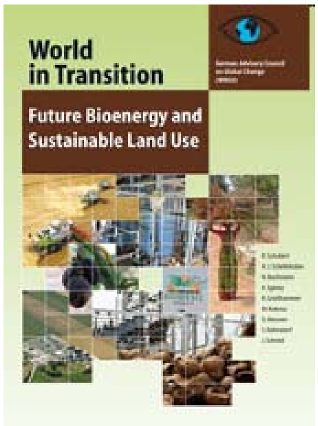
Future Bioenergy and Sustainable Land Use

Main Results of a Global Bioenergy Analysis

Dr.-Ing. Michael Sterner,
German Advisory Council on Global Change (WBGU)
Fraunhofer IWES, Kassel

IEA Bioenergy Task 38 GHG Balances Conference, Brussels, Belgium
March 8th-10th, 2010



WBGU – Council Members

Prof. Dr. Jürgen Schmid (Ingenieur für Luft- und Raumfahrttechnik), Universität Kassel
Prof. Dr. Astrid Epiney (Juristin), Université de Fribourg, Schweiz
Prof. Dr. Stefan Rahmstorf (Physiker), PIK-Potsdam
Prof. Dr. Nina Buchmann (Ökologin), ETH Zürich, Schweiz
Dr. Rainer Grießhammer (Chemiker), Ökoinstitut Freiburg
Prof. Dr. Margareta Kulessa (Ökonomin), Fachhochschule Mainz
Prof. Dr. Dirk Messner (Politikwissenschaftler), Dt. Inst. für Entwicklungsforschung, Bonn
Prof. Dr. John Schellnhuber CBE (Physiker, stv. Vorsitzender), PIK-Potsdam
Prof. Dr. Renate Schubert (Ökonomin, Vorsitzende) ETH Zürich, Schweiz

WBGU

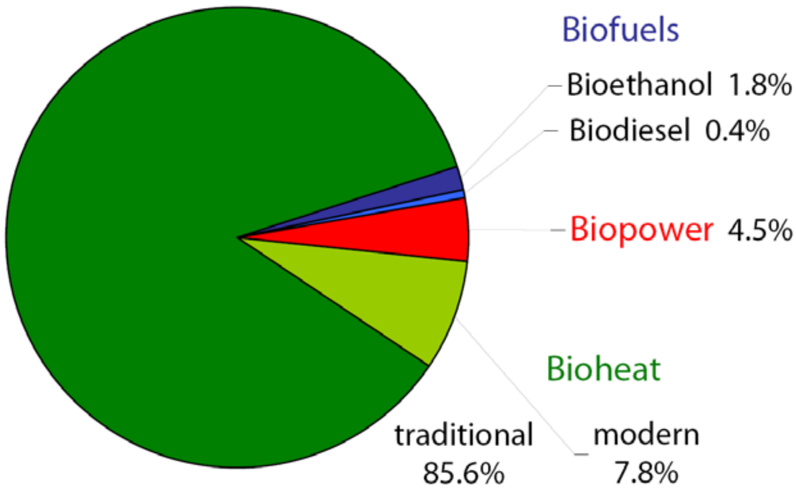
GERMAN ADVISORY COUNCIL ON GLOBAL CHANGE

Content

1. BE contribution and potential
2. Land use competitions
3. 70 pathways: energy balances
4. GHG balances & methods
5. BE in energy systems
6. Conclusions

WBGU

Global uses of bioenergy – shares and categories



- Energy crops
- Residues and waste
- Traditional biomass

Source: BP, 2008; REN21, 2008; GWEC, 2008

Global potential of bioenergy

Calculation of energy crop potential - excluding

- Areas for biodiversity conservation (beyond existing protected areas)
- Existing cropland or potential new cropland
- Areas whose conversion must be expected to cause GHG emissions that can not be compensated within 10 years

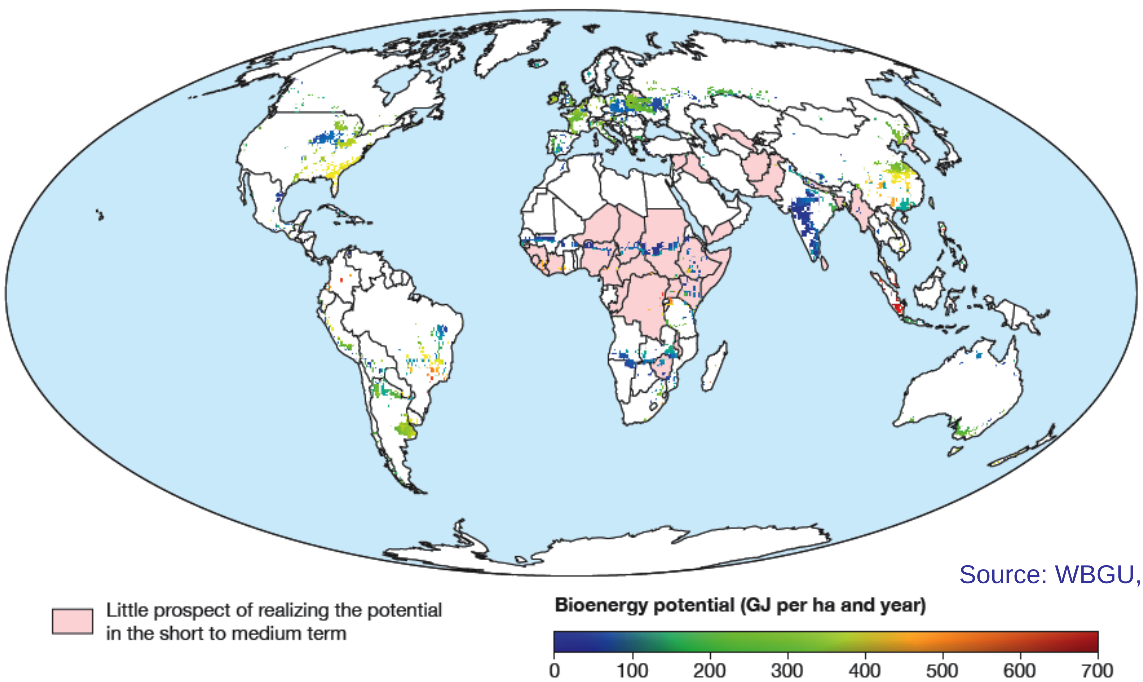
Energy crops: 30 – 120 EJ

Residues and waste: ca. 50 EJ

Traditional biomass: ca. 40 EJ

Source: WBGU, 2008

Potential regions for bioenergy (fragile states)



Source: WBGU, 2008

Global distribution of bioenergy potential

Selected region	Potential	Share of global potential
Sub-Saharan Africa	5 - 14 EJ/year	12 - 15%
China and neighbouring countries	4 - 15 EJ/year	12 - 13%
CIS	2 - 9 EJ/year	7 - 8%
Latin America and Caribbean	8 - 25 EJ/year	22 - 24%
Pacific South-East Asia	1 -11 EJ/year	2 - 9%
South Asia	2 - 4 EJ/year	3 - 6%
Europe	5 - 15 EJ/year	11 - 16%

Source: Behringer, 2008; WBGU, 2008

Content

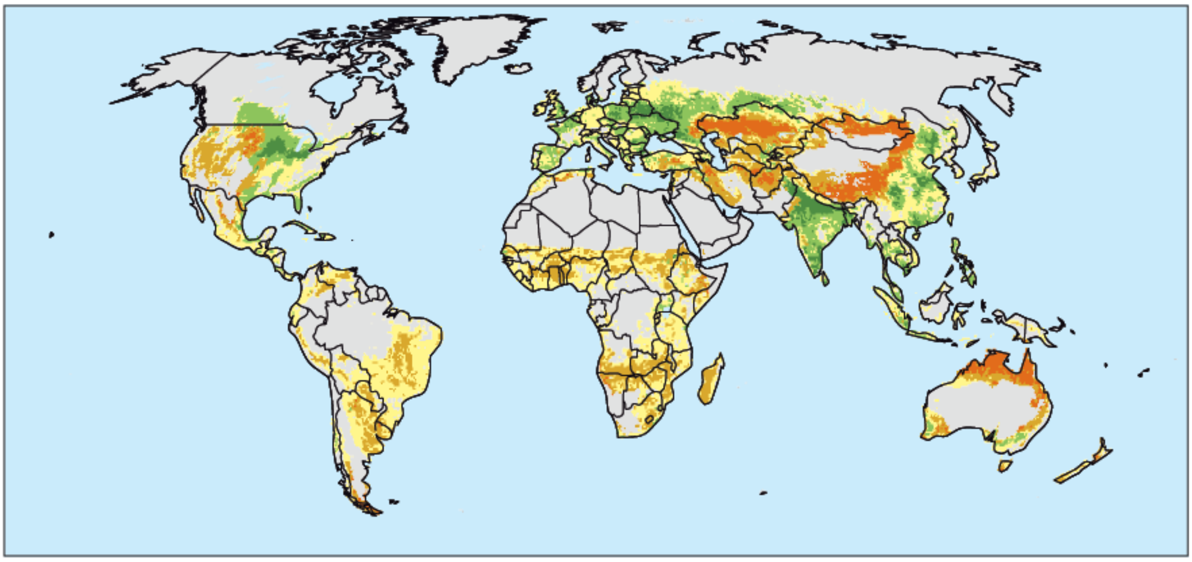
1. BE contribution and potential
2. Land use competitions
3. 70 pathways: energy balances
4. GHG balances & methods
5. BE in energy systems
6. Conclusions

Energy crops: risks & land use competition

- Food security
  - Competition with other land uses, price effects, more land for food required, area-intensive nutrition patterns
- Biodiversity
  - Monocultures, deforestation
- Soil and water
  - Degradation, exploitation, soil carbon, water use competition
- Climate
  - GHG emissions due to land-use changes, afforestation

➡ Avoided by residues and waste

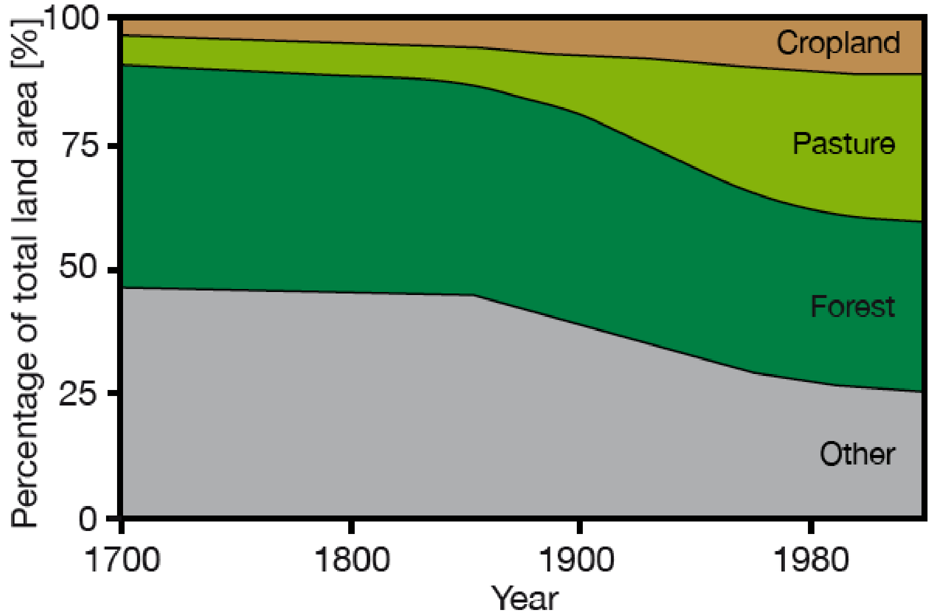
Extent of cropland and grazing land



Cropland/grazing land mosaic
Cropland > 50%
Cropland > 85%
Grazing land > 50%
Grazing land > 85%
Agriculture < 20% of land area or no growing season

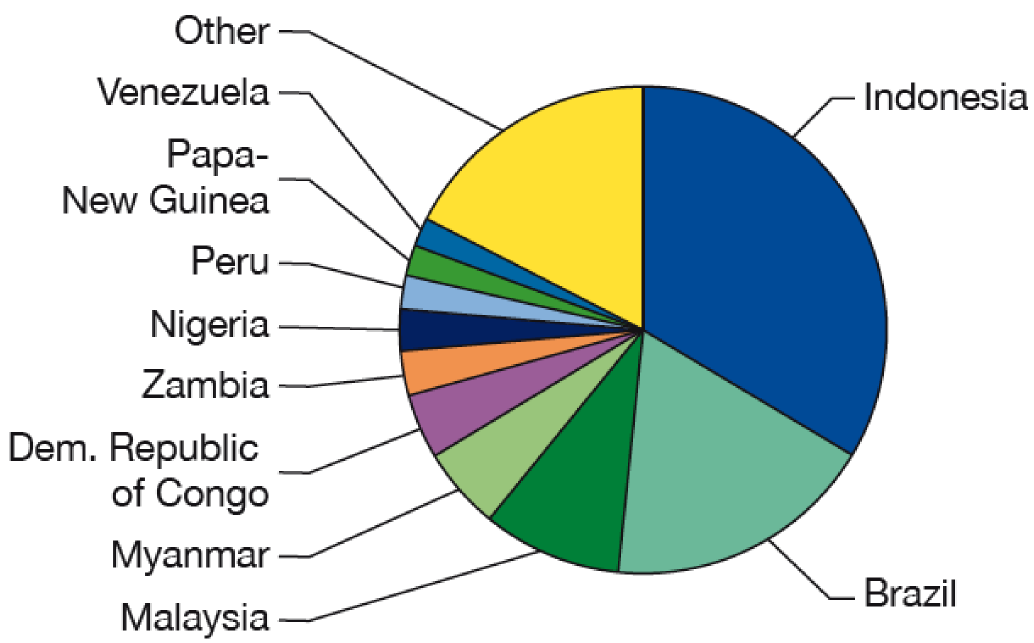
Source: UNEP, 2007

Changes in land use 1700-1995



Source: Klein, Goldewijk and Battjes, 1997

Emissions from deforestation



Source: after Houghton et al., 2003

Biomass = limited resource

Although there is potential,
biomass is a limited resource

→ **strategic use,** oriented at
- **Climate mitigation / GHG reduction potential**
- **Technical supply security**
- **Overcoming energy poverty**

Content

1. BE contribution and potential
2. Land use competitions
3. 70 pathways: energy balances
4. GHG balances & methods
5. BE in energy systems
6. Conclusions

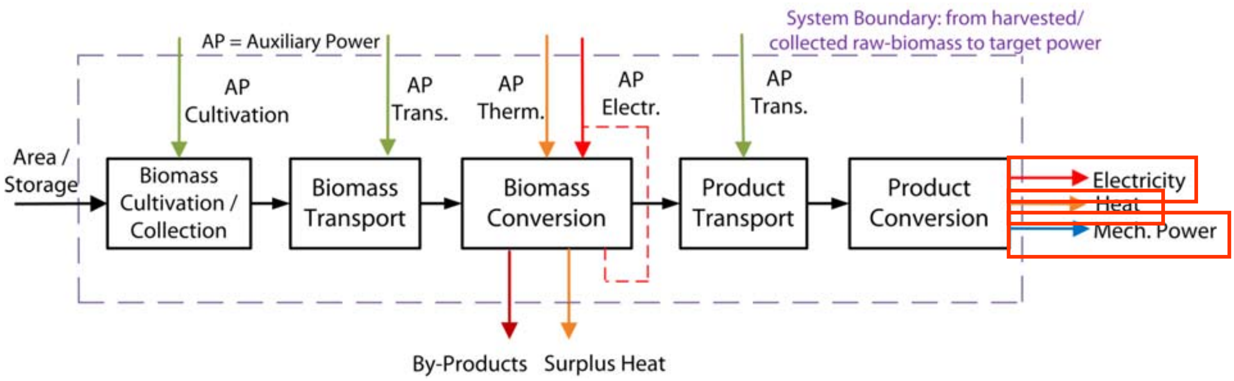
Analysis of 78 biomass pathways

Energy sector	Application	Quantity	Example pathway
Transport	1. gen. biofuels	11	Rape seed – Biodiesel – Car – 2005
	2. gen. biofuels	11	Short Rotation Coppice (SRC) Fischer-Tropsch – BTL – Car – 2030
	Electromobility	3	Wood chips SteamTurbine – electricCar – 2030
Heat	Small systems	2	Wood pellets-Heating system-2005
	Large systems	2	Wood chips-Heating system-2005
Power and heat	Liquid biofuel CHP	7	Rape seed - PlantOil-CHP-2005
	Fermentation CHP	20	Maize silage – Biogas-CHP-2005
	Gasification CHP	6	SRC - Biomethane –CombinedCycle-2030
	Direct combustion	3	Wood chips-SteamTurbine-2005
	Co-firing with coal	3	Wood pellets-CofiringCoalPowerPlant-2005

Plus traditional biomass / rural applications: 6 heat, 2 CHP

Source: Sterner, 2009

Technical conversion efficiency



$$\eta_{ex/en} = \frac{P_{out}(benefit)}{P_{in}(effort)} = \frac{P_{net\_electr\_power} + P_{mech\_power} + P_{Heat} \cdot \eta_{Carnot}}{P_{Raw\_Biomass} + P_{AP\_Cultivation} + \sum P_{AP\_Trans.} + P_{AP\_therm.} + P_{AP\_electr} - P_{By\_products}}$$

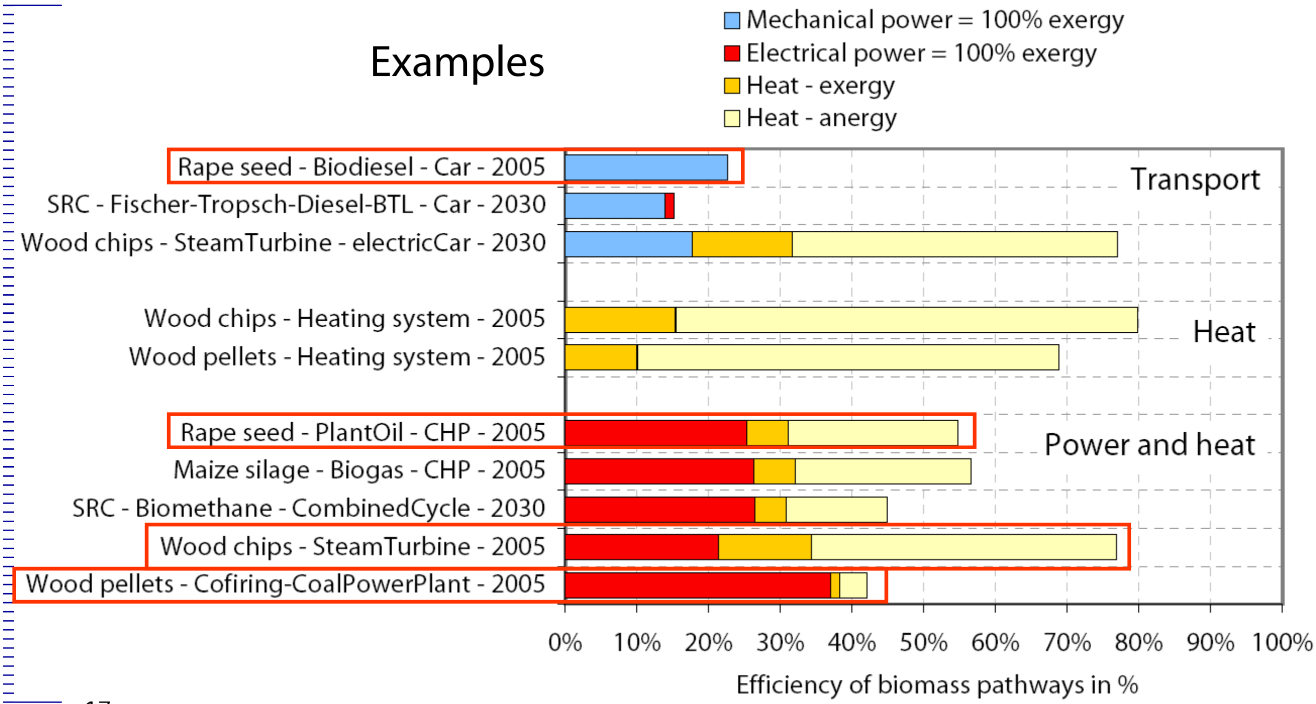
Methods:

– Efficiency VDI 4461

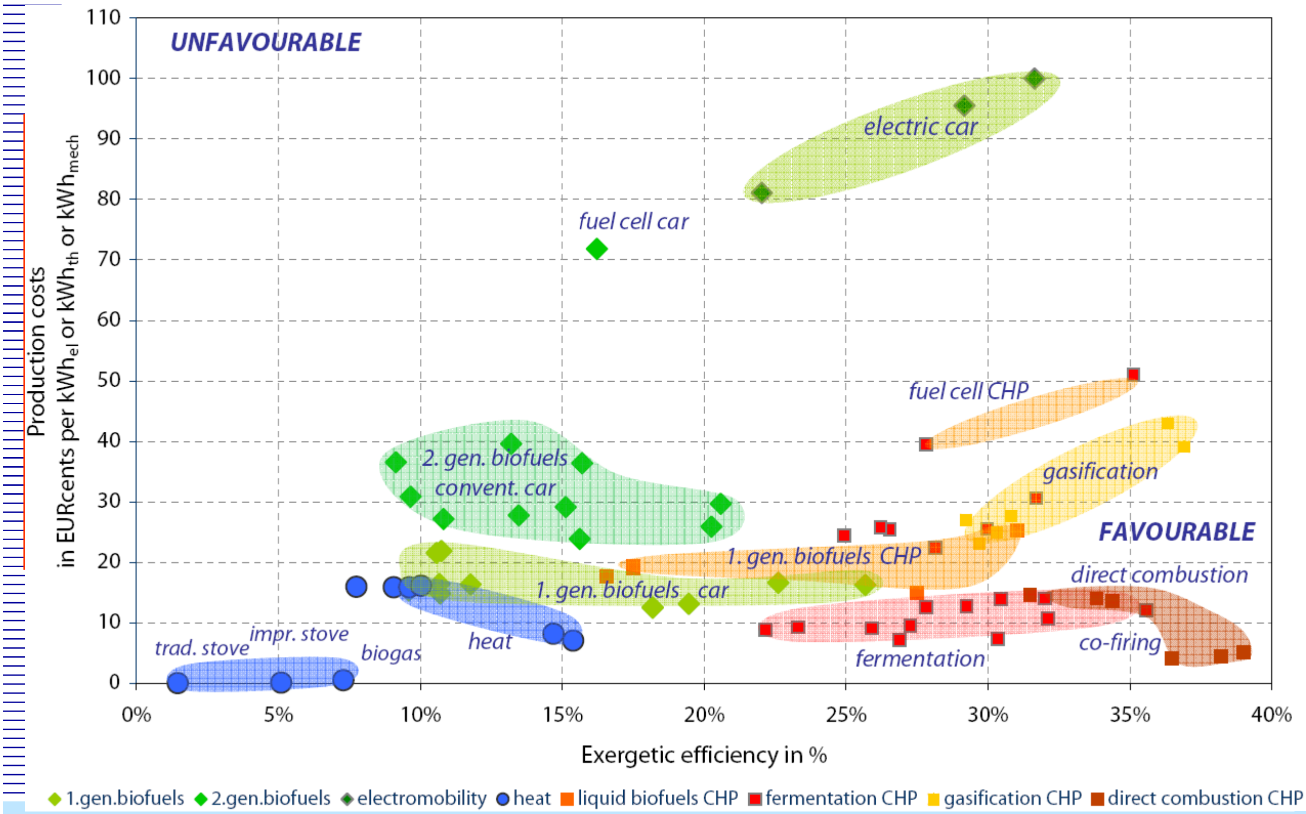
– Production costs VDI 2067 / 6025

Source: Sterner, 2009

Technical conversion efficiency in %



Source: Sterner, 2009



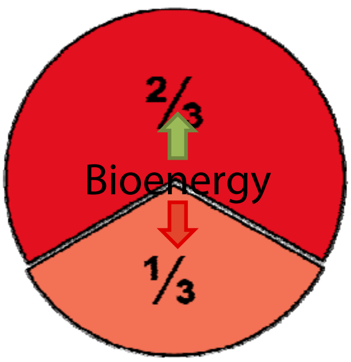
Source: Sterner, 2009

Content

1. BE contribution and potential
2. Land use competitions
3. 70 pathways: energy balances
4. GHG balances & methods
5. BE in energy systems
6. Conclusions

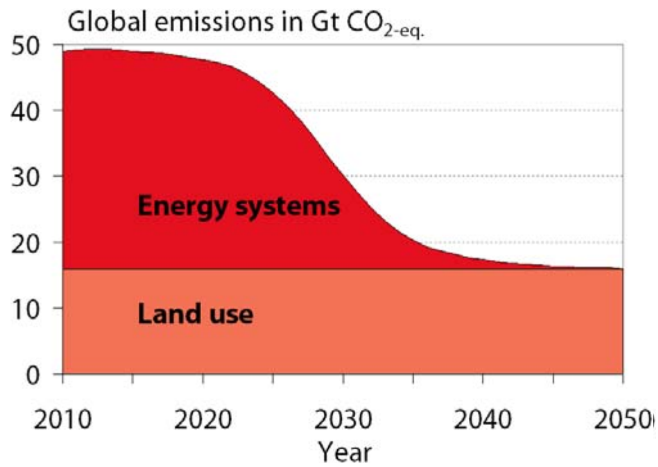
Global GHG emissions & necessary reductions

Energy systems
(power, heat, transport)



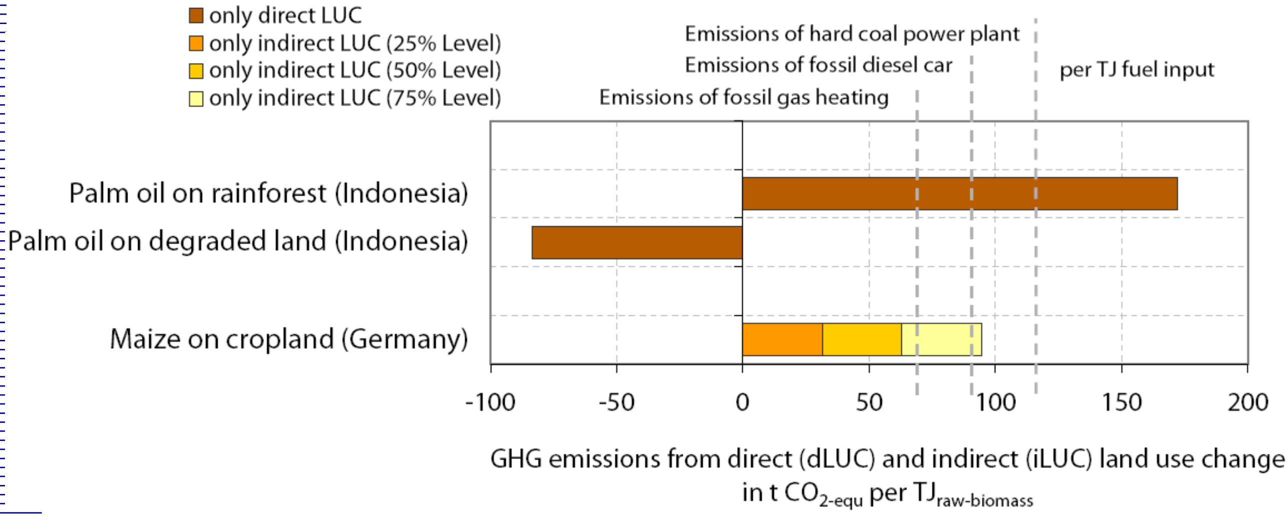
Land use
(agriculture, forestry, waste)

– Annual emissions: 50 Gt $CO_{2\text{-eq.}}$
– Limit global warming to 2° C
– Budget until 2050: 1,300 Gt $CO_{2\text{-eq.}}$



Source: Sterner, 2009

Effect of land-use changes on GHG balances



➡ Energy crops on degraded land

Source: Sterner, 2009

Effect of fossil reference systems on GHG balances

Energy sector	Reference system	Emissions in g $CO_{2\text{-eq.}}$ per kWh_{th} fuel input
Transport	Diesel	316
Heat	Oil	321
Power	Hard coal	411
	Natural gas	234

➡ Focus on carbon-intensive fuels

Methodology:

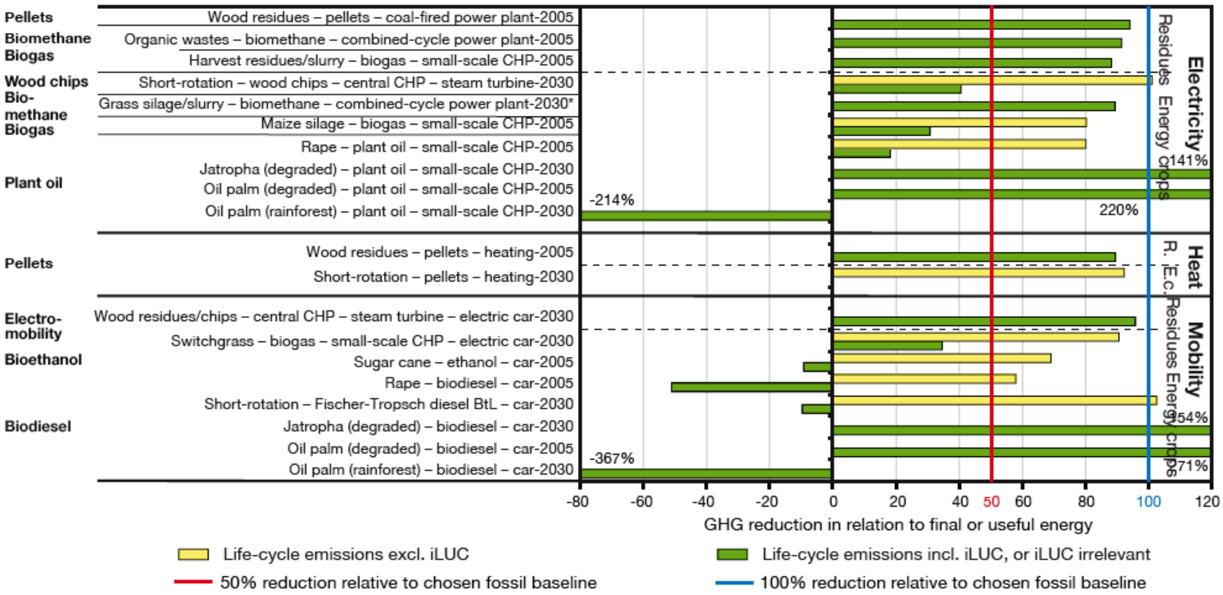
Data: Uwe Fritsche / Ökoinstitut

Model: GEMIS 4.5

Allocation method: energy content – Functional unit: various

WBGU

Relative reduction of GHG emissions in relation to final or useful energy in % compared to fossil baseline

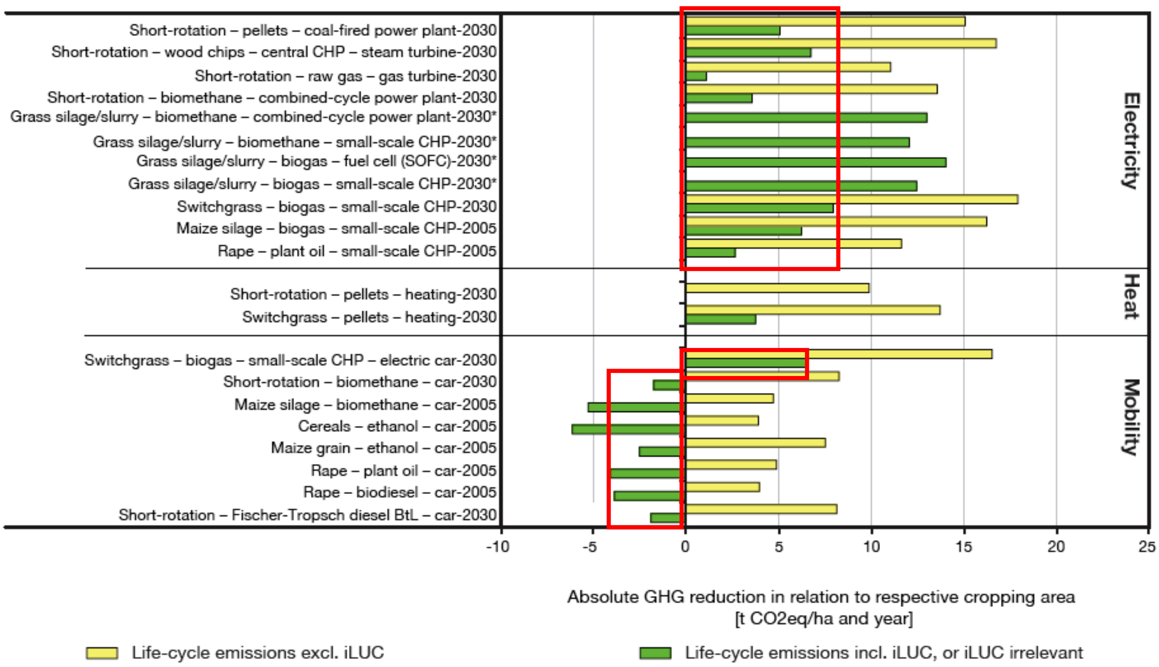


Under discussion in legislative process, but <u>not useful as standard</u>, as it is not apparent how much biomass was deployed (1 l biofuel from 1 or 10 ha?).

Source: WBGU, 2008

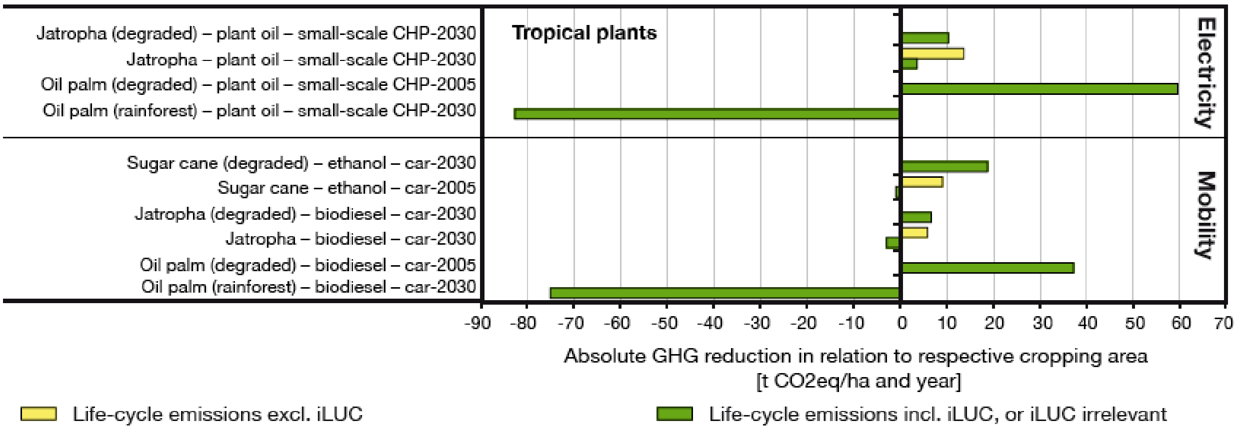
WBGU

Absolute reduction of GHG emissions for temperate energy crops, in relation to cropping area in t CO_2-eq. per hectare and year



Source: WBGU, 2008

Absolute reduction of GHG emissions for tropical energy crops, in relation to cropping area in t CO_2-eq. per hectare and year



Weaknesses of this parameter (functional unit):

- It cannot be applied to residues and waste
- The hectare yields and heating values of energy crops vary widely

Source: WBGU, 2008

Why a new GHG criterion?

Greenhouse gas standards discussed in the past:

Reduction of GHG emissions per litre petrol or diesel (in %)

It is not asked how much biomass is needed to produce the fuel.

Problem:

- limited quantity of sustainably producible biomass
- maximum climate change mitigation effect?
- area-related standard neither serves the purpose (varying hectare yields, missing residues)

WBGU proposal for standard:

→ level of GHG reduction with a given quantity of biomass.

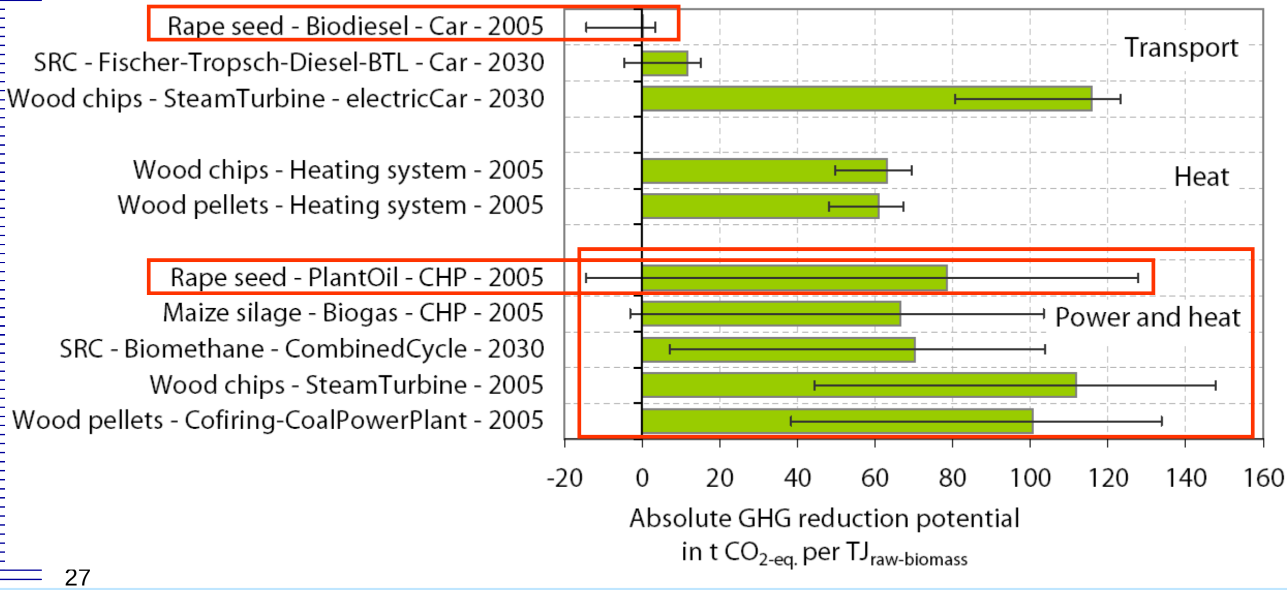
Minimum standard:

30 t CO_2eq reduction per TJ biomass feedstock deployed.

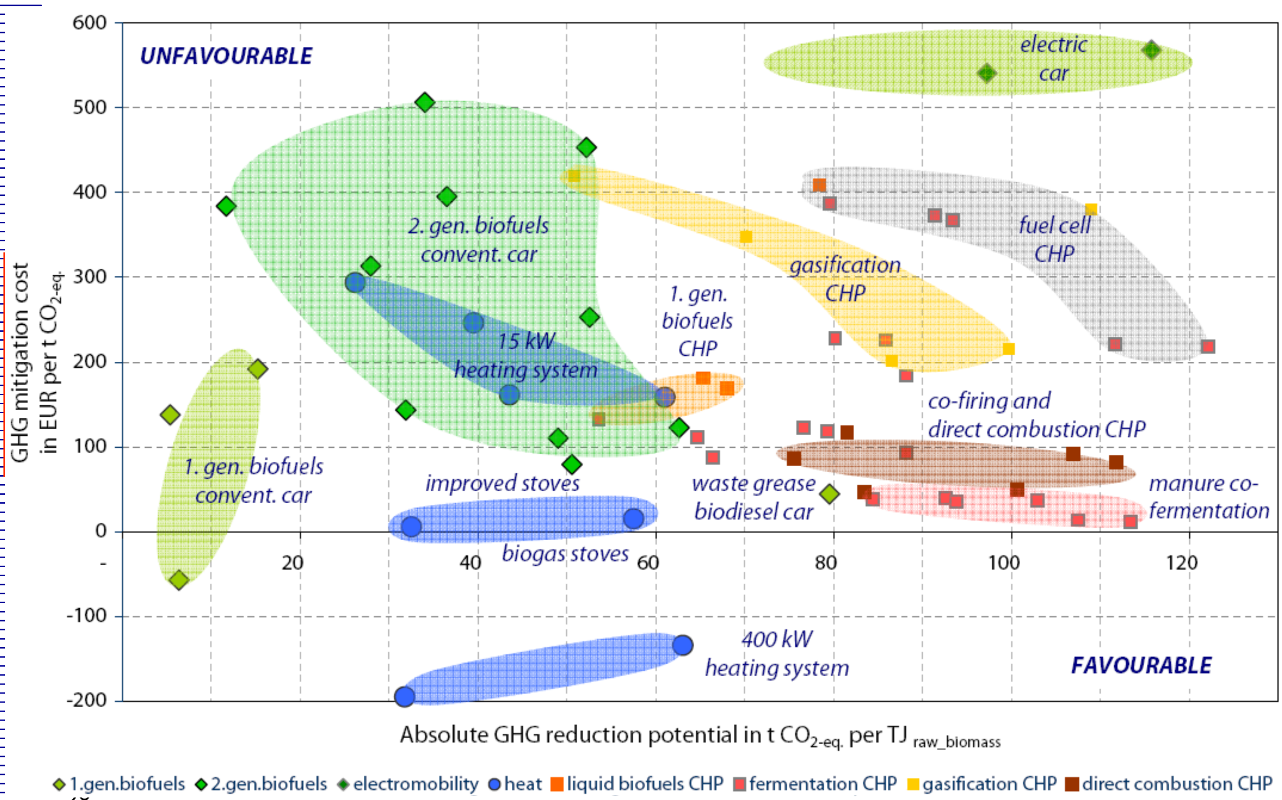
The outcome: in electricity generation (in most countries) → much greater mitigation effect than in transport sector with the same quantity of biomass

GHG reduction potential in t $CO_{2\text{-eq.}}$ per $TJ_{raw\text{-}biomass}$

Examples



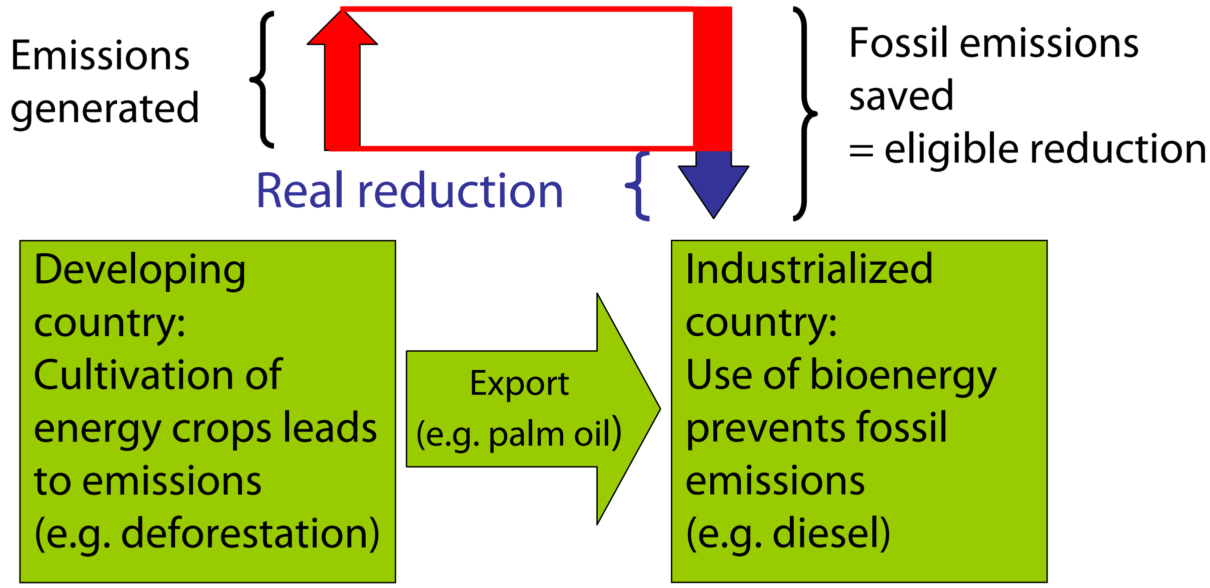
Source: Sterner, 2009



Source: Sterner, 2009

WBGU

False incentives created by the Kyoto Protocol



Eligible (“accountable”) reduction > real reduction

Source: WBGU, 2008

WBGU

Climate change mitigation potential of bioenergy

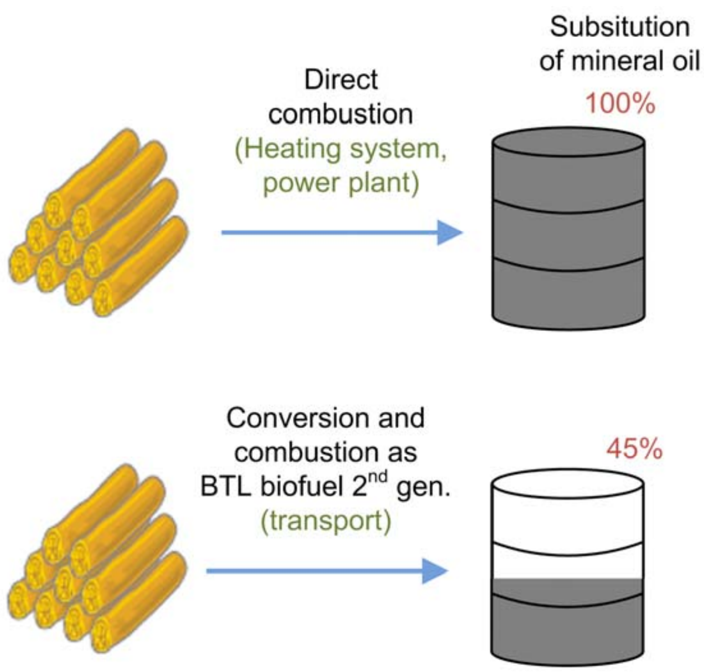
- Sustainable technical bioenergy potential: 80 - 170 EJ per year, economic: roughly half (timeline: 2050)

- Using this full potential with the best pathways (no land-use changes, biomass substitutes mainly coal) 60 t CO_2eq per TJ raw biomass
  → saving GHG emissions of 2-9 Gt CO_2eq per year
  → avoid about 5-20% of present global GHG emissions

Content

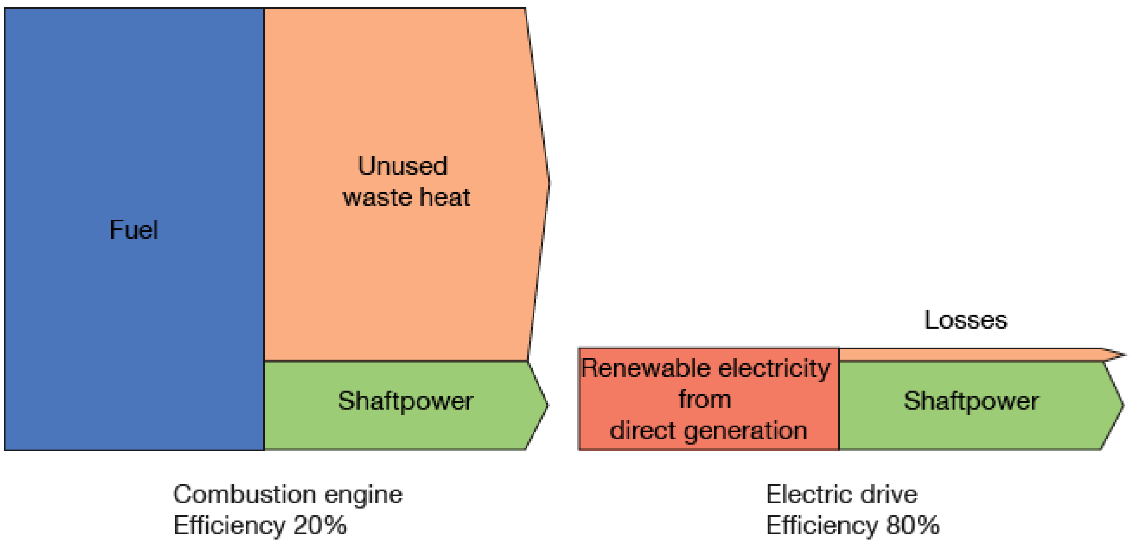
1. BE contribution and potential
2. Land use competitions
3. 70 pathways: energy balances
4. GHG balances & methods
5. BE in energy systems
6. Conclusions

Woody biomass as mineral oil substitute



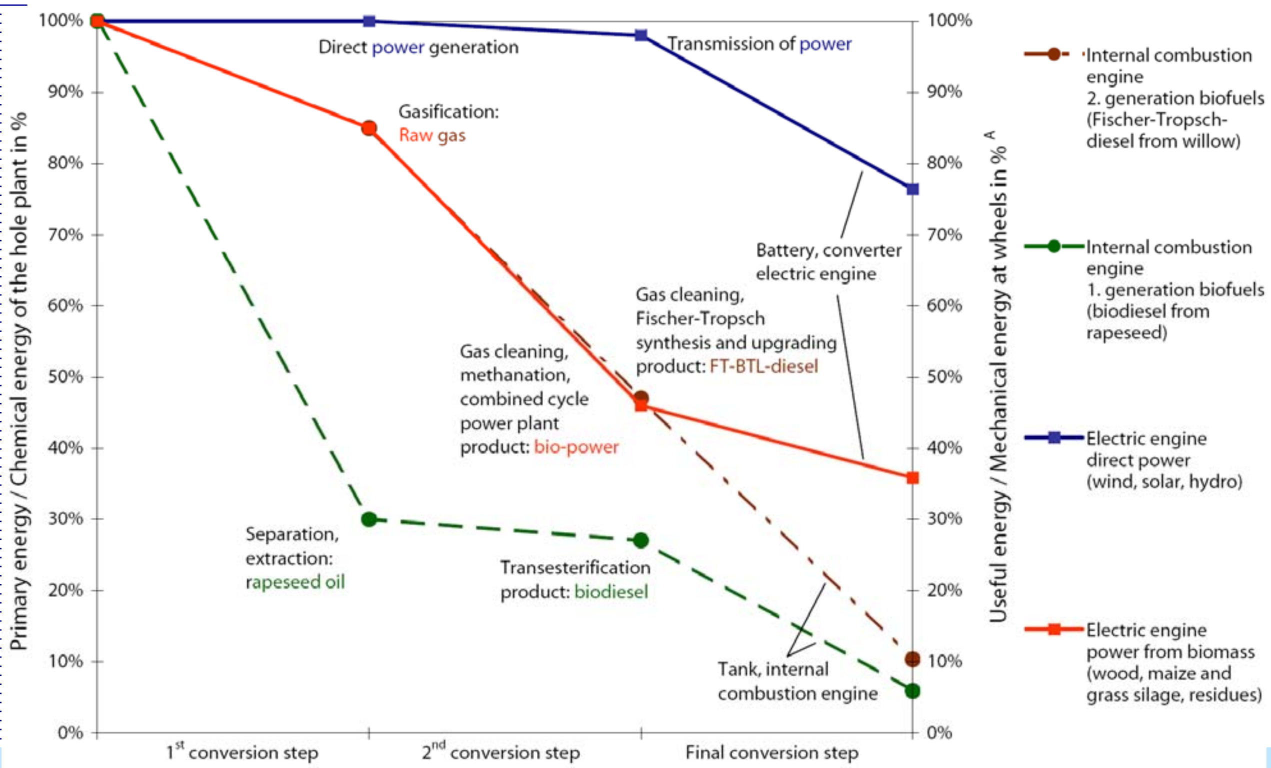
Source: WBGU, 2008

Energy efficiency in transportation: Combustion engine vs. electric drive



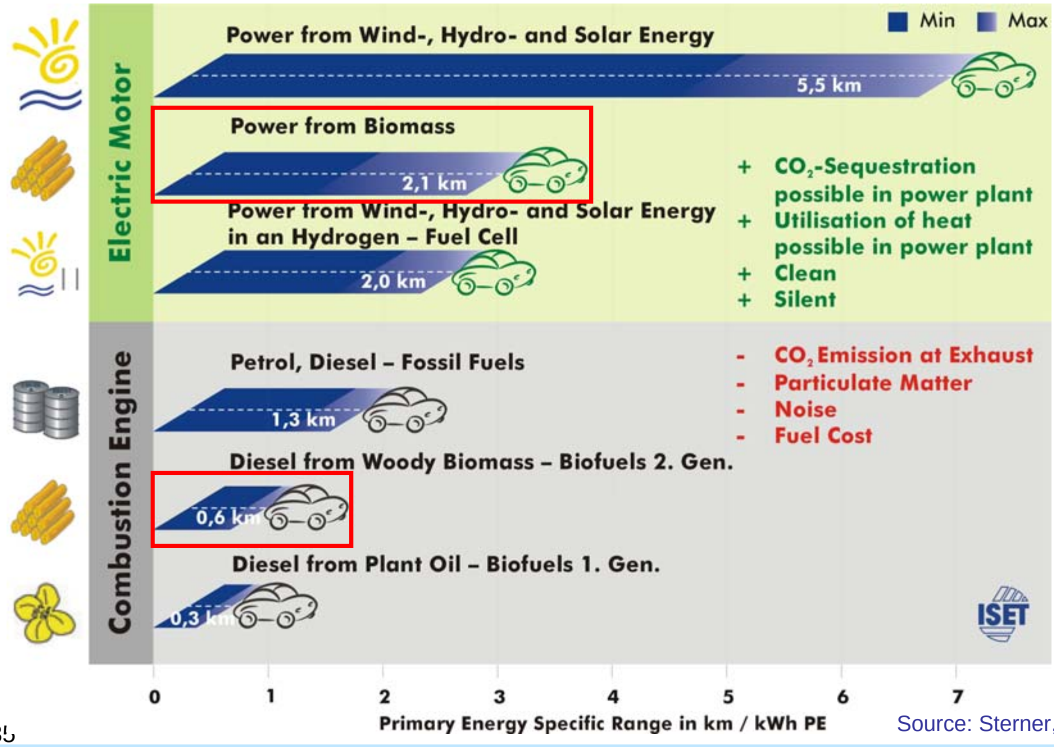
Source: WBGU, 2008
+ Sterner et al, 2008

Efficient use of bioenergy in mobility



Source: WBGU, 2008

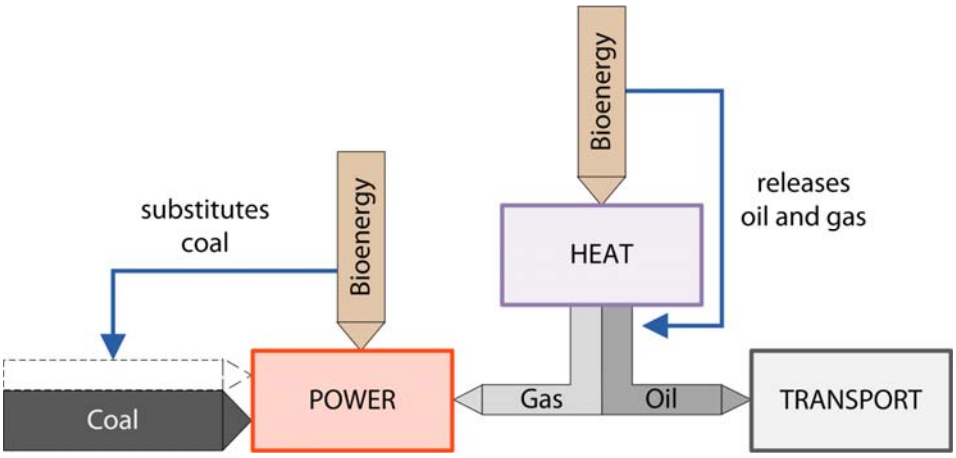
Electromobility with biomass – Range of a car



Source: Sterner, Schmid, 2008

Energy systems – modern bioenergy

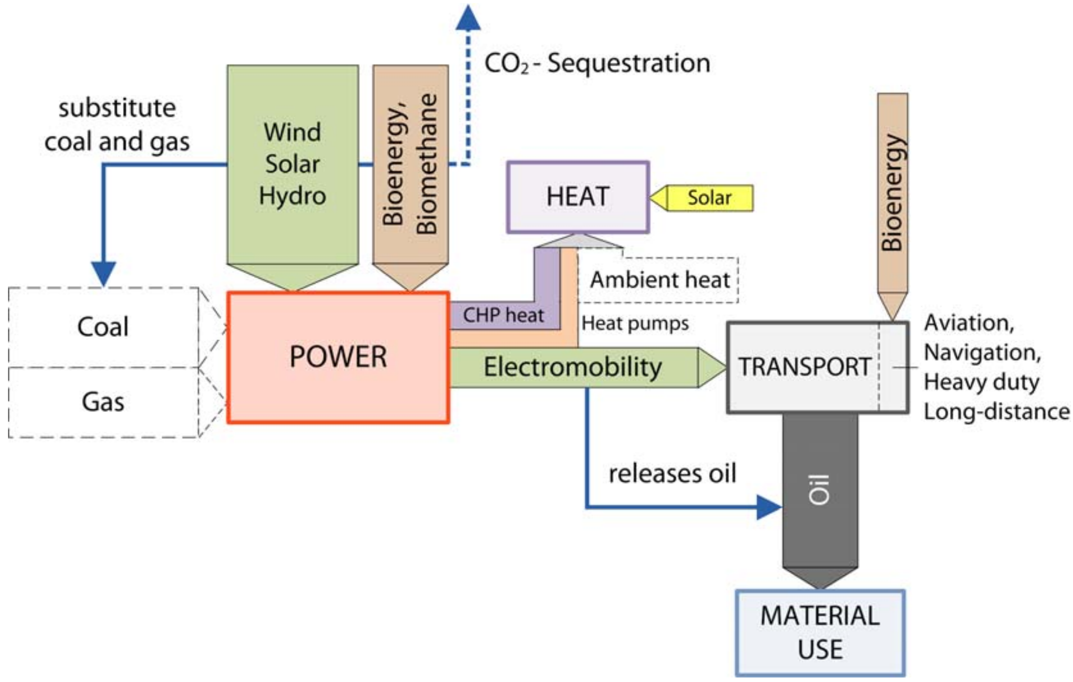
1. Replacing carbon-intensive energy at low costs
   → low hanging fruits first



Source: WBGU, 2008

Energy systems – 2. strategic functions

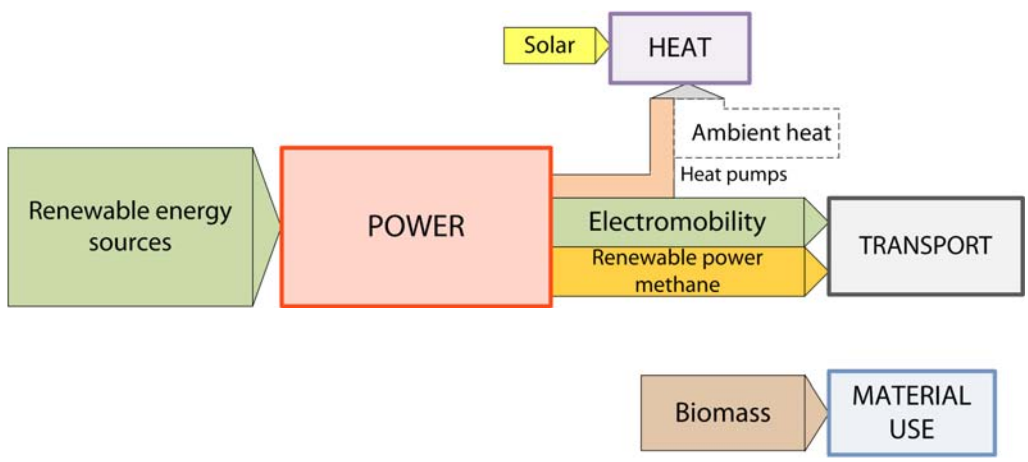
Balancing power and high energy density fuel



Source: Sterner, 2009

Energy systems – 3. carbon source

Replacing fossil fuels in chemical industry



Source: Sterner, 2009

Bioenergy in developing countries

- **In the past: Inefficient and harmful to health**
  Efficiency: 5–10%

- **Simple alternatives: Improved cooking stoves** (efficiency 30–40%) **and small-scale biogas digesters in households, small-scale plant-oil CHP units, biomass gasification facilities instead of coal-fired power plants for electricity generation**




Source: Private Photos, 2008

Content

1. BE contribution and potential
2. Land use competitions
3. 70 pathways: energy balances
4. GHG balances & methods
5. BE in energy systems
6. Conclusions

Criteria for a bioenergy sustainability standard

- Reduction of **life-cycle GHG emissions** (min. 30 t CO_2 per TJ biomass feedstock, incl. direct and indirect land-use changes)
- Avoidance of indirect **land-use changes** (iLUC factor)
- Preservation of **protected areas** and of areas of high conservation value
- Maintenance of **soil quality** and fertility
- Sustainable use of (forest) **residues**
- Sustainable management of **water resources**
- Prevention of undesirable consequences of the use of **genetically modified organisms**
- Observation of elementary **ILO core labour standards**

Global land-use management as a major future task

- Rising demand for **food**
  due to growing population (+ 50% by 2030)
- Changes in nutrition patterns and **diets**
  due to growing welfare
- Constraints on potential **yields**
  due to land and water scarcity, soil degradation and climate change
- Rising pressure on **land-use**
  due to growing importance of energy crops

⇨ Use bioenergy discussion to establish sustainability in land use

WBGU

Conclusions on bioenergy (1)

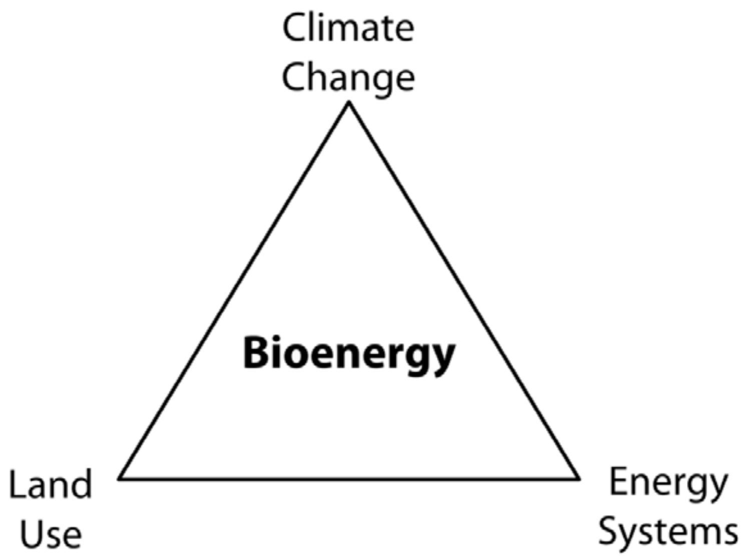
- Climate protection and climate damage are close-up
  → Use of **perennials** and **marginal, degraded land**
- Maximum climate change mitigation by bioenergy
  → **substitute coal**
  → Power generation, **CHP,** not as biofuels in transport
  promote instead **electromobility**
- Prevent emissions from land-use changes:
  Prioritize **use of residues**

WBGU

Conclusions on bioenergy (2)

- Main energy efficiency potential: Overcome **traditional bioenergy use** and mitigate health hazards
- Bioenergy (**Energy crops**) are a **‚brigde'** into a **sustainable energy future** until 2030/2050
  - **All available fertile land** →nurish increased global population (by 2030, 50% more **food** comodities will be required)
  - Future main strategic use of biomass → **material use** in industry to substitute fossil feedstocks (chemicals, plastics, etc.)
    Energy can be provided by other means, carbon not.
  - Future energy demand → met by **other renewable energy sources** in a more economic and climate friendly way
    (almost **no GHG emissions** and **no feedstock costs** of wind, solar, hydro, etc.)

Triangle of sustainable bioenergy



Source: Sterner, 2009

Main Sources

WBGU (2008): Future bioenergy and sustainable land use. Flagship report 2008. Berlin: WBGU – German Advisory Council on Global Change. http://www.wbgu.de

Sterner (2009): Bioenergy and renewable power methane in integrated 100% renewable energy systems; Limiting global warming by transforming energy systems. Dissertation. Renewable Energies and Energy Efficiency 14. kassel university press, ISBN: 978-3-89958-798-2. http://www.upress.uni-kassel.de/publi/abstract.php?978-3-89958-798-2

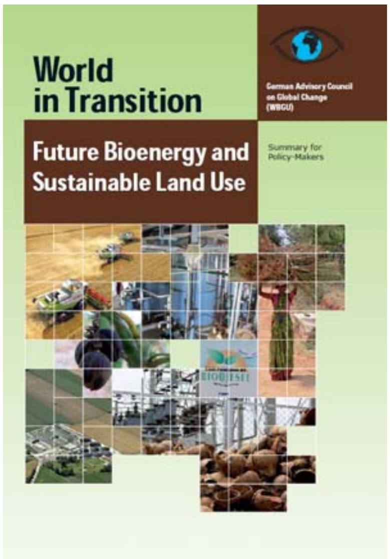
Contact

Dr.-Ing. Michael Sterner

msterner@iset.uni-kassel.de

Tel. +49 – 561 – 72 94 361

www.iset.de
www.wbgu.de



**Factsheet and Book
online available for free at
www.wbgu.de**

Thank you!