System analysis of overall efficiencies of different routes for bioenergy

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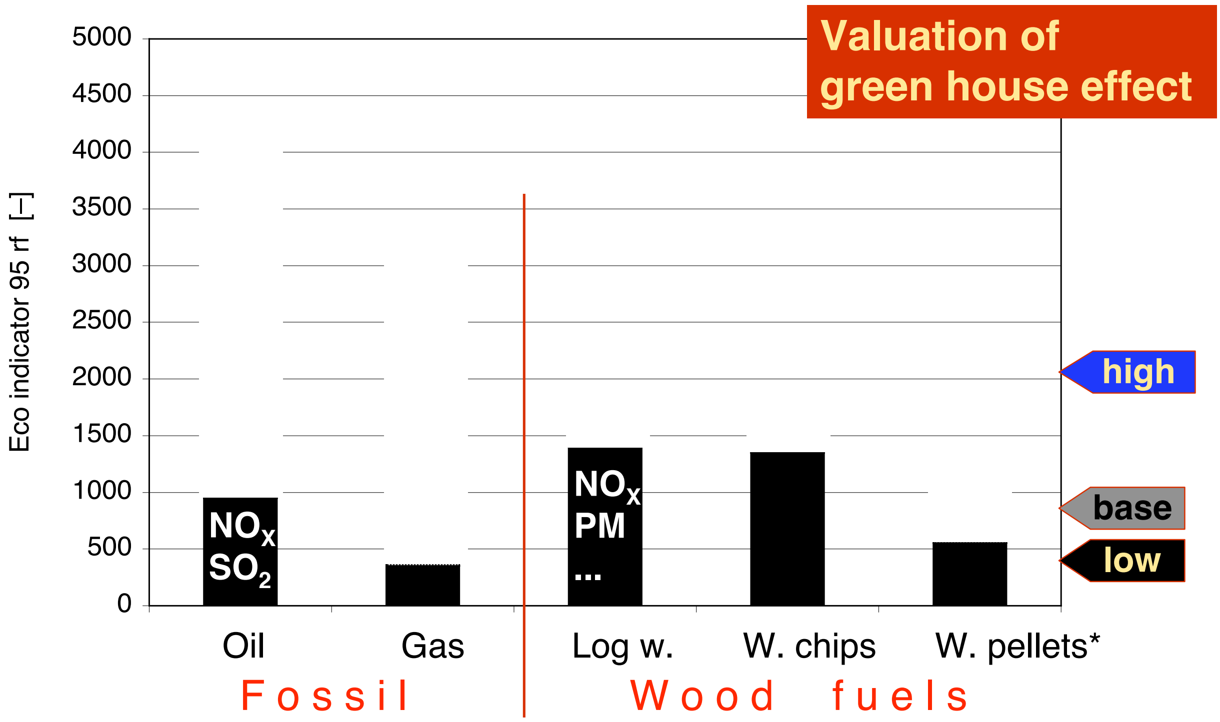
1. Motivation
2. Methodology
3. Heating Systems
4. Power Production
5. Biofuels
6. Conclusions

Life Cycle Assessment (LCA)



[Kessler&Frischknecht 2000] *[Nussbaumer 2001]

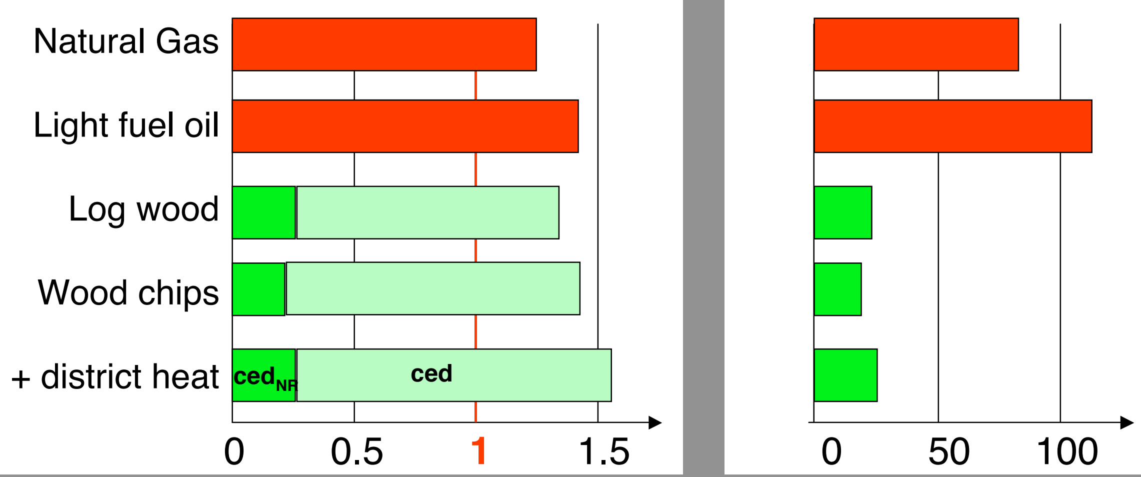
Cumulative Energy Demand

ced_{NR} [MJ primary non-ren. / MJ collectible]

ced [MJ primary / MJ collectible]

Greenhouse gas emissions

[t CO_2 / TJ collectible]



Data from [Hartmann & Kaltschmitt 2002]

Background

Life Cycle Assessments (LCA) are useful, but

.... present aggregated data

.... are influenced by a valuation of CO_2 versus other environmental impacts, which is **subjective**

The **primary energy efficiency** is only one aspect

.... but it is the most relevant one for energy systems

.... CO_2 is correlated to ced_{NR}

Aim

Assessment of the **primary energy efficiency** of **biomass** based energy systems

Sensitivity analysis for the main parameters:

- Plant efficiency
- Transport distance
- Fuel pretreatment

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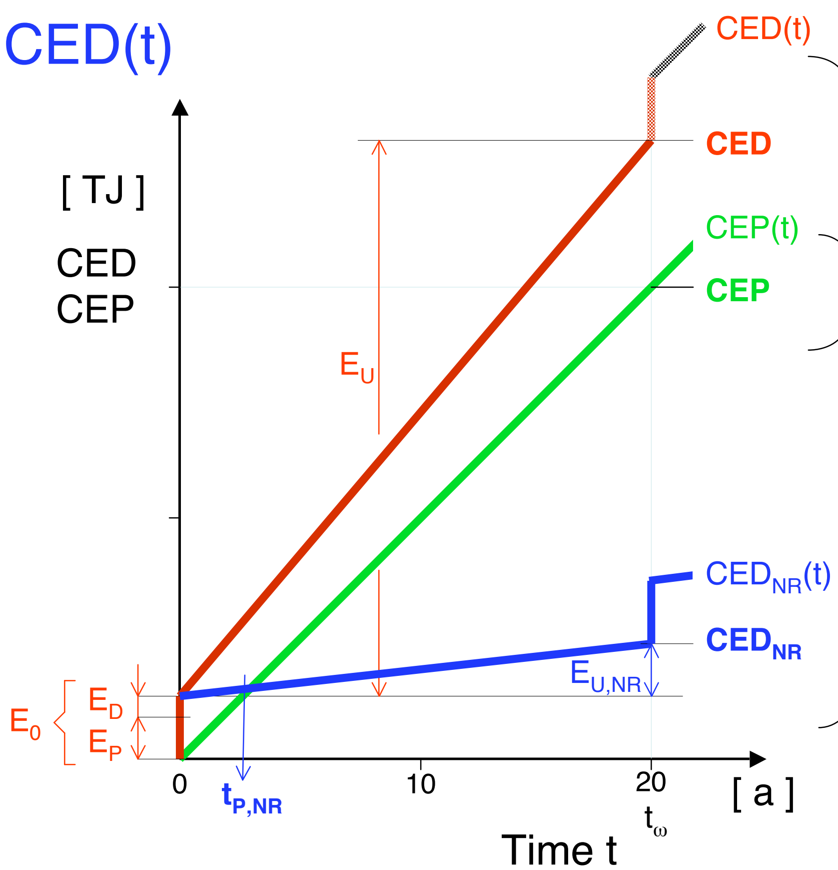

Specific CED

$$ced = \frac{CED}{CEP} > 1$$

Energy Yield Coefficient

$$EYC = \frac{CEP}{CED} < 1$$

Nonrenewable ced

$$ced_{NR} = \frac{CED_{NR}}{CEP}$$

Nonrenewable EYC

$$EYC_{NR} = \frac{CEP}{CED_{NR}}$$

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Assumptions

Primary energy = lower heating value **LHV** of wood harvested without leaves

Collectible energy = heat delivered to the building

Annual plant efficiency = efficiency without district heat
= **80%** for reference case

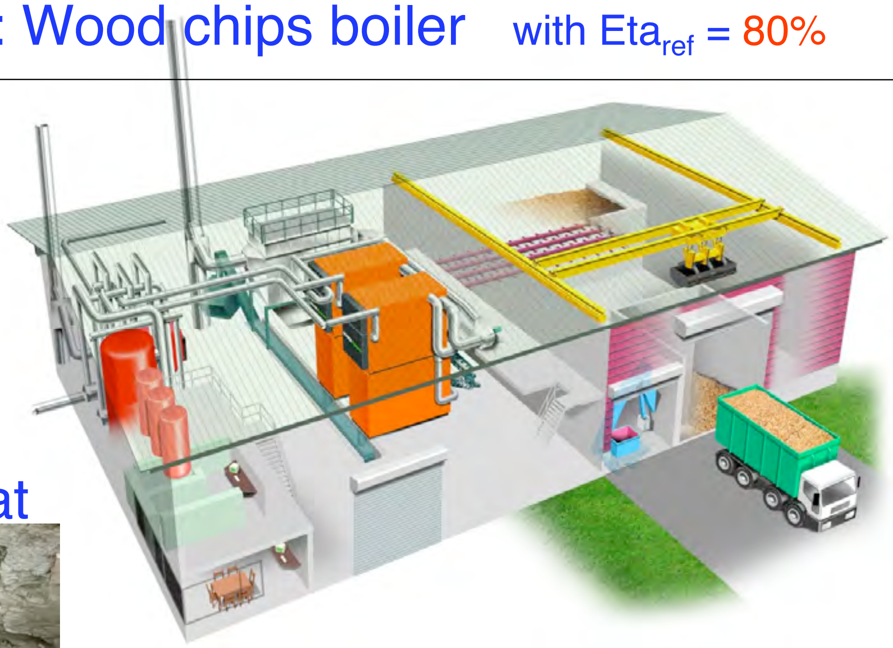
Electricity is rated with **2.5** corr. to the COP of a heat pump

Diesel is accounted with 1.25 due to embodied energy

Plant life time = 20 a

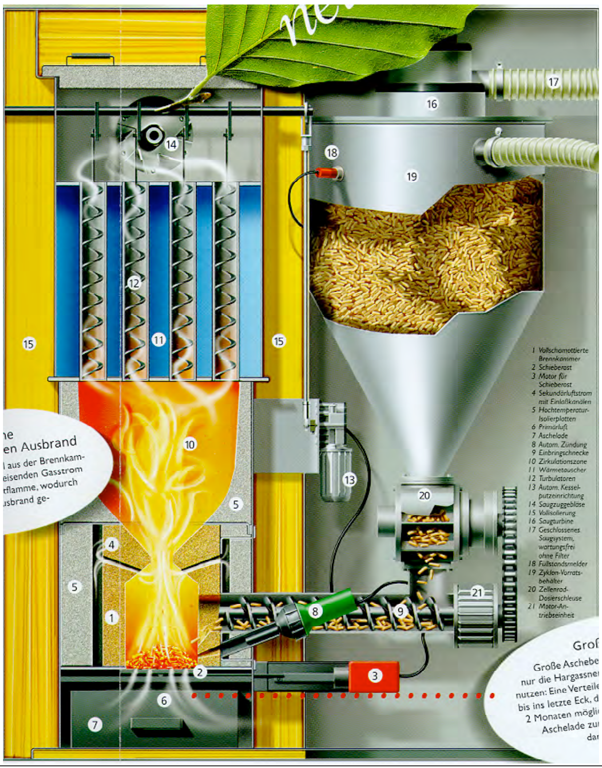
Scenario 1: Log wood boiler with Eta_{ref} = 80%

Scenario 2: Wood chips boiler with Eta_{ref} = 80%



+ District heat

Scenario 3: Pellet boiler with Eta$_{ref}$ = 80%

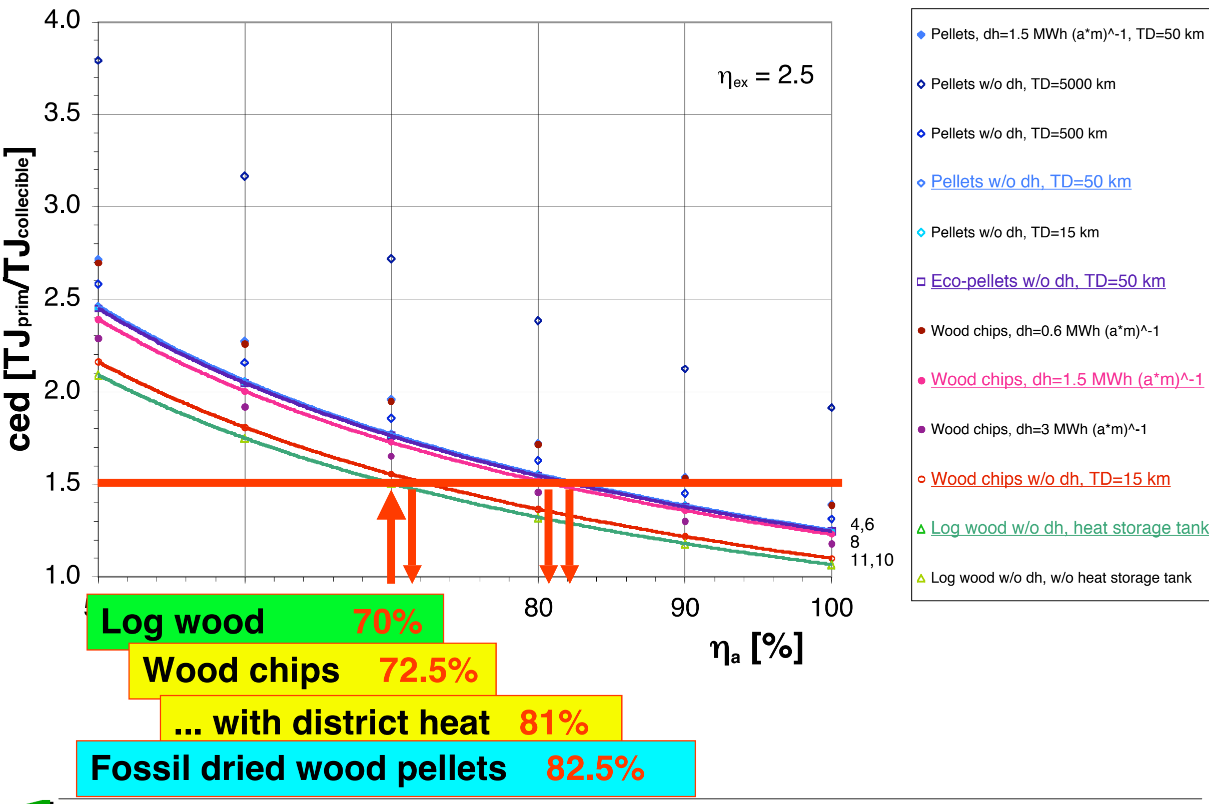


Energy Yield Coefficient for heating

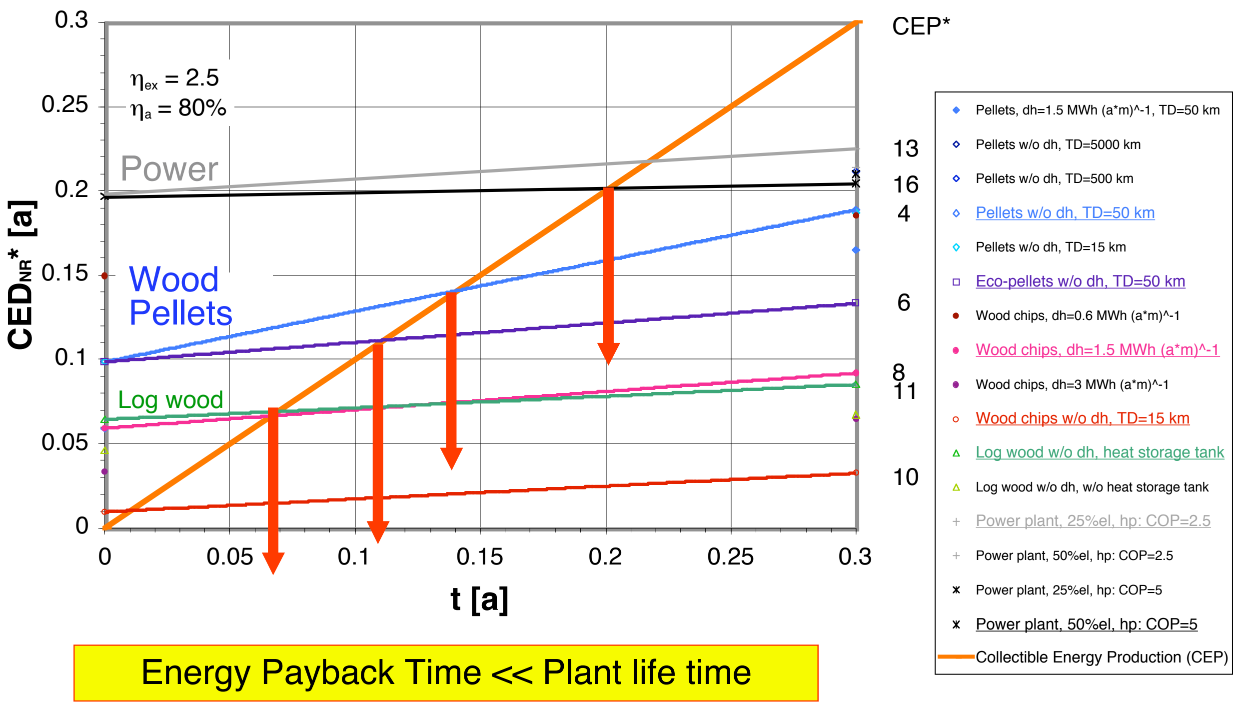
	Lit	EYC$_{NR}$ [TJ/TJ]	Wood / Oil [–]
Log wood boiler	1	13.8	19.4
Wood chips without district heat	1	13.0	18.3
Wood chips with district heat with 3 MWh a^{-1}m^{-1}	1	9.4	13.2
with 1.5 MWh a^{-1}m^{-1}	1	9.0	12.6
with 0.6 MWh a^{-1}m^{-1}	1	7.9	11.1
Eco wood pellets with wood for drying	1	8.3	11.7
Wood pellets with oil for drying of wet saw dust	1	3.3	4.6
Light fuel oil boiler with flue gas condensation	2	0.71	1

1: [Nussbaumer 2004]
2: [Kessler et al. 2000]

ced as function of annual plant efficiency

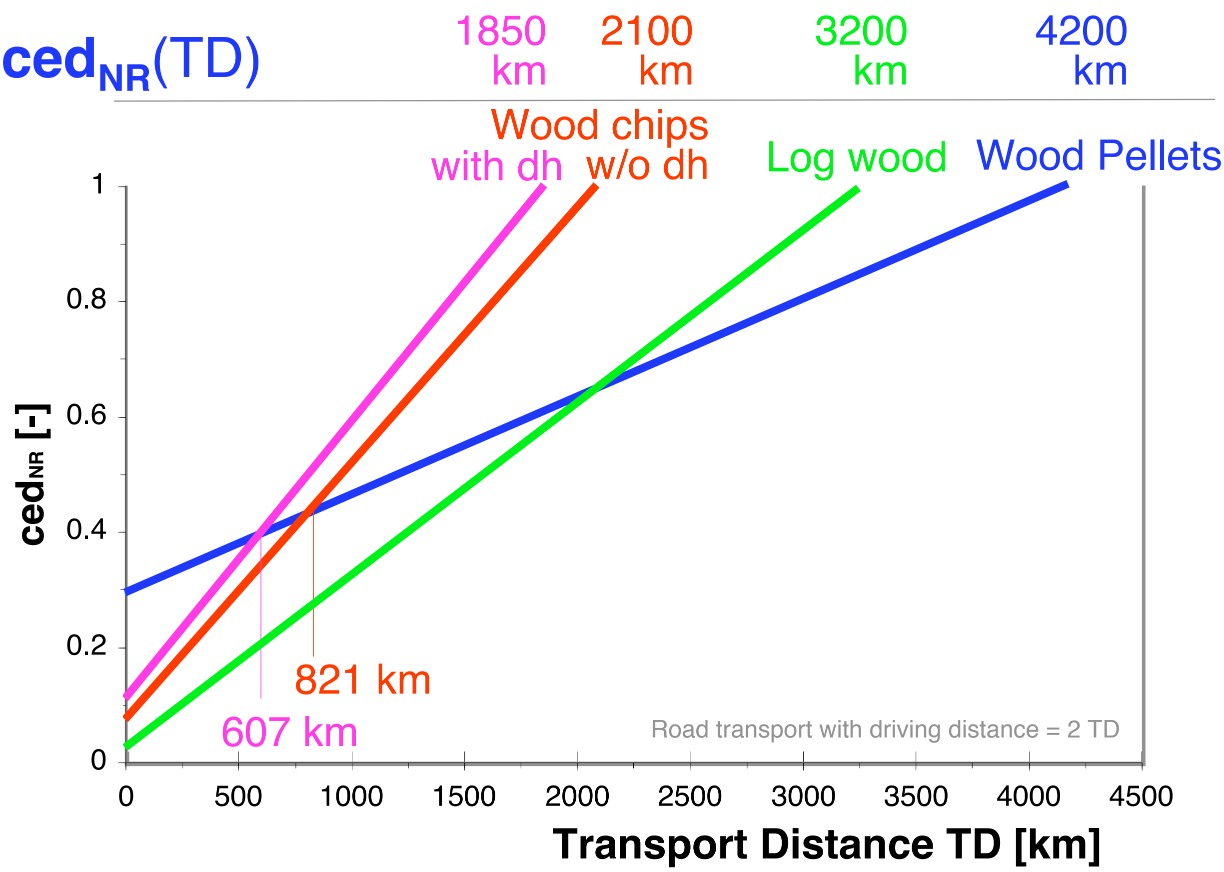


CED_{NR} as function of plant life time



Energy Payback Time << Plant life time

ced_{NR}(TD)



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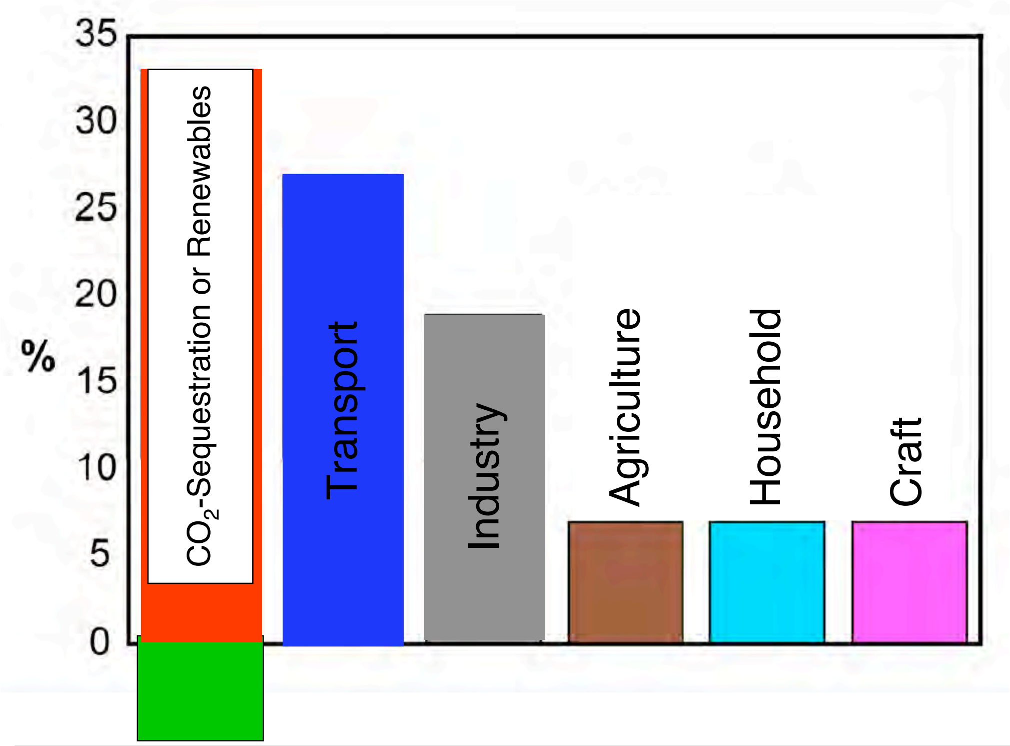
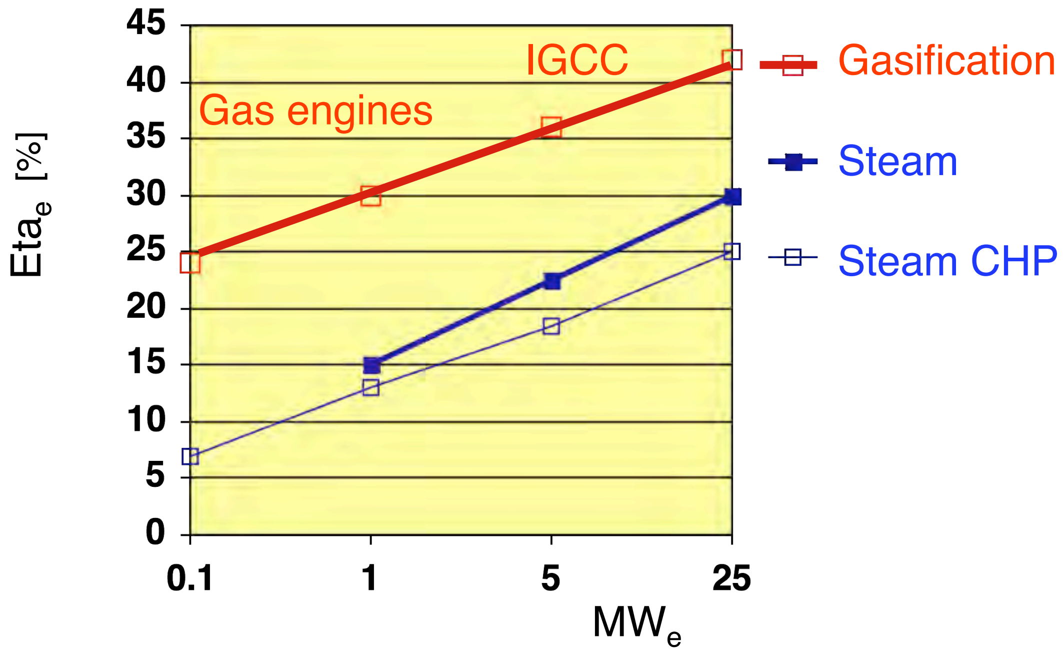
Sources of Greenhouse Gas Emissions

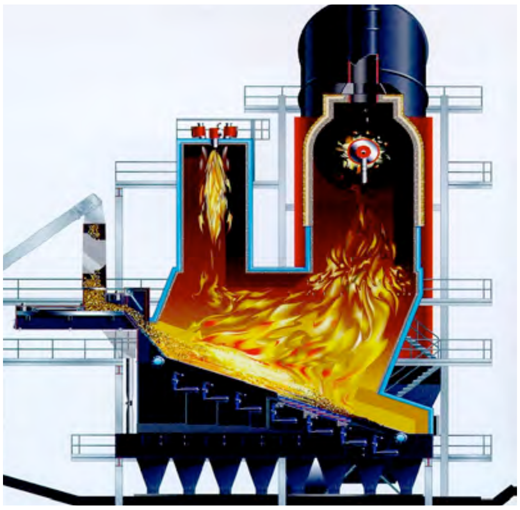


Efficiency of power production from biomass



Scenario 4a: Power production with Eta = 25%

Example: Steam plant with 10 – 20 MWe



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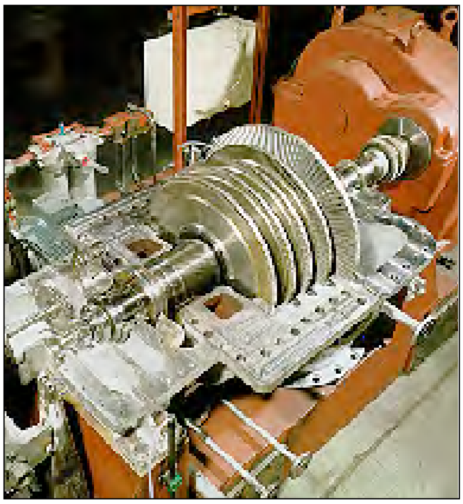
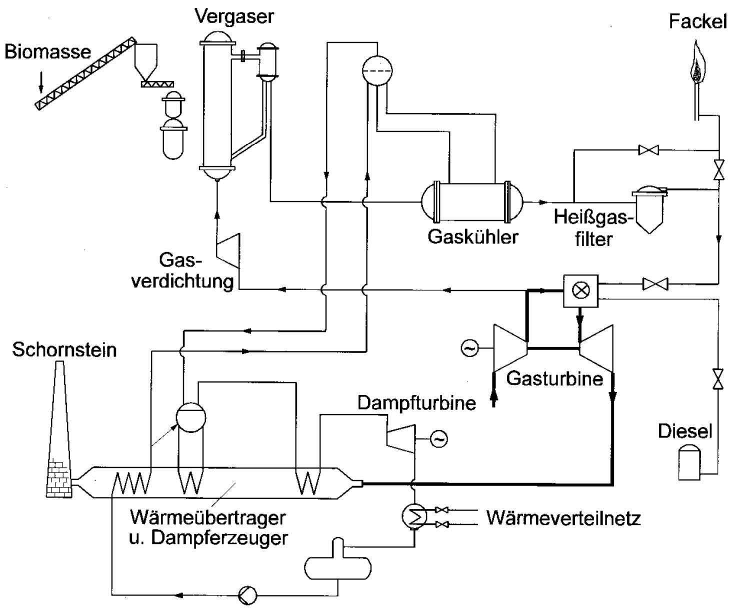


Scenario 4b: Power production with Eta = 50%

Example: Integrated Gasification Combined Cycle with Eta_e > 40% for 100 MWe



Energy Yield Coefficient for heat and power

	Lit	EYC_{NR} [TJ/TJ]
Log wood boiler	1	**13.8**
Wood chips without district heat	1	**13.0**
Wood chips with district heat with 1.5 MWh $a^{-1}m^{-1}$	1	**9.0**
Eco wood pellets with wood for drying	1	**8.3**
Power plant & heat pump with 25% el and COP = 2.5	**1**	**10.1**
Power plant & heat pump with 50% el and COP = 5	**1**	**27.7**

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1 [Nussbaumer 2004], 3 [Hartmann&Kaltschmitt 2002]
4 [Studer et al. 1991], 5 [Wörgetter et al. 1999], 6 [Osteroth 1992]

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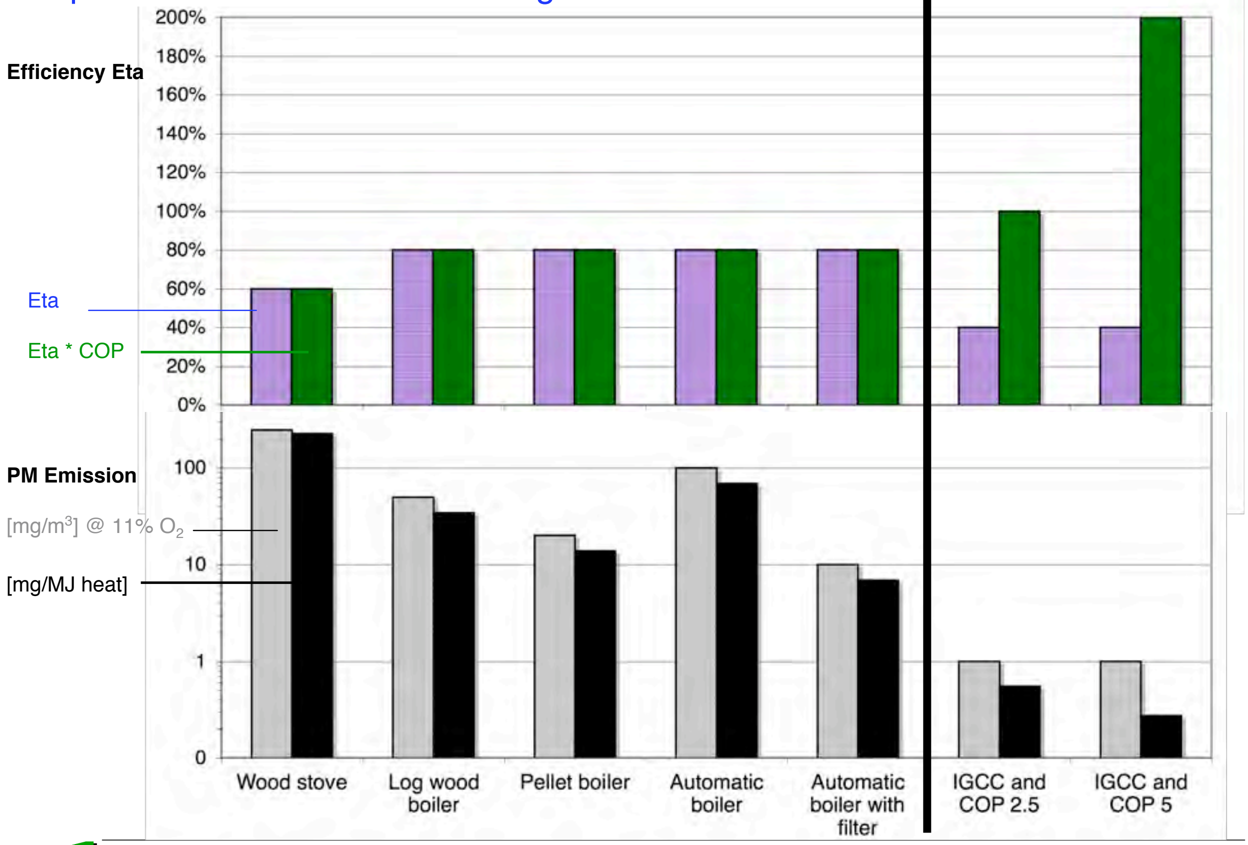
Comparison — Wood heating — Wood IGCC



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Energy Yield Coefficient for power and fuels

	Lit	EYC_{NR} [TJ/TJ]
Log wood boiler	1	13.8
Wood chips without district heat	1	13.0
Wood chips with district heat with 1.5 MWh $a^{-1}m^{-1}$	1	9.0
Eco wood pellets with wood for drying	1	8.3
Power plant & heat pump with 25% el and COP = 2.5	1	10.1
Power plant & heat pump with 50% el and COP = 5	1	27.7
Bio Diesel without / with side products	3,4,5	1.5 / 2–3
Ethanol from sugar beets in Europe	3	2.1
Ethanol from maize or potatoes / cereals in Europe	6	1.2 / 1.3 ?
2nd Generation Biofuels (e.g. FT-Diesel)	-	?

1 [Nussbaumer 2004], 3 [Hartmann&Kaltschmitt 2002]
4 [Studer et al. 1991], 5 [Wörgetter et al. 1999], 6 [Osteroth 1992]

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Conclusions

1. The method of Cumulative Energy Demand and Energy Yield is valuable to compare different bioenergy routes in one sector and to investigate the influence of parameters.
2. However, applications for heat, power, and transport cannot be compared directly and hence needs reference scenarios.
3. If nowadays energy systems are assumed as reference scenarios, the potential to substitute fossil fuels is likely to exhibit the following ranking:
    1. highly efficient power production
    2. efficient heating systems
    3. Biofuels for transport

Conclusion

Fossil fuel substitution and CO_2 reduction with biomass seem most efficient in the following order:

1. Highly efficient power production
2. Efficient heating systems
3. Biofuels

Acknowledgements

- IEA Bioenergy Task 32
  Biomass Combustion and Co-firing
- Swiss Federal Office of Energy

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Downloads

Nussbaumer T, Oser, M: Evaluation of Biomass Com-bustion based Energy Systems by Cumulative Energy Demand and Energy Yield Coefficient, IEA 2004

www.ieabcc.nl or www.verenum.ch

Nussbaumer T: 9. Holzenergie-Symposium, Zürich 2006

www.holzenergie-symposium.ch

or via link from www.verenum.ch

The end

1st Generation Biofuels: Plant methyl ester

Oil plants only
Low yield per hectare

Energy Yield Coefficient =

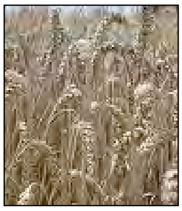
1.5 without side products

2.5 with side products

1st Generation Biofuels: Plant methyl ester

1st Generation Biofuels: Bioethanol



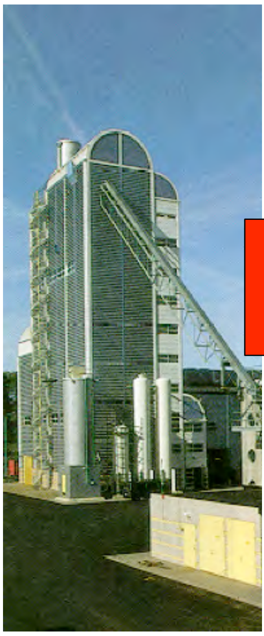
EYC = 2.1 ? 1.2 ... 1.5

Hefe-Enzyme

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

Glukose → Ethanol + Kohlendioxid

2nd Generation Biofuels from Synthesis



CO + H_2

Examples

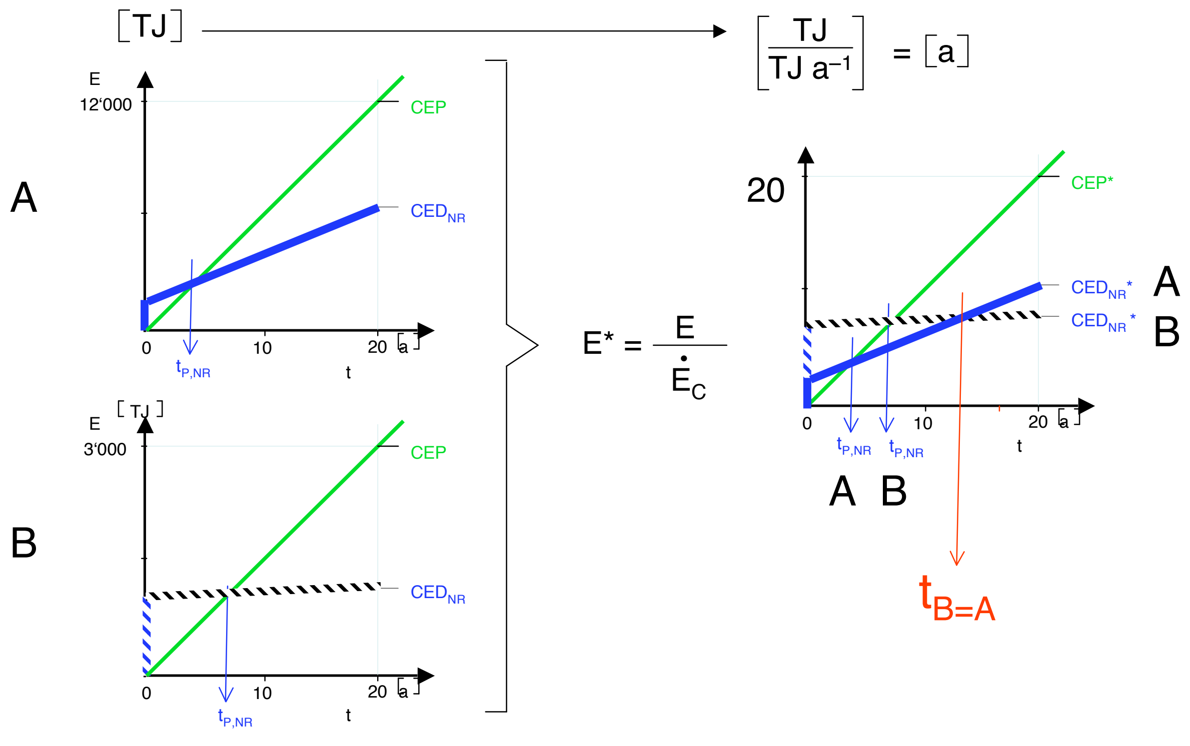
„Biomass-to-Liquids, BtL“
via Fischer-Tropsch (FT-Diesel)
$CO + H_2 \rightarrow C_nH_{2n/+1/+2} + H_2O$

Hydrogen via CO-Shift
$CO + H_2O \rightarrow CO_2 + H_2$

Methane via Methanisation
$CO + 2\ H_2 \rightarrow CH_4$

LHV Biofuel / LHV Biomass < 50...55%
EYC = ?

Transformation CED in [TJ] to CED* in [a]



1. Motivation
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3. Results for different Energy Systems
4. **Influence of Transport Distance**
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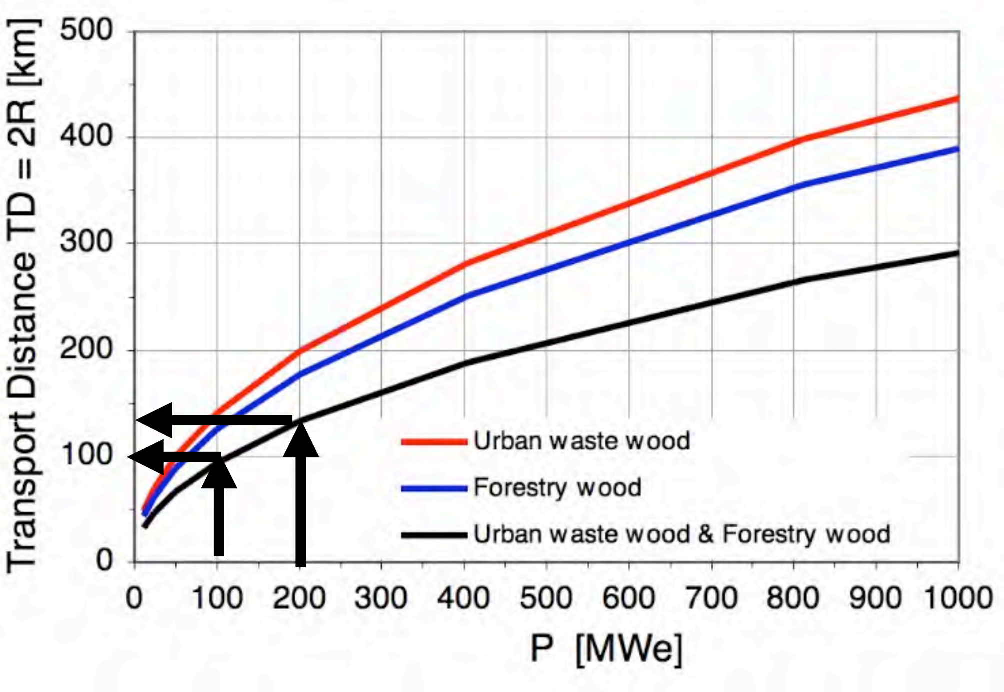
Transport Distance = 2 x Radius (due to empty return drice)



Plant efficiency and Net efficiency including transport