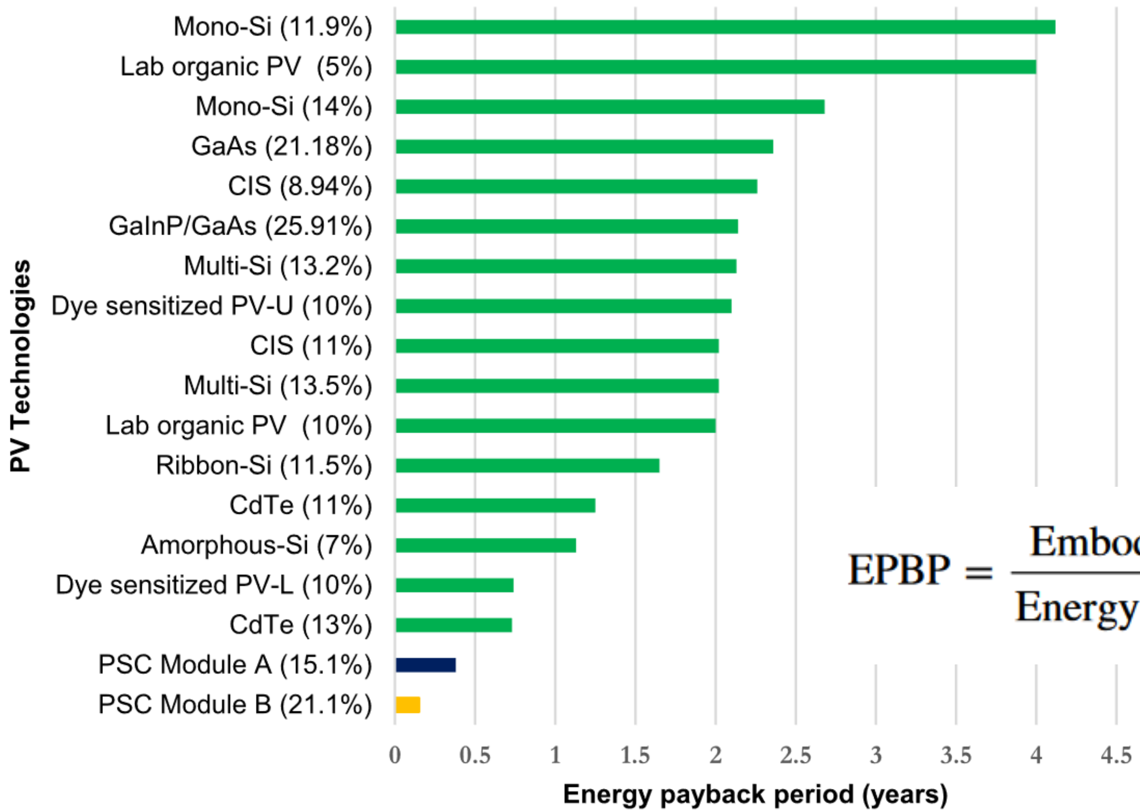
PV efficiency



(Bhandari, et.a.. (2015).. *Renewable and Sustainable Energy Reviews, 47 133-141*)

Energy pay back period (years)



$$\text{EPBP} = \frac{\text{Embodied energy } (\text{kWh/m}^2)}{\text{Energy output } (\text{kWh/m}^2\text{/year})}$$

Fig. 16. Comparison of EPBP of existing PV technologies with PSC. Data for other PV technologies are obtained from García-Valverde et al. [10].

(Ibn-Mohammed et al. 2017. Perovskite solar cells: An integrated hybrid lifecycle assessment and review in comparison with other photovoltaic technologies. Renewable and Sustainable Energy Reviews. 1321-1344.)

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Comparison of Environmental impacts indicators for different solar cells

(Muteri et al. 2020. Review on Life Cycle Assessment of Solar Photovolaic Panels. Energies, 13, 252-?)

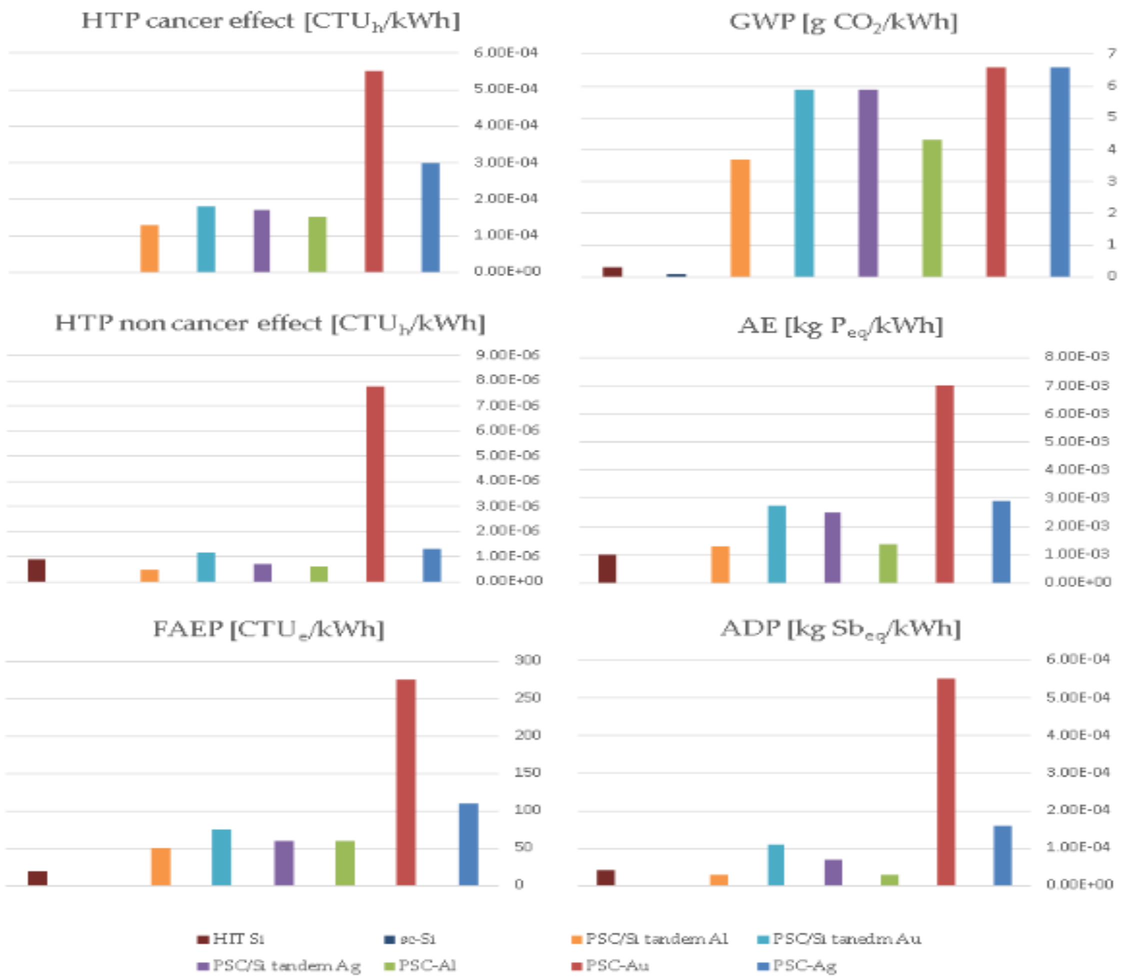
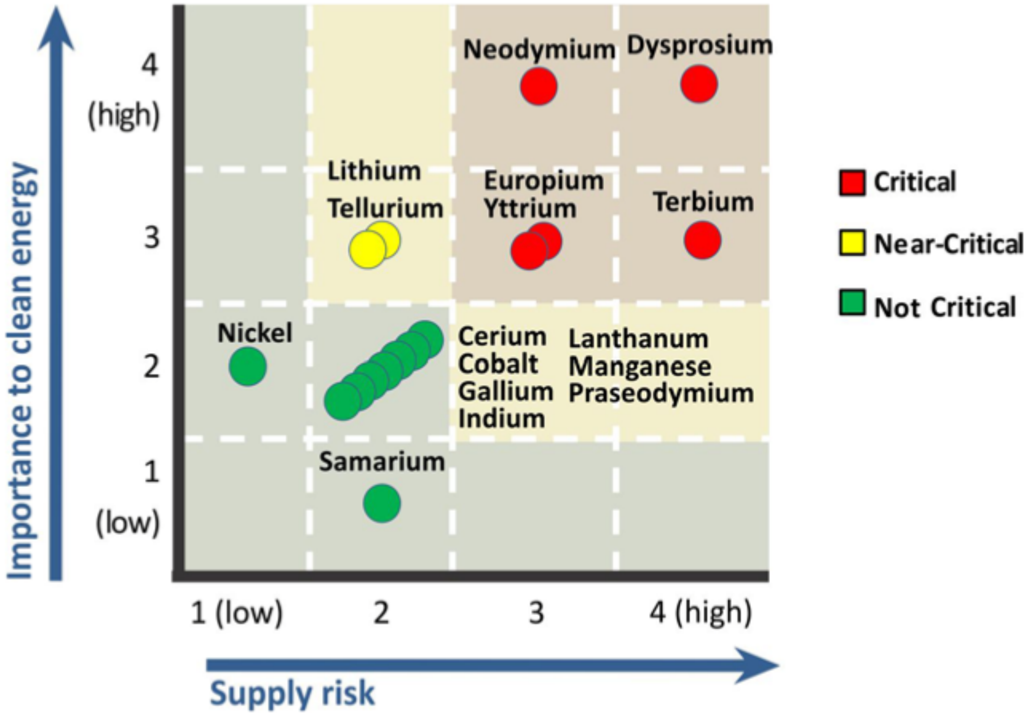


Figure 2. Environmental impacts of different solar cells [66].

Medium term material criticality in (*U.S. Dep of Energy)*

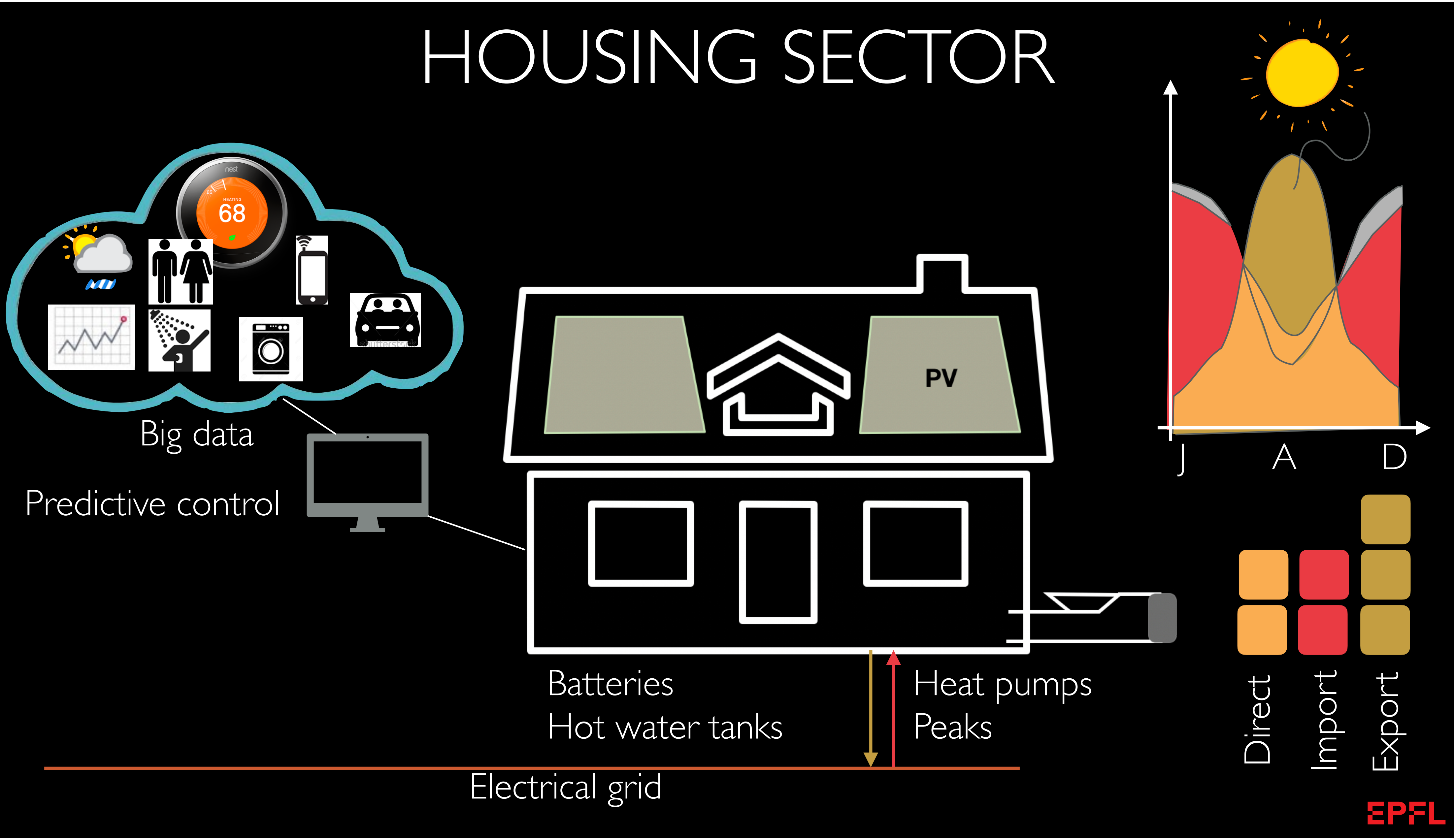
Innovation is needed in the long term to contribute reducing the quantity of critical metals used in energy technologies



(U.S. Dep of Energy. 2011. Critical Material Strategy)

CIRAIG

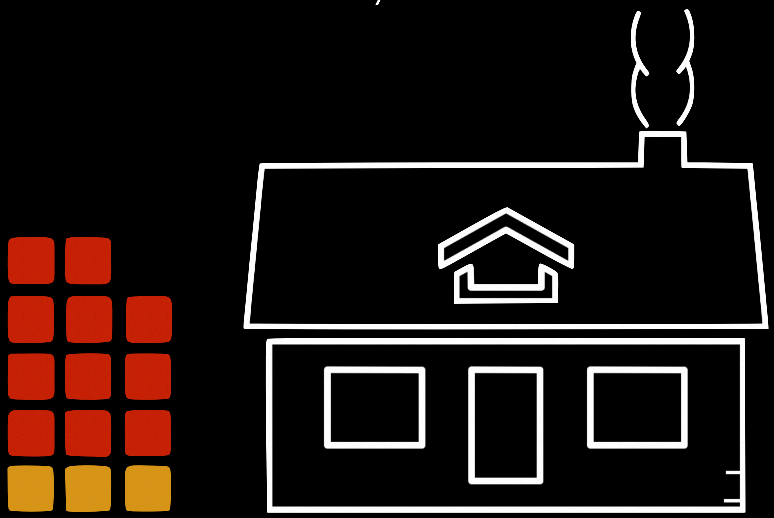
HOUSING SECTOR



FROM FOSSIL FUEL TO RENEWABLES

3.8

tons CO_2 /year/100 m^2



170

CHF/month/100 m^2

Energy : **140** CHF/month/100 m^2

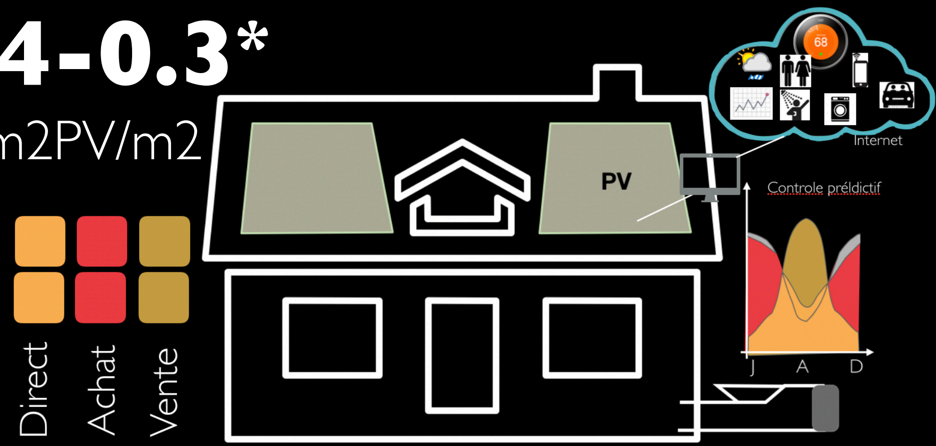
Investment : **30** CHF/month/100 m^2

0.18-0.07*

tons CO_2 /year/100 m^2

0.4-0.3*

m2PV/m2



*renovation

163

CHF/month/100 m^2

Energy : **50** CHF/month/100 m^2

Investment : **113** CHF/month/100 m^2

EPFL

Energy services to buildings

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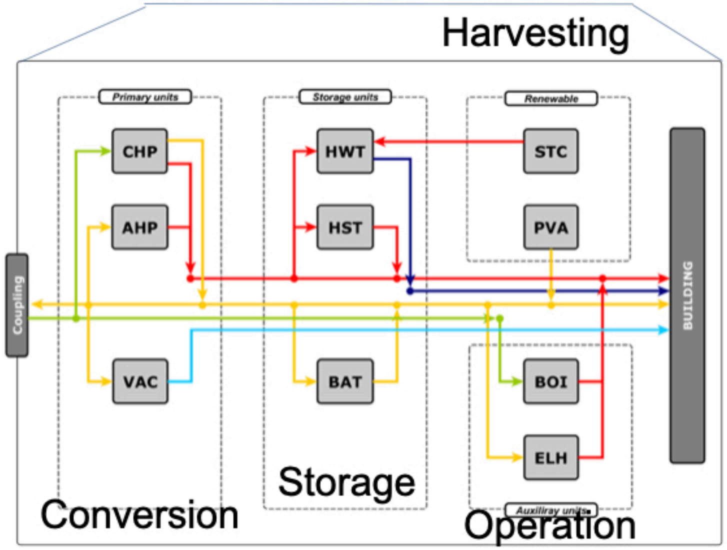
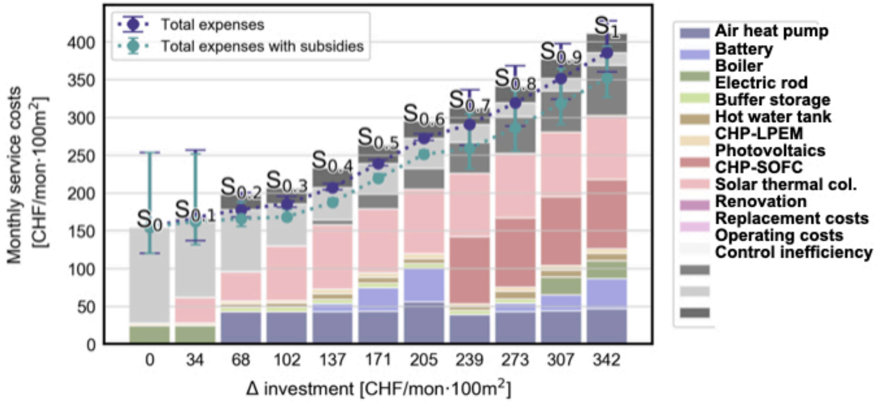
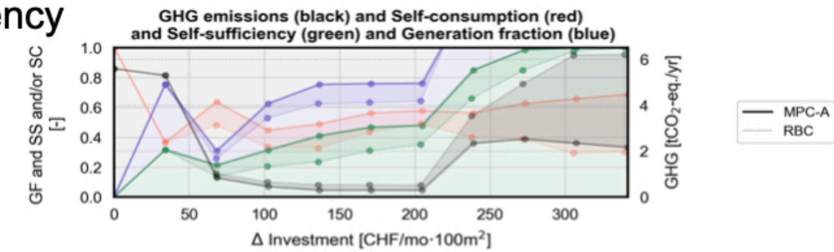
Integrating biomass in building energy systems : project in collaboration with gaznat



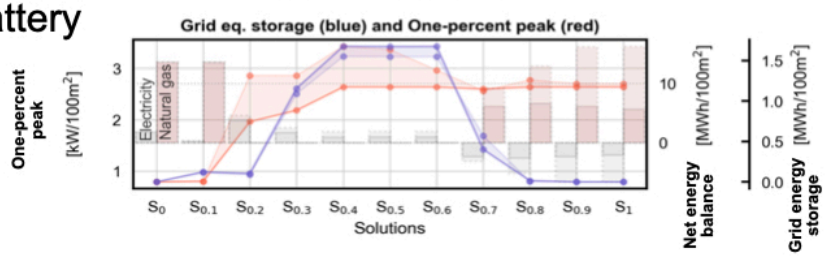
List of energy conversion solutions



Self sufficiency



Hidden battery



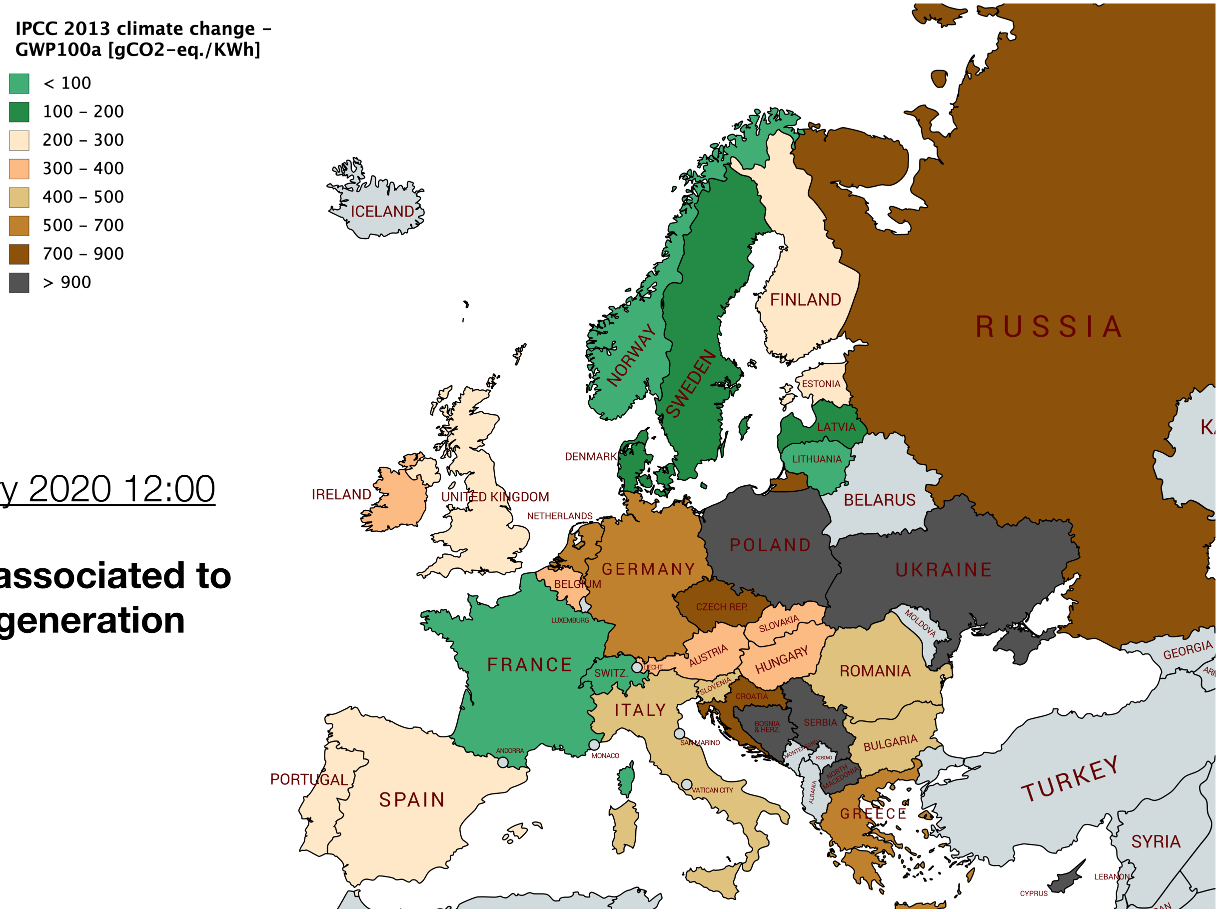
31 Types of buildings
7 Climatic zones
6 typical communes

Dynamic LCA - real time emissions

IPESE
Industrial Process and Energy Systems Engineering

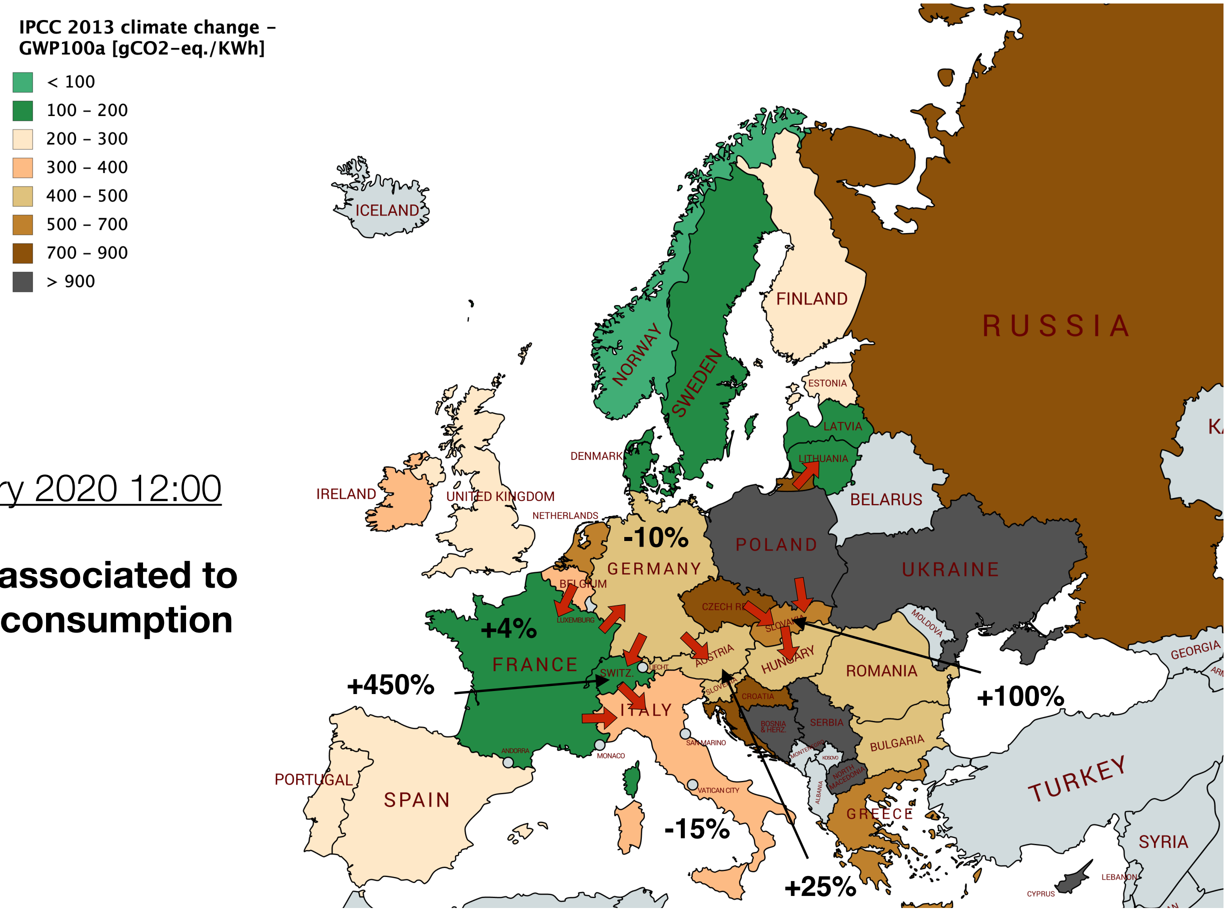
26th January 2020 12:00

GWP100a associated to electricity generation



Dynamic LCA - effect of exchanges

IPESE
Industrial Process and Energy Systems Engineering



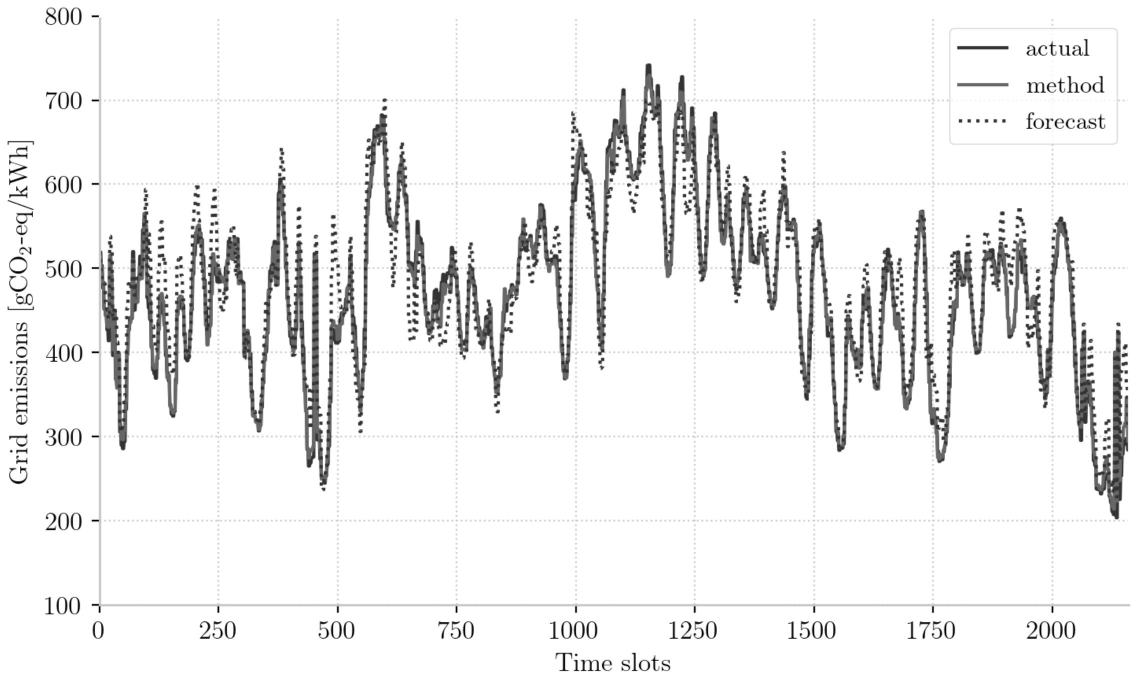
<u>26th January 2020 12:00</u>

GWP100a associated to electricity consumption

Predictions - data driven models

IPESE
Industrial Process and Energy Systems Engineering

Germany (April 2018) - **Random Forest regressor**



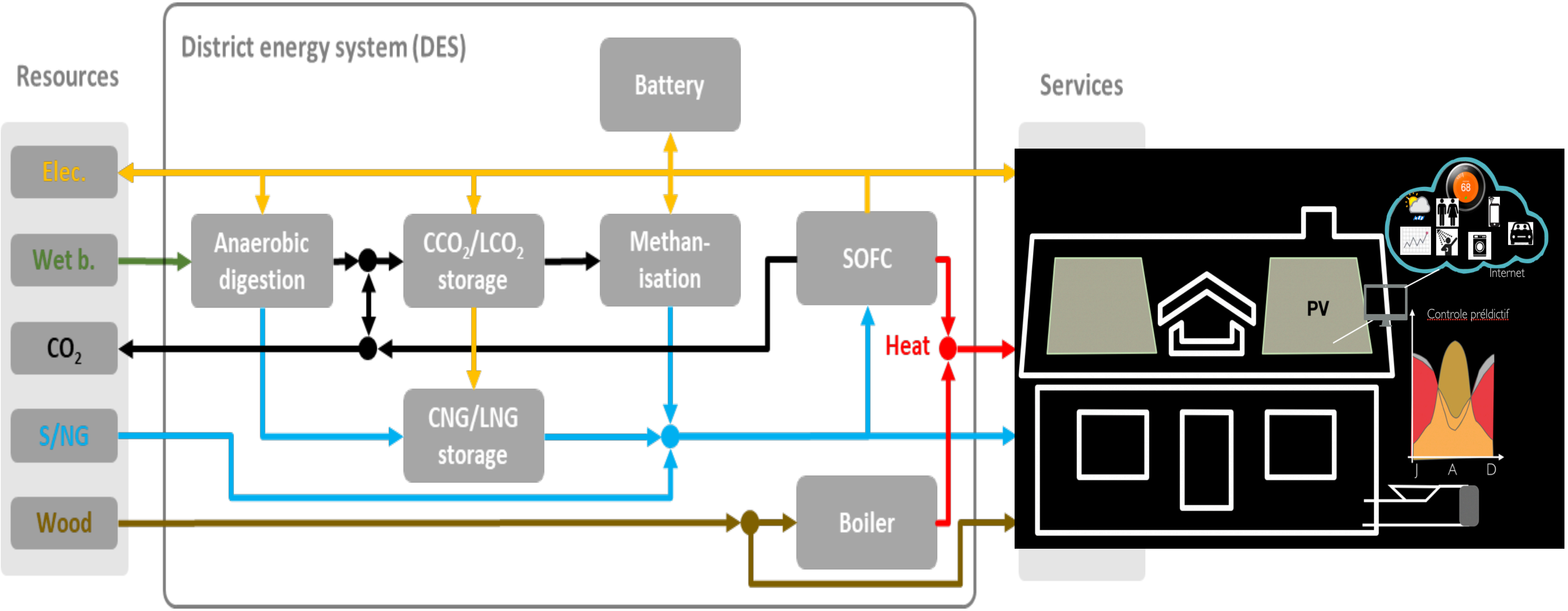
Trained over 17,322 data split in train and test sets

R^2 train: 0.996
R^2 test: 0.943

Reproduced trend:

R^2 method: 0.989
R^2 forecast: **0.931**

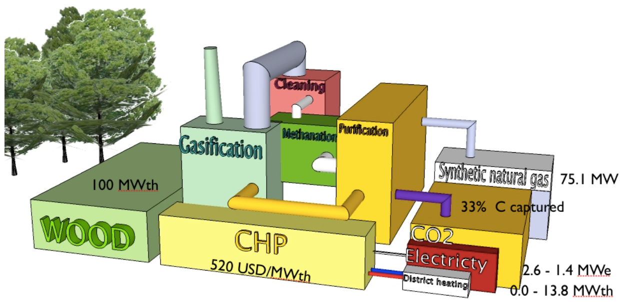
Integrating biomass in district systems



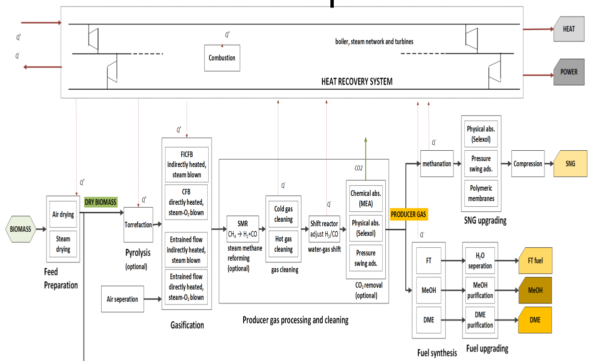
François Maréchal – francois.marechal@epfl.ch

Systematic method for process system design options

2C(H2O) -> CH4 + CO2

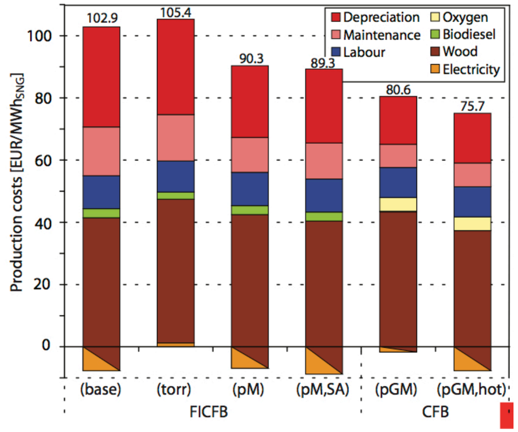


Process superstructure



Comparing options

Total production costs



Systematic generation

Gasification:
FICFB
- ○ air drying
- △ + torrefaction
- × steam drying
- ◇ + torrefaction

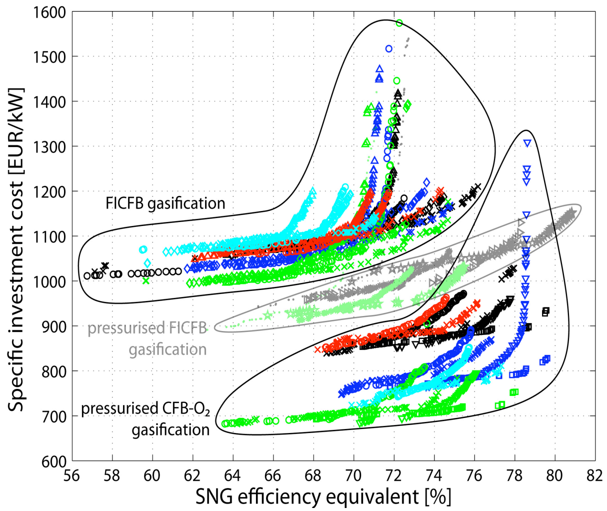
pressurised FICFB
- · air drying
- • air drying, gas turbine
- ▷ steam drying, gas turbine
- ☆ + hot gas cleaning

CFB-O_2
- ○ air drying
- ▽ + hot gas cleaning
- × steam drying
- □ + hot gas cleaning

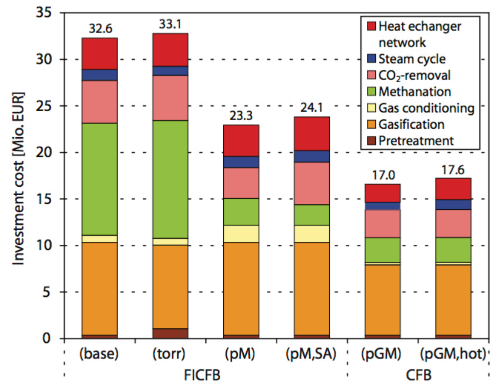
Separation:
PSA
- ■ downstream
- ■ upstream of methanation

Phys. abs.
- ■ downstream
- ■ upstream of methanation

Membranes
- ■ downstream of methanation



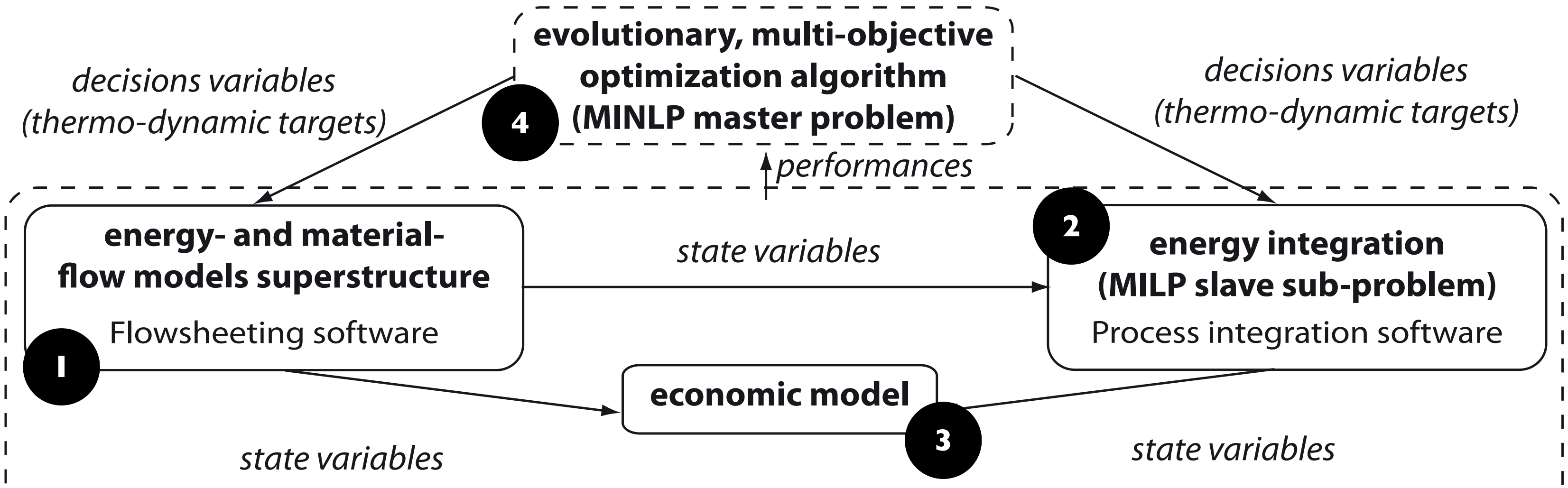
Investment cost



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

Note : 1.5 years of calculation time !

Using optimisation to extract solutions



Gerber, Léda, Martin Gassner, and François Maréchal. "Systematic Integration of LCA in Process Systems Design: Application to Combined Fuel and Electricity Production from Lignocellulosic Biomass." *Computers & Chemical Engineering* 35, no. 7 (December 9, 2010): 1265–1280. http://linkinghub.elsevier.com/retrieve/pii/S0098135410003595.

Thermo-economic optimisation

DOF of the system = N_{state variables} - N_{Flowsheet model equations}

N_{Decision variables} = DOF - N_{Context specifications}

- Degree of freedom for which I do not have any rationale to fix the value
- I only know the possible range $X_{d,min} \leq X_d \leq X_{d,max}$
- I would like to fix the value of X_d so that it minimise an objective function

$$
\begin{array}{llll}
\min\limits_{X_{state}} & CT(X_{state}) & & \\
\text{Subject to} & F(X_{state}) = 0 & & \text{Flowsheet model} \\
 & S(X_{state}) = 0 & & \text{Context specifications} \\
 & G(X_{state}) \geq 0 & & \text{Inequality constraints} \\
 & X_{state} = \{X_{flows}, X_{Parameters}, Y_{decision}\} & & Y_{decision} \epsilon \{Yes(1), No(0)\}
\end{array}
$$

$Y_{d,} X_d$ is a subset of X_{state}

$Y_{d,} X_d$ defines the process configuration from the superstructure

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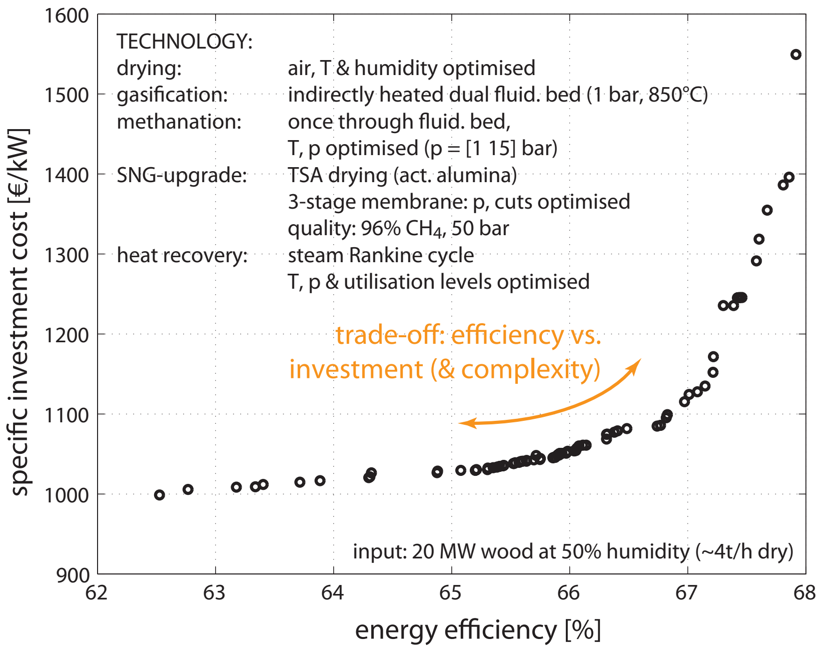
and Energy Systems
Engineering

Thermo-economic optimisation

Trade-offs: efficiency and scale vs. investment

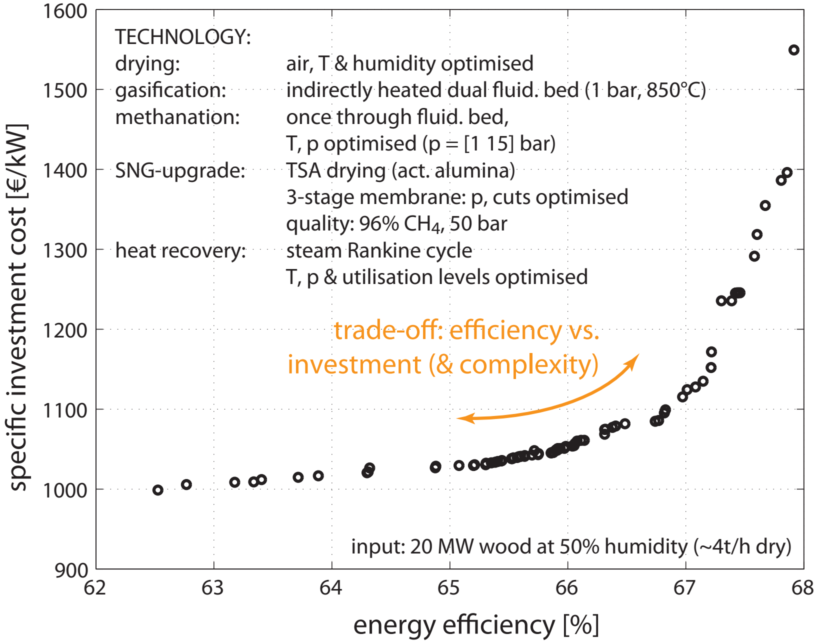
Efficiency vs. investment:

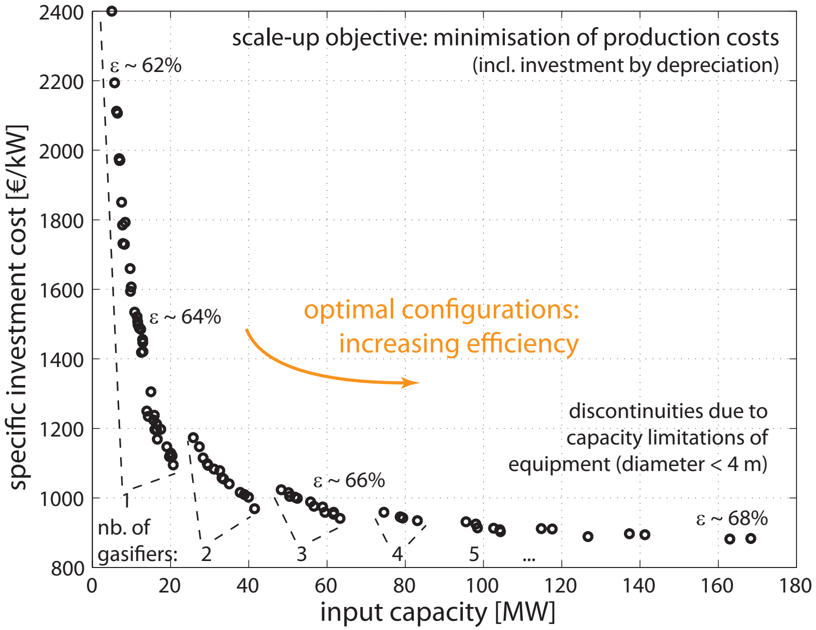


Thermo-economic optimisation

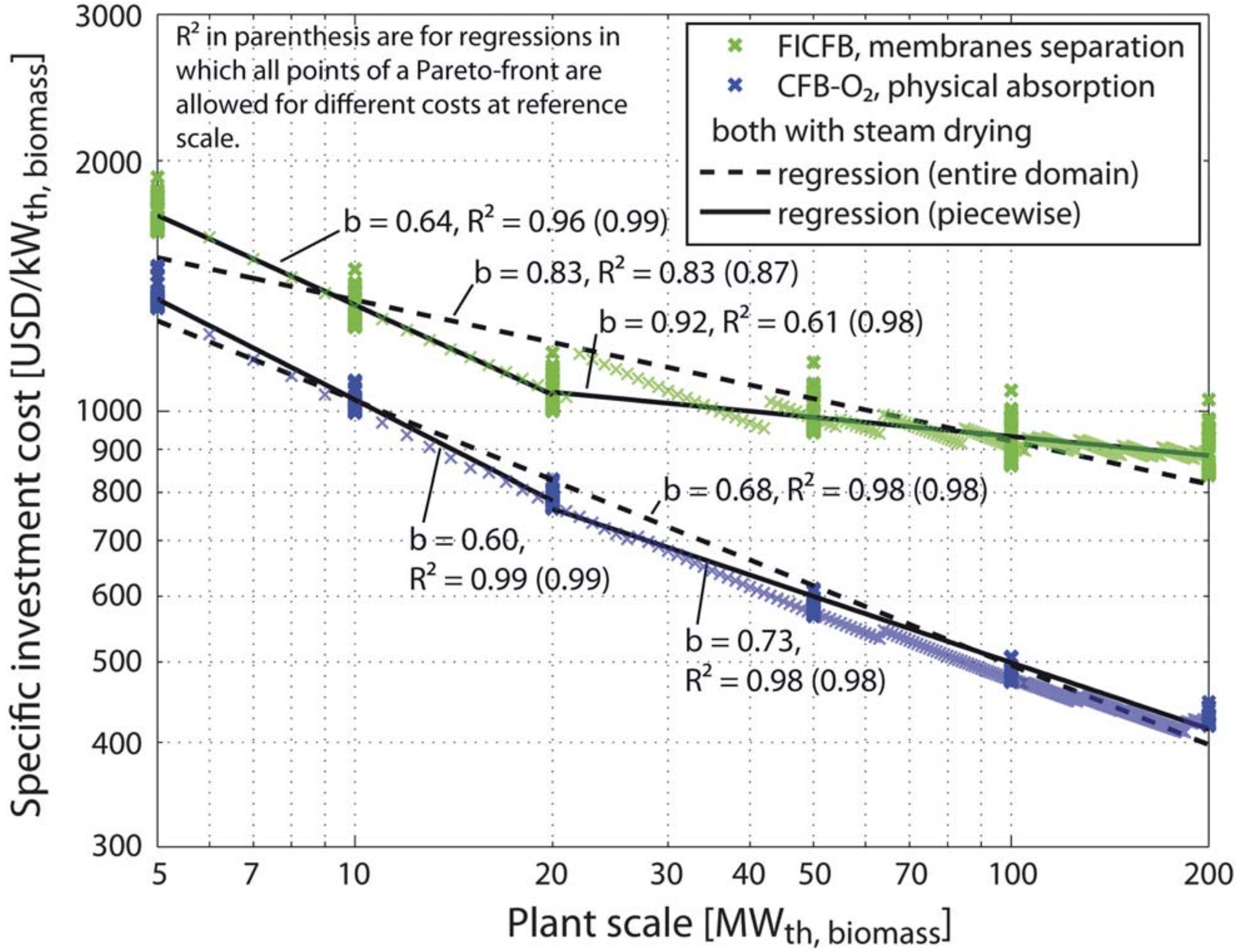
Trade-offs: efficiency and scale vs. investment

Efficiency vs. investment and optimal scale-up:





Investment as a function of biomass feed



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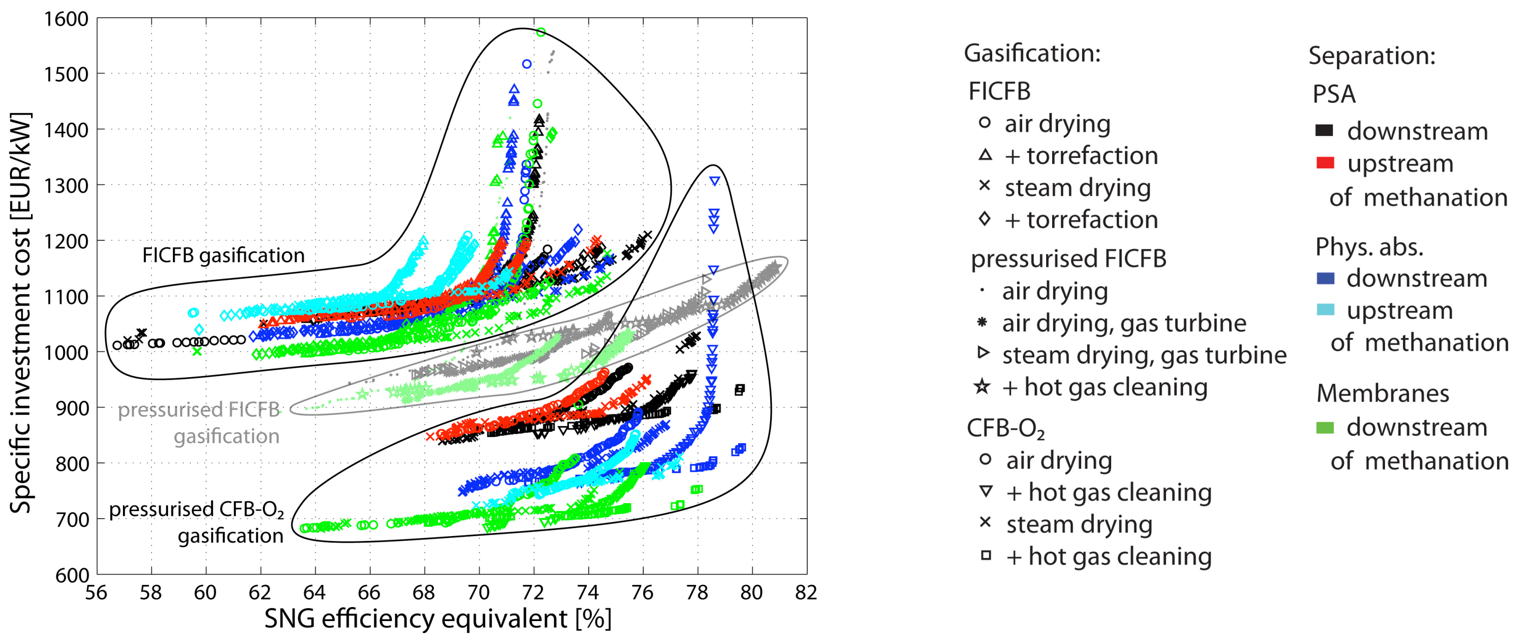
8. Analysing the results

- **Each point of the Pareto is a process design**

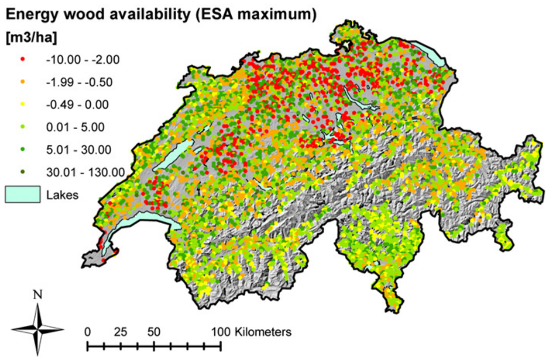
Thermo-economic Pareto front (cost vs efficiency):



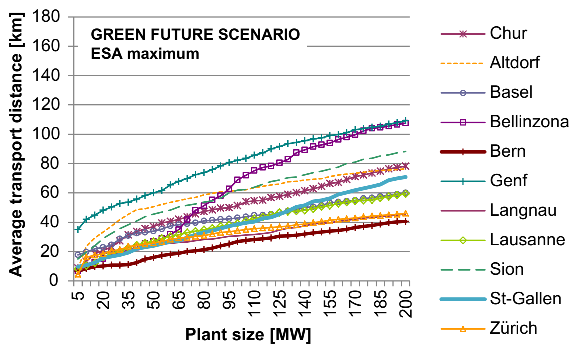
→ *The best solution is the pressurised directly heated gasifier*

Plant location

Area = 40 km2

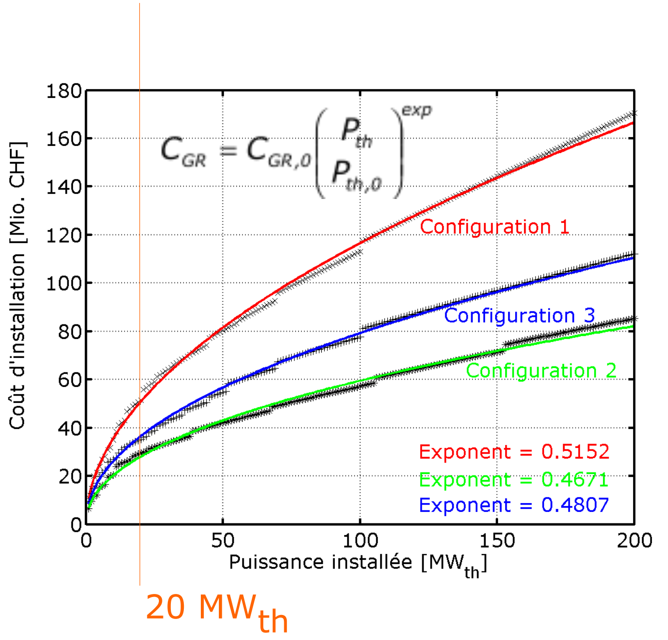


Transport = 10 % of the energy



Process Size => Investment

20 MW_{th}:
- 51.4 Mio. CHF (1)
- 29.5 Mio. CHF (2)
- 35.4 Mio. CHF (3)

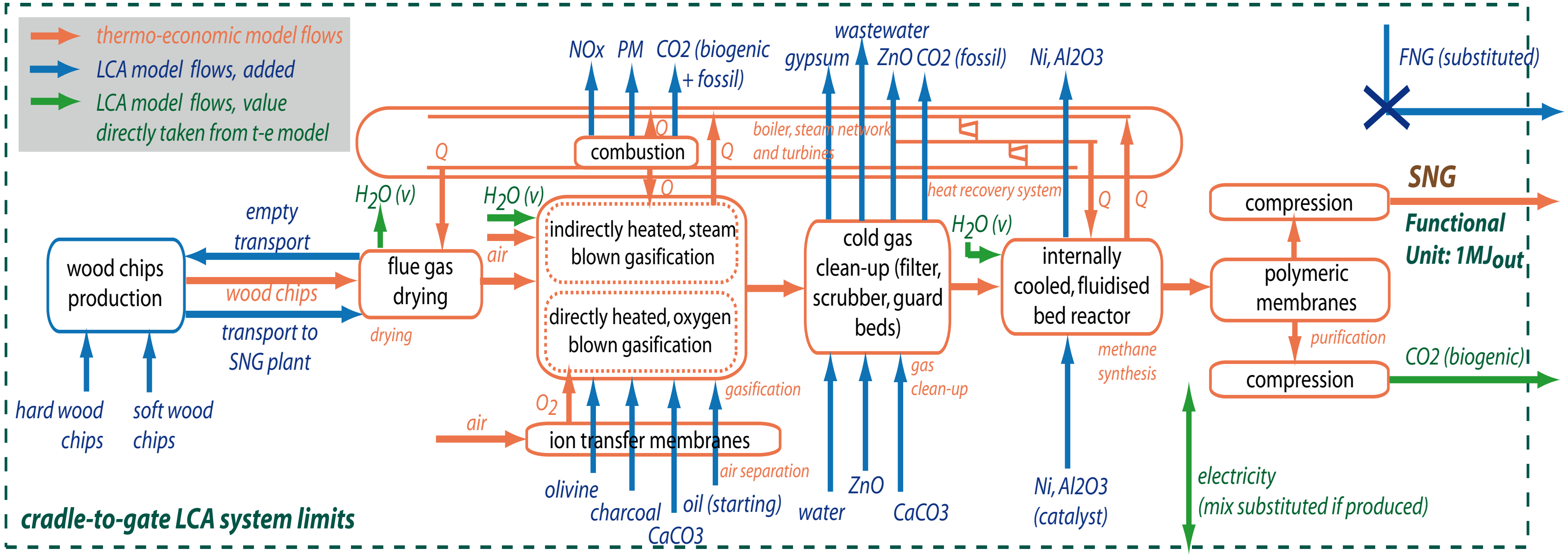


Efficiency : 5000 Wyear/year/ha

Environmental Process performance indicators

Identification of Life Cycle Inventory elements

- **Process superstructure, extended with LCI**

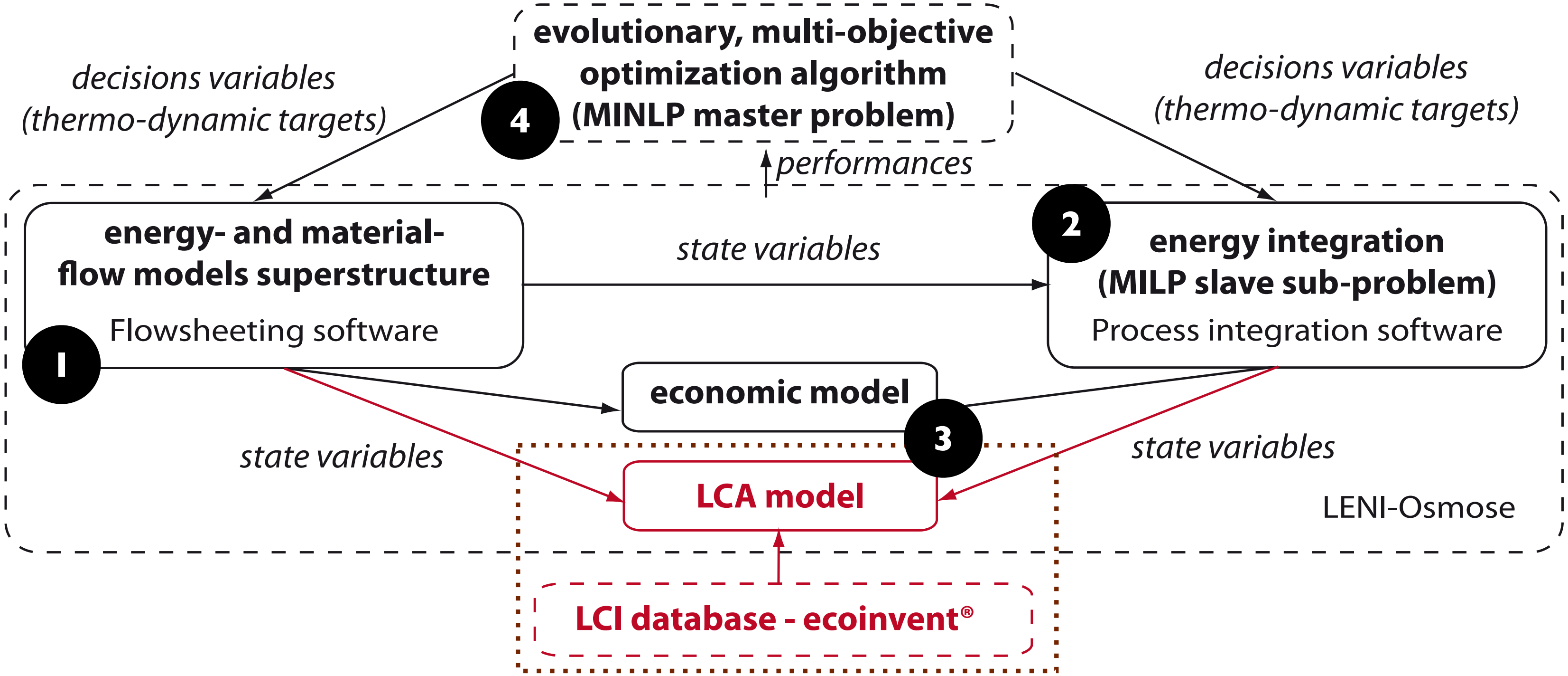


➡ **use of ecoinvent emission database (1) for each LCI element, to take into account off-site emissions**

(1)

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

Computational framework



Gerber, Léda, Martin Gassner, and François Maréchal. "Systematic Integration of LCA in Process Systems Design: Application to Combined Fuel and Electricity Production from Lignocellulosic Biomass." *Computers & Chemical Engineering* 35, no. 7 (December 9, 2010): 1265–1280. http://linkinghub.elsevier.com/retrieve/pii/S0098135410003595.

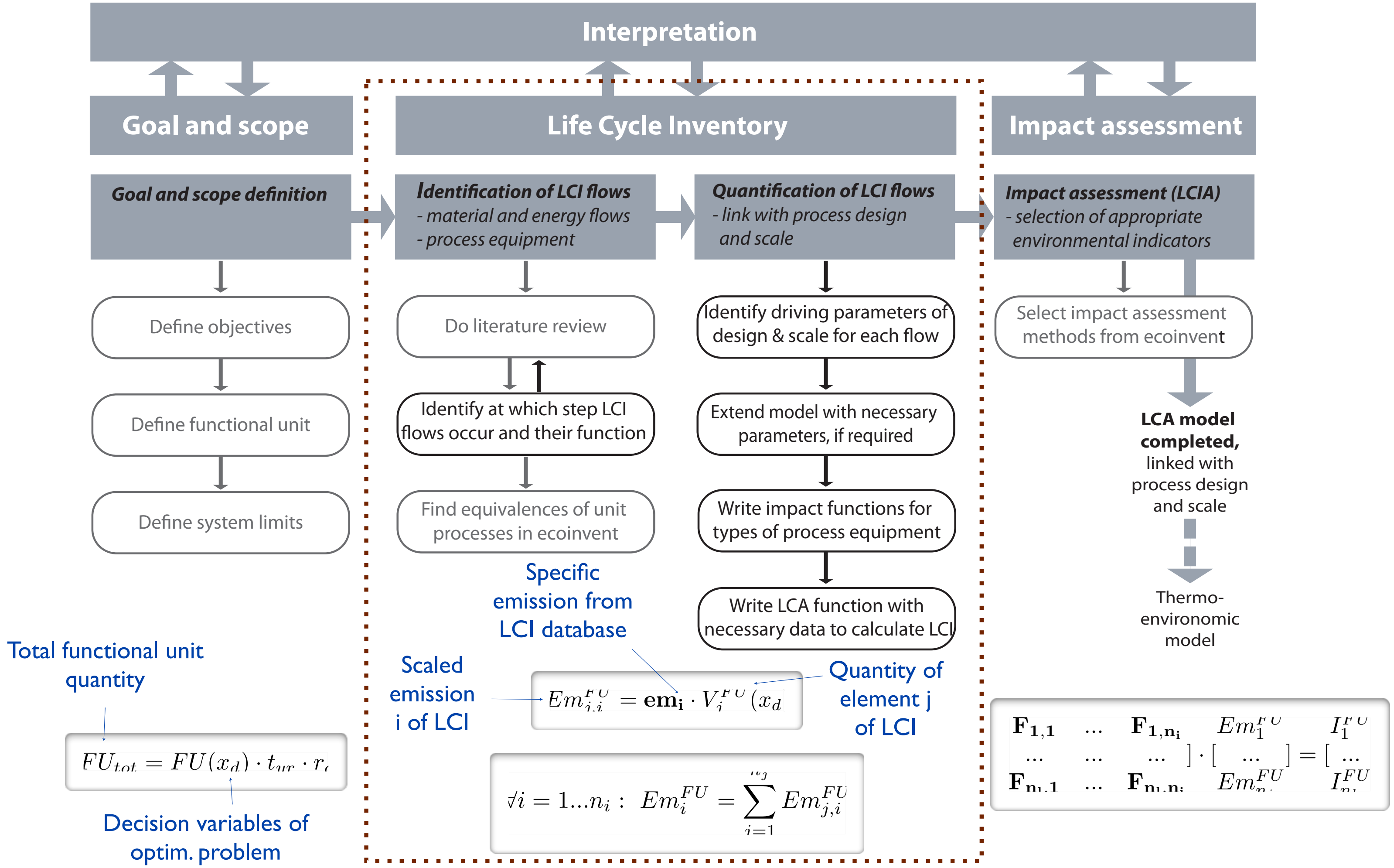
LCA in Osmose

- 3 elements type can be declared in the LCI:

	Components	Unit processes	Elementary flows
Definition	corresponds to a piece of process equipment	contains the cumulated life cycle inventory emissions and extractions	a single emission (or extraction) generated by the model
Database equivalence	in the «components» database, listed in EnergyTechnologies documentation	in the «unit processes» category	in the «elementary flows» category

In multi-model: pay attention to the risk of double-counting (ex: electricity balance) or intermediate flows (ex: logistics)

Guidelines for LCA model



LCI scaling of process equipment

- Analogy with economies of scale for equipment investment estimation

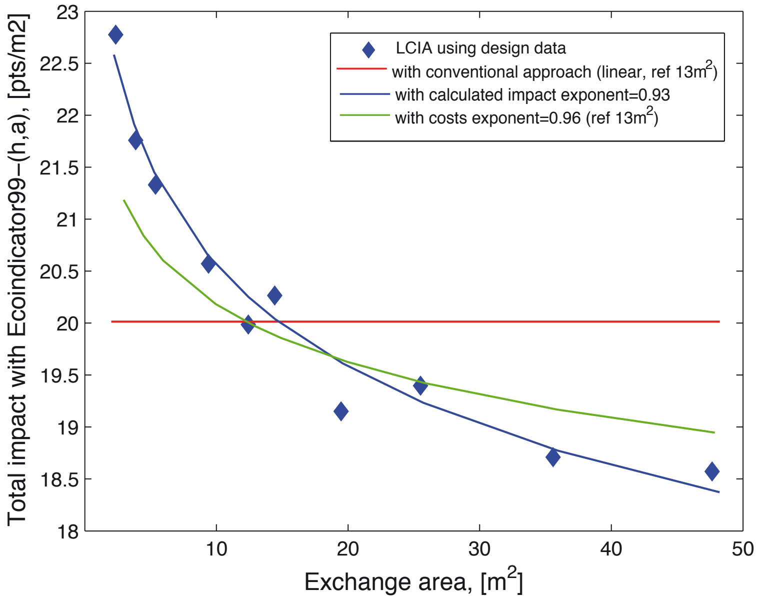
Scaled emission of element j of LCI; Functional parameter of element j; Impact exponent; Correction factor if necessary

$$\frac{Em_{j,i}}{\mathbf{Em_{j,ref,i}}} = n \cdot \left(\frac{A_j(x_d)}{n \cdot \mathbf{A_{j,ref}}}\right)^{\mathbf{k_{j,i}}} \cdot \mathbf{c_j},\ A_j \in [A_{j,min}; A_{j,max}]$$

$$n = [int(\frac{A_j}{\mathbf{A_{j,max}}}) + 1$$

Reference emission of element j; Decision variables of MOO problem

- Example of heat exchanger
  - shell and tube heat exchanger
  - functional parameter: exchange area, in m^2



LCI scaling of process flowsheet and auxiliary flows

- Process flowsheet

Quantity directly calculated by the process flowsheet, varies as a function of d.v. of MOO problem

$$V_j^{FU} = \frac{V_j(x_d) \cdot t_{yr} \cdot r_c}{FU_{tot}(x_d)}$$

- Example: quantity of RME for scrubbing at gas cleaning
  - *volumetric flow rate from gasification...*
  - *... gasification pressure (d.v.)*

- Auxiliary flows
  - No systematic formulation but in general:

$$V_j^{FU} \sim V_{j,init}(x_d), \dot{\alpha}_j, t_{yr}, r_c$$

Initial quantity

Turnover

- Example: auxiliary flows for reactors (olivine, charcoal, ...)

$$\dot{m}_{j,reac} = V_{reac}(x_d) \cdot \dot{v}_{j,reac}$$

reactor volume, scaled non-linearly

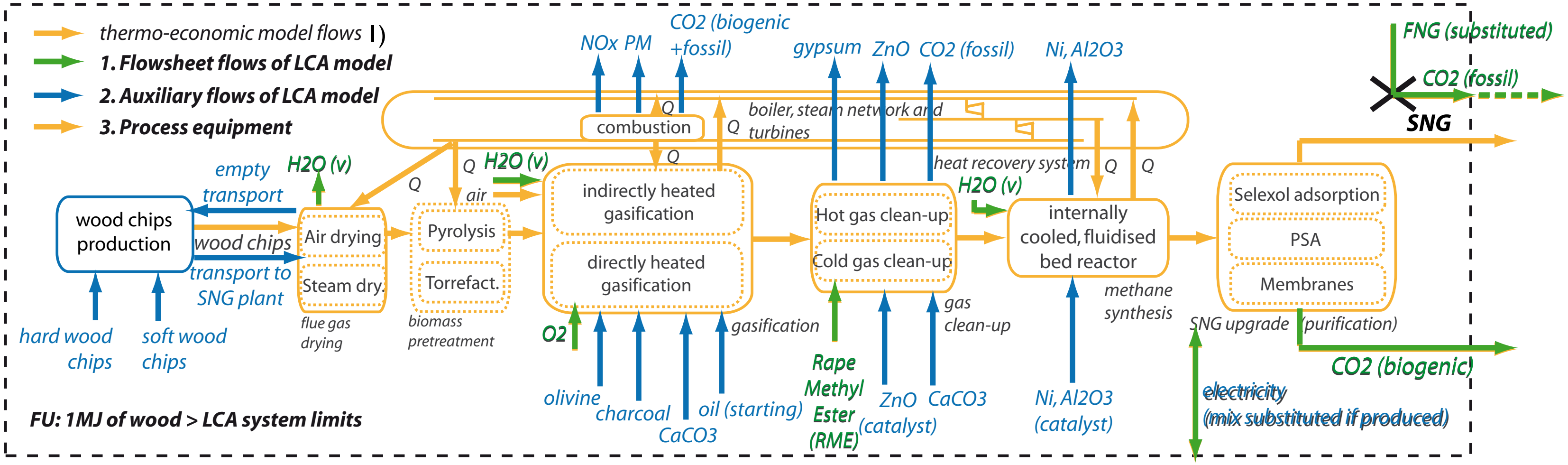
specific mass consumption rate of material per unit volume

  - *Method better than conventional LCA?*

Multi-objective optimisation

- Residual wood for combined Synthetic Natural Gas (SNG) and electricity production:

functional unit is the wood processed at plant entry



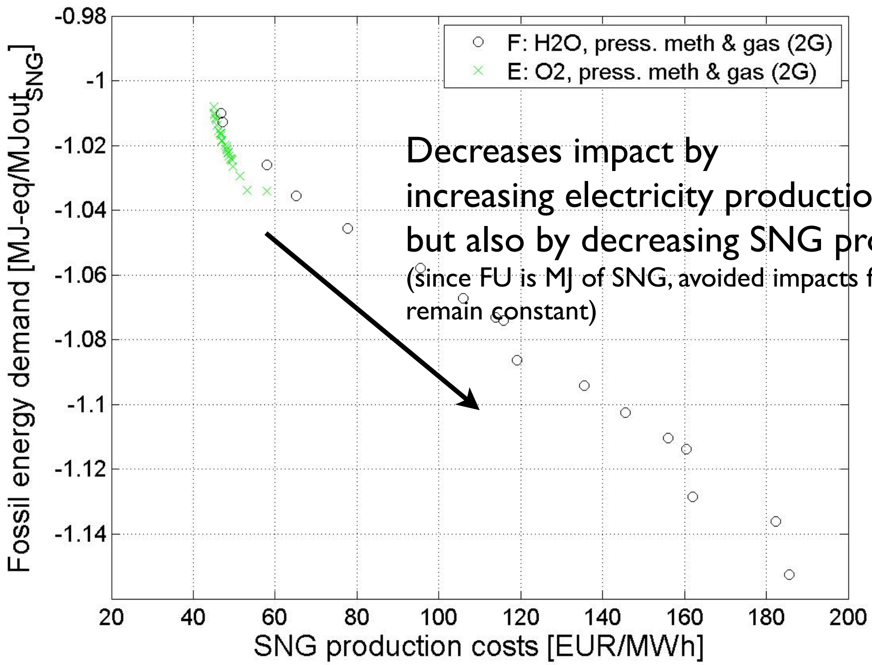
Objectives

- Wood processing benefit
- Environmental impact
- Size of the plant

1) M. Gassner, 2010, *Process design methodology for thermochemical production of fuels from biomass. Application to the production of synthetic natural gas from lignocellulosic resources.* PhD thesis, EPFL

LCI: a few traps to avoid

- Definition of system function and thus FU
    - Example: for SNG production, FU taken was first the MJ of SNG



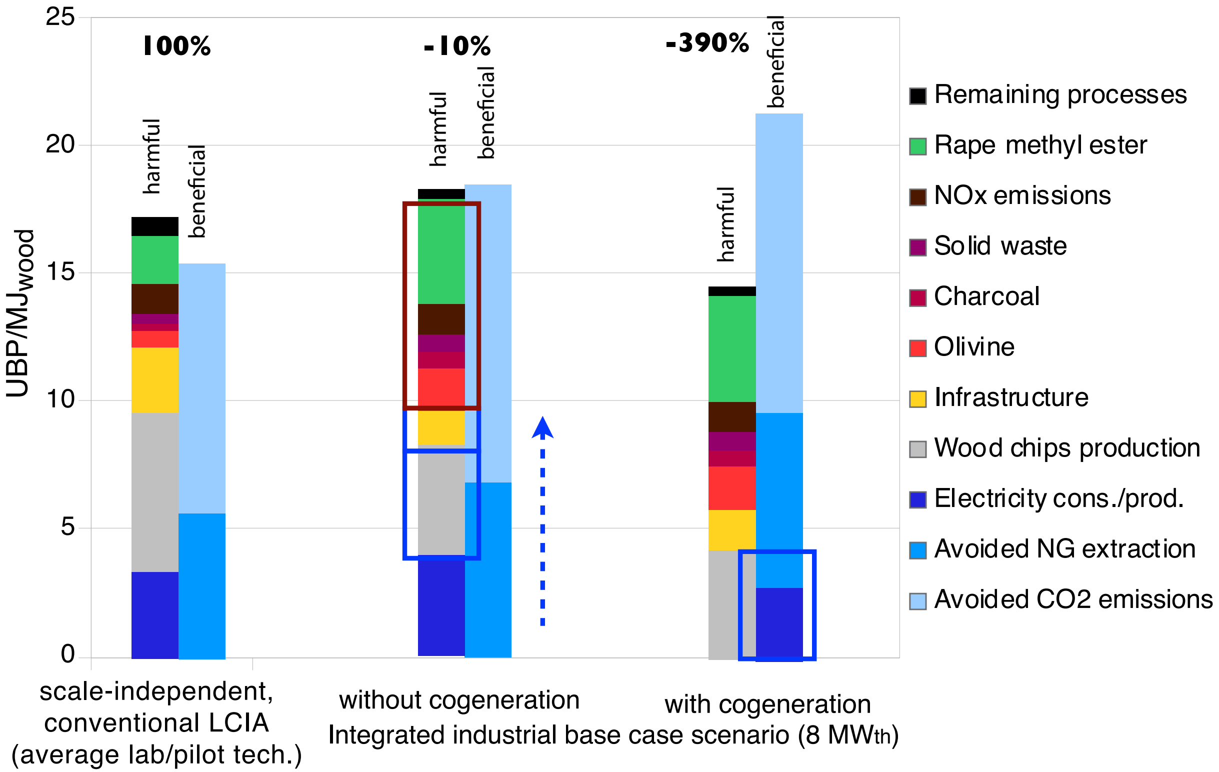
Decreases impact by
increasing electricity production ...
but also by decreasing SNG production!
(since FU is MJ of SNG, avoided impacts from SNG remain constant)

Function of the process
is actually to convert biomass in
multiple energy services!

- new FU: MJ of wood!

Comparison with conventional LCA

- pilot-scale vs integrated process for wood conversion to SNG & electricity (Ecoscarcity06)



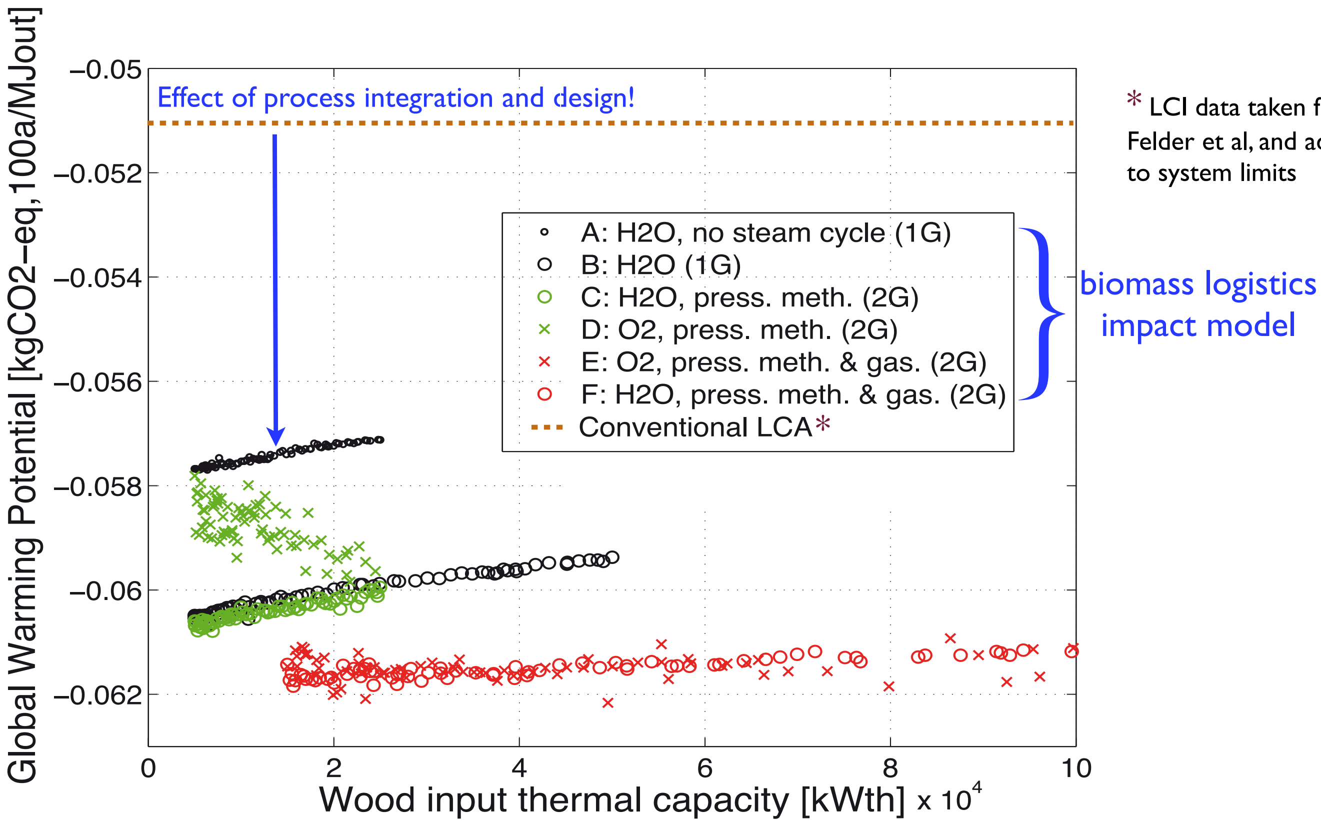
- *Significant differences due to developed methodology*
- *Generation of optimal scenarios?*

Multi-objective optimization

- Environomic optimal process design
  - ➡ 2 objectives
    - economic → *Biomass profitability*
    - environmental → *Ecoscarcity06 (Single score)* / *Ecoindicator99-(h,a) (Single score)*
- Effect of technology and scale
  - 6 technological alternatives (clusters)
  - 19-21 decisions variables
    - process scale [5-200 MWth]
    - operating conditions

Integration of LCIA in the methodology
Perspective: plant scale-up vs. biomass logistics

The biomass Logistics has an influence on the plant impact



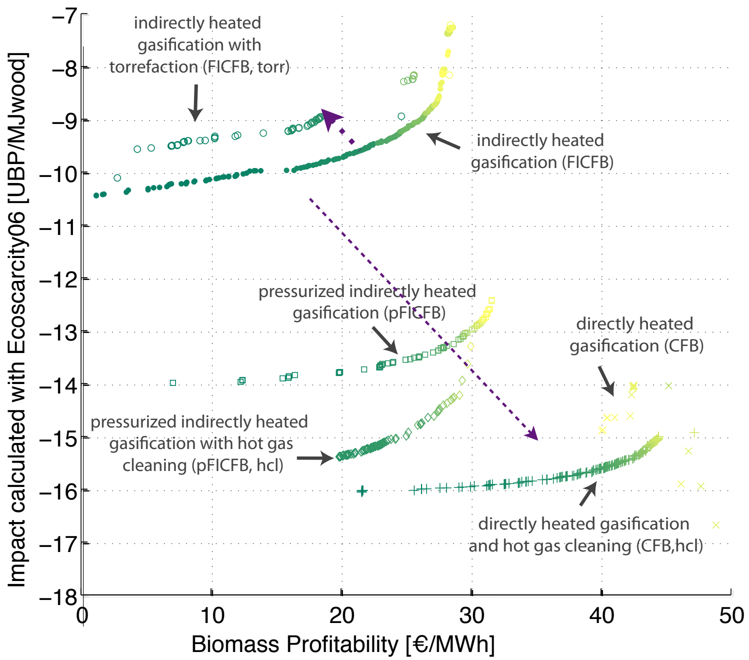
* LCI data taken from Felder et al, and adapted to system limits

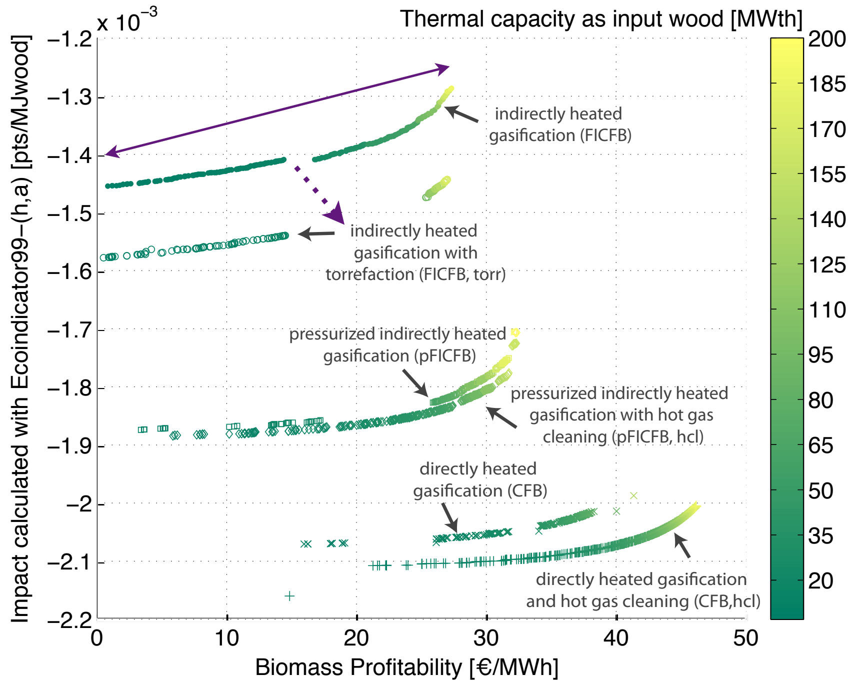
→ *Optimal plant size with respect to biomass logistics*

Gerber, Léda, Martin Gassner, and François Maréchal. "Integration of LCA in the optimal design of energy conversion systems: The example of SNG production from lignocellulosic biomass." *Comput .Chem. Eng.* In press (2011).

Multi-objective optimization results

- Optimal configurations





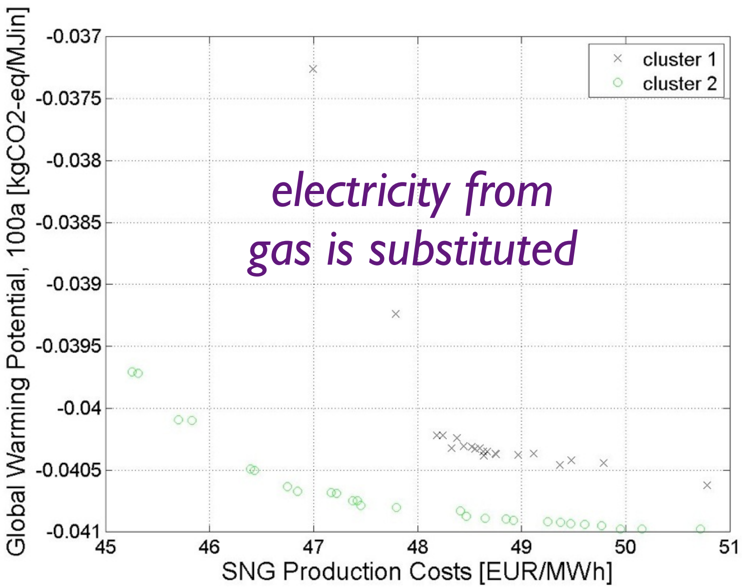
1. Process scale

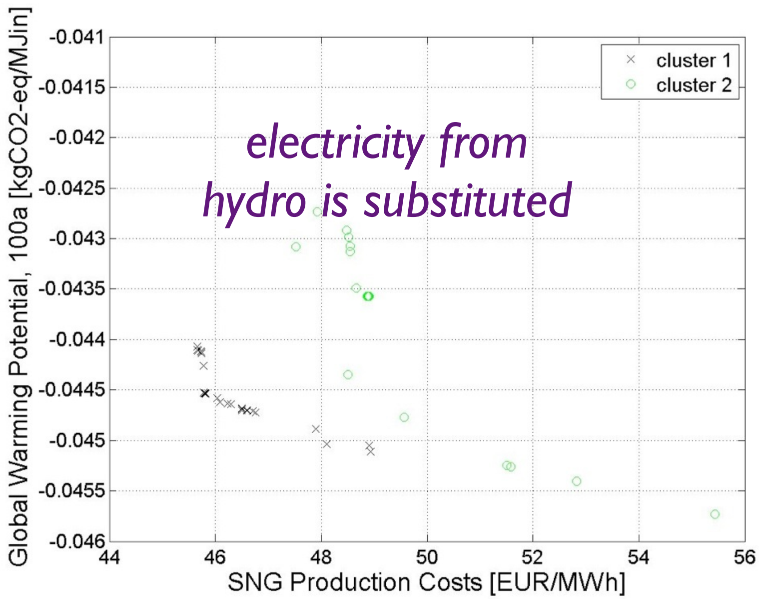
2. Technology evolution

3. Environmental objective function

LCI: a few traps to avoid

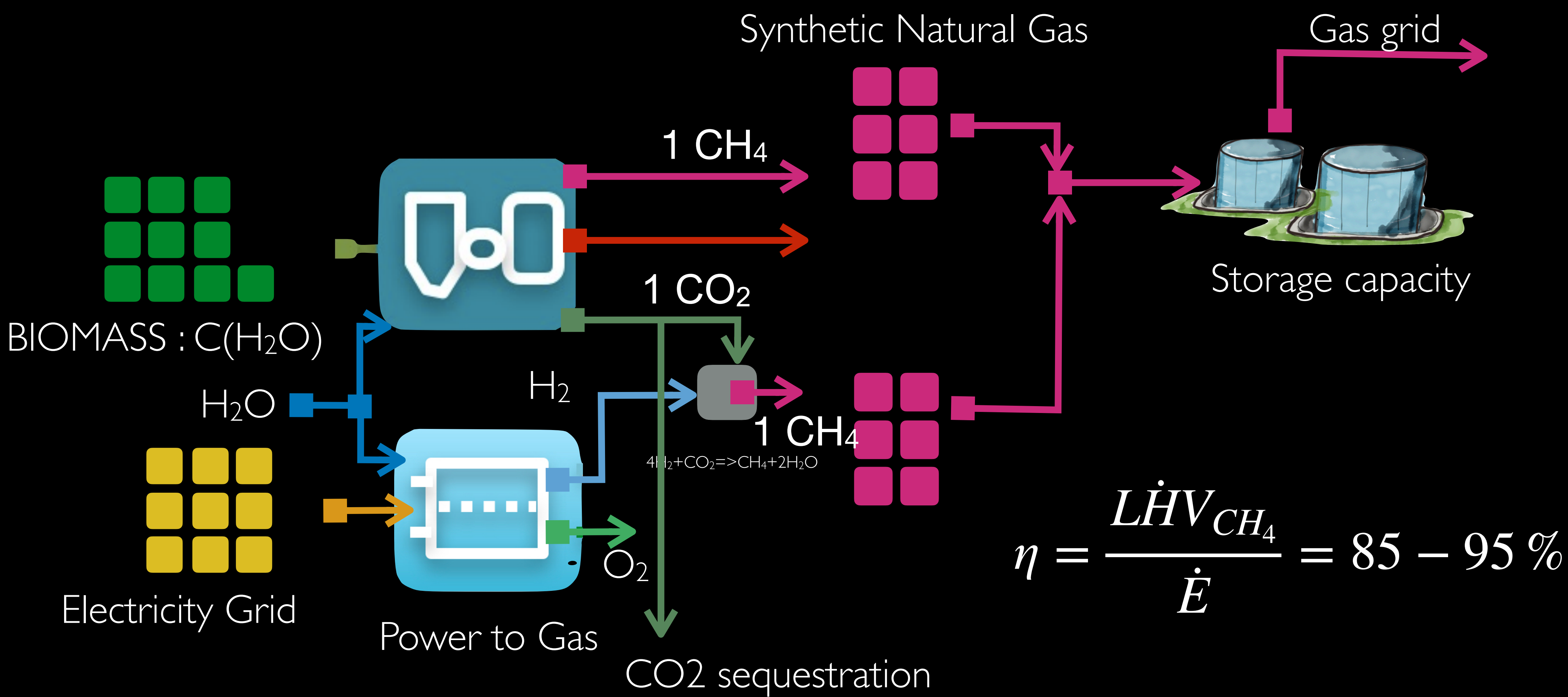
- Assumptions regarding the mix greatly influe on the decision making...





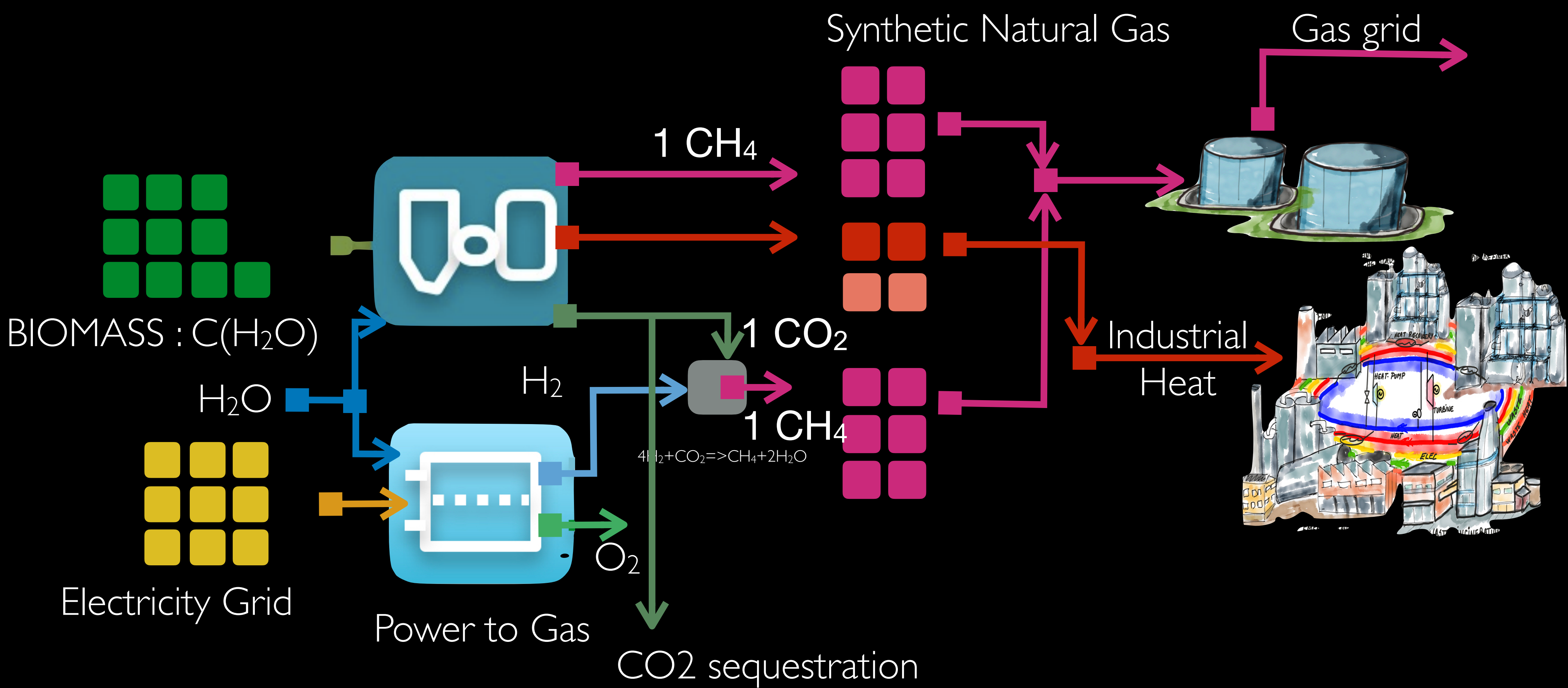
Best technology changes in function of avoided impacts!

ON THE USE OF BIOMASS AS AN ENERGY MANAGEMENT DEVICE



Gassner, Martin, and François Maréchal. "Thermo-economic optimisation of the integration of electrolysis in synthetic natural gas production from wood." Energy 33.2 (2008): 189-198.

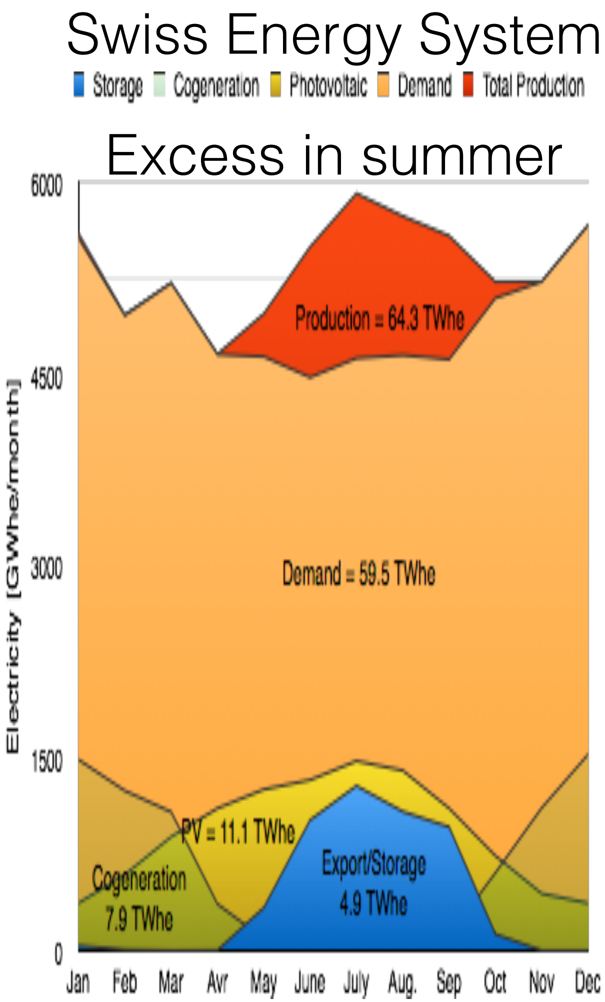
EFFICIENCY IS A SOURCE OF RENEWABLE ENERGY

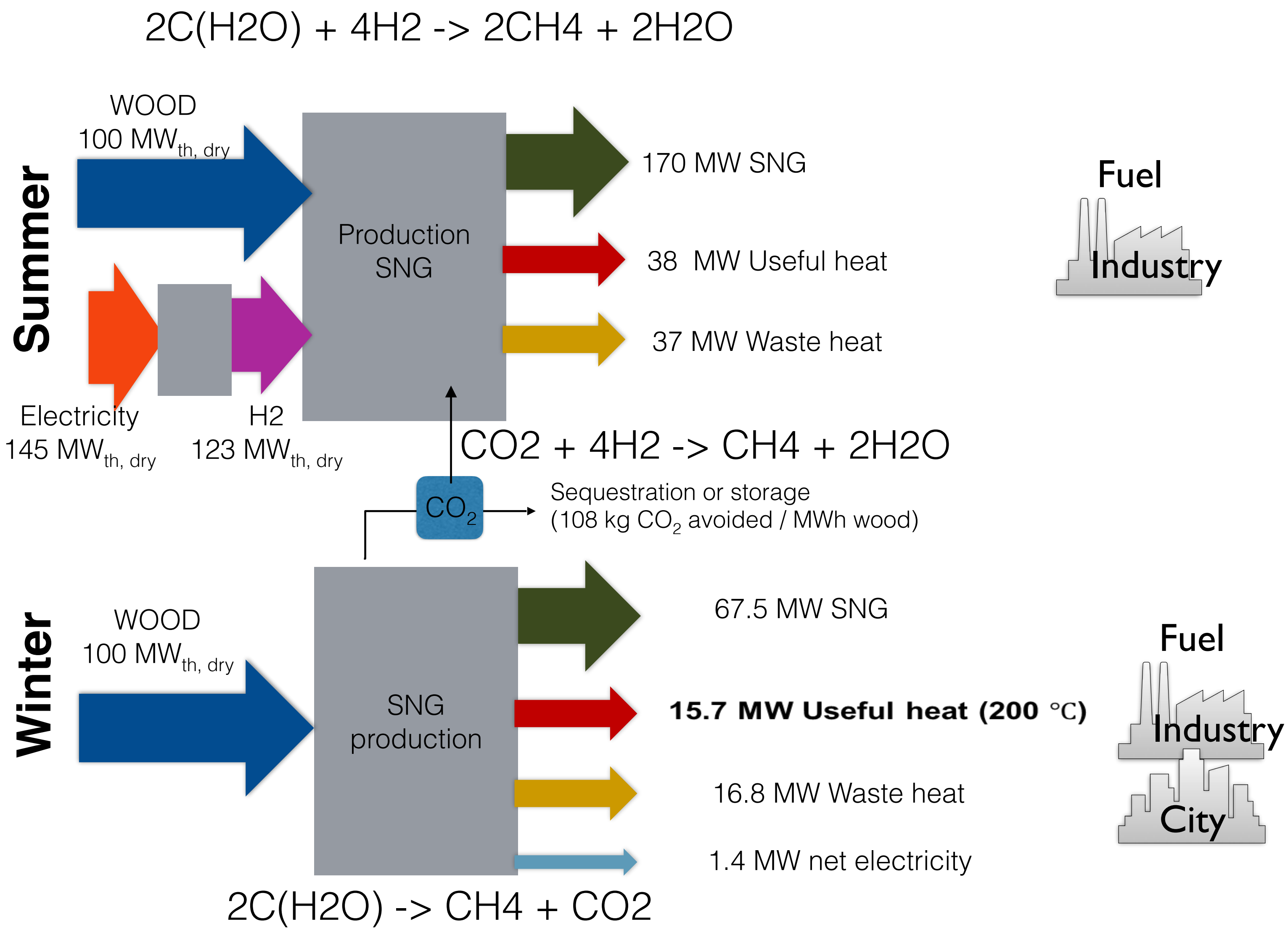


Gassner, Martin, and François Maréchal. "Thermo-economic optimisation of the integration of electrolysis in synthetic natural gas production from wood." Energy 33.2 (2008): 189-198.

EPFL

Combined heat, fuel and storage from biomass





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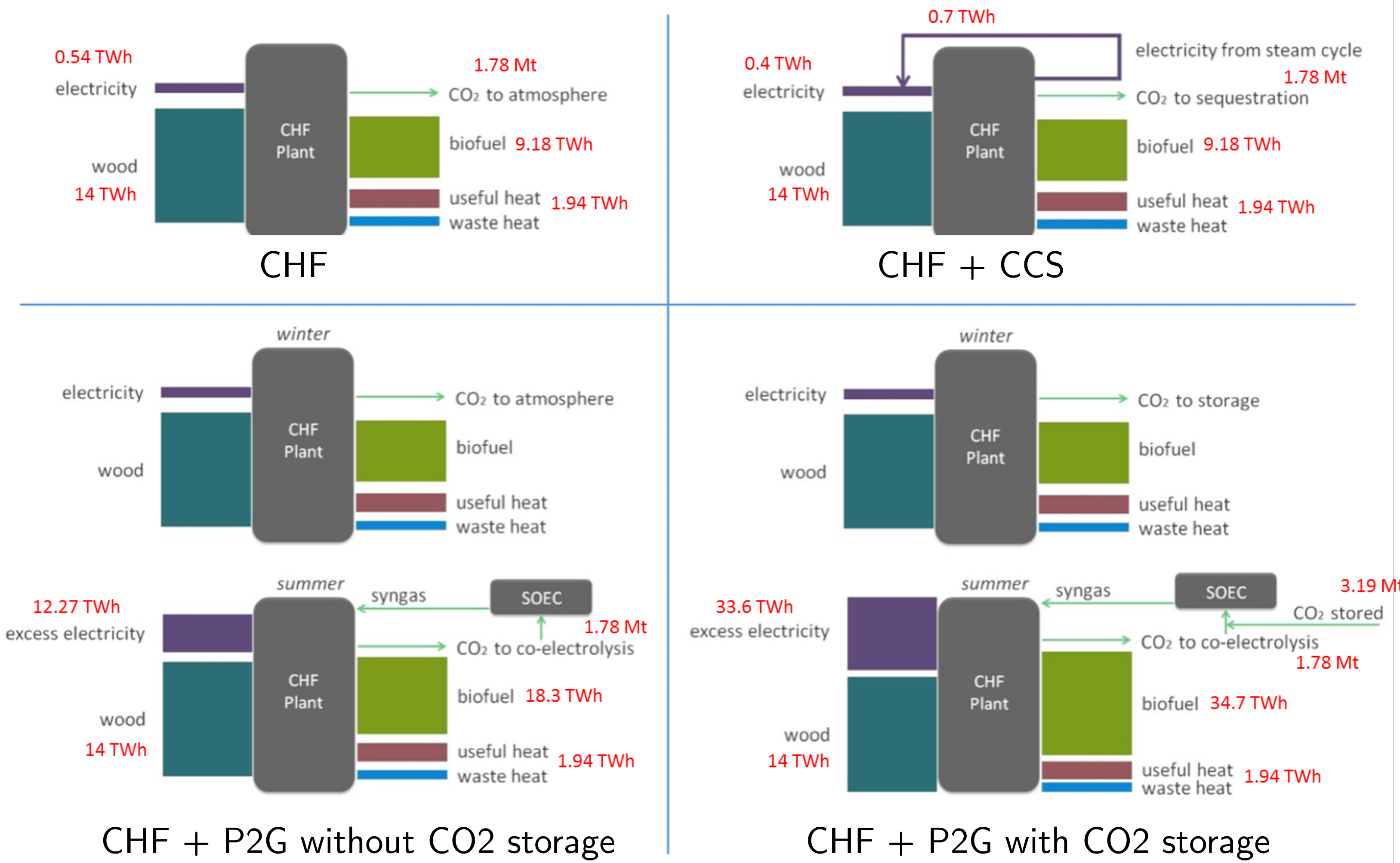
Combined Heat and Fuel (CHF) production
Substituted fossil carbon per unit of biogenic carbon in wood

1.6
wood boiler

2.8
wood boiler



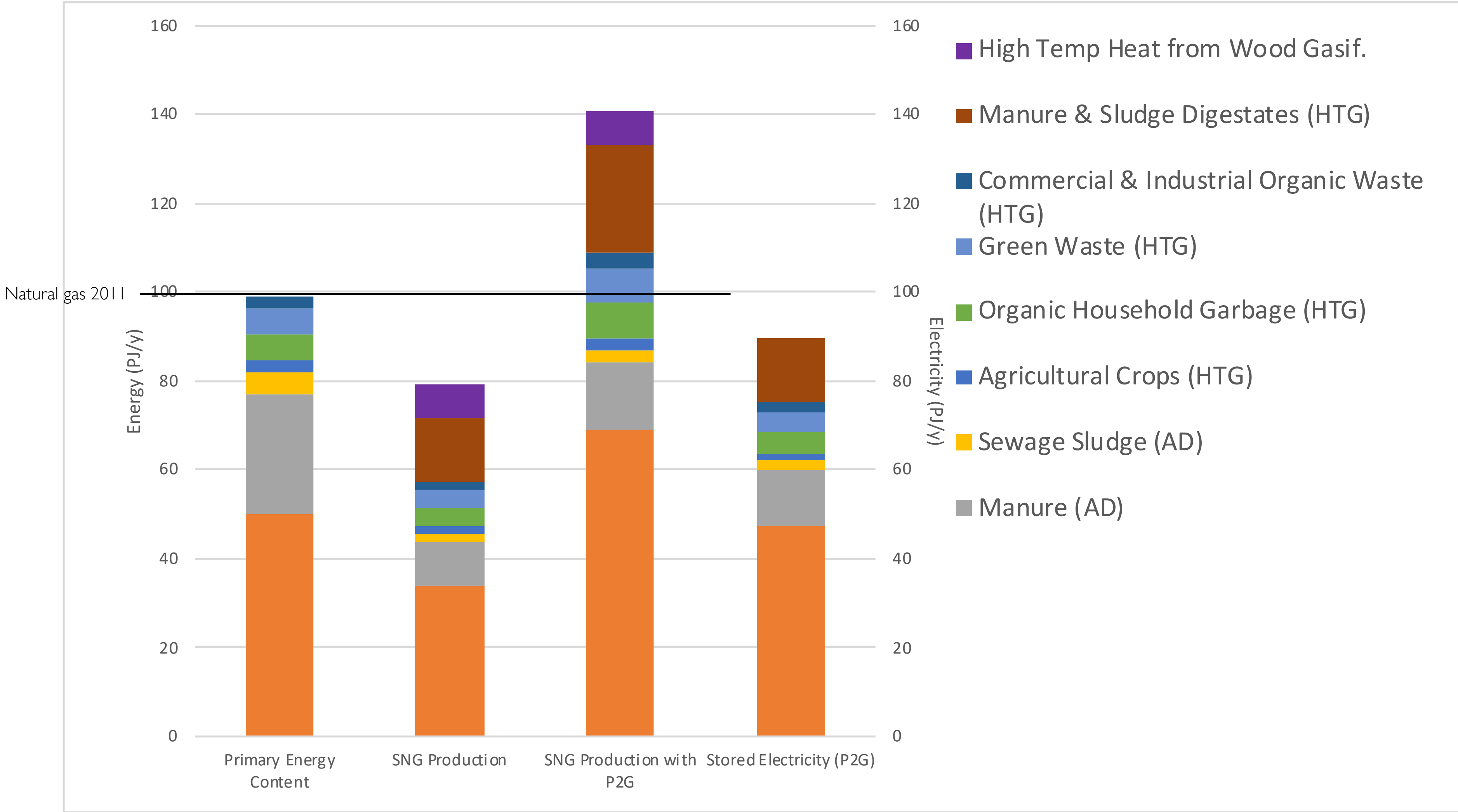
2.1
wood boiler

3.0
wood boiler

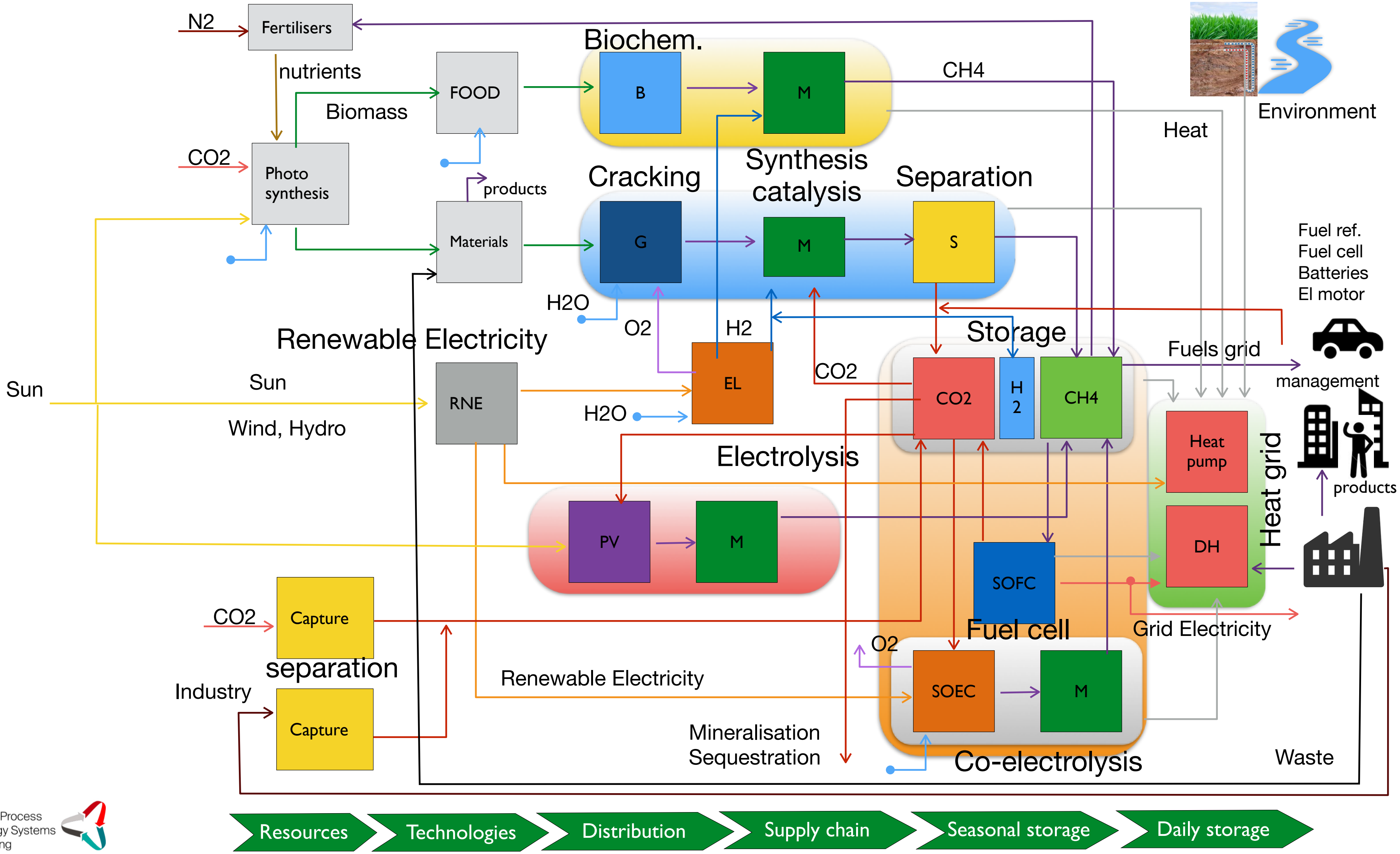
For wood boiler (WB) 0.3 kg of fossil carbon are substituted per kg of biogenic carbon

Celebi, et al. *Chemical Engineering Science* 204 (2019): 59-75.

SNG from biomass potential in Switzerland

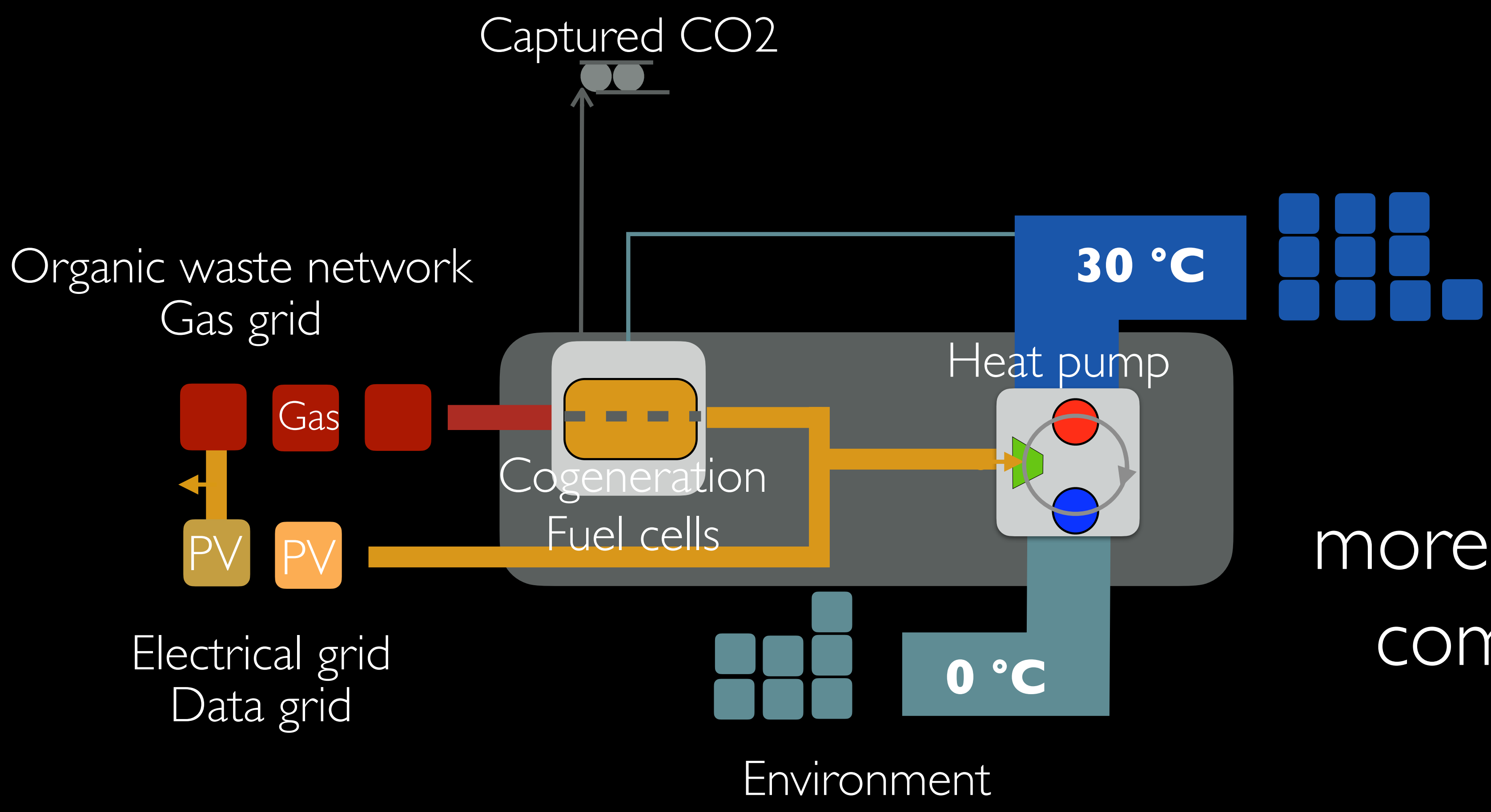


The integated energy system design : sizes and smart operation



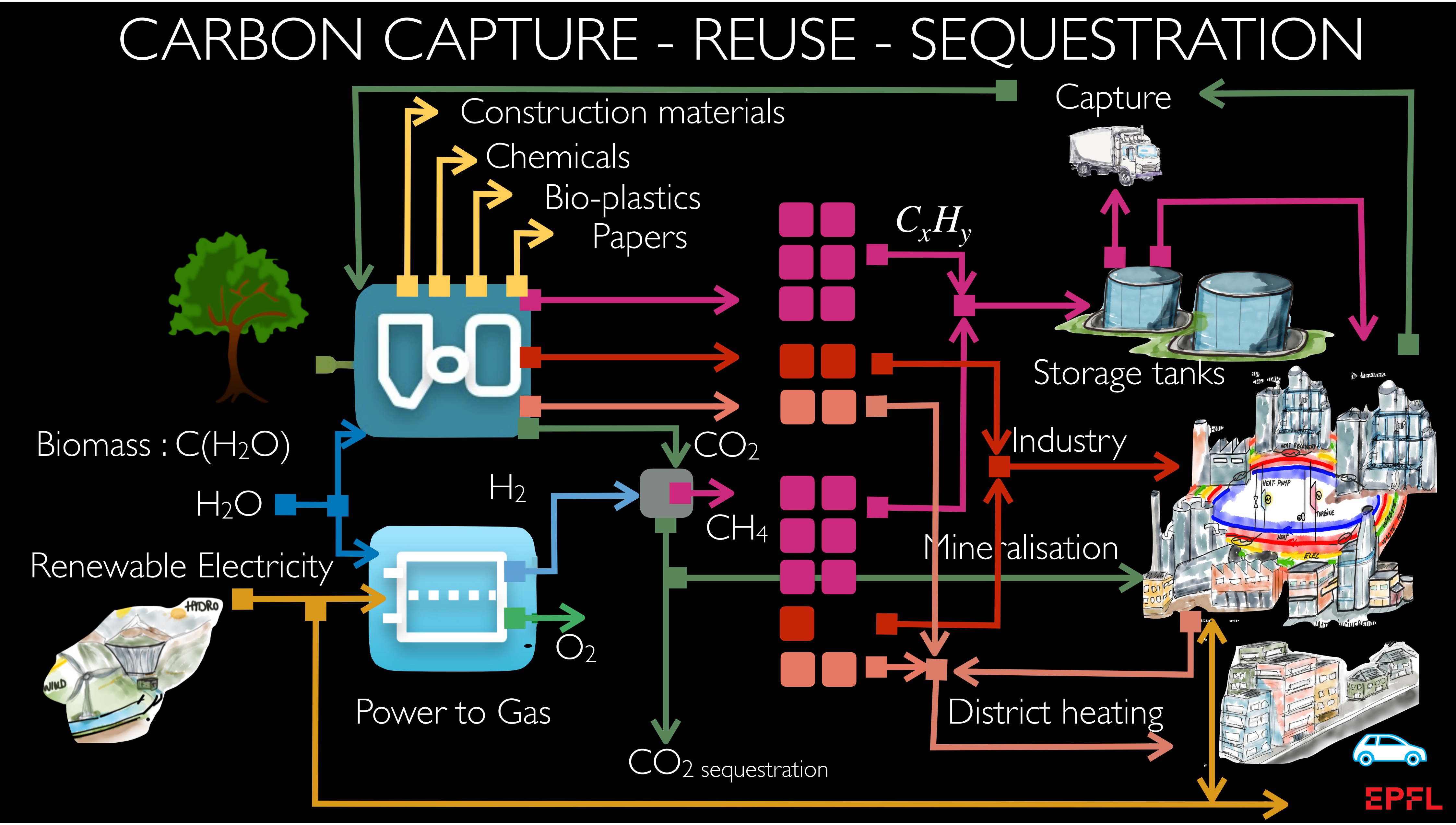
IPESE Industrial Process and Energy Systems Engineering

A NEW GAS BOILER



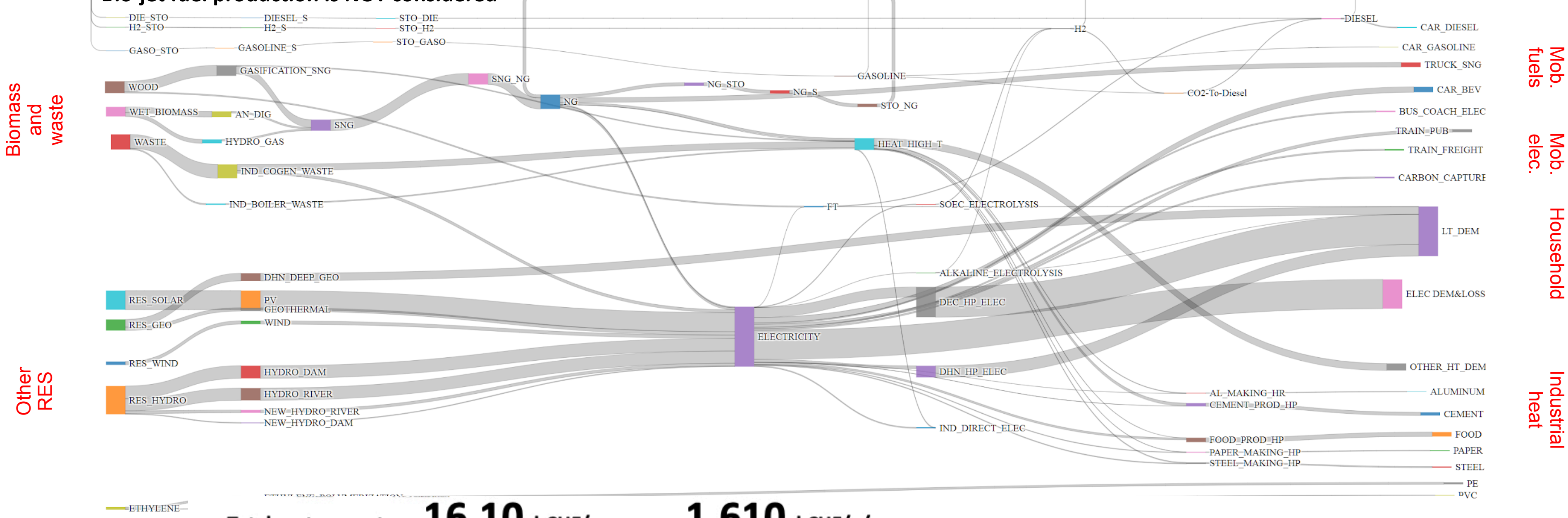
5x

more heat than combustion


CARBON CAPTURE - REUSE - SEQUESTRATION
Capture
Construction materials
Chemicals
Bio-plastics
Papers
C_xH_y
Storage tanks
Biomass : $C(H_2O)$
CO_2
H_2O
H_2
CH_4
Industry
Mineralisation
Renewable Electricity
HYDRO
WIND
O_2
Power to Gas
District heating
CO_2 sequestration
EPFL

Decarbonization of the Swiss Energy System

Bio-jet fuel production is NOT considered



Total system cost : 16.10 bCHF/y **1.610 kCHF/y/cap**

CO_2 sequestrated : 11.3 Mt/y **1.1 ton/y/cap**

Energy flows (TWh/y)

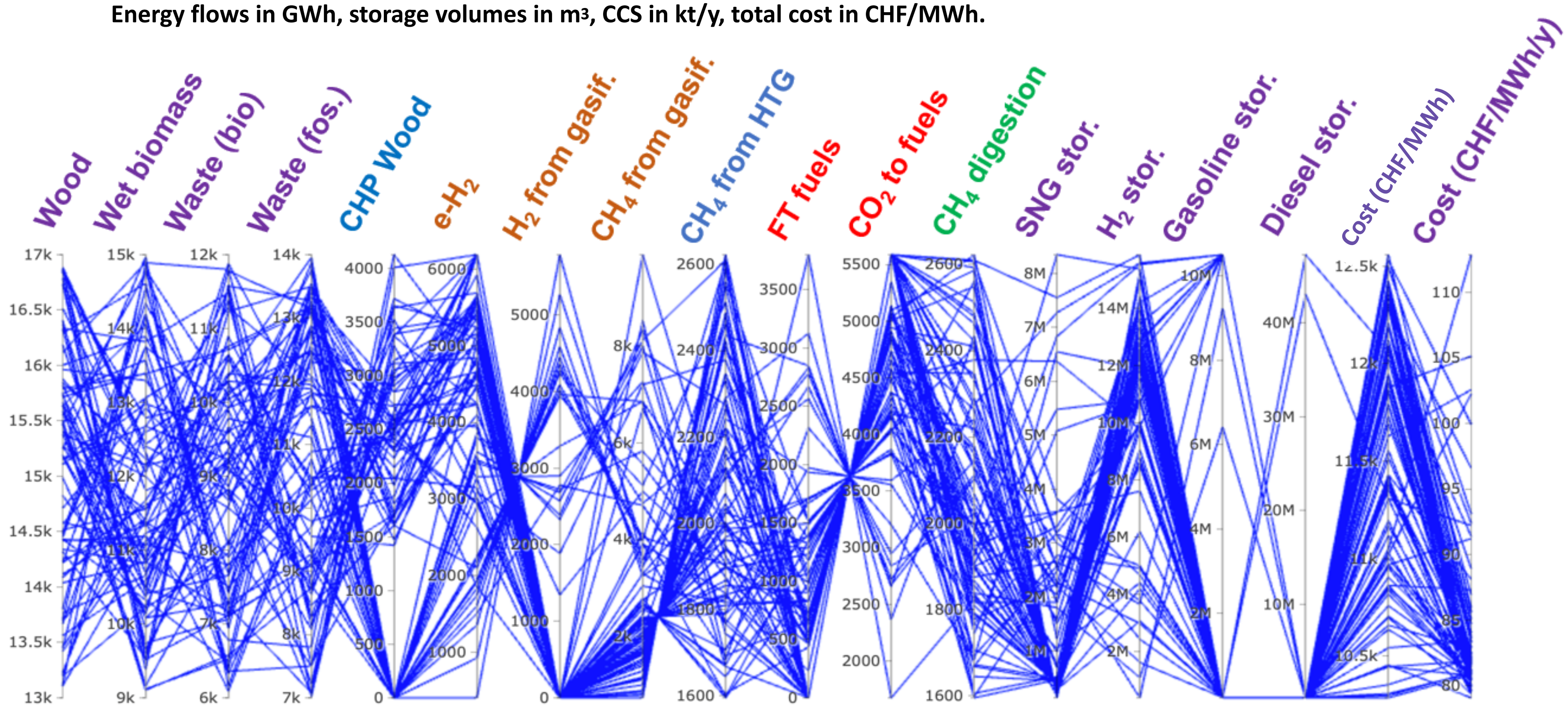
Other Renewables:	70.7	Biomass / waste: 47.5		Biofuels:	15.9		
Hydro:	37	Wood:	15.3	bio-SNG:	14.5		
Wind:	4.3	Wet biomass:	12.5	bio-H_2:	0		
PV:	25	Waste:	19.7	bio-gasoline:	0.2		
Geothermal:	4.4			bio-diesel:	1.2		
Electricity:	74.8	HT Heat:	10.9	electrolysis:			
		biomass conversion:	1.3 (12%)	H_2:	0.73		

Fuel storage (*10^3 m^3):	
bio-SNG:	6053
H_2:	2711
bio-gasoline:	0.8
bio-diesel:	5.3

François Marechal – francois.marechal@epfl.ch

Multiple solutions for the energy systems : Net zero CO2 Switzerland : collection of options

Energy flows in GWh, storage volumes in m³, CCS in kt/y, total cost in CHF/MWh.



Total System Costs

79 - 112

CHF/MWh

~

1570 - 2250

CHF/y/cap

~

82 - 117 %

of today's energy system

CO_2 Sequestrated

1.05 – 1.26

t/y/cap

Li, X., Damartzis, T., Stadler, Z., Moret, S., Meier, B., Friedl, M., & Maréchal, F. (2020). Decarbonization in complex energy systems: a study on the feasibility of carbon neutrality for Switzerland in 2050. *Frontiers in Energy Research*, *8*, 274.

Take home message

- Impact is not only local emissions
- Renewable energy means harvesting
  - Impact is associated to investment
- People define the needs
  - functional unit definition
- Efficiency define the energy consumption
  - Investment in efficiency creates impact
- The energy system is used to produce the investment
  - Solar panels will be created by renewable based energy mix

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