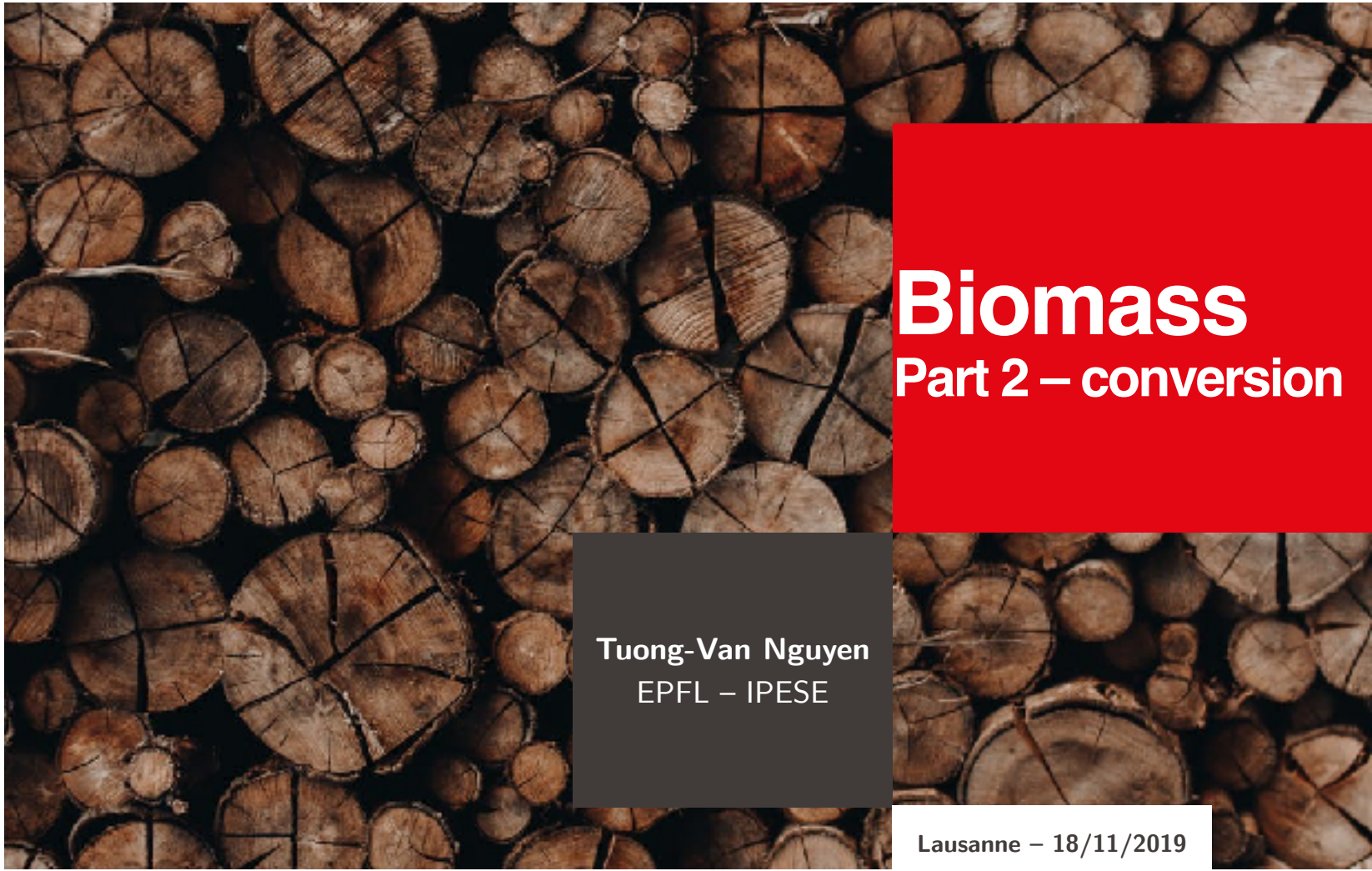

Biomass
Part 2 – conversion

Tuong-Van Nguyen
EPFL – IPESE

Lausanne – 18/11/2019

École polytechnique fédérale de Lausanne

Biomass conversion

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Biomass conversion

DRY BIOMASS

WET BIOMASS

MARINE BIOMASS

RESOURCES

CONVERSION

HEAT

POWER

BIOFUELS

CHEMICALS

DEMANDS

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Goals

- **Identify** the suitable conversion routes for various types of biomass
- **Describe and compare** the various conversion pathways
- **Mention** the advantages, drawbacks and challenges related to biofuels

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Introduction

The food vs fuel dilemma

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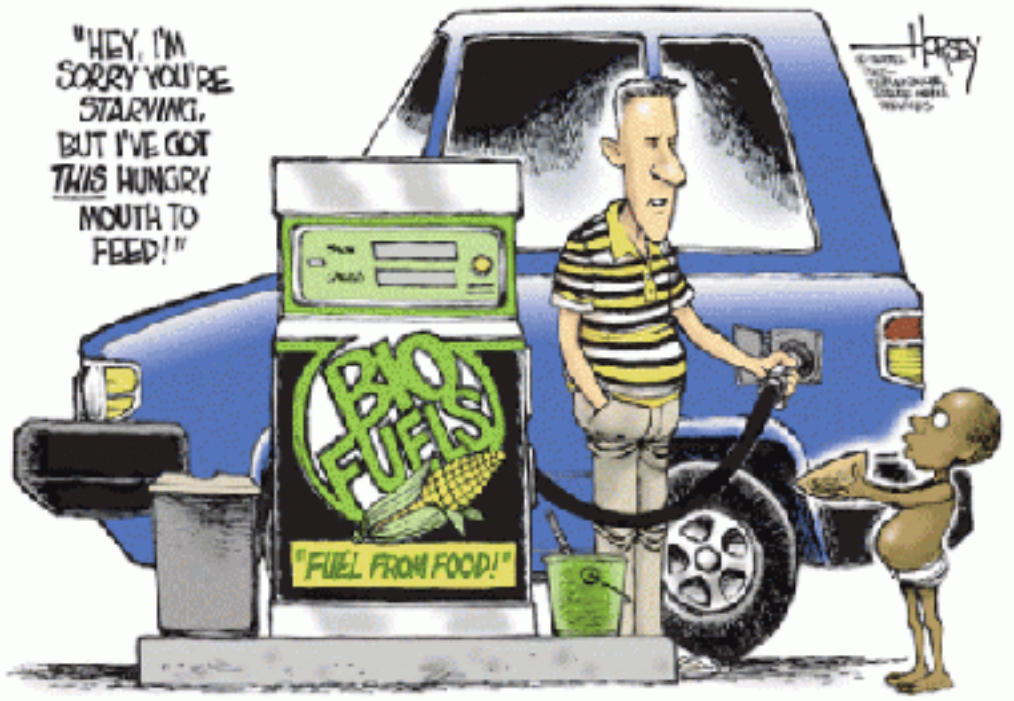
The use of biomass for bioenergy competes with food supply ?



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Competition food/energy

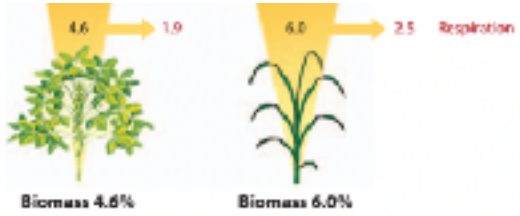
Theoretically harvestable

2900 EJ/yr

≠

Sustainably exploitable

270 EJ/yr



= **5.4 times** the primary energy demand

≠

= **0.5 times** the primary energy demand

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Competition food/energy

DIRECT

INDIRECT

ORIGIN

BIOMASS RESOURCE

LAND USE

FOOD

BIOFUEL/BIOENERGY

END-USE

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Competition food/energy : only for edible ressources

DRY BIOMASS



- Wood
- Agricultural co-products
- Energy crops

WET BIOMASS

EDIBLE



- **Agricultural products**
- Industry co-products
- Organic waste

MARINE BIOMASS

- Algae

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Biomass conversion

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Biomass conversion

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WET BIOMASS

- **Edible** products
  - *Starch*
  - *Sugar*
  - *Animal fats*

FIRST GENERATION

BIOFUELS

RESOURCES CONVERSION DEMANDS

Biomass conversion

Ethanol fuel production in Brazilian biorefineries

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Biomass conversion

- Biomass

DRY BIOMASS

- Wood

- Agricultural co-products
- Energy crops

WET BIOMASS

- Industry co-products
- Organic waste

BIOFUELS

SECOND GENERATION

RESOURCES **CONVERSION** **DEMANDS**

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Biomass conversion

Dimethylether (DME) production

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Biomass conversion

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THIRD GENERATION

MARINE BIOMASS

- Algae

BIOFUELS

RESOURCES

CONVERSION

DEMANDS

Combustion
- biomass to heat/power

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- Biomass

DRY BIOMASS

- Wood
- Agricultural co-products
- Energy crops

COMBUSTION

HEAT

POWER

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RESOURCES

DEMANDS

- The “old” way (prehistoric times)

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- The "modern" way

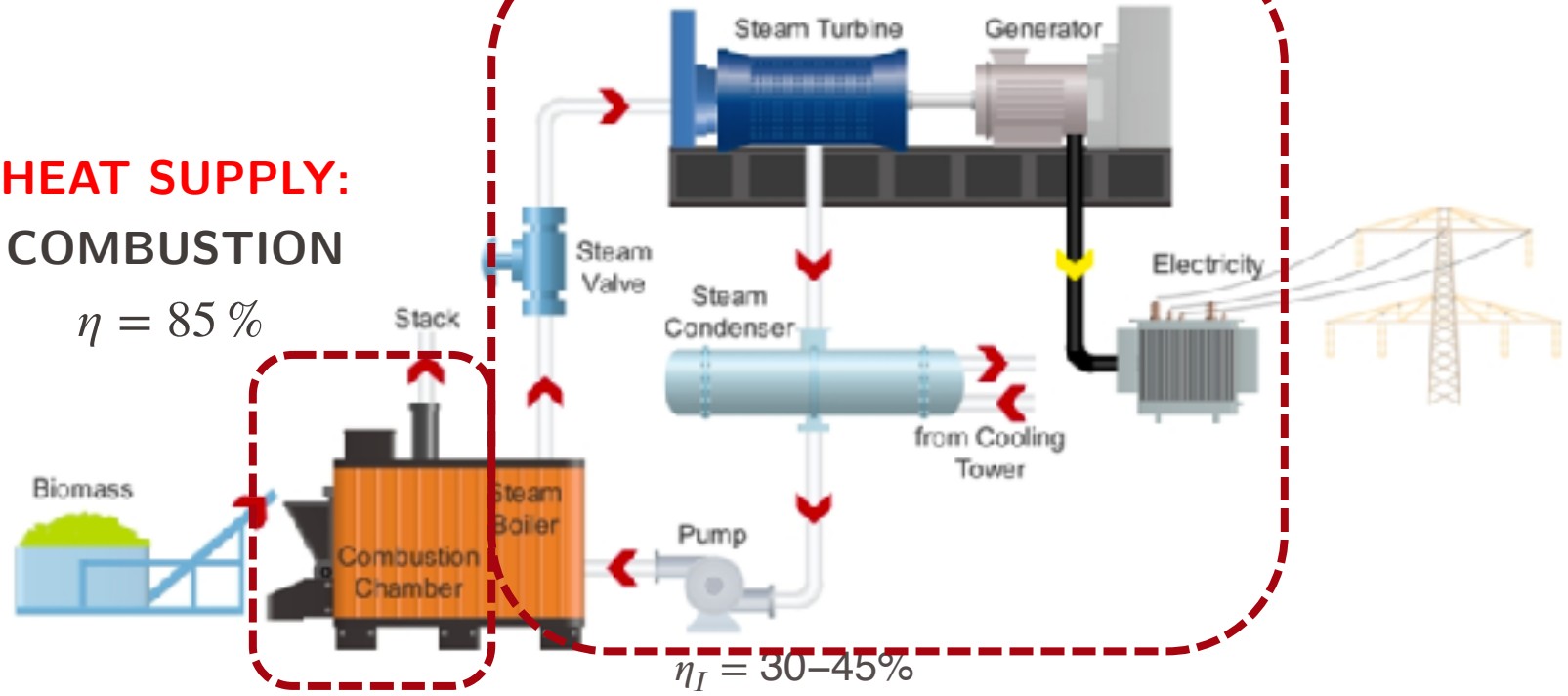
POWER GENERATION:

RANKINE CYCLE ($\eta = 40\,\%$)

HEAT SUPPLY:

COMBUSTION

$\eta = 85\,\%$



$\eta_I = 30–45\%$

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- Air pollution issues

PM

CO

PAH

NO/NO_2

SO_2

HCl

...

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Gasification
- biomass to heat, power, fuels and chemicals

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A German car with gasification (1946)

A North-Korean truck with gasification (2014)

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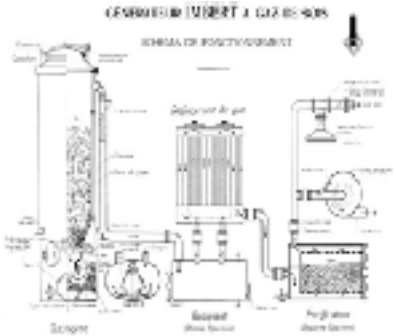
Gasification

- Biomass

DRY BIOMASS

WET BIOMASS



GASIFICATION

HEAT

POWER

BIOFUELS

CHEMICALS

RESOURCES

DEMANDS

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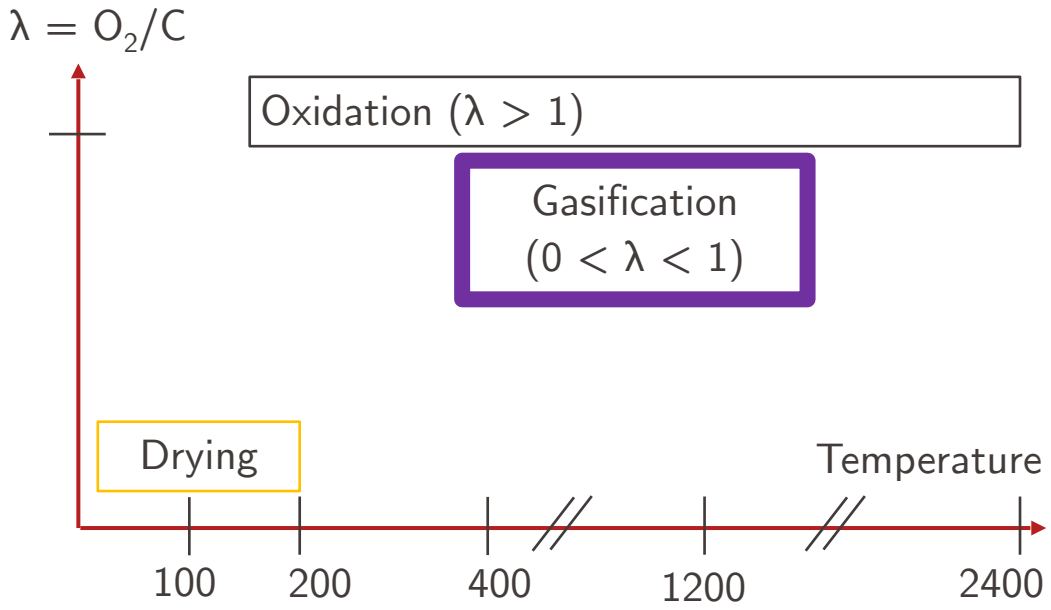
Gasification depends on the temperature



- Gasification = "staged" oxidation

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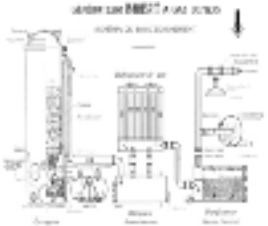
- The “old” way

“Dry” + “wet” biomass

Gasification



Syngas ($CO+H_2+CH_4$)

Gas combustion

Biofuel/heat (transportation)

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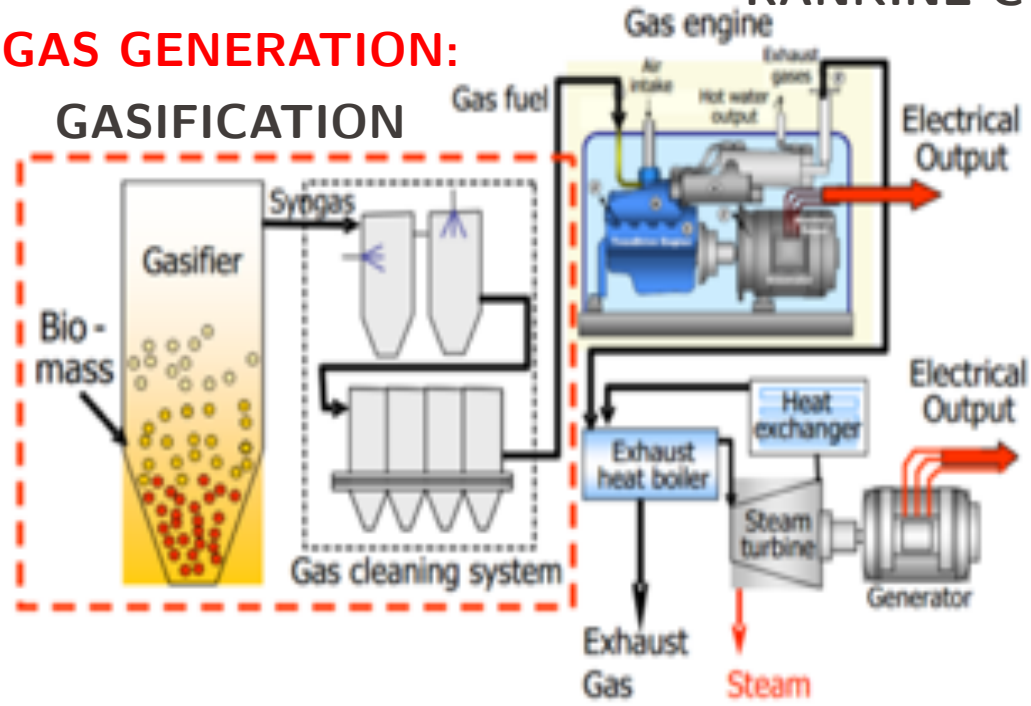
- The Guessing power plant (Austria)

GAS GENERATION:

GASIFICATION

POWER GENERATION:

RANKINE CYCLE



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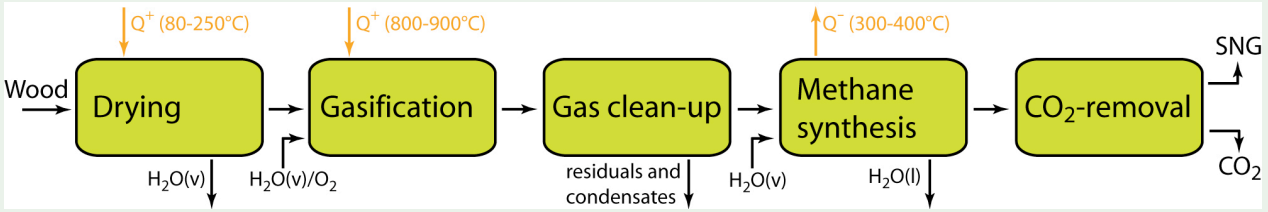
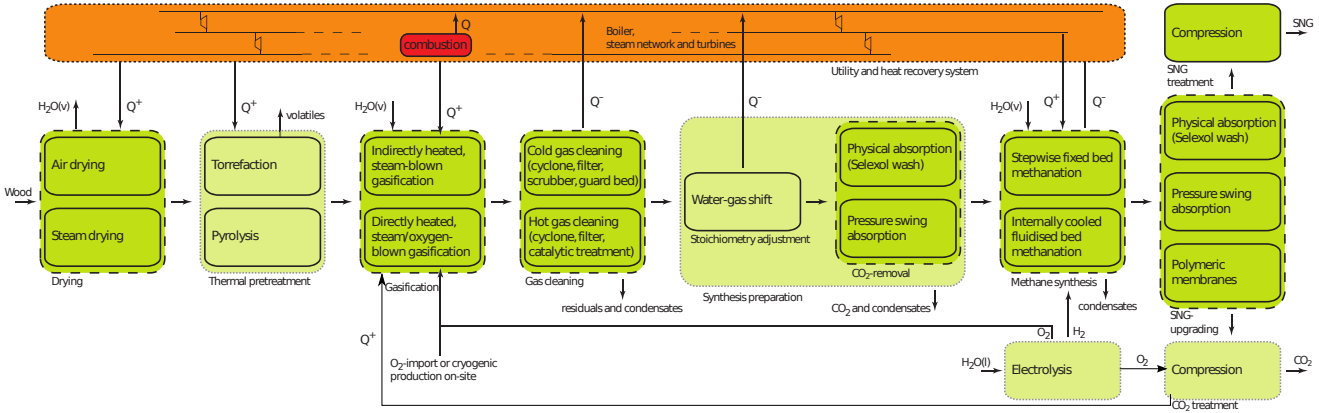
Production of synthetic natural gas (SNG)

Example: Common wood to SNG route



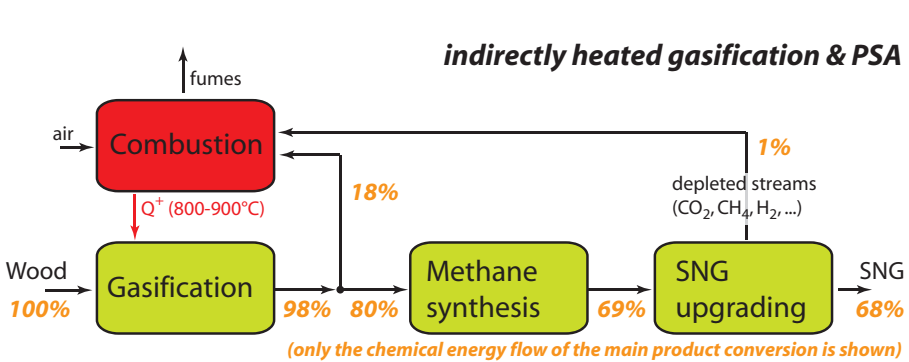
$$CH_{1.35}O_{0.63} + 0.3475H_2O \xrightarrow{\Delta H^0 = -10.5\ kJ/mol_{wood}} 0.51125CH_4 + 0.48875CO_2$$

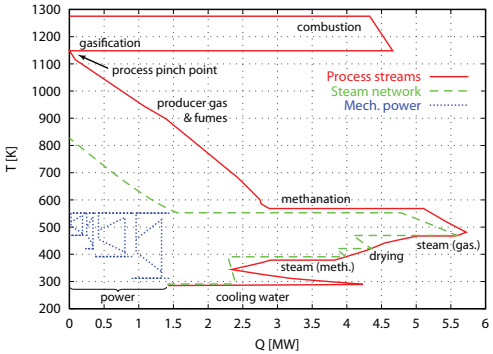
Process superstructure



Synthetic Natural Gas Production efficiency

Some (non-optimised) scenarios for conventional SNG production:



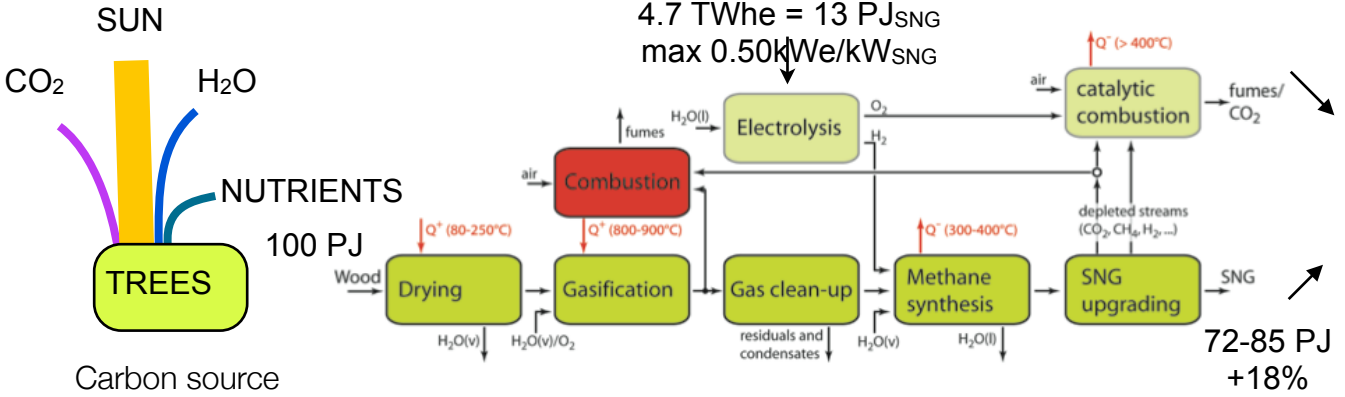


input: 20 $MW_{th,wood}$

			FICFB			CFB	
		(base)	(torr)	(pM)	(pM, SA)	(pGM)	(pGM, hot)
Consumption	Wood	100%	100%	100%	100%	100%	100%
	Biodiesel	1.8%	1.6%	1.8%	1.8%	0.1%	-
	Electricity	-	0.5%	-	-	0.9%	-
Production	SNG	67.7%	72.1%	67.5%	67.8%	74.0%	74.0%
	Electricity	2.9%	-	2.6%	3.3%	-	1.6%
Overall efficiency		69.4%	70.7&	68.8%	69.8%	73.2%	75.6%

Long term electricity storage by converting electricity to fuel

Power to gas concept



WOOD

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

Natural Gas CO2 (pure)

$$\Delta E^+ + 4H_2O \rightarrow CH_4 + 2H_2O + 2O_2$$

+ 4 H2 + CH4 - CO2 + 2 H2O

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

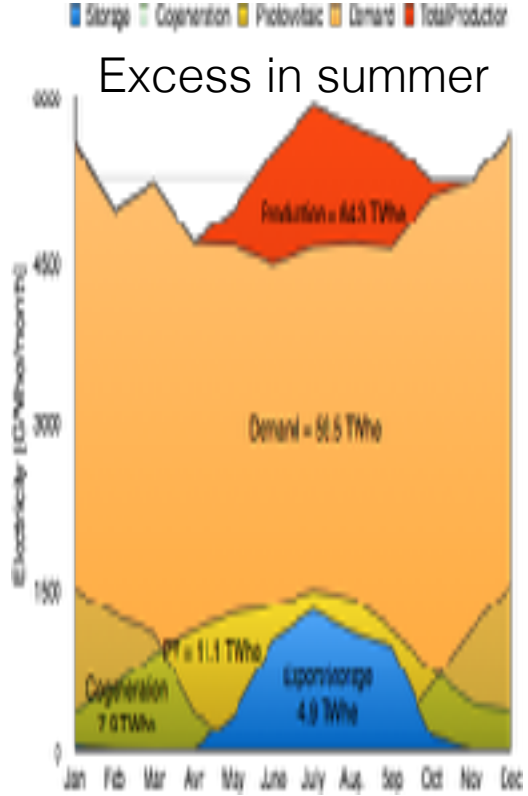
Storage as transportation fuel

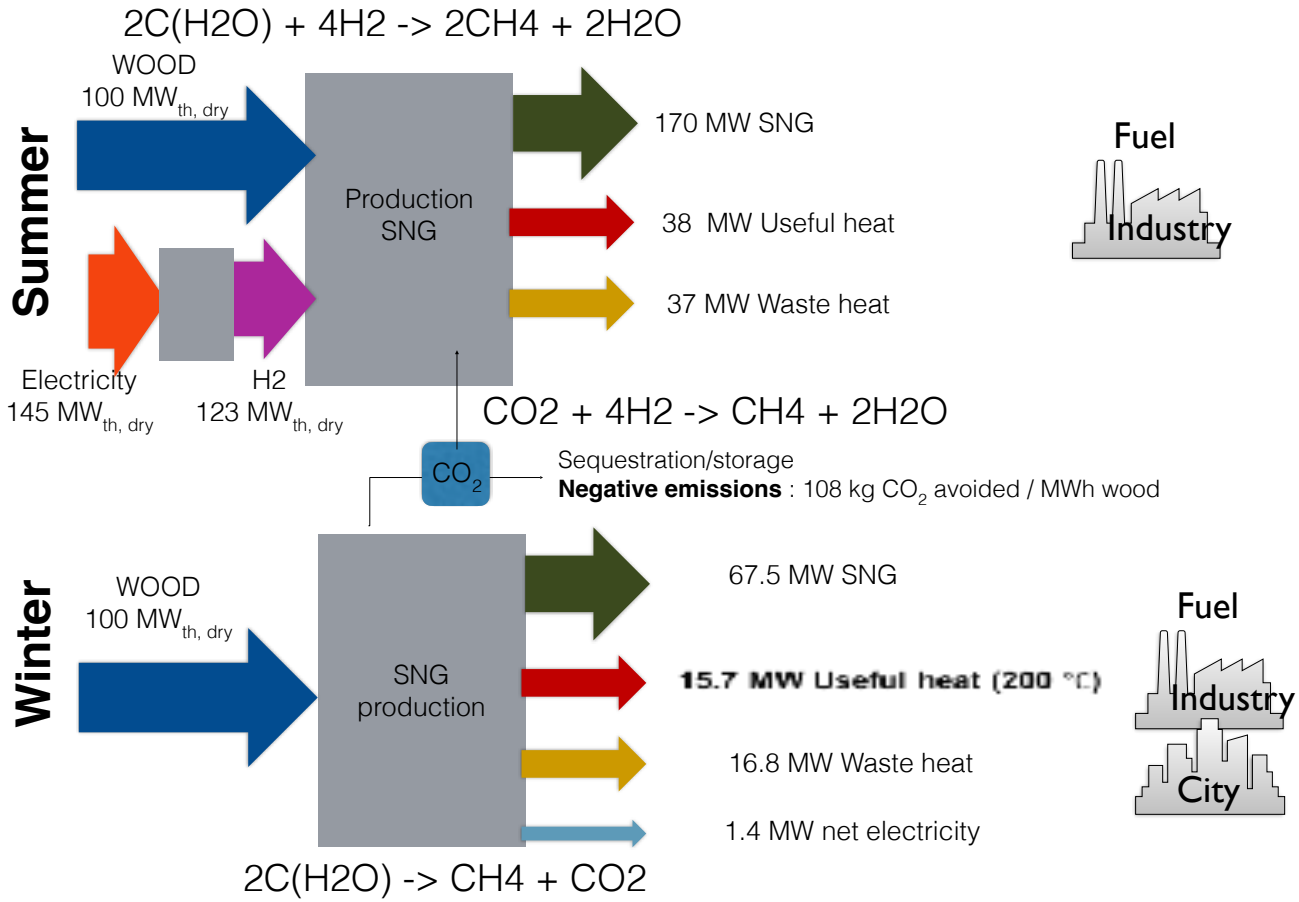
$$\eta_c = \frac{\Delta CH4^-_{LHV}}{\Delta E^+} = 85\%$$

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

Combined heat, fuel and sequestration from biomass

Swiss Energy System





Pyrolysis
- biomass to fuels

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Pyrolysis

- Biomass

DRY BIOMASS

WET BIOMASS

PYROLYSIS

HEAT

POWER

BIOFUELS

CHEMICALS

RESOURCES

DEMANDS

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Pyrolysis

A modern oven with a pyrolytic mode (2019)

Plenty of tires to treat (2019)

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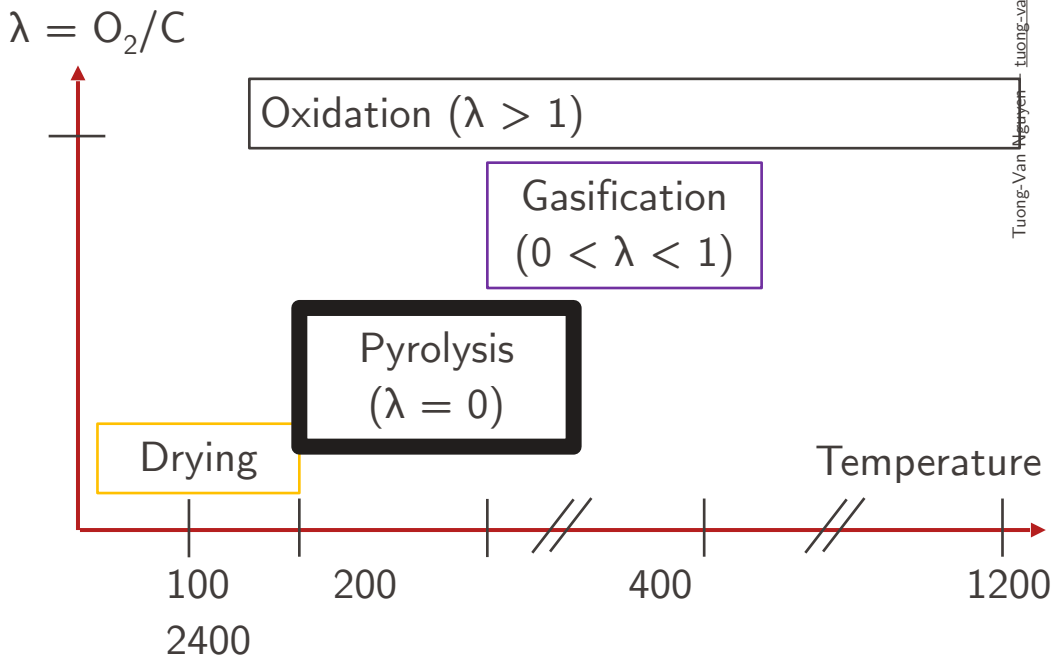
Pyrolysis

Thermal decomposition

- Inert environment (no H_2O, no O_2)
- Fast (s to hr)

High heating rate



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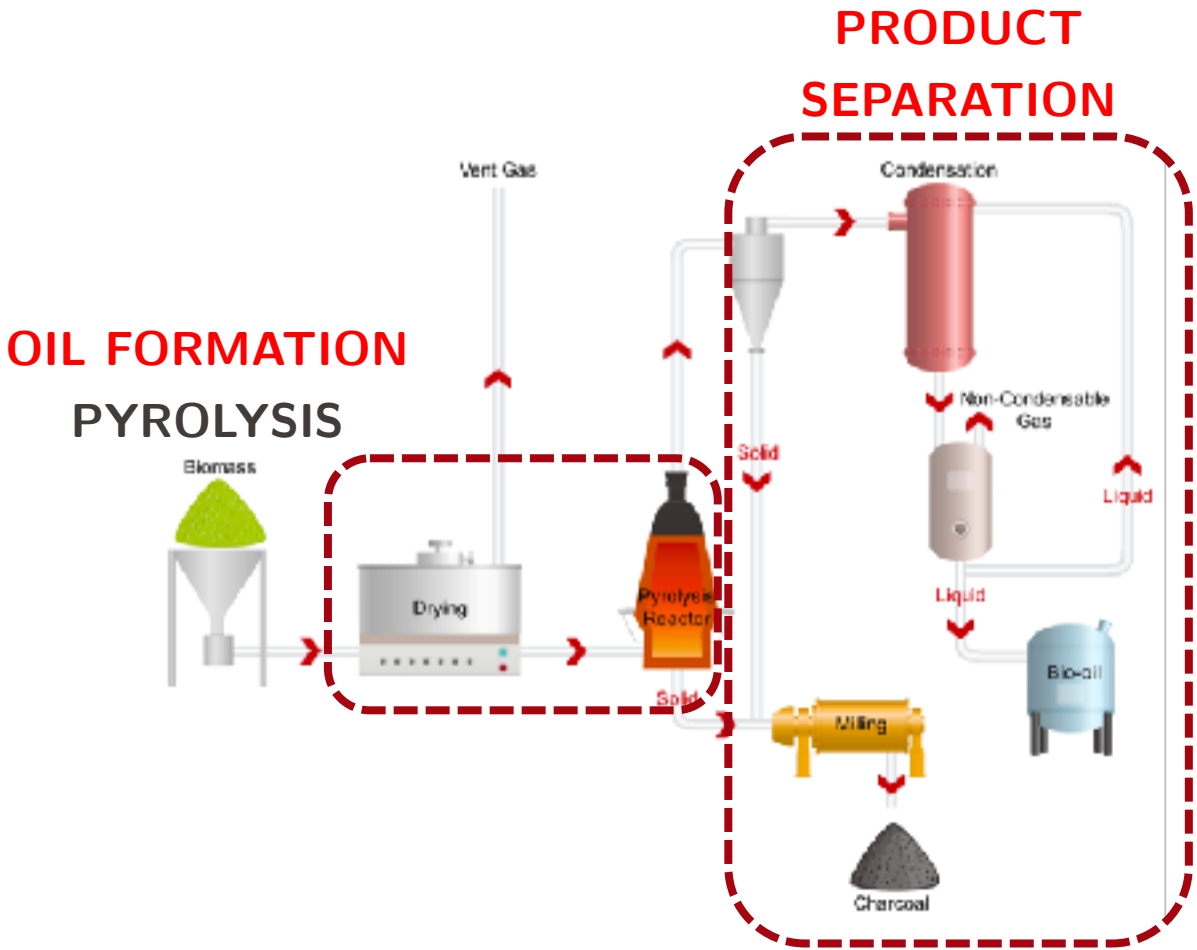
Pyrolysis



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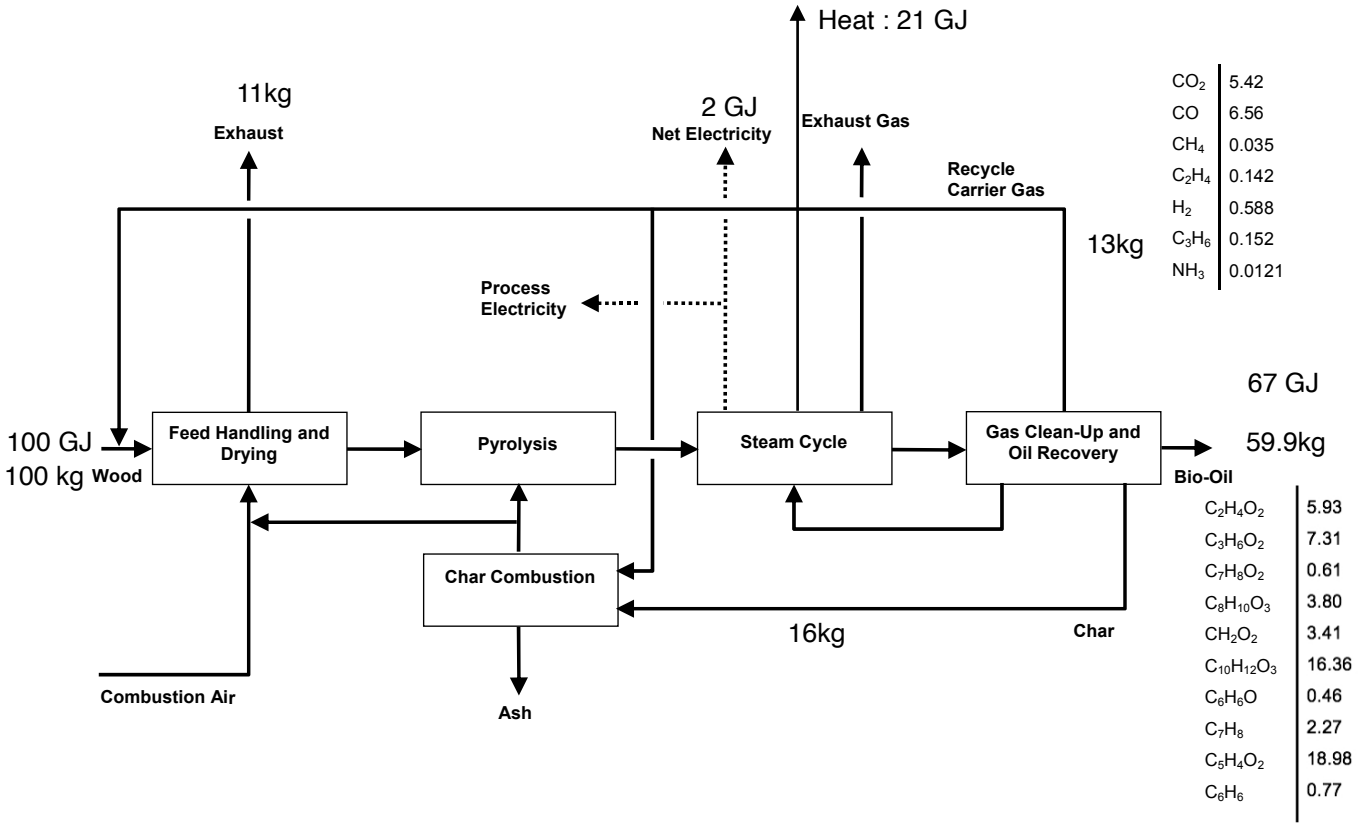
Typical pyrolysis process



Biomethanation

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WET BIOMASS

BIOMETHANATION

HEAT

POWER

BIOFUELS

CHEMICALS

Tuong-Van Nguyen

RESOURCES CONVERSION DEMANDS

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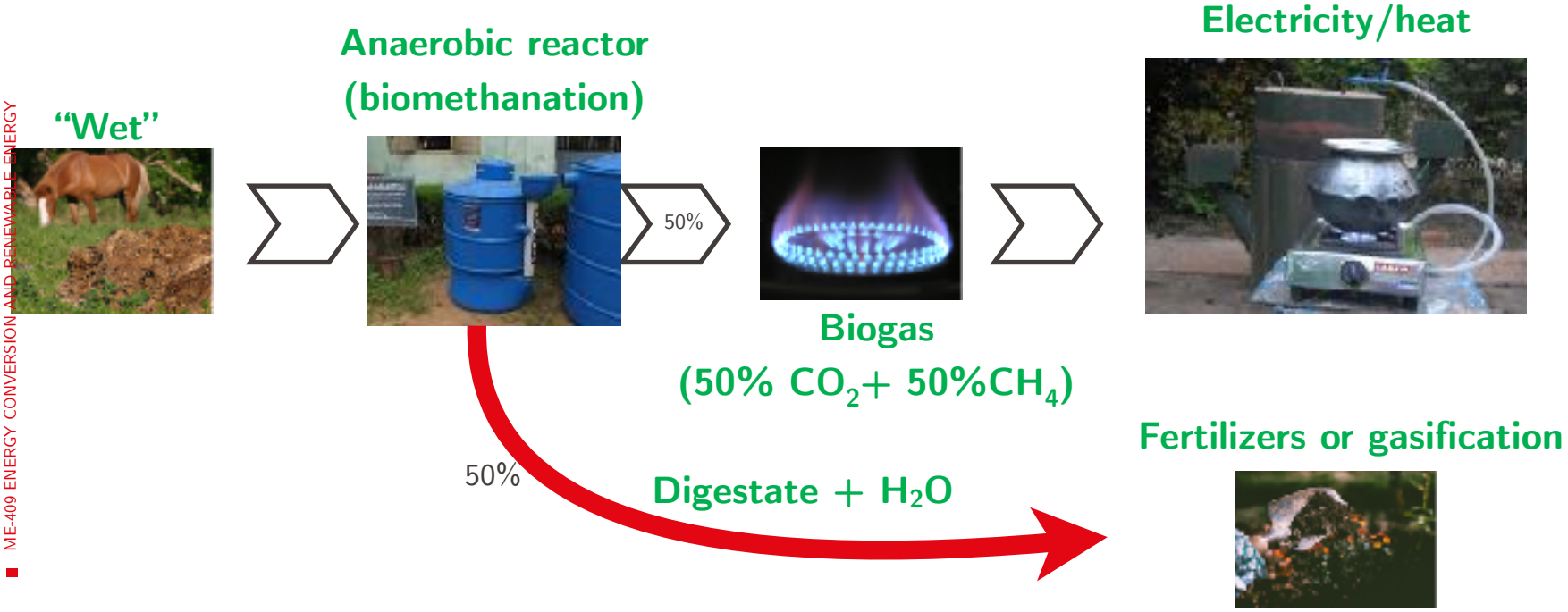
A Swiss Cattle (2019)

Biogastaaget Amanda (2019)

- A **"well-observed"** phenomenon – the classic use "small-scale"
  - Developing countries (1-5 kg per day)



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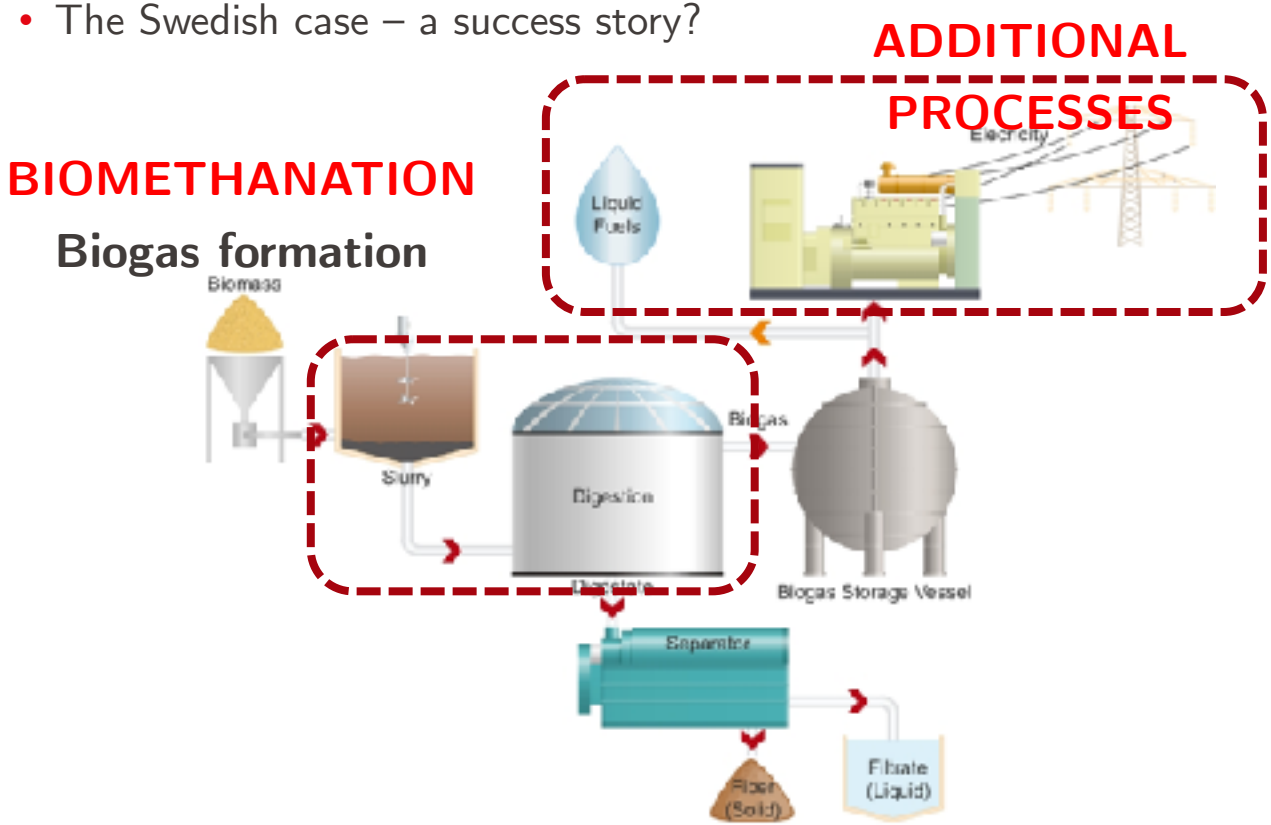
- The "**more advanced**" use
  - The Swedish case – a success story?



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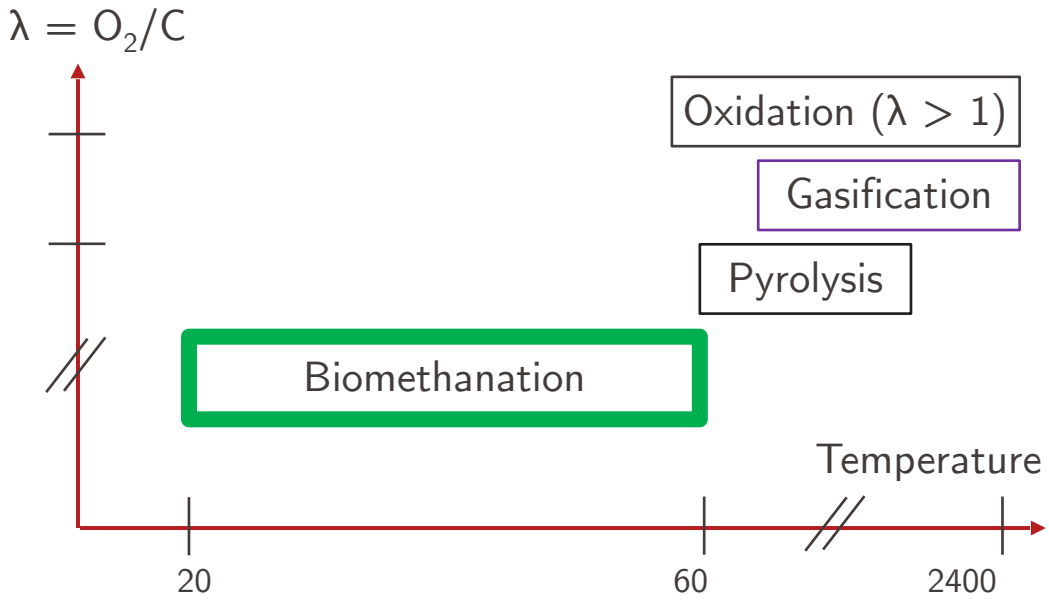
Biomethanation

= Transformation by **micro-organisms**

- **Anaerobic** environment (no O_2)
- Slow (weeks)
- pH = 6.5-7.5



Fermentation

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FERMENTATION

- Biomass

$$3CH_2O \rightarrow 2\,C_2H_5OH + 2\,CO_2$$

Ethanol : 26.8 MJ/kg

RESOURCES

DRY BIOMASS

WET BIOMASS 

CONVERSION

Residues (CH_2O)

15-20 MJ/kg

DEMANDS

HEAT 

POWER 

BIOFUELS 

CHEMICALS 

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Beers in the sun (2019)

Ethanol samples (2019)

C_2H_5OH

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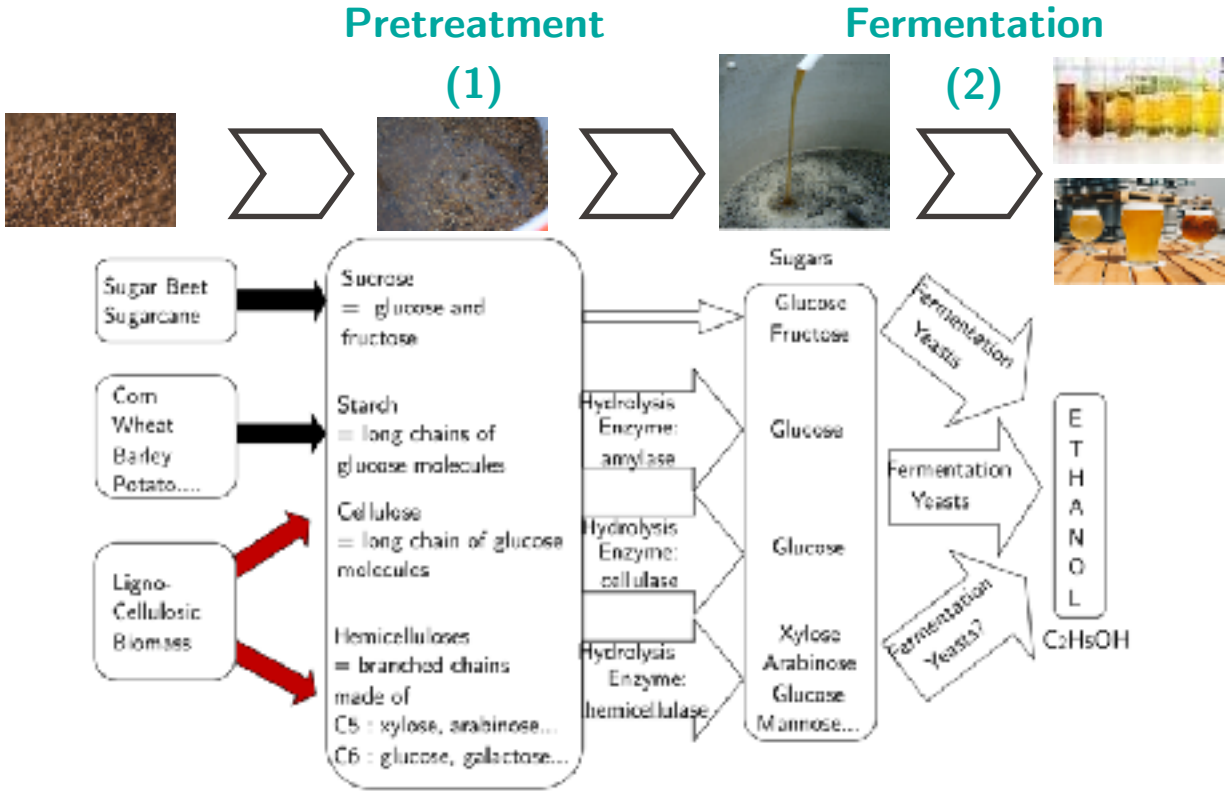
Fermentation



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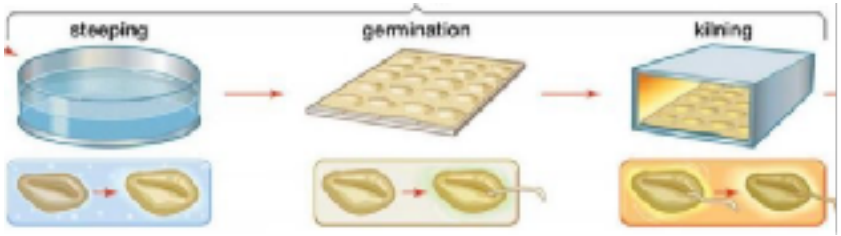
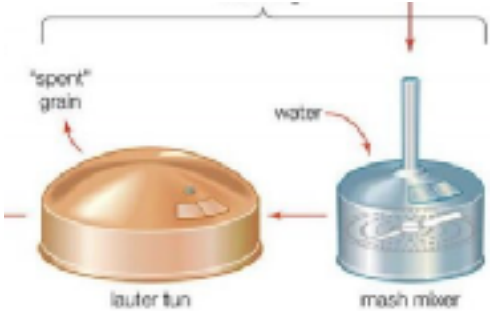
Pretreatment = breaking down **big molecules**

Barley grains (type of biomass)

$(C_6H_{10}O_5)_n + H_2O \rightarrow (C_{12}H_{22}O_{11})$ and other sugars



Malted barley (with enzymes)



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Fermentation = converting maltose and other sugars into ethanol

Wort

Yeast

Fermentation

"Beer"

$$C_{12}H_{22}O_{11} + H_2O + \text{invertase} \rightarrow 2\ C_6H_{12}O_6$$

maltose **glucose**

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$

glucose **ethanol**

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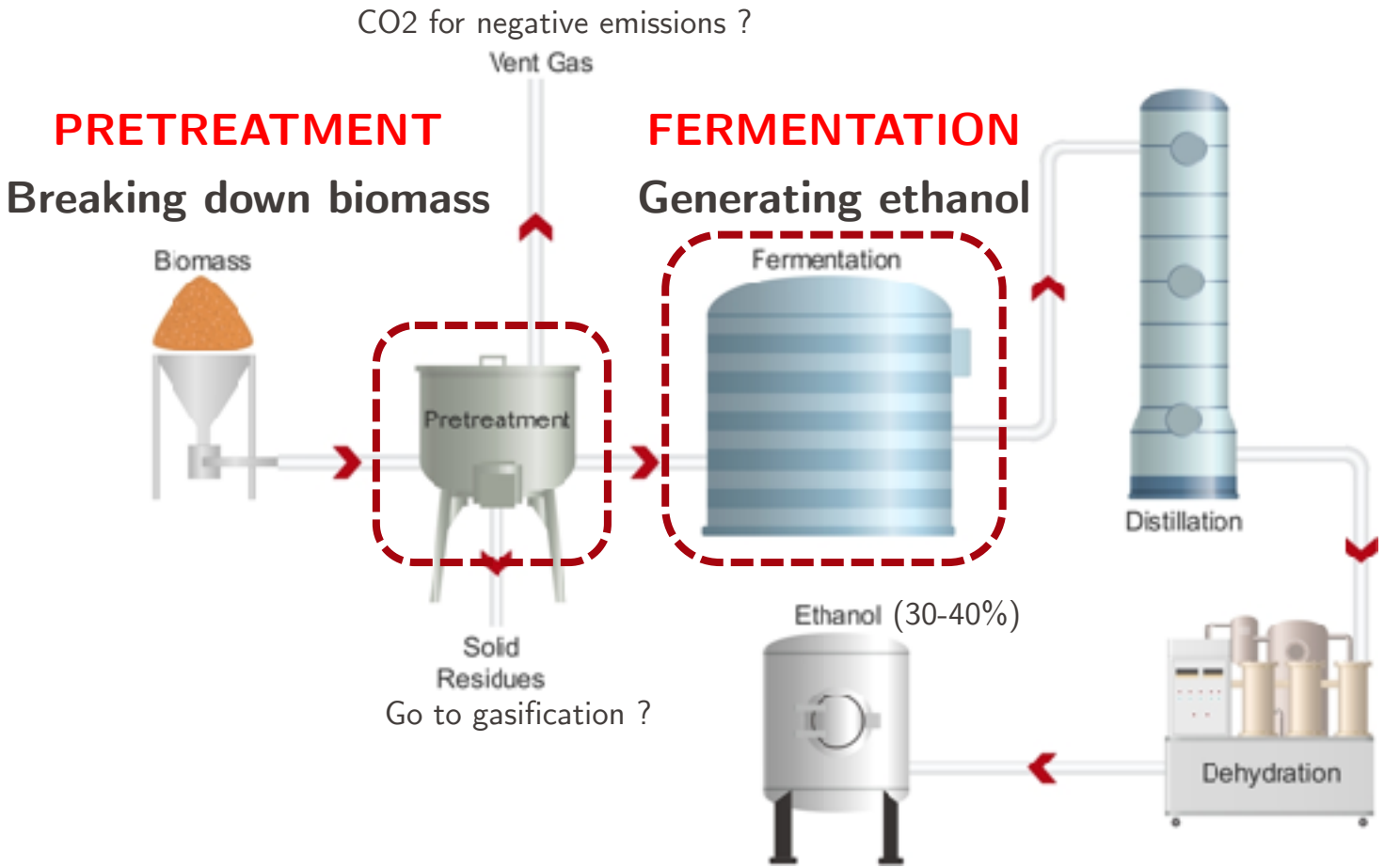
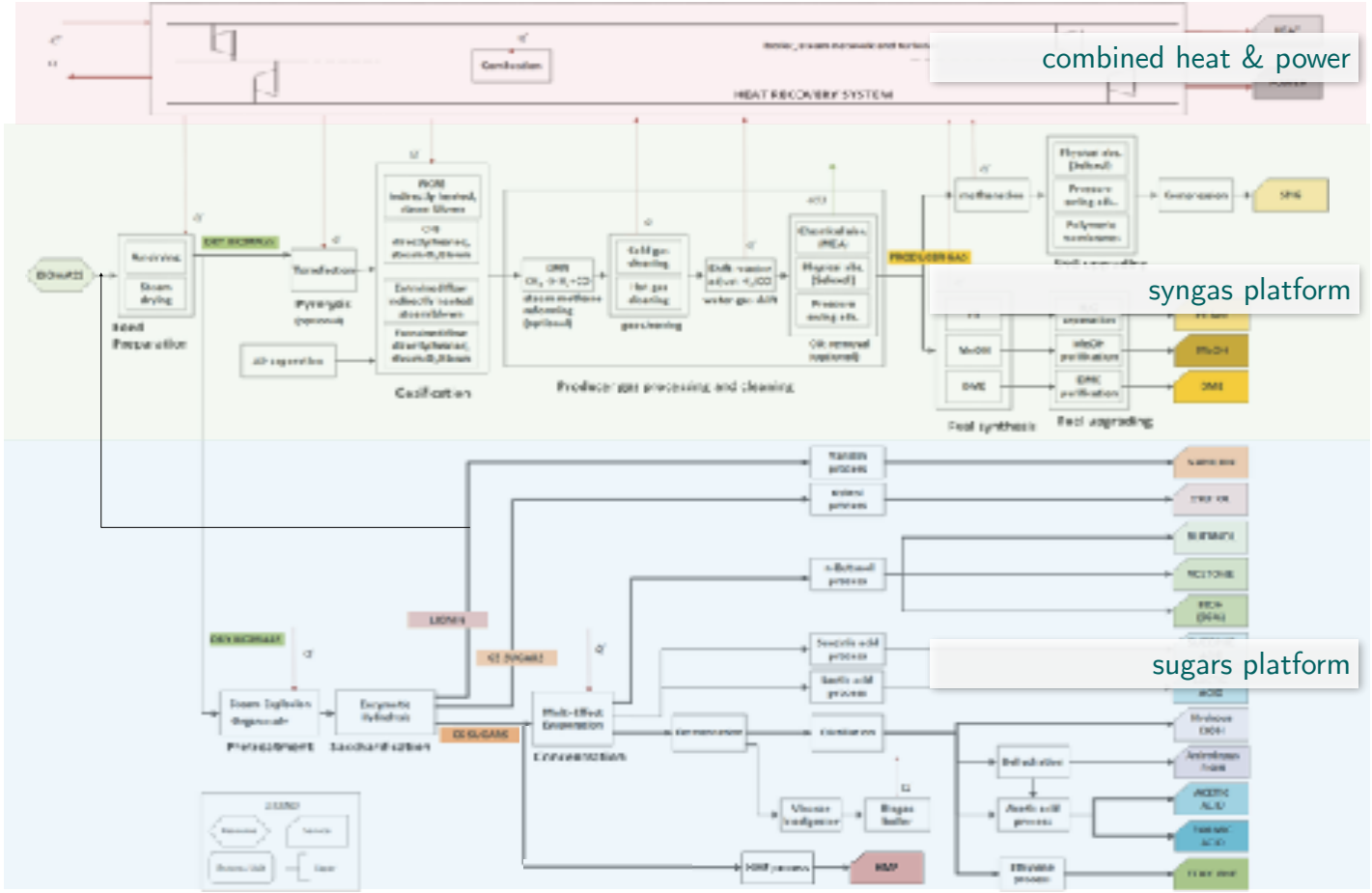


Biorefineries



Biomass and energy systems

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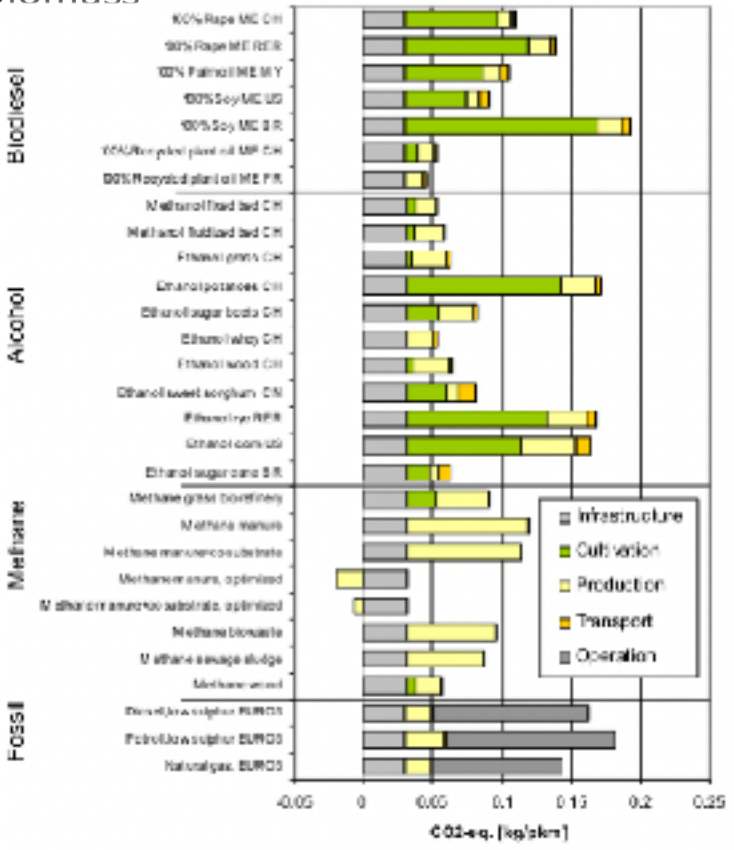
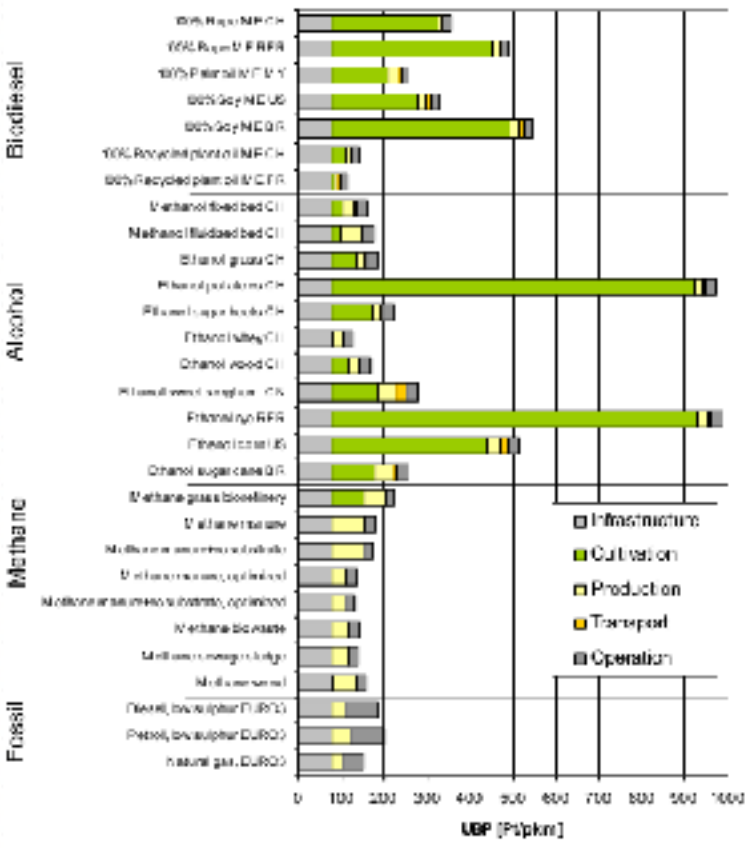
Life cycle performance

- Biomass





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HOME » NEWS » NEWS TOPICS » HOW ABOUT THAT?

Stockholm's rabbits burned to keep Sweden heated

The bodies of thousands of wild rabbits culled each year from Stockholm's parks are being used to fuel a heating plant in central Sweden.

Six thousand bunnies were killed last year Photo: GETTY IMAGES

By Allan Hall
3:09PM BST 13 Oct 2009

Animal rights activists have claimed that domestic pets are also being rounded up and incinerated.

"Those who support the culling of rabbits think it's good to use the bodies for a good cause. But it feels like the power company is trying to turn the animals into an industry rather than look at the main problem," said Anna Johannsson of the Society for the Protection of Wild Rabbits.

How about that?
News » World News » Europe » Sweden »

In How About That?

Pictures of the day

Pictures of the day

Great bolts of lightning

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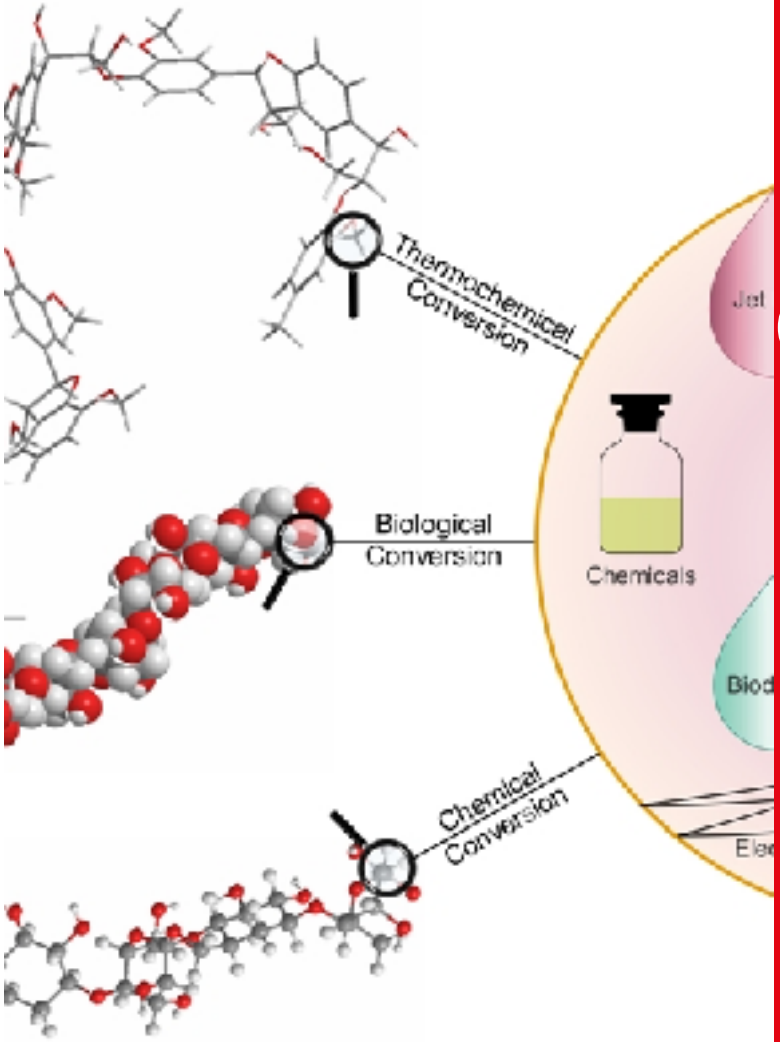
Conclusion



Take-home message

- Two main types of **biomass conversion**: **thermochemical, biological**
- **Products:** electricity, heat, fuels, chemicals and sequestrated CO2 (negative emissions)
- **Combustion** = conventional way (dry); **Gasification & pyrolysis** (dry/wet) = well-known, but need improvement
- **Biomethanation & Fermentation** = well-known, but technological/scale limits
- **Biomass challenges** – food, biogenic carbon, technologies, environmental impact



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Questions ?

Tuong-Van Nguyen