Energy System Modelling
in the context of climate change

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Outline

- Challenges to the energy system
- Strategies to reduce CO_2 emissions from the energy system
- Alternative transportation fuels
- Group exercise – ”Best use of biomass?”
- The GET-model
- Discussion – “biofuels for transport or not?”
- Why two similar models get different results
- How to interpret model results

Challenges to the energy system

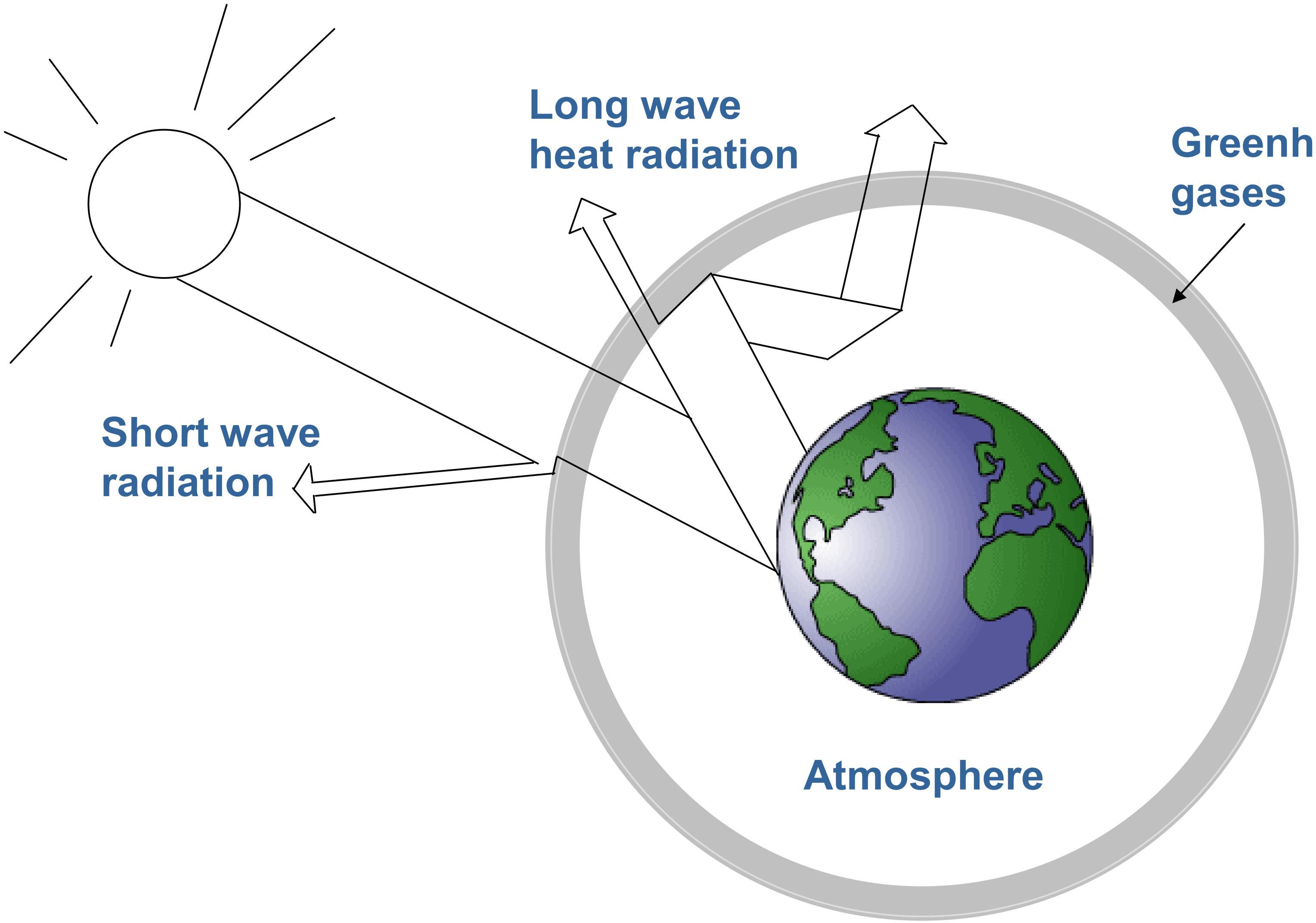
The Energy System (electricity, heat and transportation fuels) faces at least three long-term challenges

i. The resource base

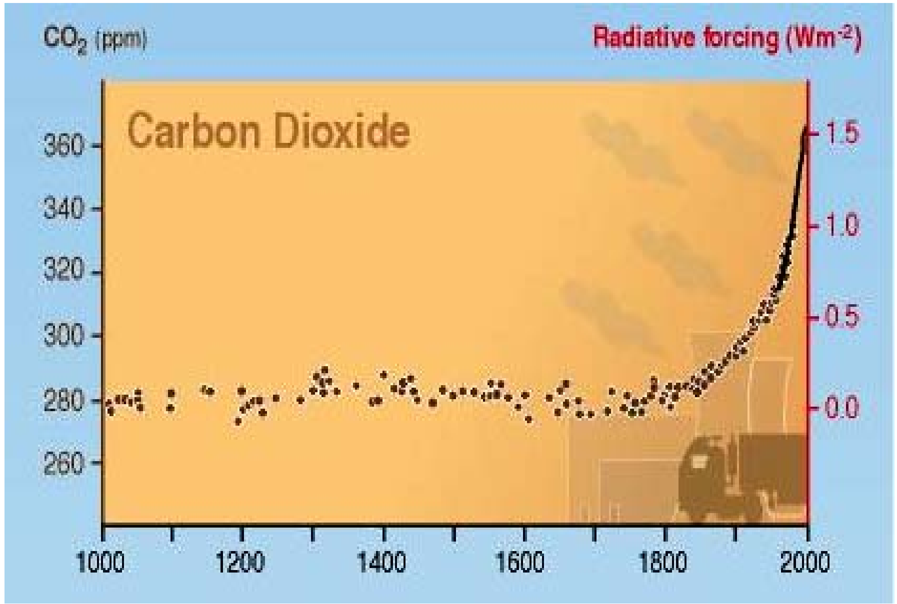
ii. Energy security

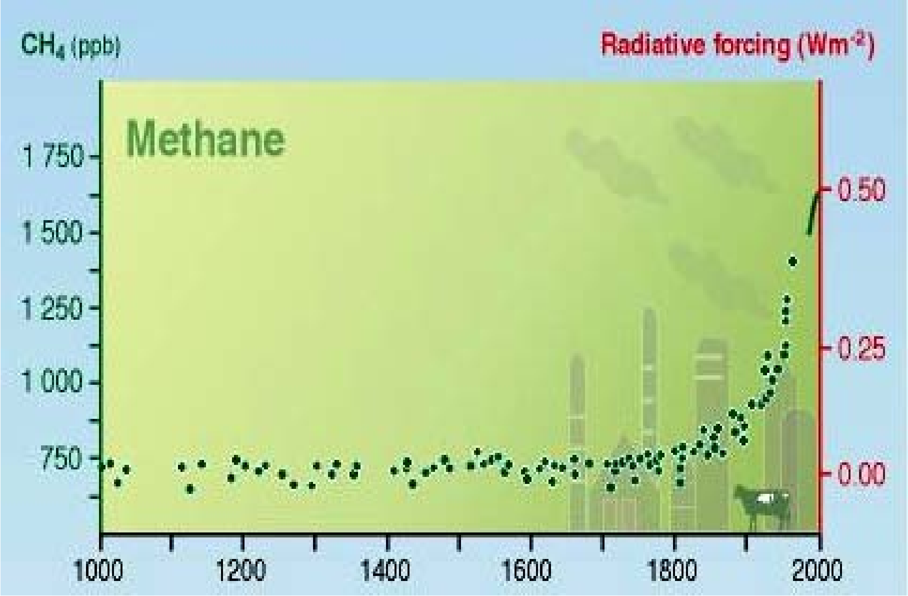
iii. Impact on global climate

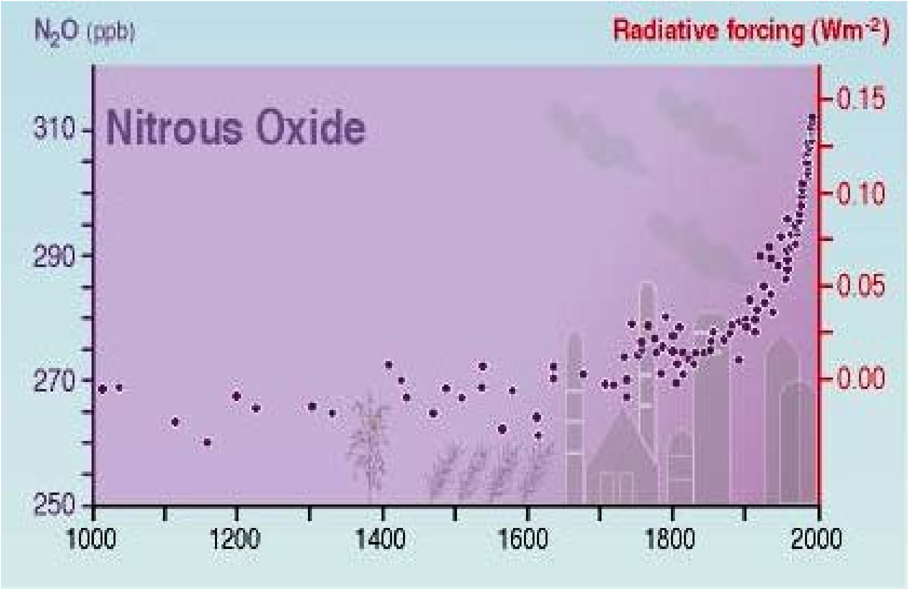
The greenhouse effect



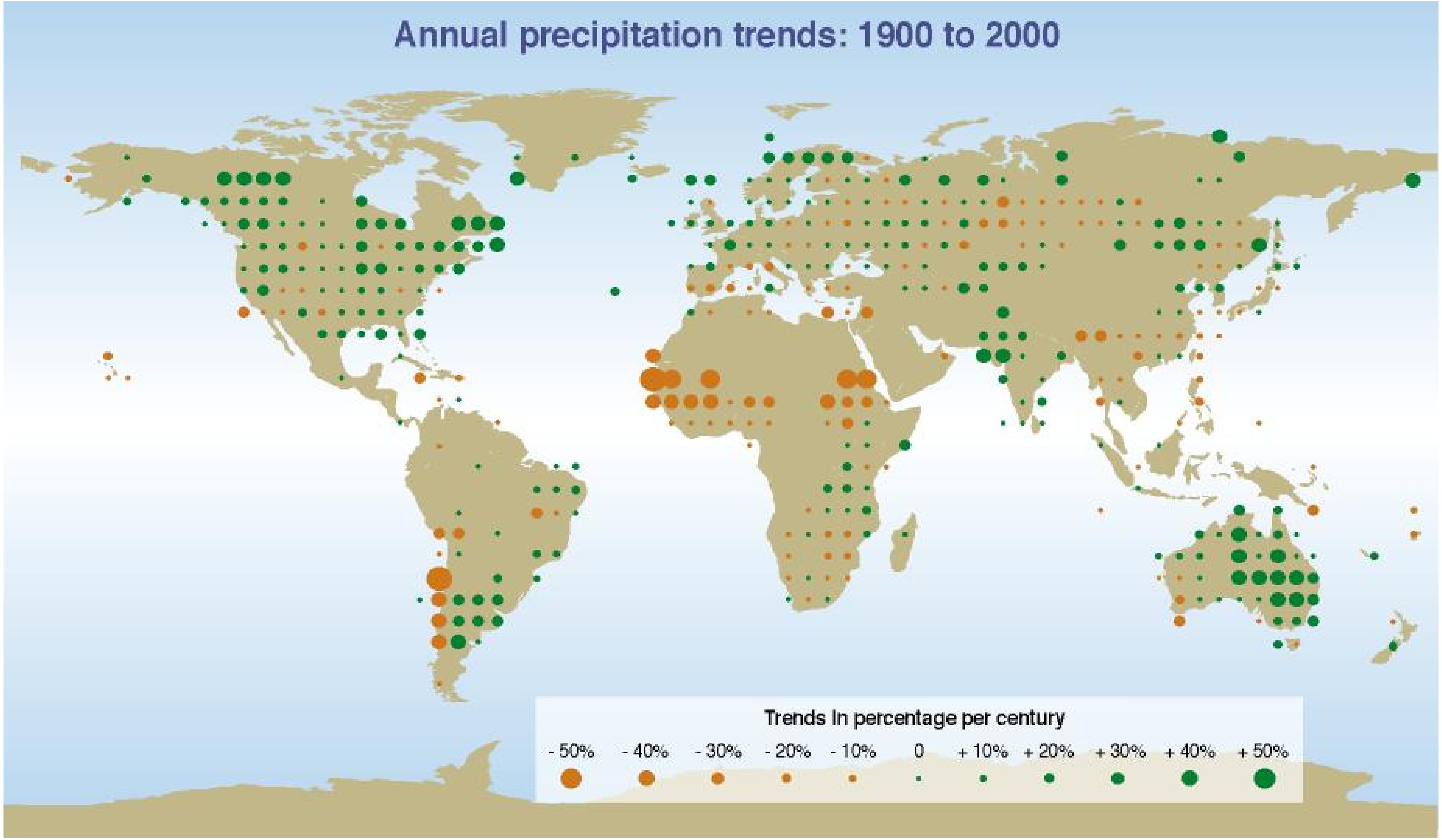
The concentration of the three most important greenhouse gases





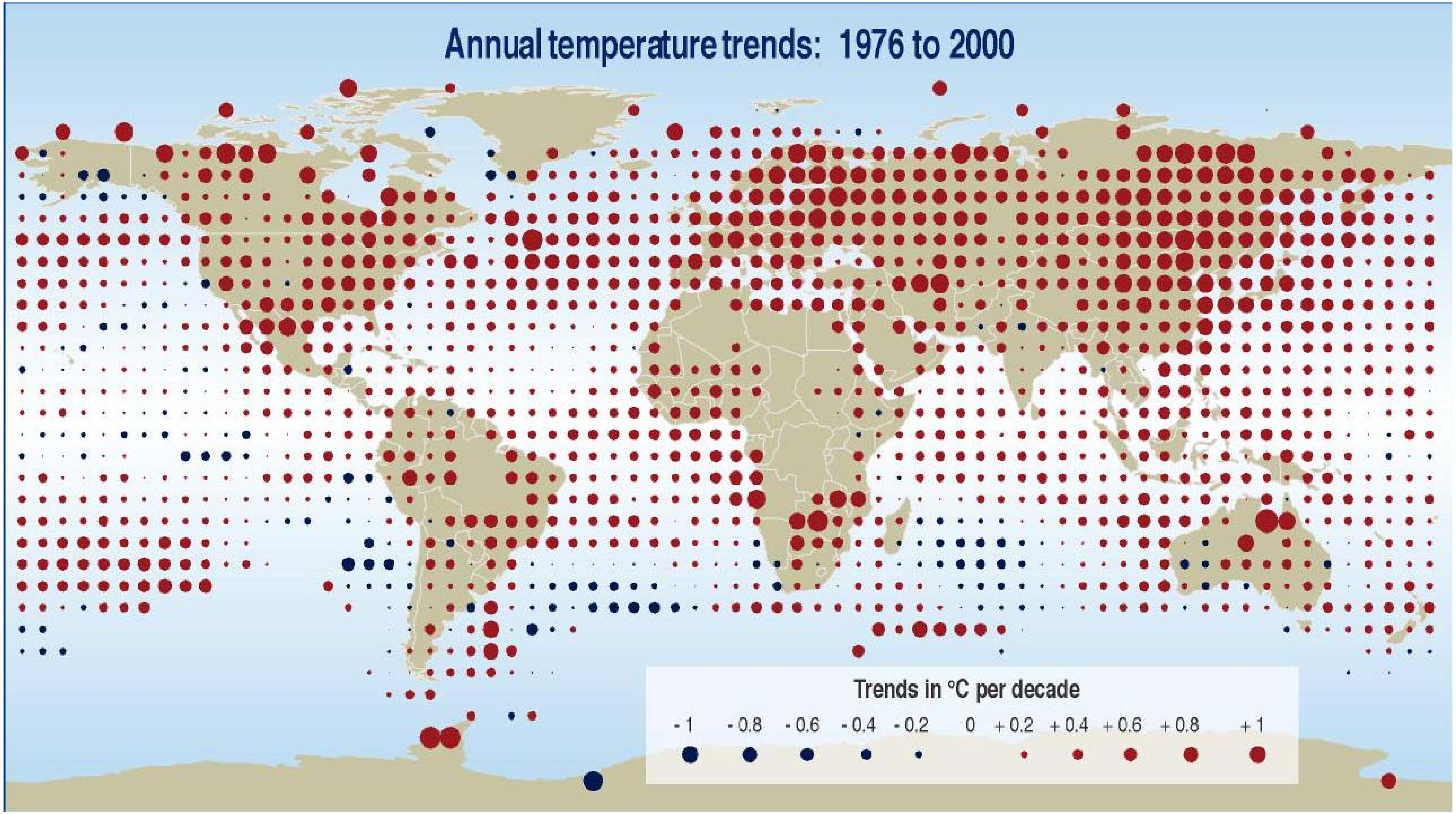


Annual precipitaion pattern has changed



Source: www.ipcc.ch

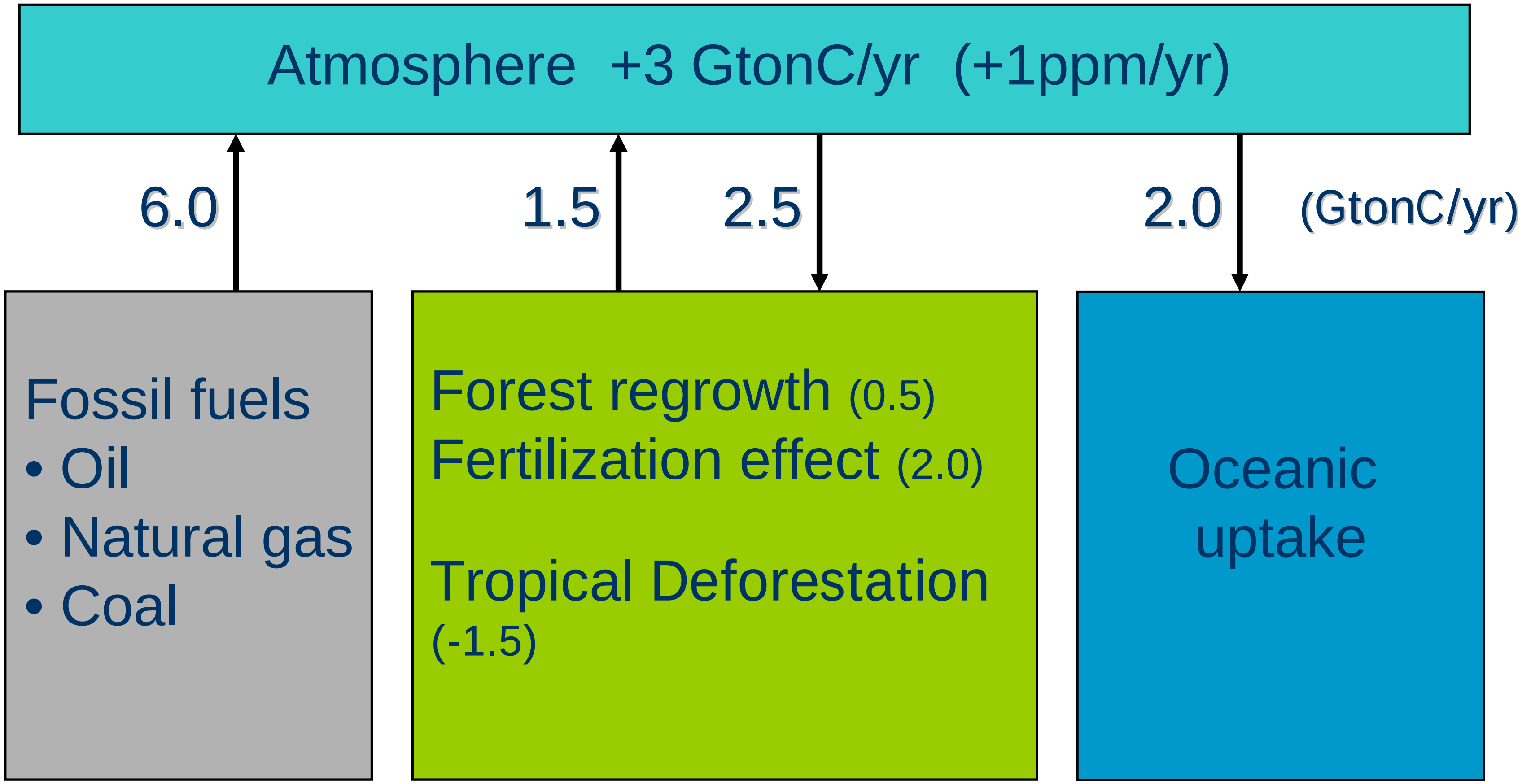
Annual temperature pattern has changed

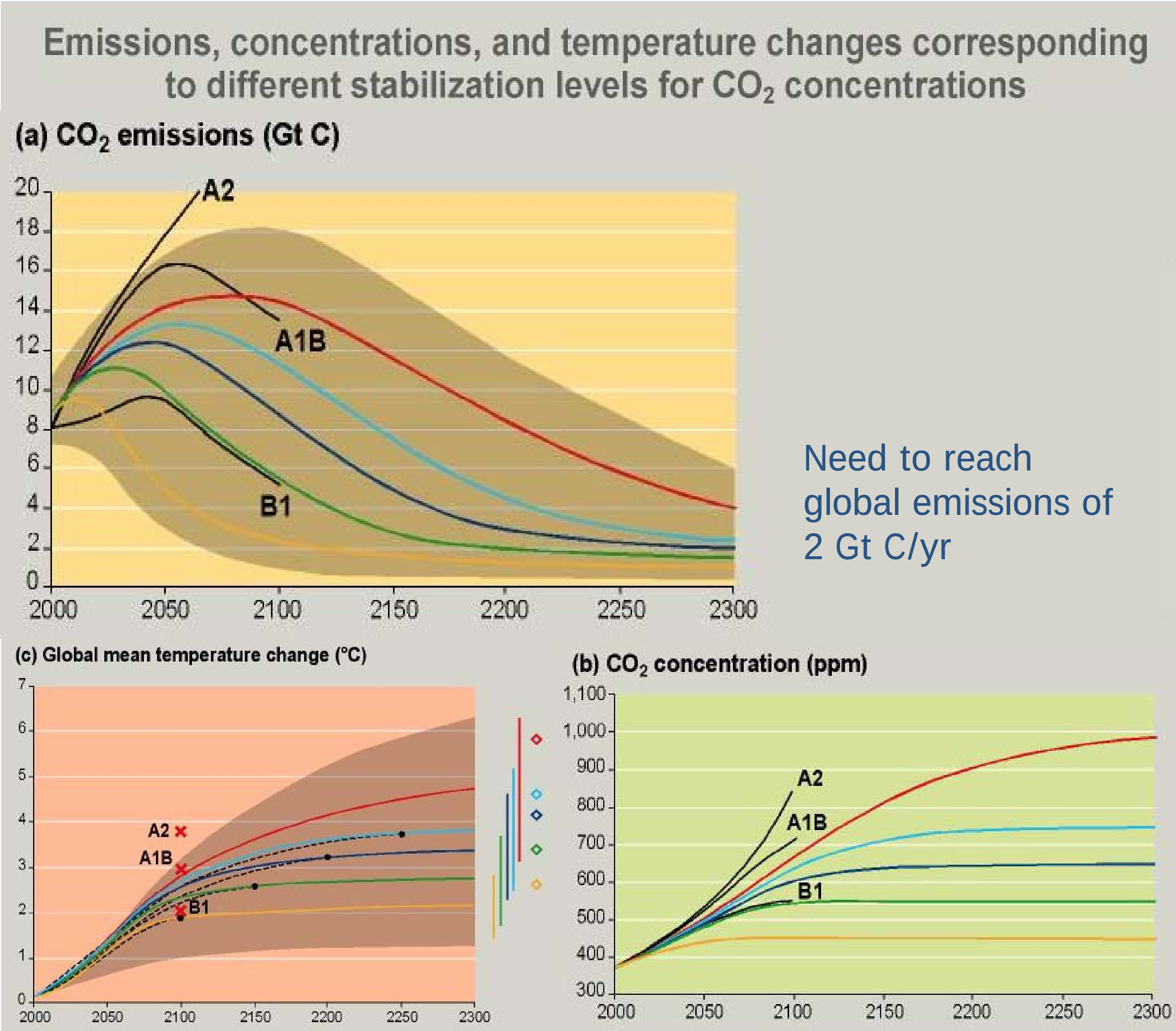


Source: www.ipcc.ch

Human influences on the carbon-cycle

Combustion of fossil fuels and deforestation are the most important anthropogenic sources for CO_2 emissions to the atmosphere

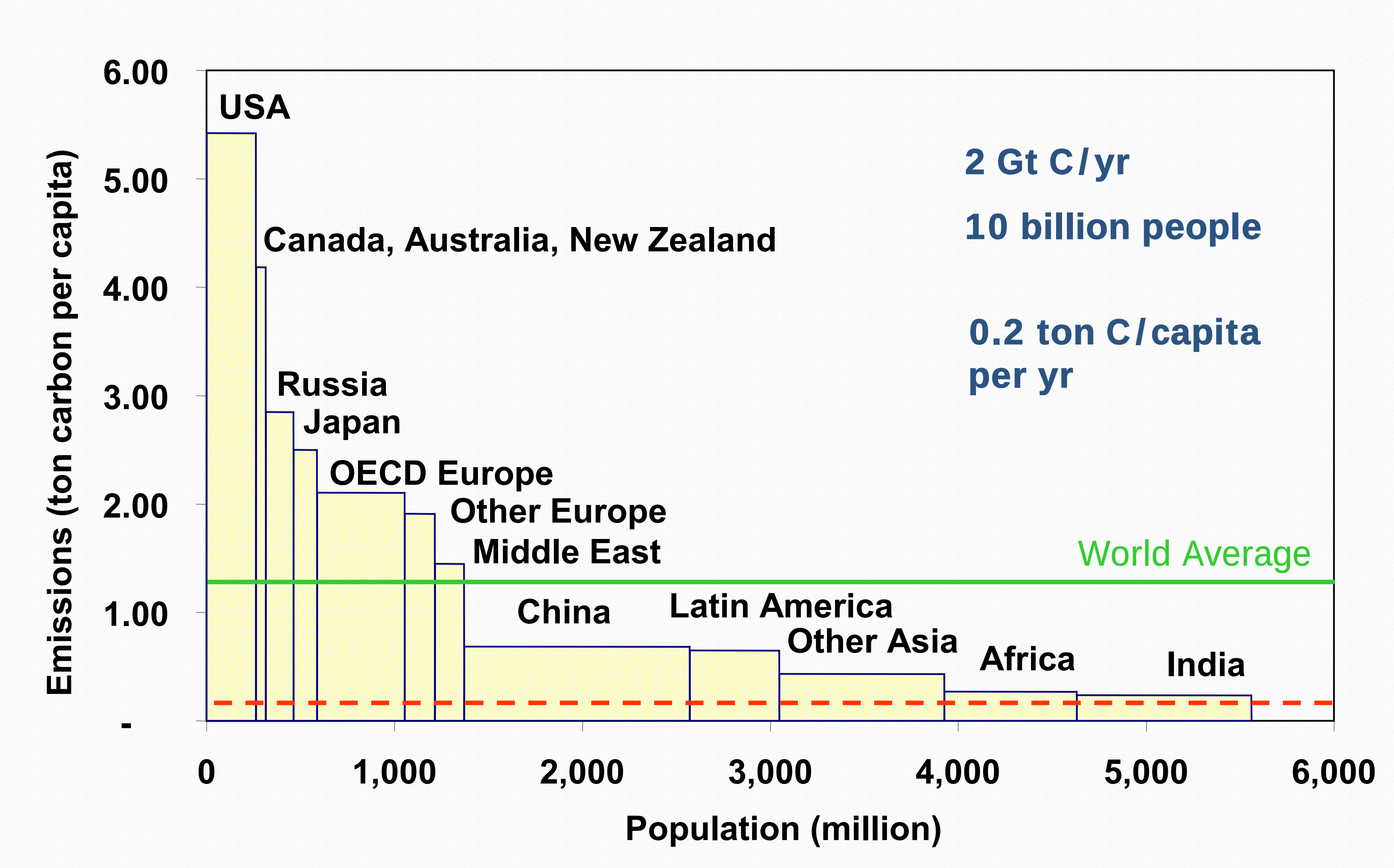




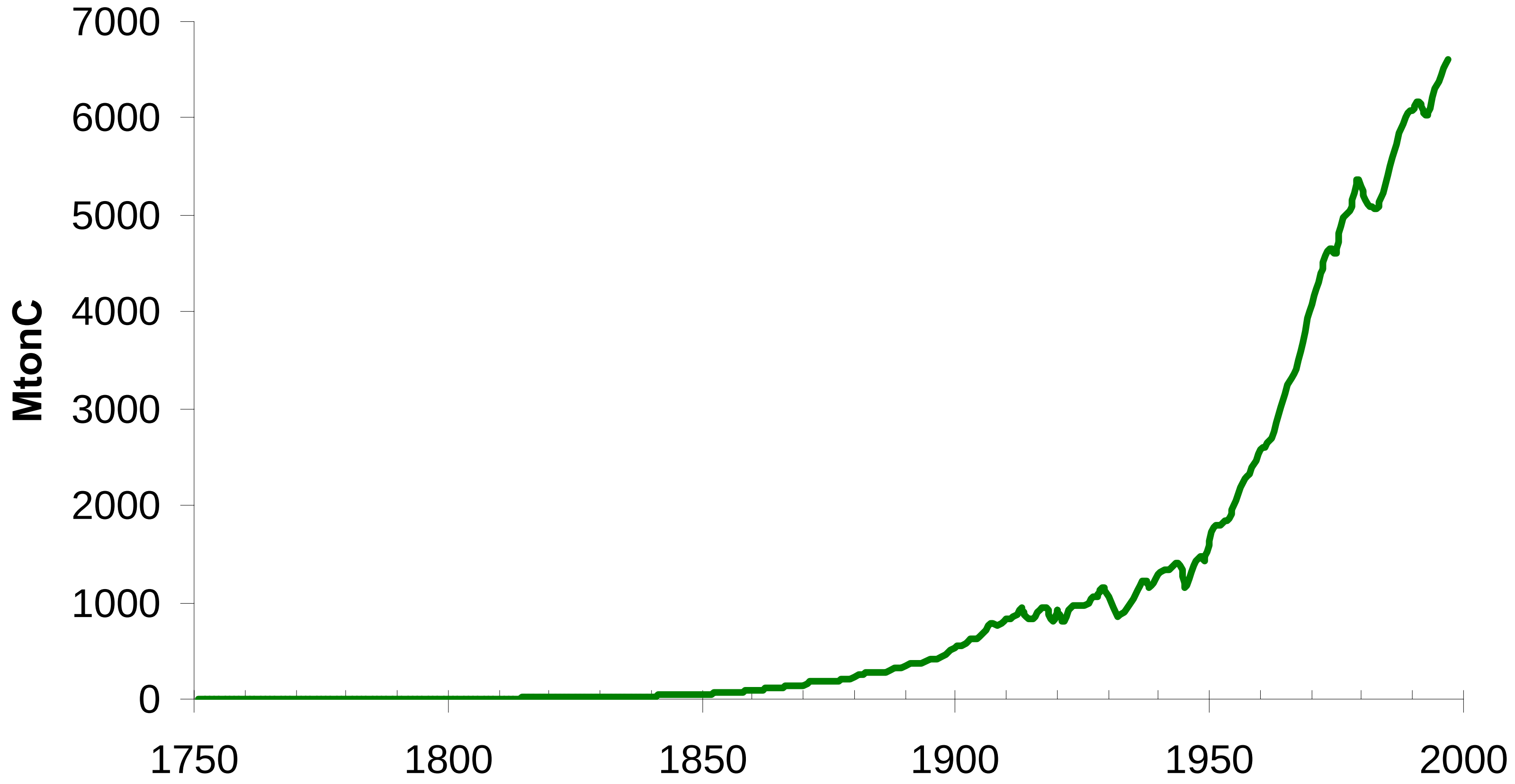
Need to reach global emissions of 2 Gt C/yr

Källa: www.ipcc.ch

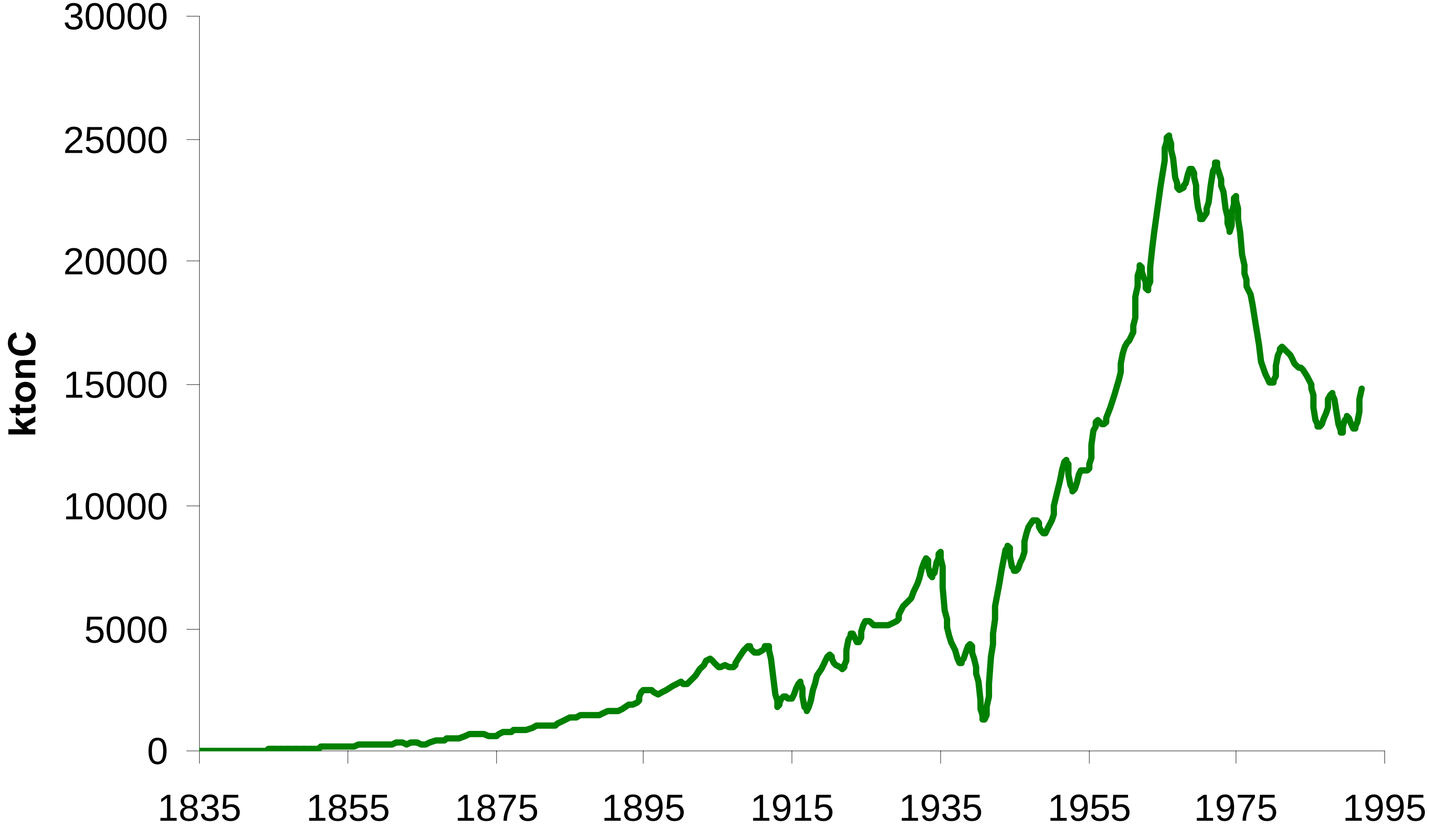
CO_2-C emission per capita, 1998



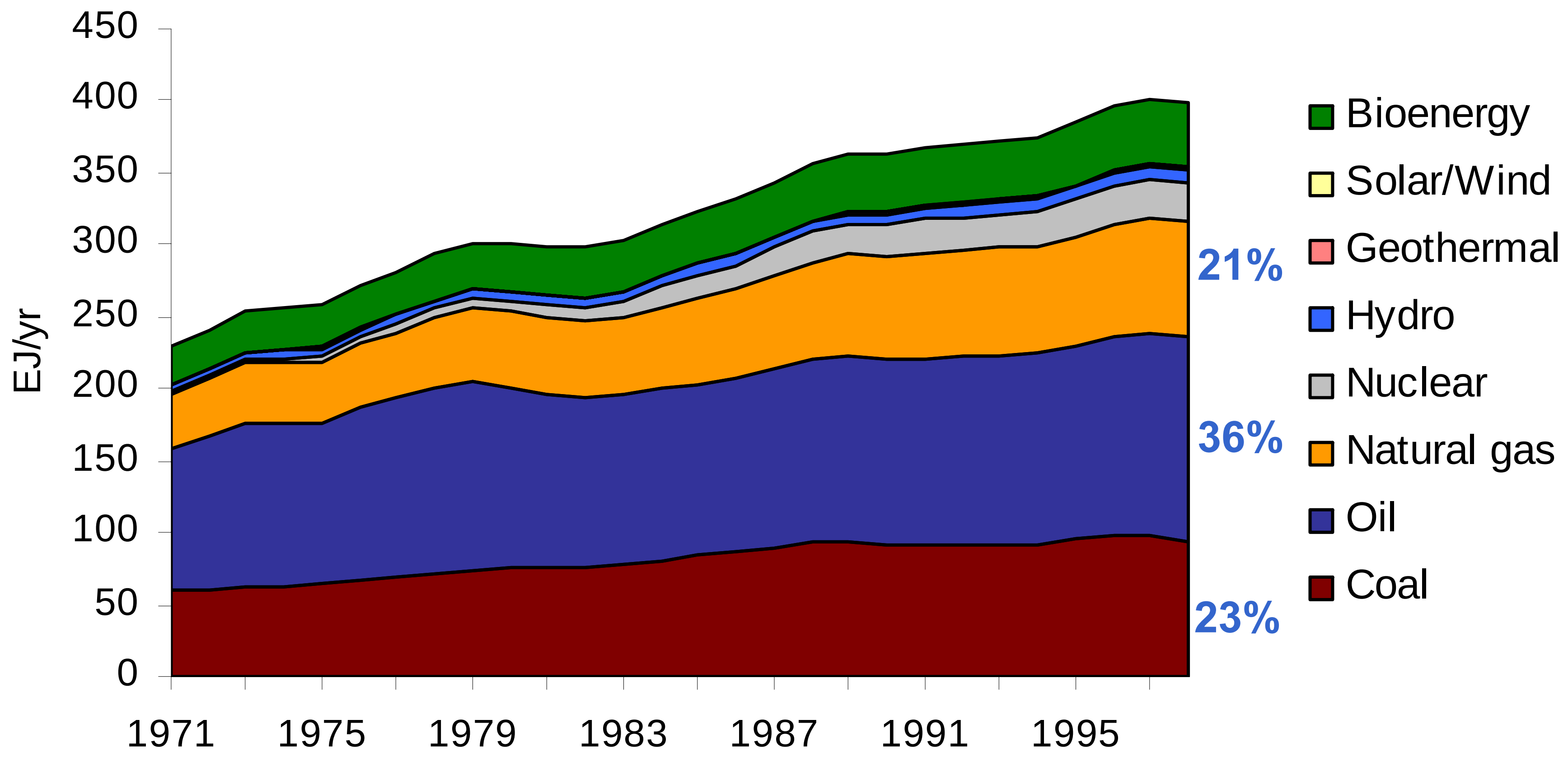
Historical global emissions of CO_2 from fossil fuel combustion

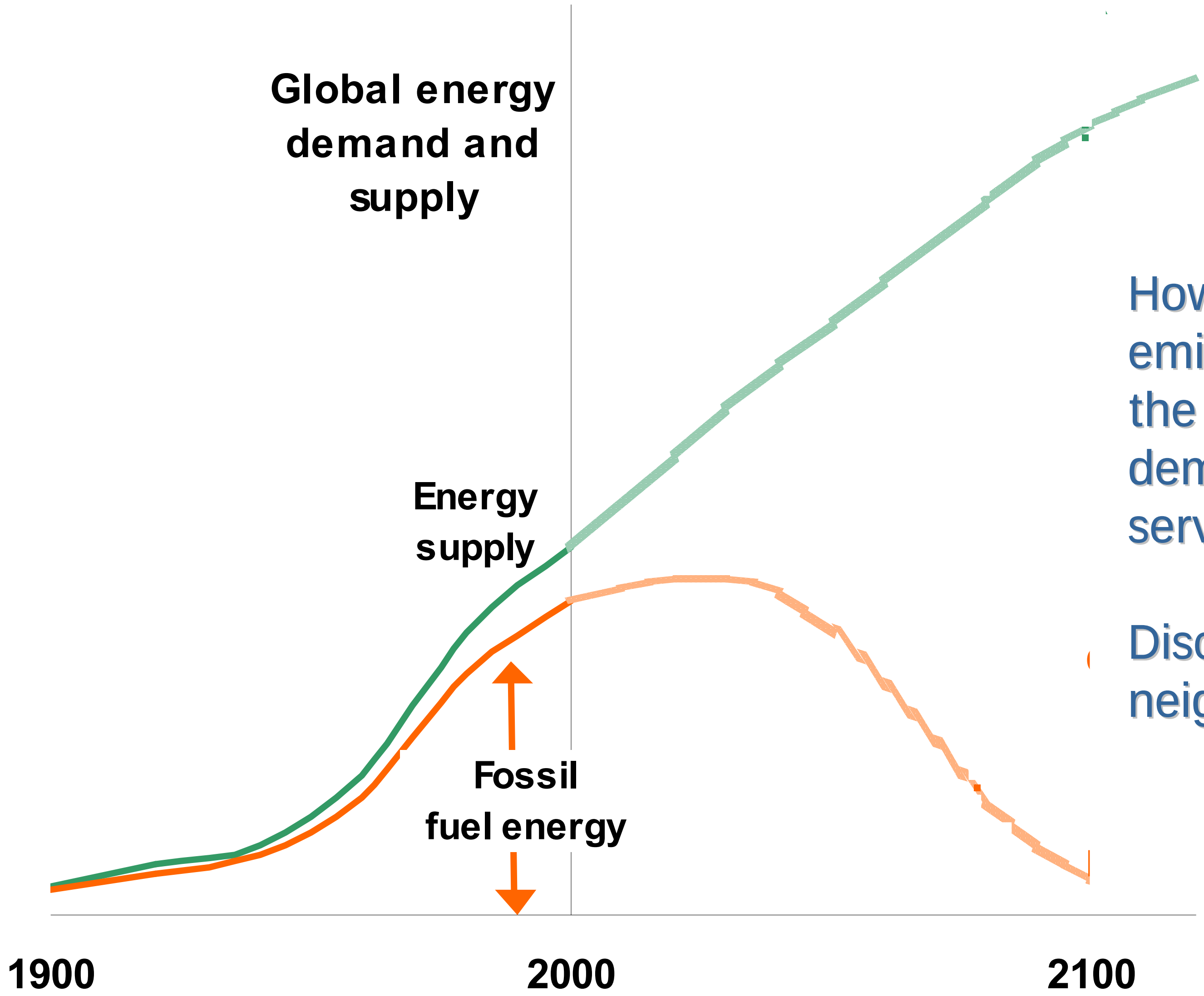


Historical Swedish emissions of CO_2 from fossil fuel combustion



Global primary energy supply





How can the CO2-emission decrease at the same time as the demand for energy service increase?

Discuss with your neighbour.

An Environmental Impact Formula

$$I = P \cdot A \cdot T$$

$$impact = person \cdot \frac{consumption}{person} \cdot \frac{impact}{consumption}$$

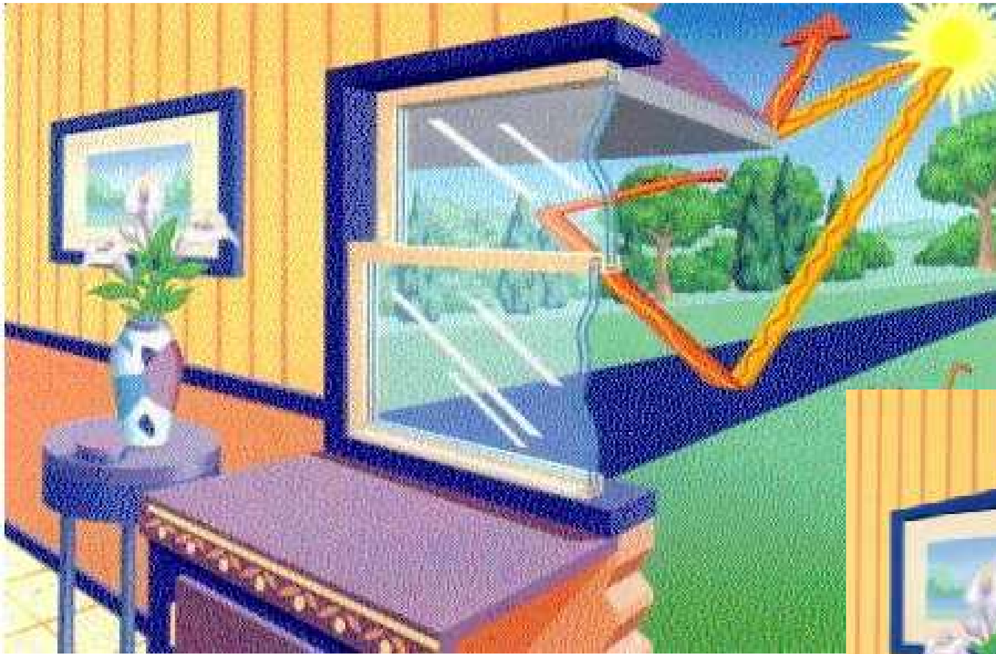
I: impact (on environment)

P: population

A: affluence - consumption per person (living standard)

T: technology - impact per consumption (technology development)

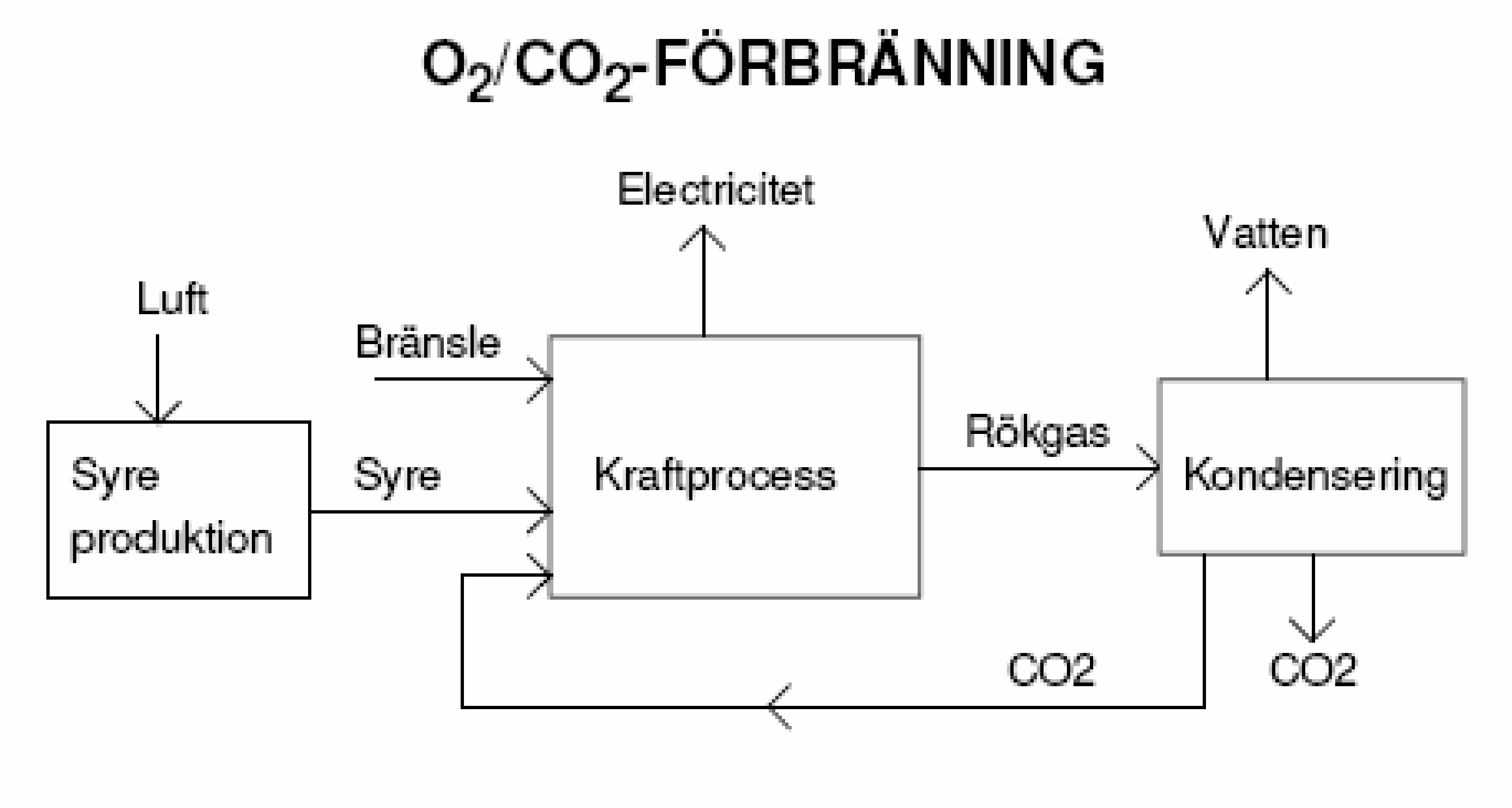
Energy efficiency



Carbon Capture and Storage (CCS)

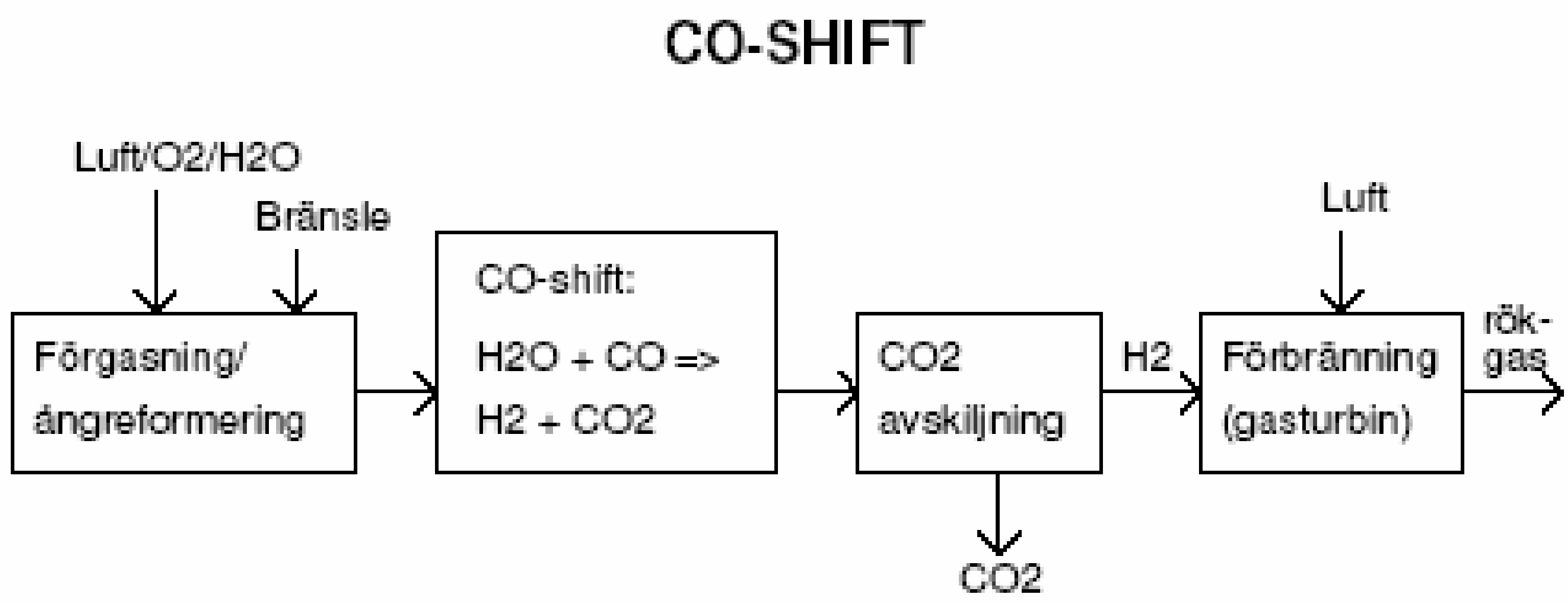
- After combustion of fossil fuels.
- Before combustion.
- Can be used in a near future
- Relatively low costs
- Only possible to use on large plants

CCS after combustion of fossil fuels



Anders Lyngfelt, Energisystem, Chalmers, 20031107

CCS before combustion



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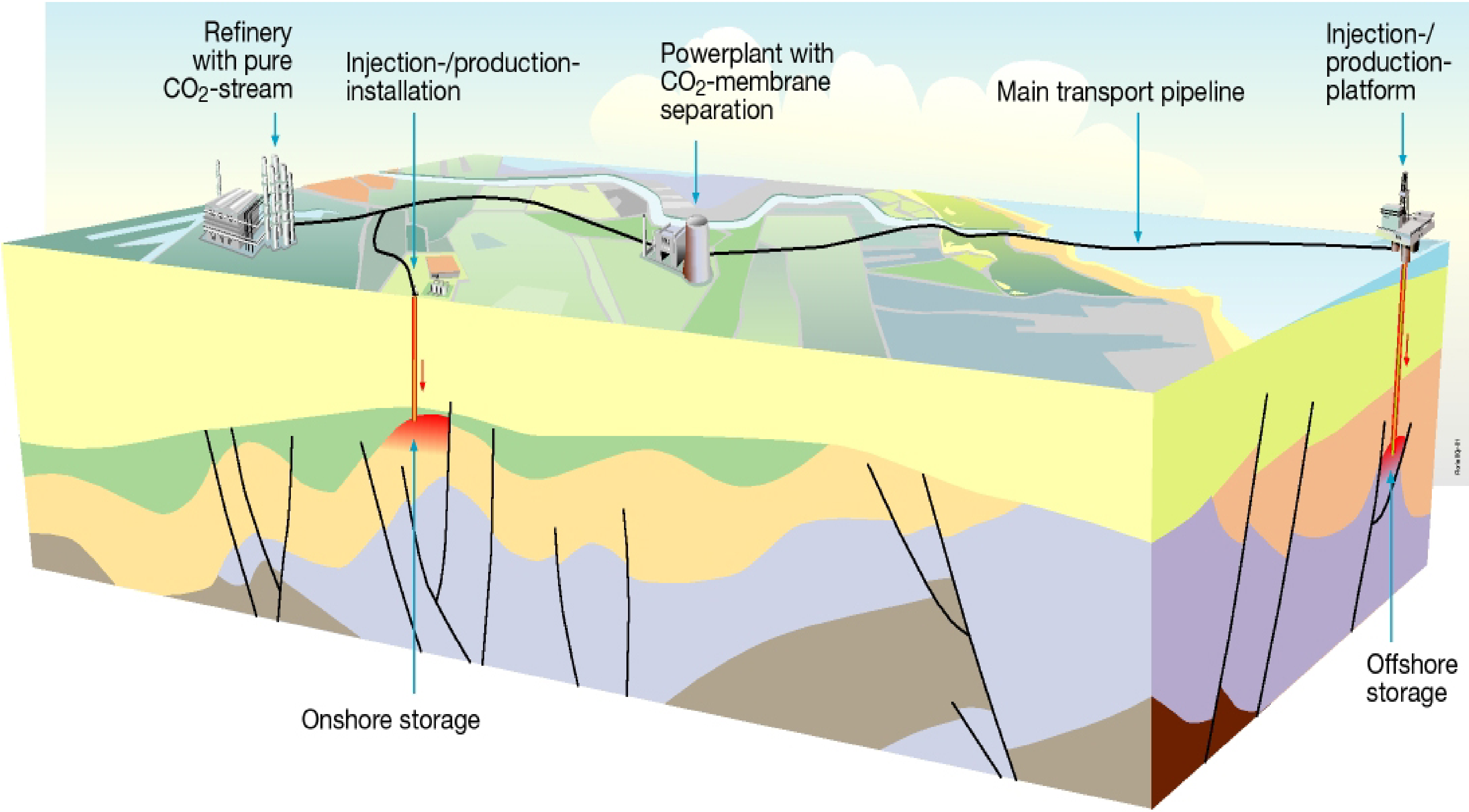
CO_2 Capture, Transport & Storage



Solar and wind

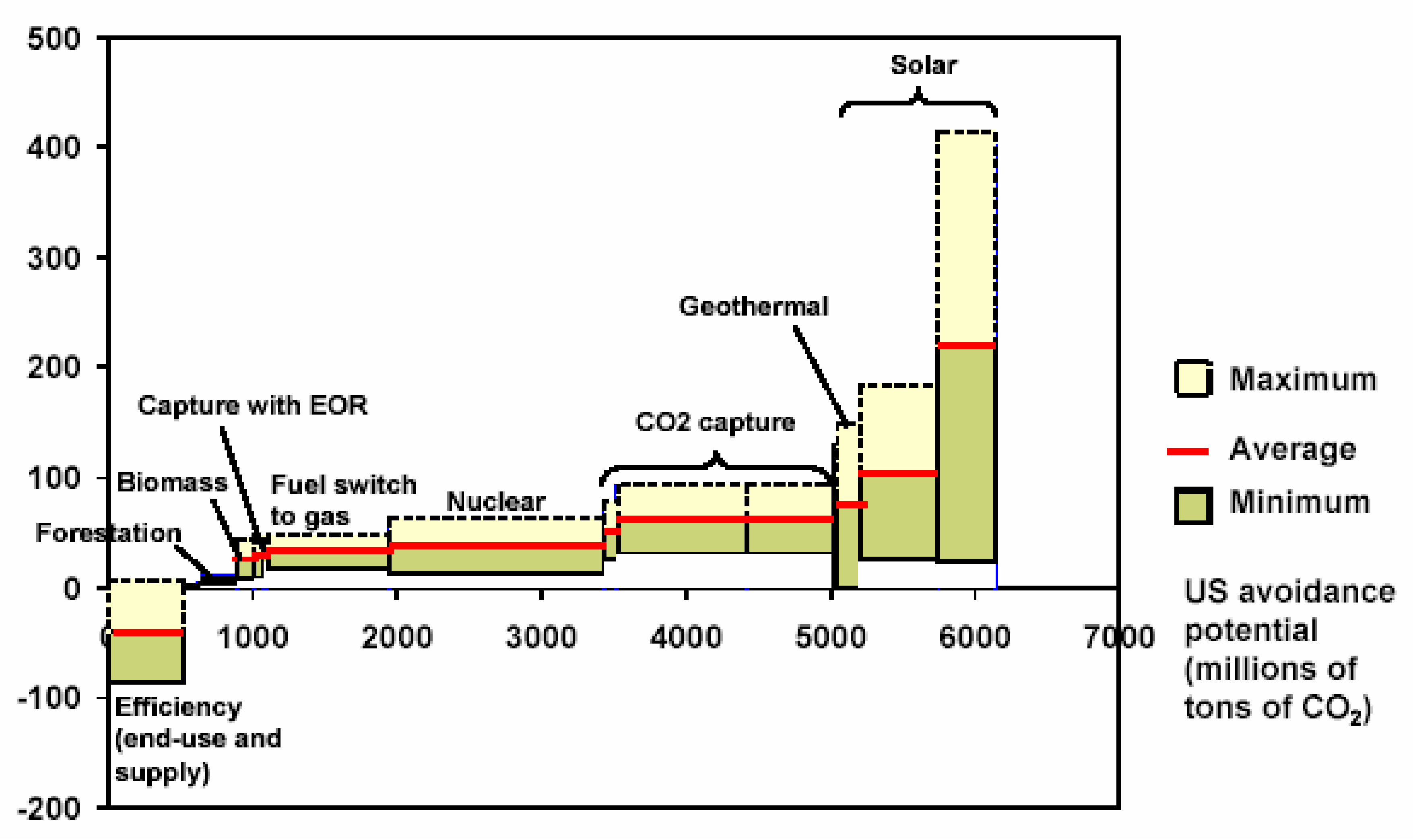
- Intermittent
- Large potential.

Biomass

- Low cost
- Available technology
- Large potential

CO_2 avoidance cost

(1990$ per ton of CO_2 avoided)



Exercise:
”Best use of biomass?”

"Best use of biomass?"

- Assume a global biomass supply potential of 200 EJ (10^{18} J) per year.
- Assume $10*10^9$ people in a future world
- Assume the total demand of 100 GJ/capita per year (an ambitious low energy demand)
- How many percent of the total global energy demand can by supplied from biomass, if 100% conversion efficiency?
- Consider the following different conversion efficiencies

  - Bio-heat 90%
  - Bio-el 50%
  - Biofuels for transport 50%
- In which sector can biomass replace the largest amount of fossil fuels?

Biomass

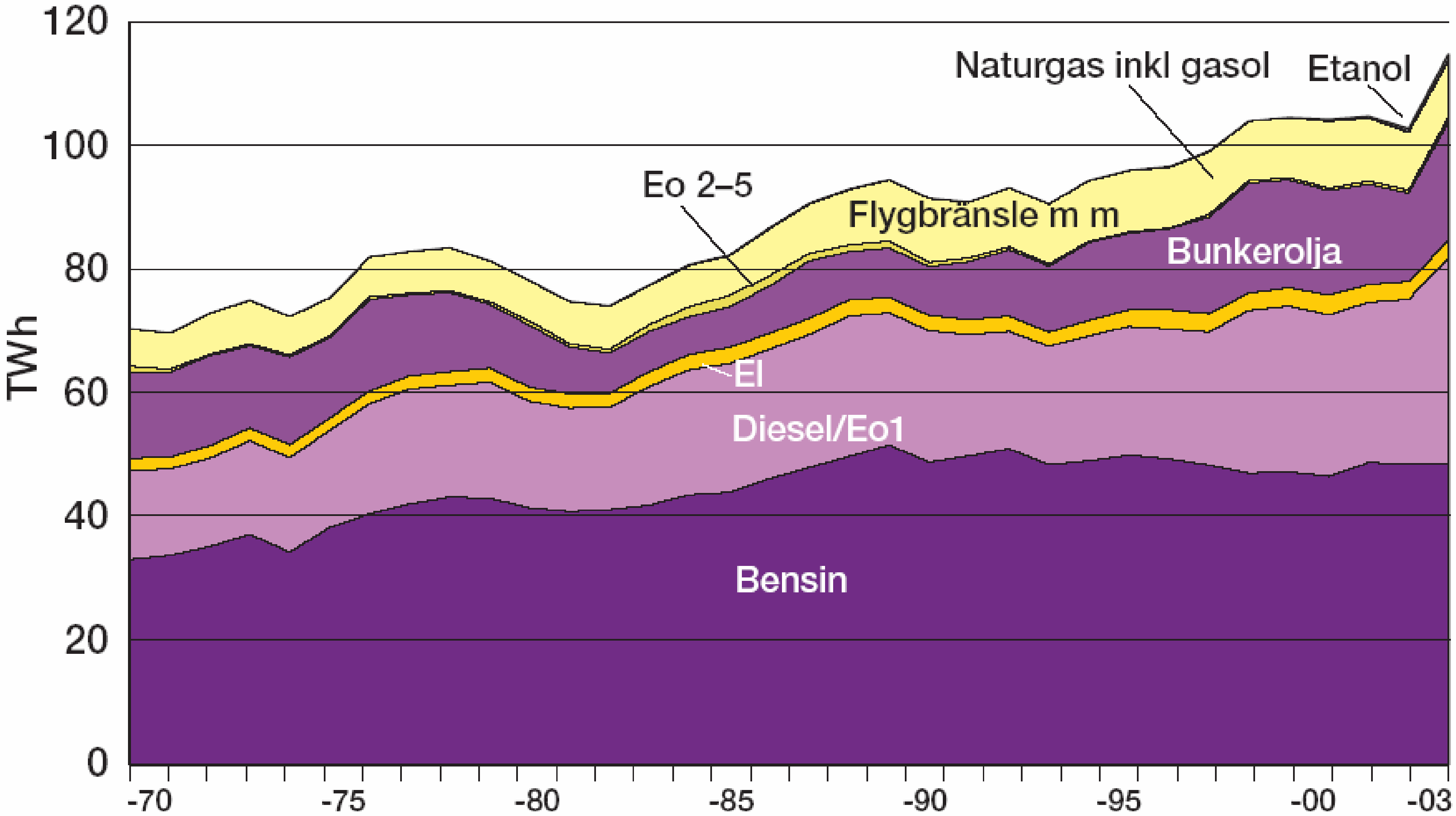
- Can be used to produce electricity, heat and/or be used for the production of transportation fuels.
- Large potential but not large enough to replace all fossil fuels in all sectors.

Answers:

- Global energy demand: 1000 EJ/yr
- Biomass supply potential: 200 EJ/yr
- If 100% conversion efficiency: Biomass can be used for 20 % of the global demand. (Need to prioritize where to use biomass)
- Highest conversion efficieny in the heat sector. Biomass can replace most fossil fuels if used for heat production.

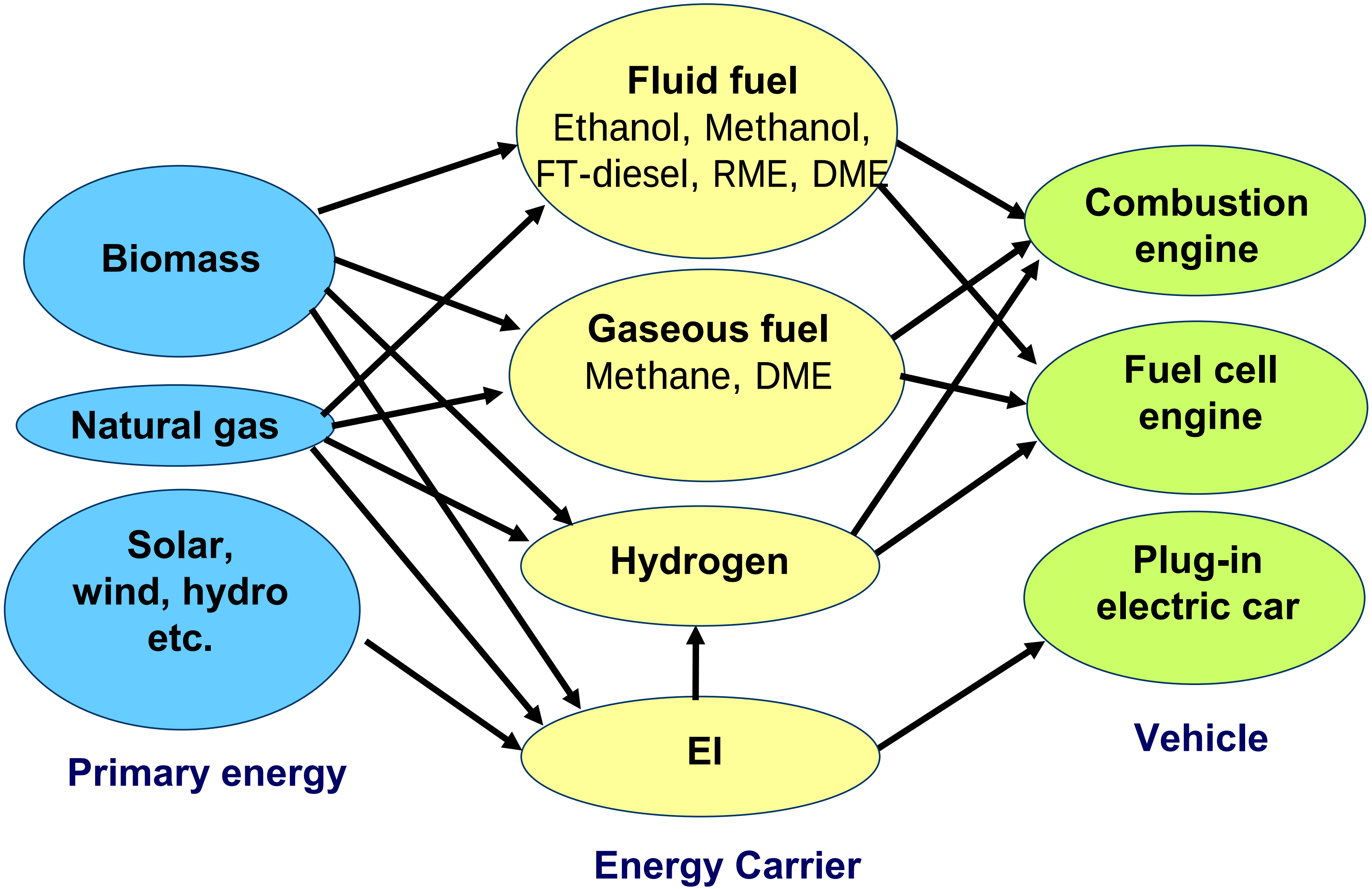
Can alternative transportation fuels play a role?

Energy in the Swedish transportation sector

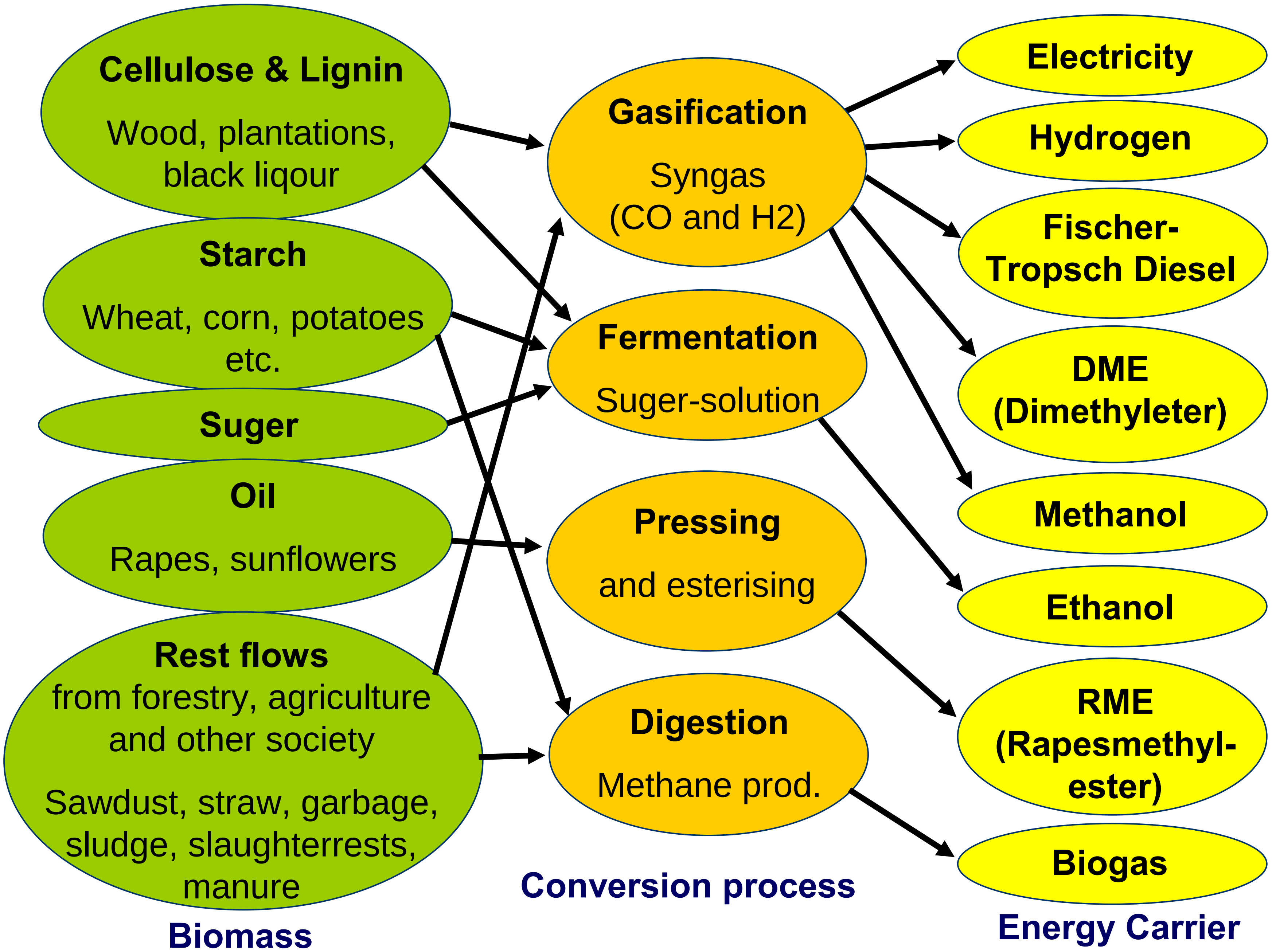


Source: SCB, Energimyndighetens bearbetning, Energiläget 2004.

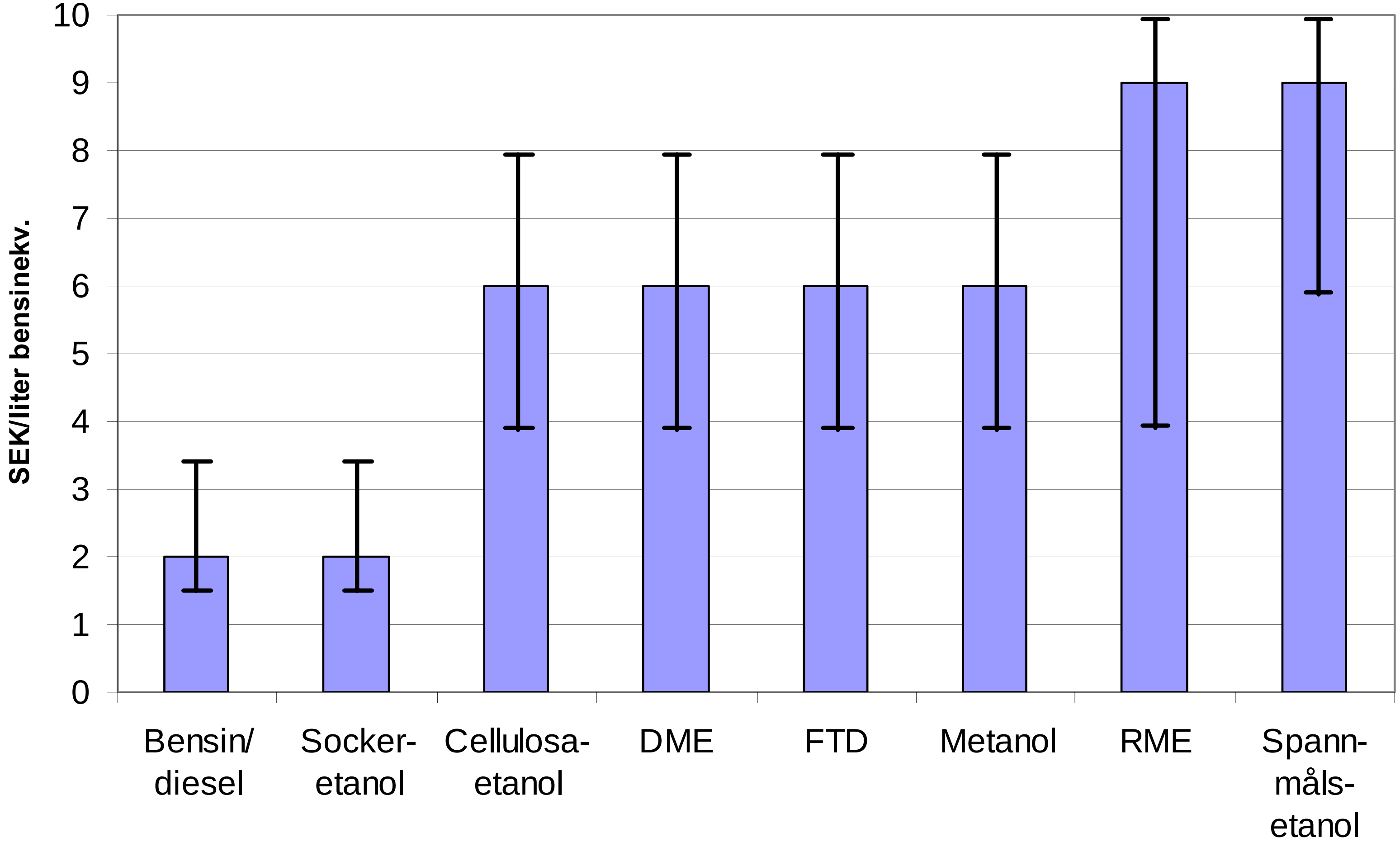
Alternative transportation fuels



Biofuels for transportation



Three generel sizes on production costs



Land use when producing wheat-ethanol

Each liter ethanol demand 2.65 kg wheat
Yield in Sweden (and Europa) is approx 6 ton wheat per ha

	Ethanol for Swedish transport sector 95 TWh (16 G liter)	
Land use need for 95 TWh ethanol	Appr. **7 Mha**	

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Relative total Swedish agriculture area (2,7 Mha)	Appr. **3 times larger area**	

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Relative total Swedish agriculture area possible to grow wheat (1,2 Mha)	Appr **6 times larger area**	

Land use when producing wheat-ethanol

Each liter ethanol demand 2.65 kg wheat
Yield in Sweden (and Europa) is approx 6 ton wheat per ha

	Ethanol for Swedish transp sector 95 TWh (16 G liter)	**Etanol for EU-15 transport sector 3900 TWh (655 G liter)**
Land use need for 95 TWh resp. 3900 TWh ethanol	Appr. **7 Mha**	Appr. **289 Mha**
Relative total Swedish agriculture area (2,7 Mha) resp. EU-15 (73 Mha)	Appr. **3 times larger area**	Appr. **4 times larger area**
Relative total Swedish area possible to grow wheat (1,2 Mha)resp. EU-15 (38 Mha)	Appr **6 times larger area**	Appr. **8 times larger area**

Wheat-ethanol can not replace gasoline/diesel by itself

To be able to reach low CO2-concentration targets for the transportation sector, more efficient fuels have to be developed.

Summary on how to change the energy system:

The CO_2-emissions from the energy system can be reduced by

- Using LESS energy.
- Using OTHER primary energies (instead of fossil).
- Using fossil energy without emitting CO_2 to the atmosphere. Carbon Capture and Storage technology

How can we reduce CO_2-emission at lowest cost?

The GET models

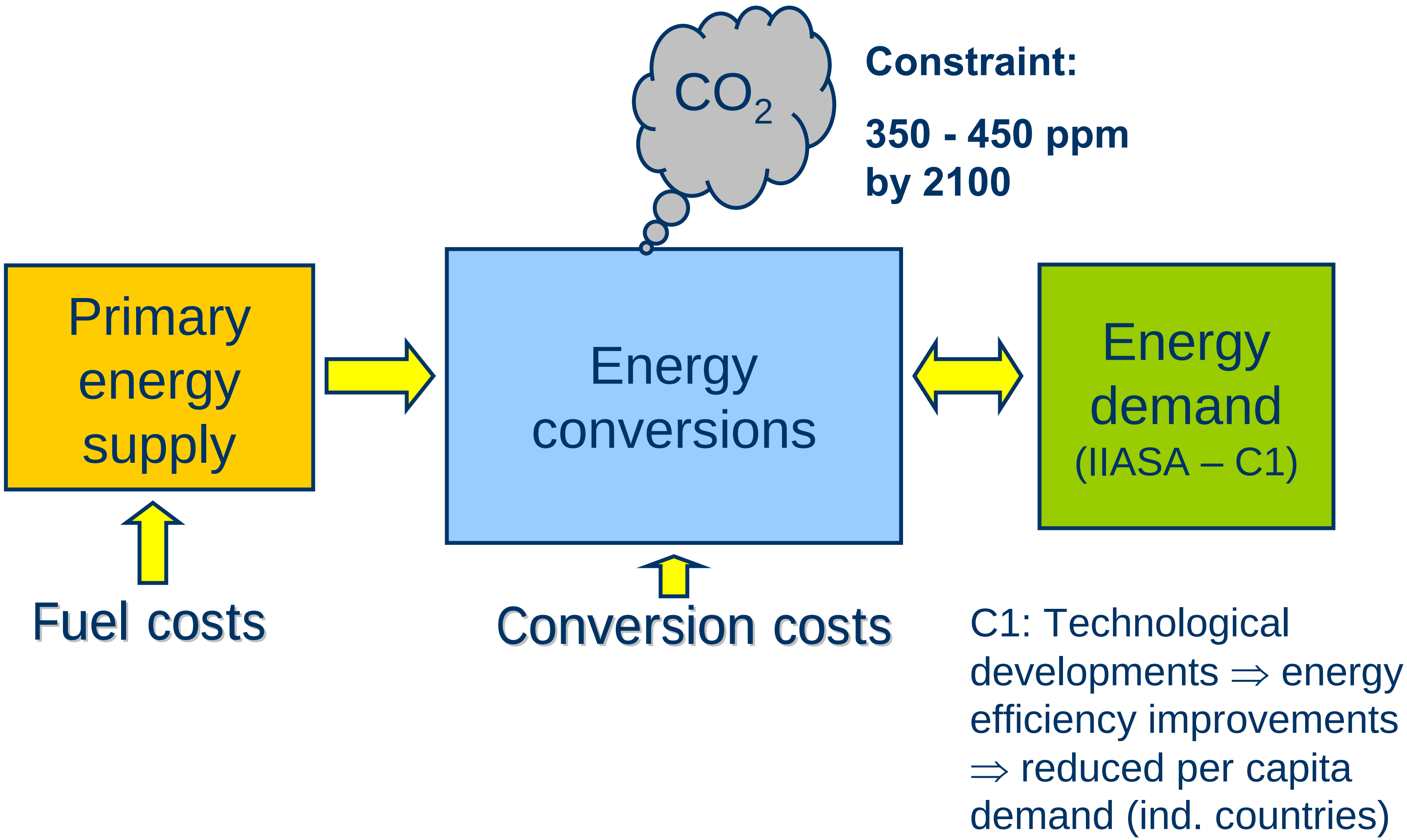
GET 1.0 global
GET-R 1.0 regionalized version
GET 5.0 BECS

(GET – Global Energy Transition)

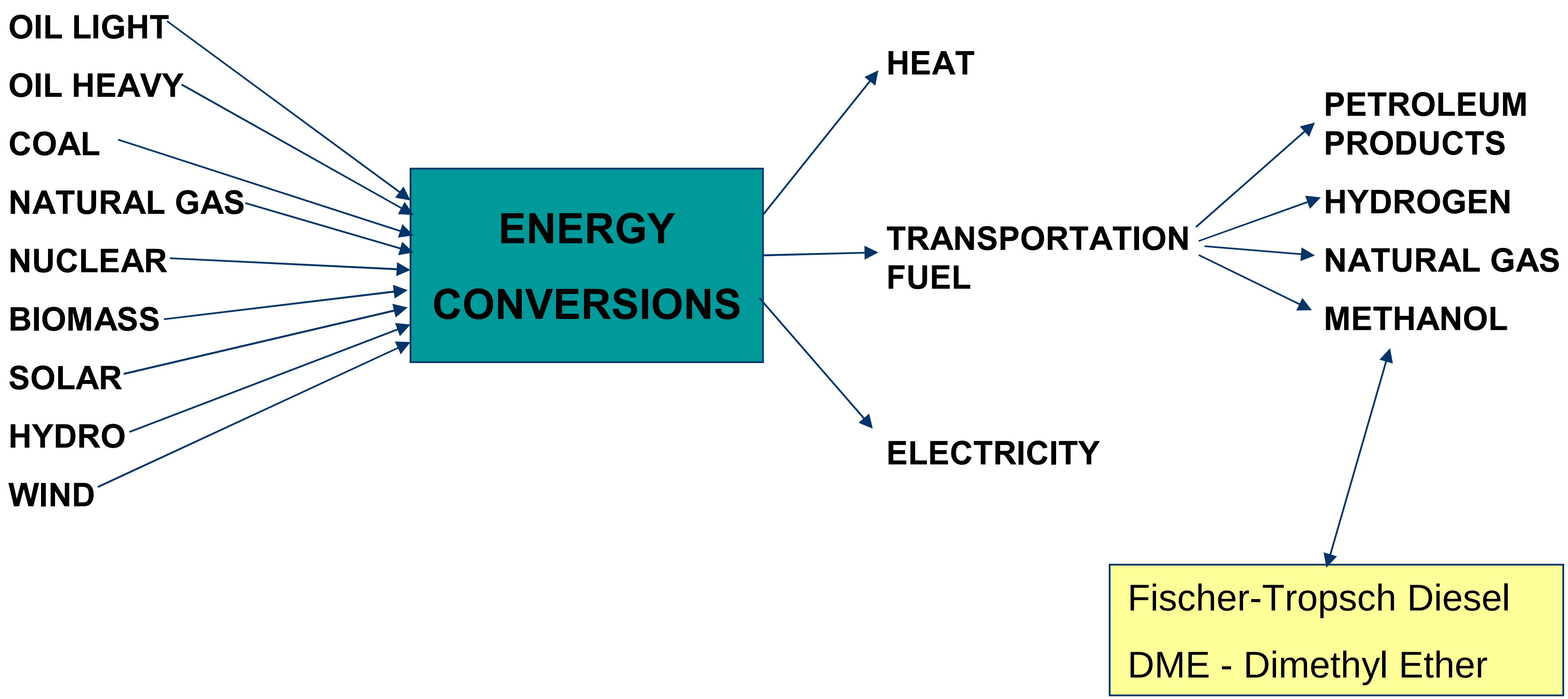
(BECS - Biomass Energy with CO_2 Capture and Storage)

Linear Global Energy System Model

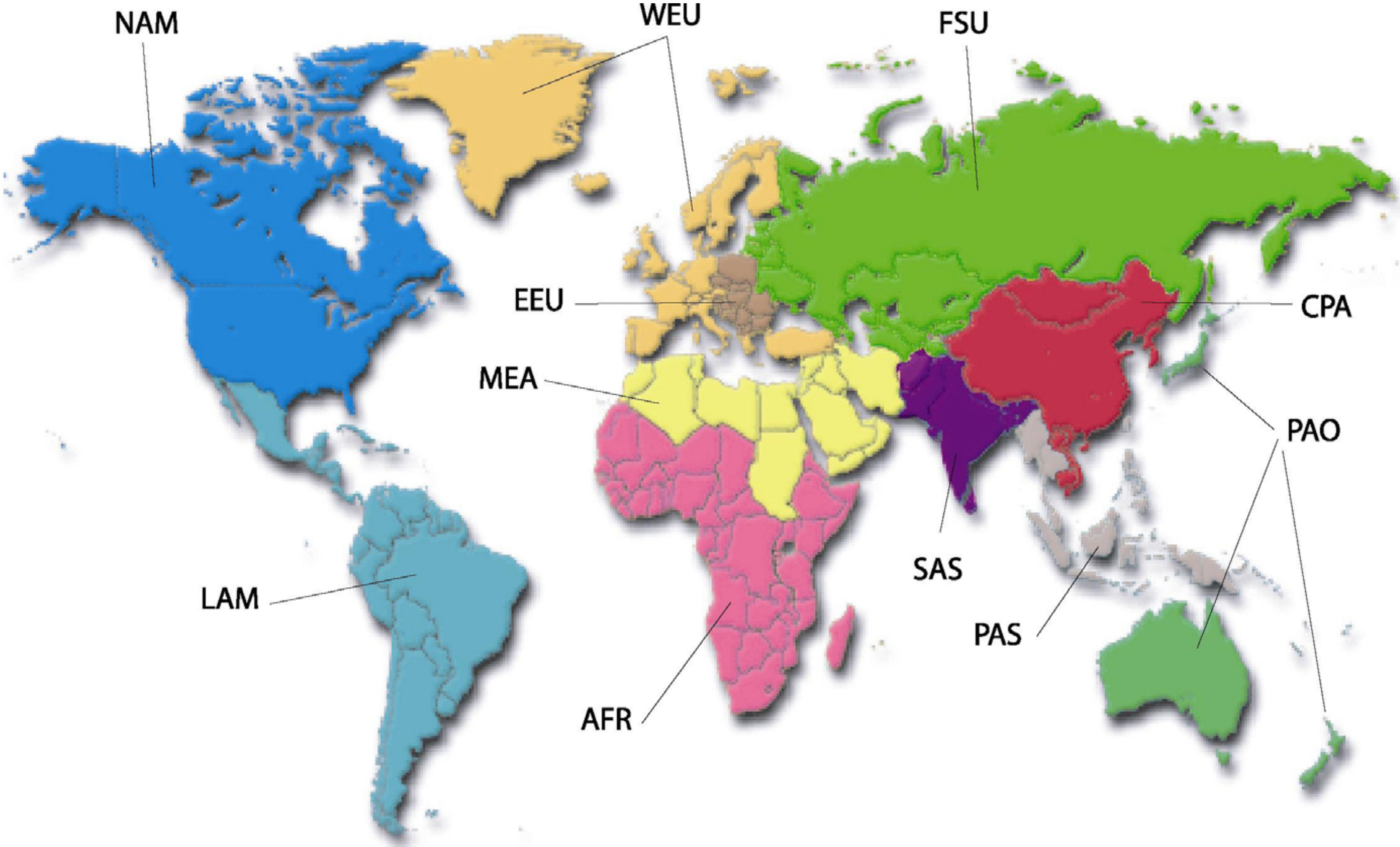
Minimises costs



Basic Flow Chart of Supply and Fuel Choices



Regions



Questions asked in a GET study

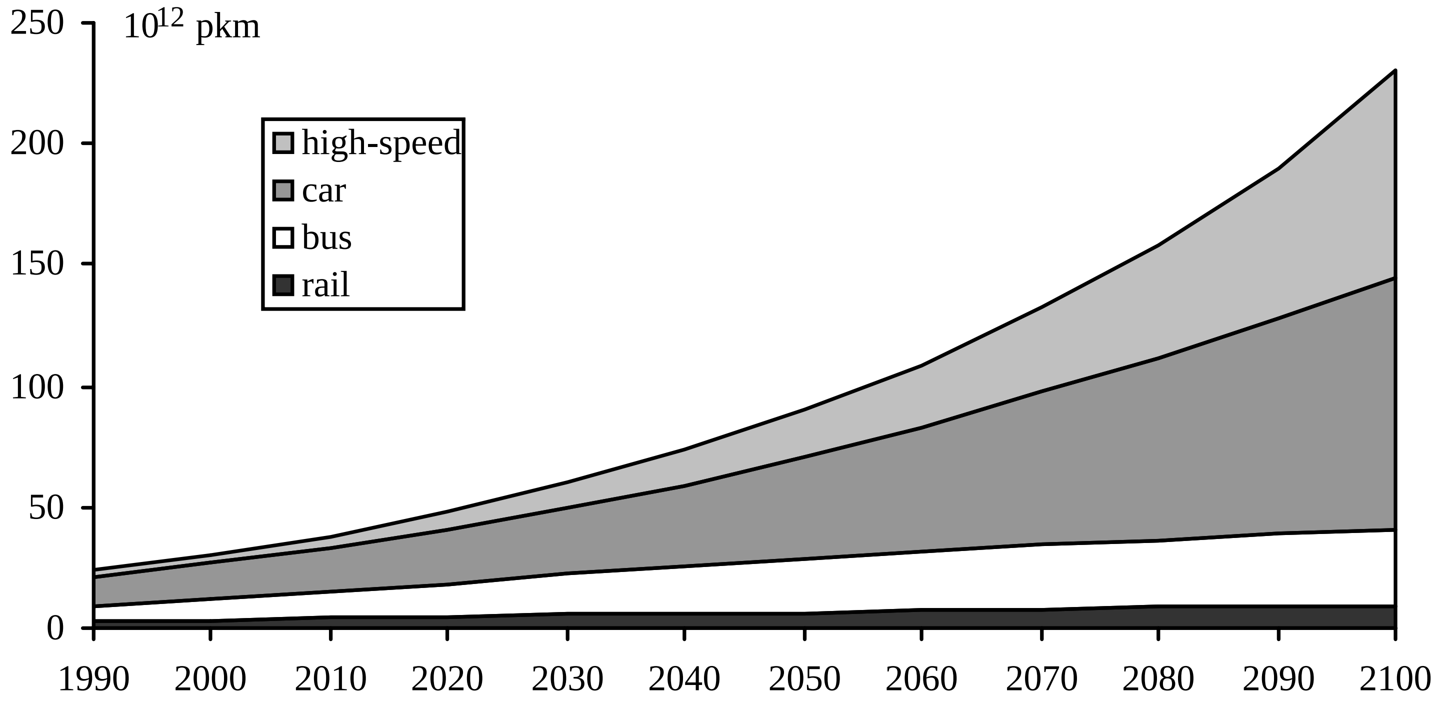
1. **When is it cost-effective to carry out the transition away from gasoline/diesel?**

2. **To which fuel is it cost-effective to shift?**

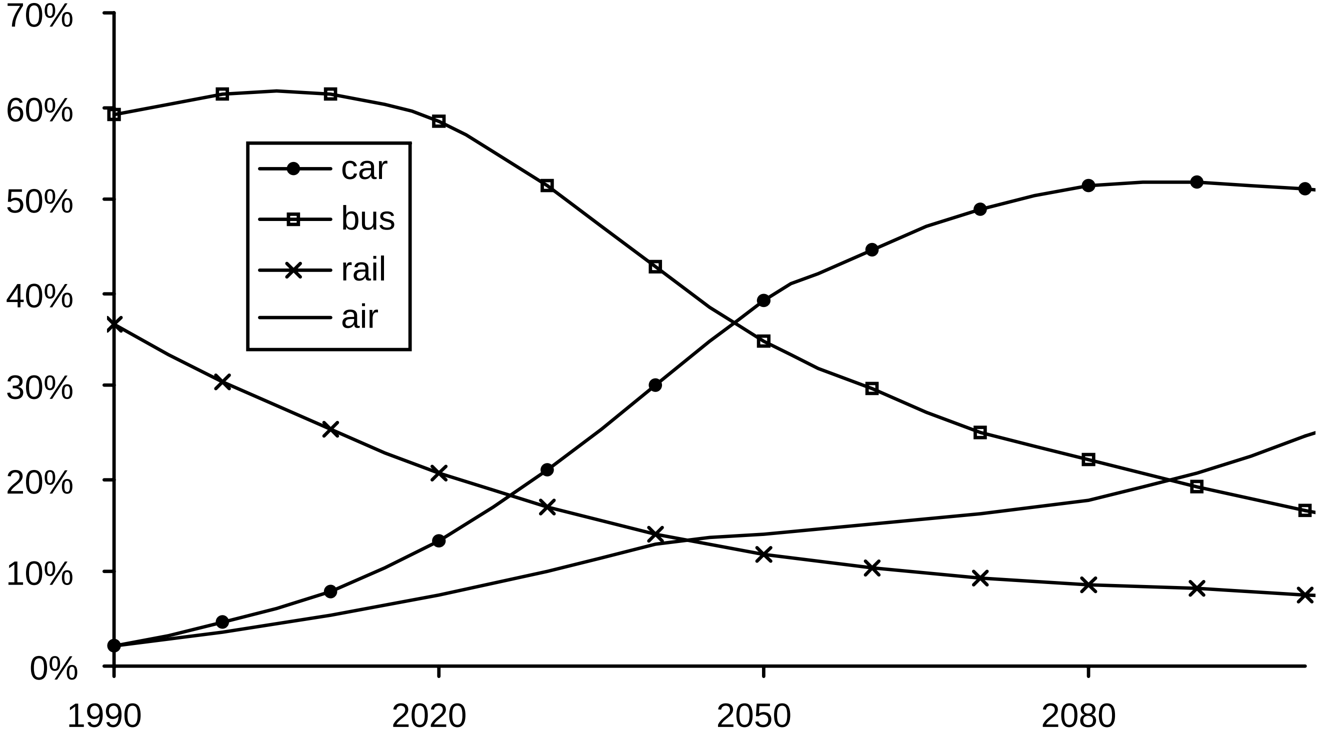
Transportation scenarios

- Zahavi's rule of 1 hour travel/day
- Choice of transportation mode determined by GDP/cap
- Economic development following IIASA/WEC C1 scenario

Future mobility of world population



Modal split in CPA



Energy demand

- Heat and electricity demand follow scenario "C1" developed by IIASA. (Ecological and Energy efficiency improvements)
- Per capita income increases
  - Industrialized regions GDP from 20,000 USD/yr to 50,000 USD/yr
  - Developing regions to Western Europe level
- Passenger transportation increases ten fold. For example an Americans use of aviation increase from 4,300 km/year to 40,000 km/year.
- 0.5 cars/capita - current car density in Germany.
- 5 billion cars by the year 2100

Some cost-assumptions and conversion efficiencies

Primary energy	Secondary energy	Capital cost [USD/kW]	η	Load factor
Oil	Petro	1000	0.9	0.8
Oil	Heat	100	0.9	0.7
Oil	Electricity	1000	0.5	0.7
Biomass	MEOH	1300	0.6	0.8
Biomass	Heat	300	0.9	0.7
Biomass	Electricity	1300	0.5	0.7
Natural gas	MEOH	500	0.7	0.8
Natural gas	Heat	300	0.9	0.7
Natural gas	Electricity	700	0.6	0.7

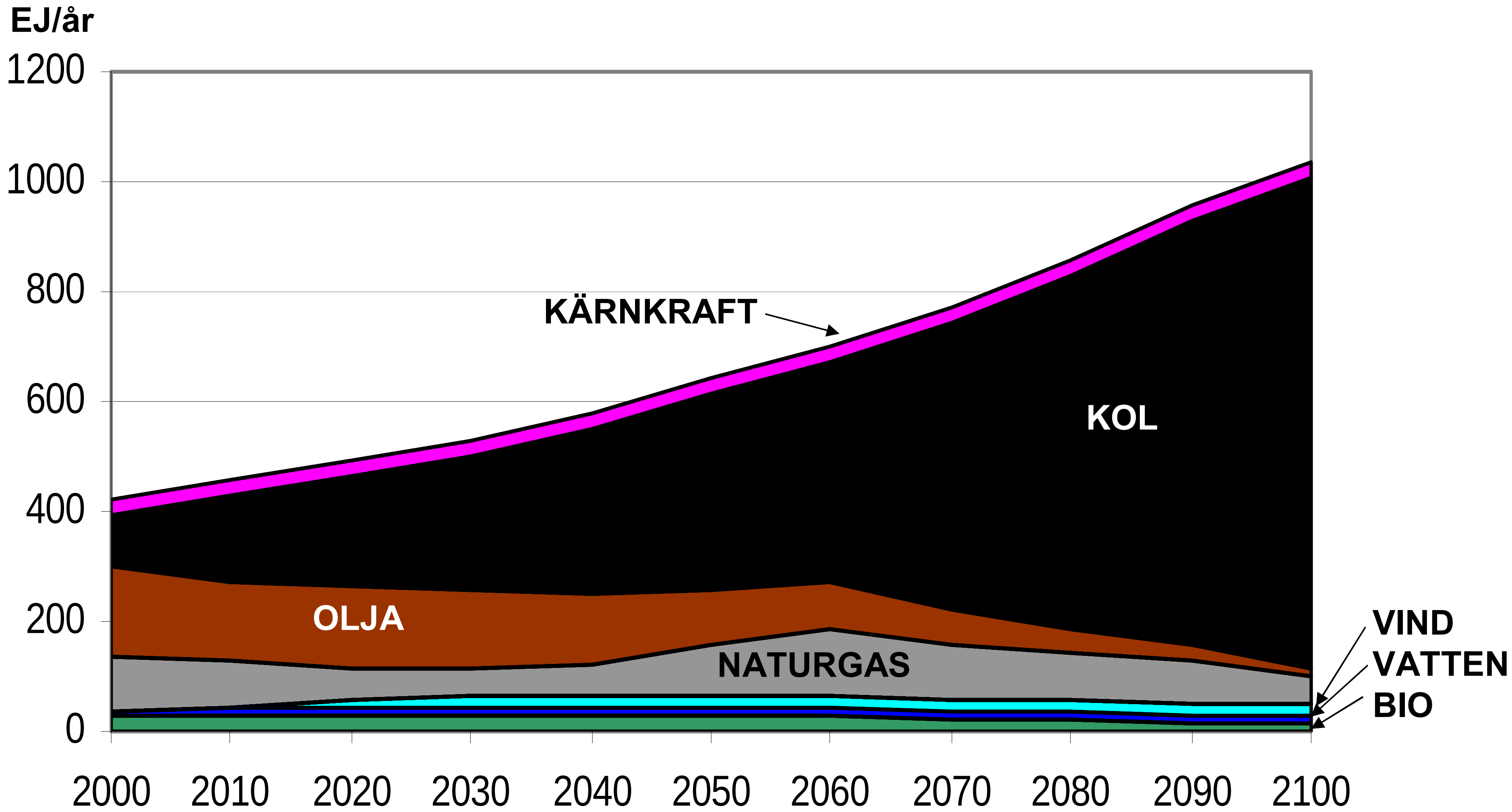
Things not taken into account in this modell

- Local pollutions
- Energy security (less dependency on imported oil)
- Agriculture policy
- Regional industry policy
- Afforestation
- Public acceptance for new technologies

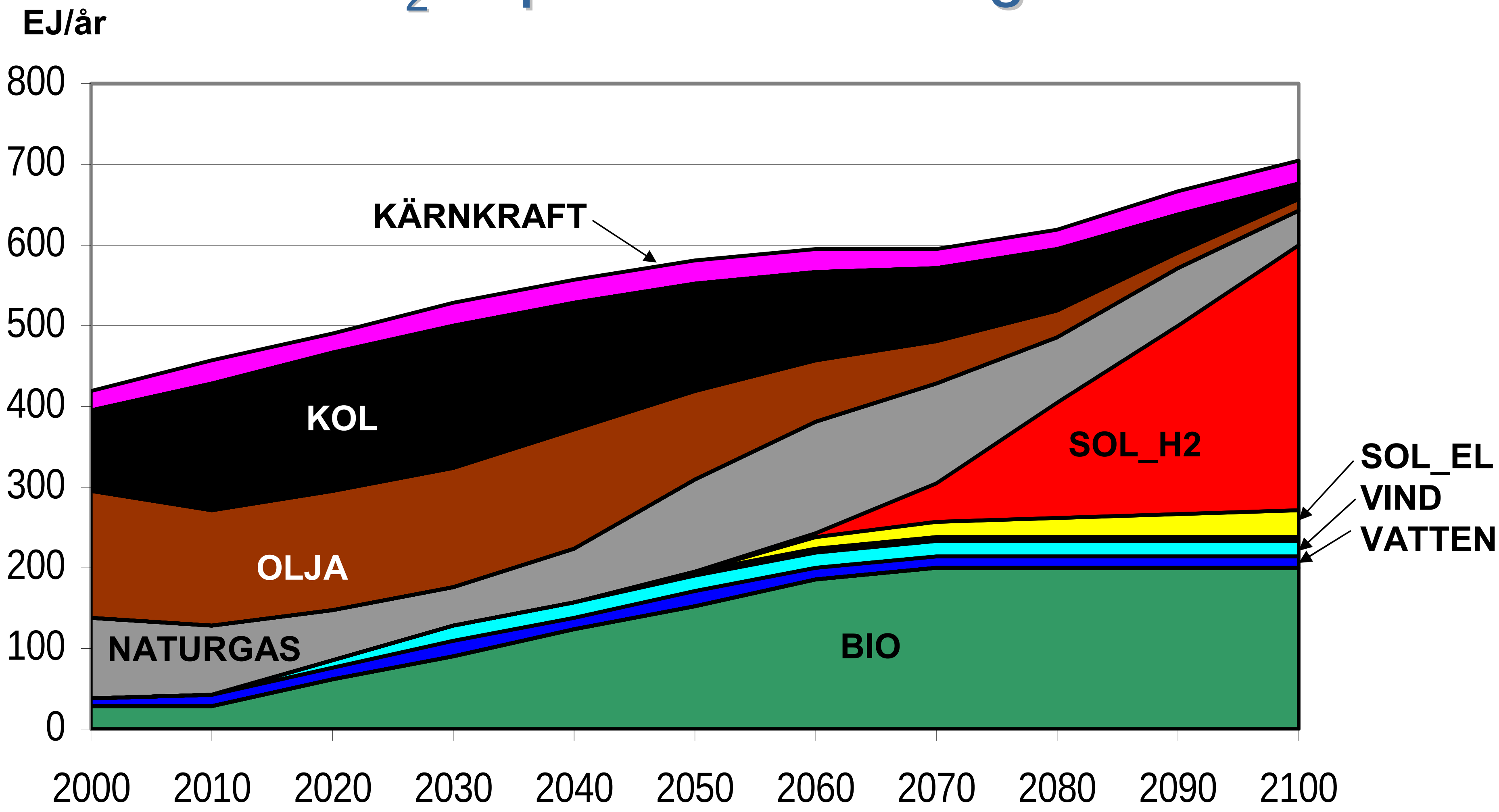
Constraints
to avoid solutions that are unrealistic

- The contribution of nuclear is fixed to current level
- The maximum expansion rates of new technologies is set so that it takes 50 years to change the entire energy system.
- Limitation on the contribution of intermittent electricity sources is maximised to 30% of the electricity use.
- To simulate the actual situation in developing countries at least 20% of the heat demand needs to be produced from biomass the first decades.
- The amount of biomass that can be used for energy purpose is maximised to 200 EJ/yr.

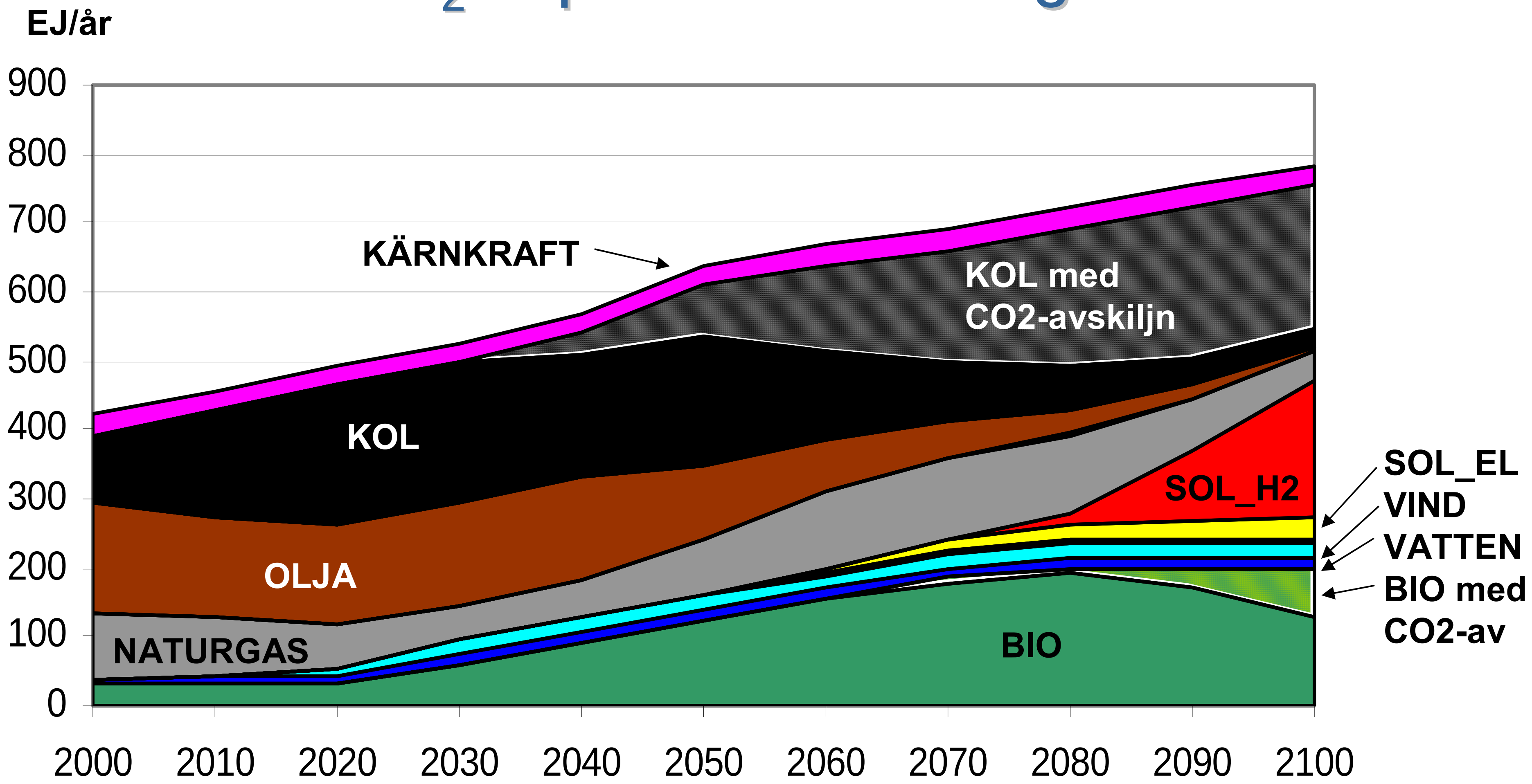
Global energy supply with no CO_2 constraint



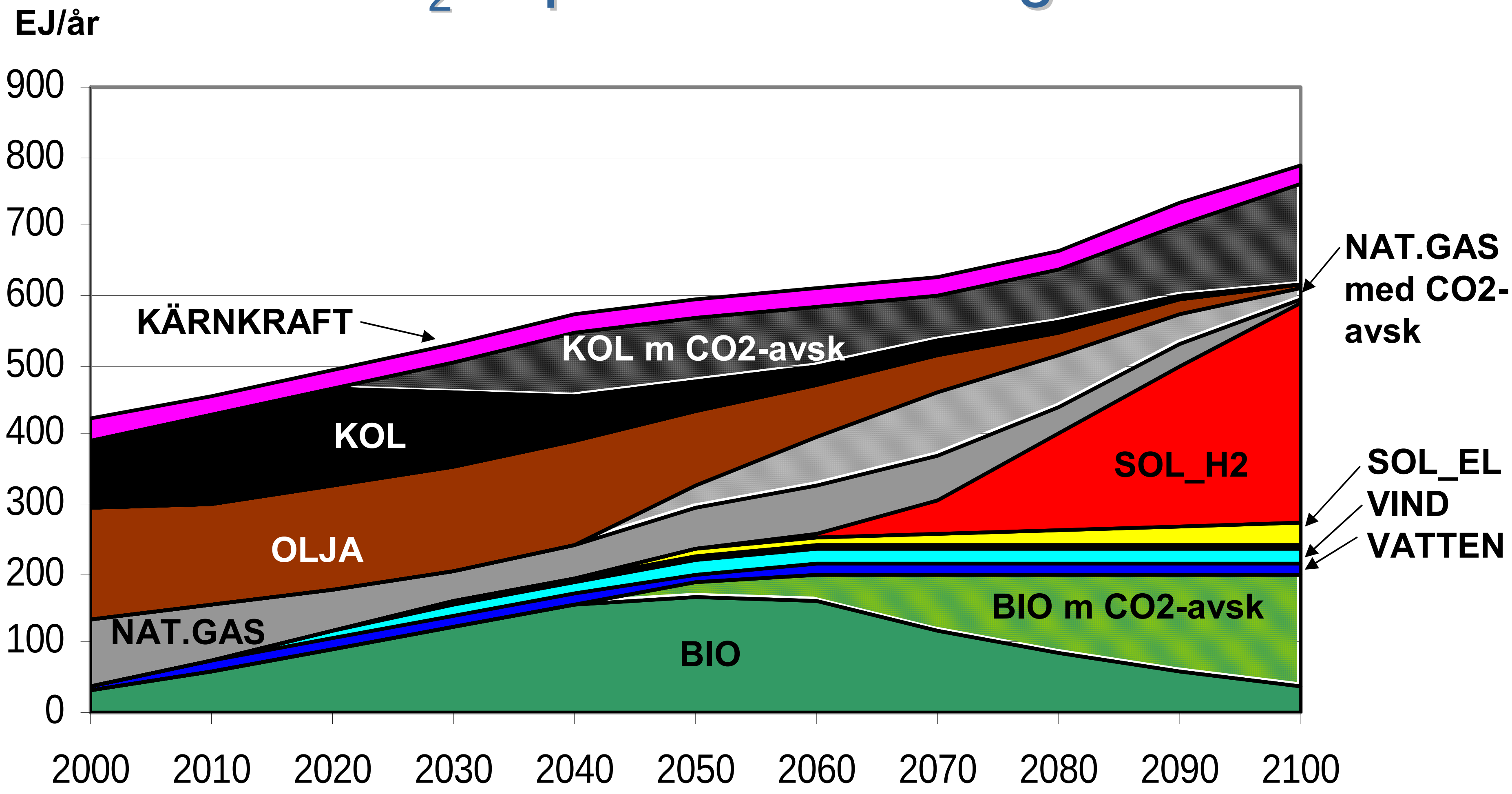
Global energy supply – CO_2-target 450 ppm, no CO_2 capture and storage techn.



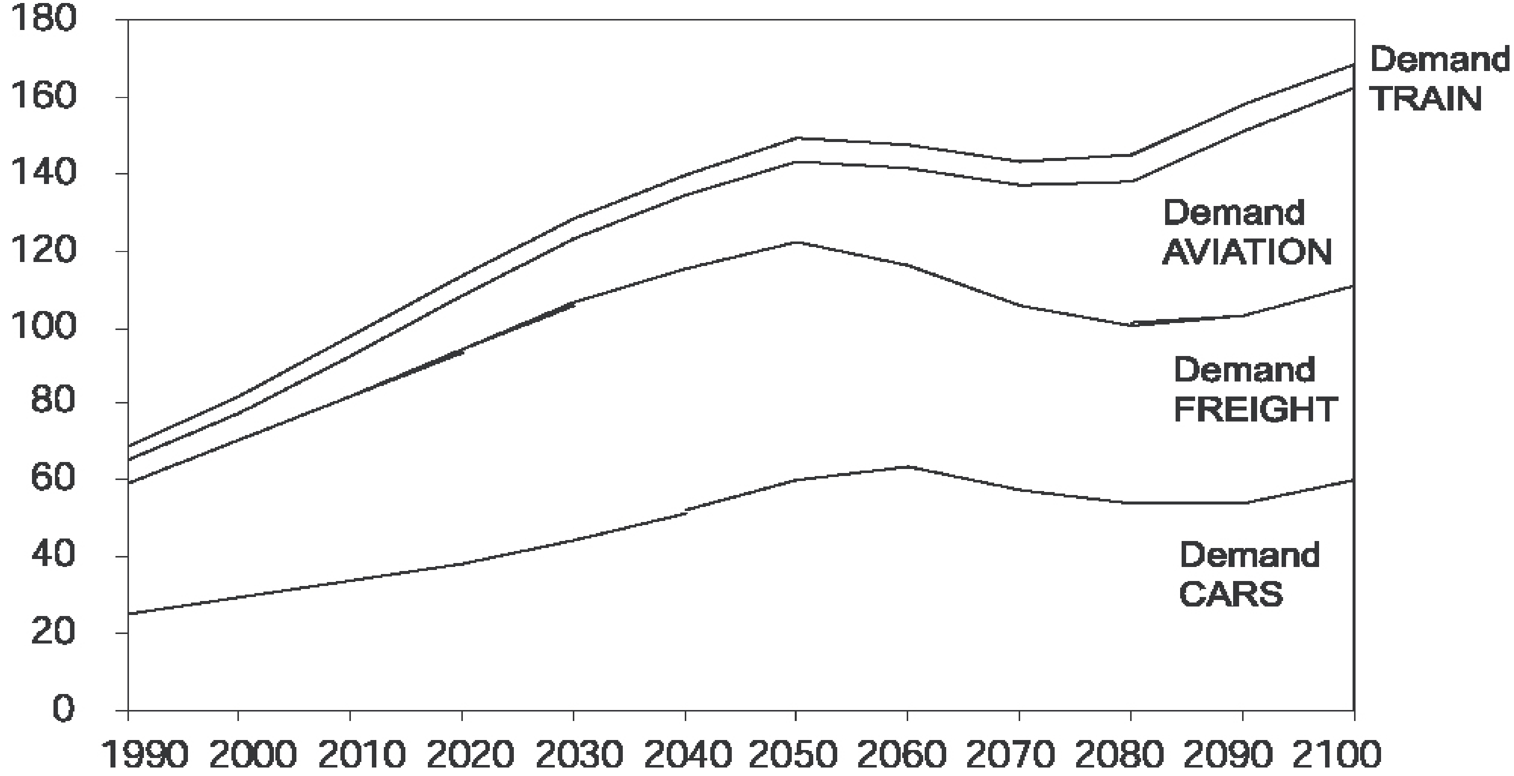
Global energy supply – CO_2-target 450 ppm, with CO_2 capture and storage techn.



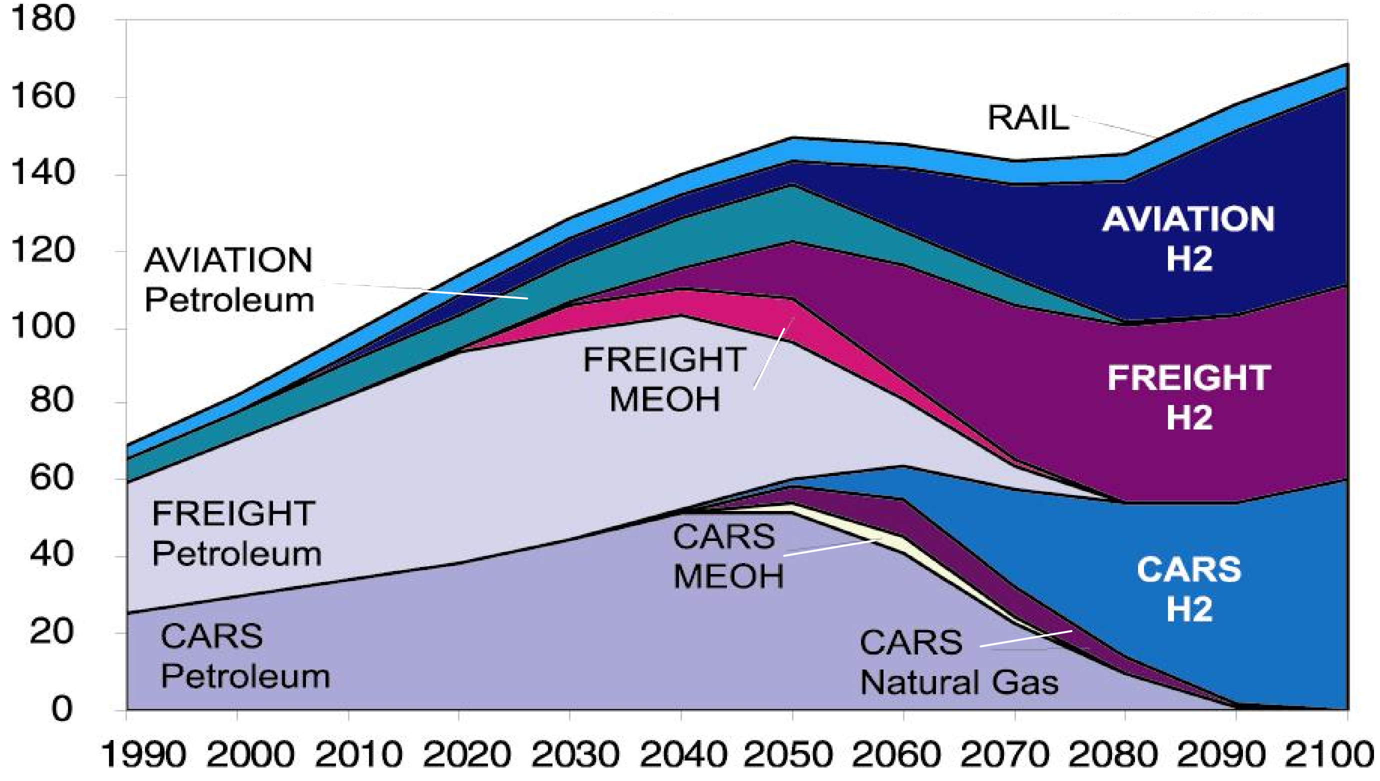
Global energy supply – CO_2-target 350 ppm, with CO_2 capture and storage techn.



Energy Demand for Transportation [EJ/yr]

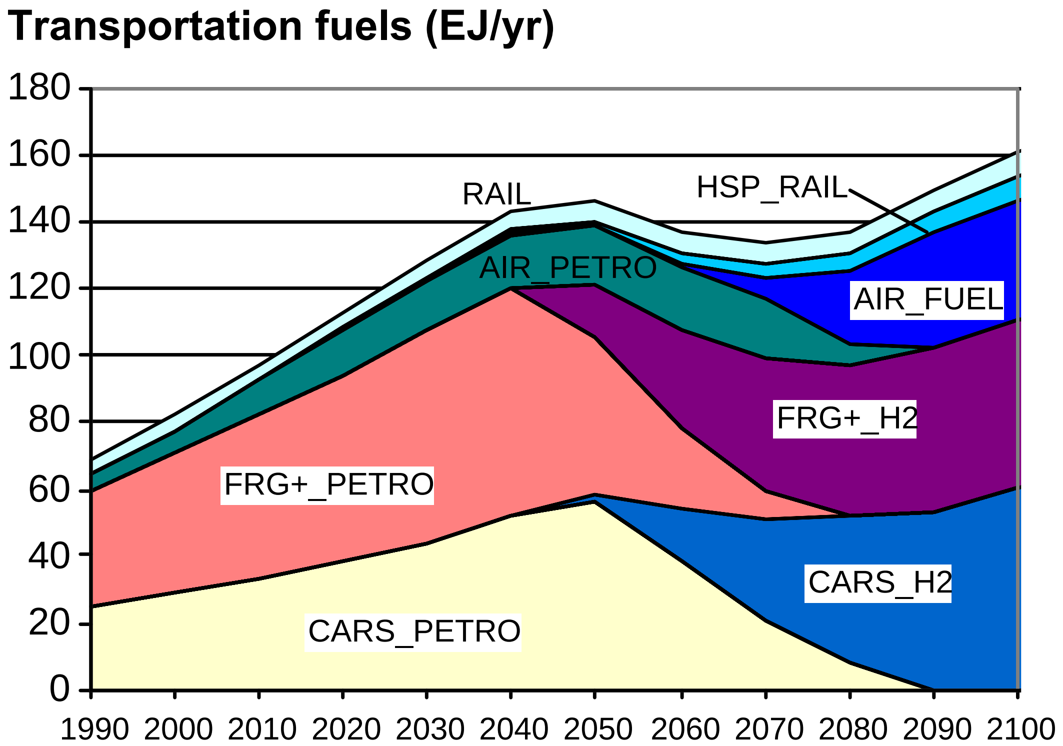


Transportation Fuel 400 ppm [EJ/yr]



Sensitivity analysis

- Biomass availability
- Oil and gas resources
- Discount rate 2%-5%
- Extra costs fuel cell cars
- H2 infrastructure costs



Answer to question No 1

Transition away from gasoline/diesel starts around year 2030 in group freight

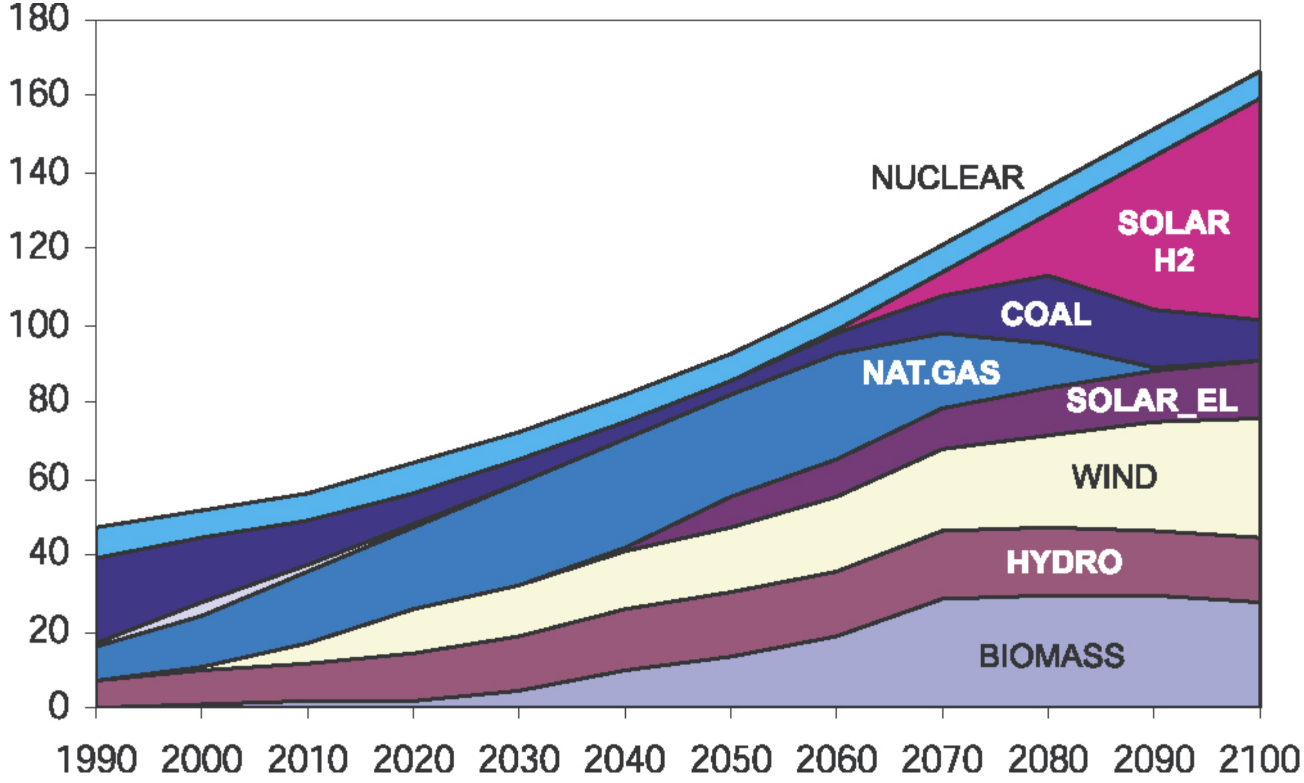
Some decades later in group cars

Answer to question No 2

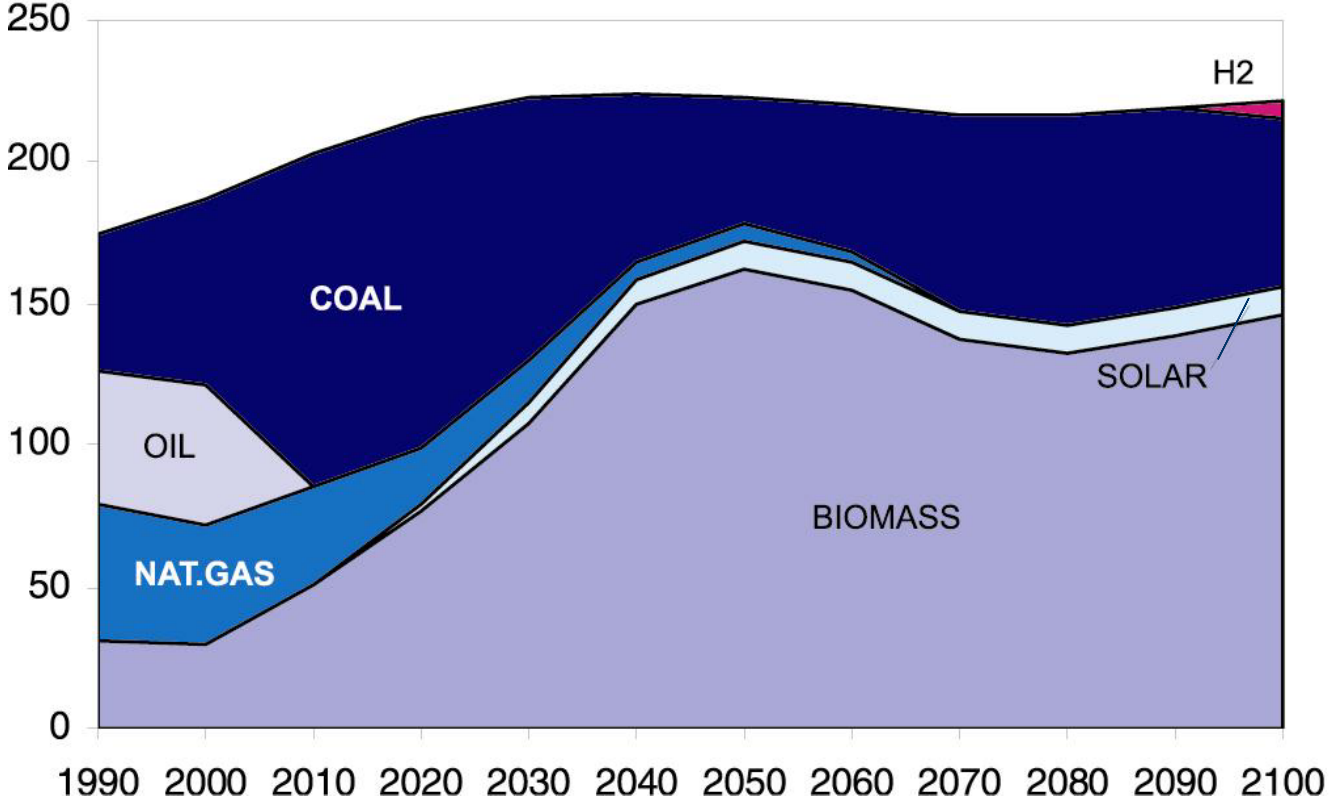
Hydrogen is the most
cost-effective fuel
in the long run

Why not biomass in the transportation sector?

Electricity Production 400 ppm [EJ/yr]



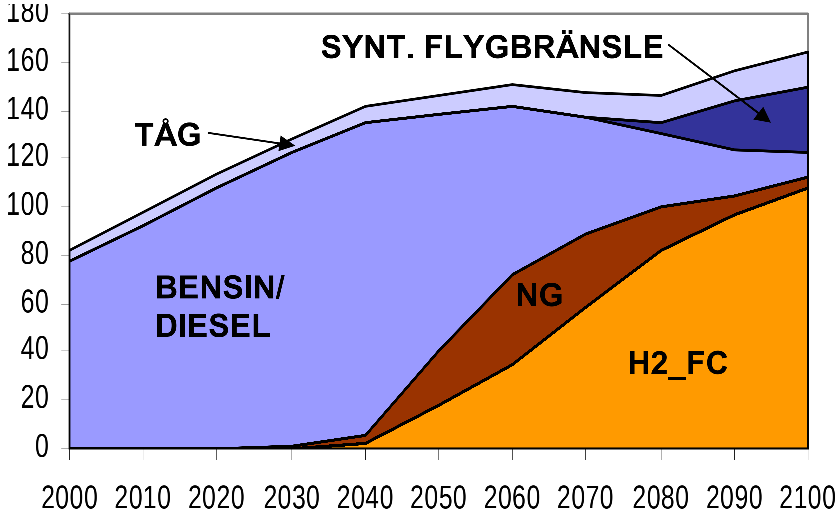
Heat Production 400 ppm [EJ/yr]



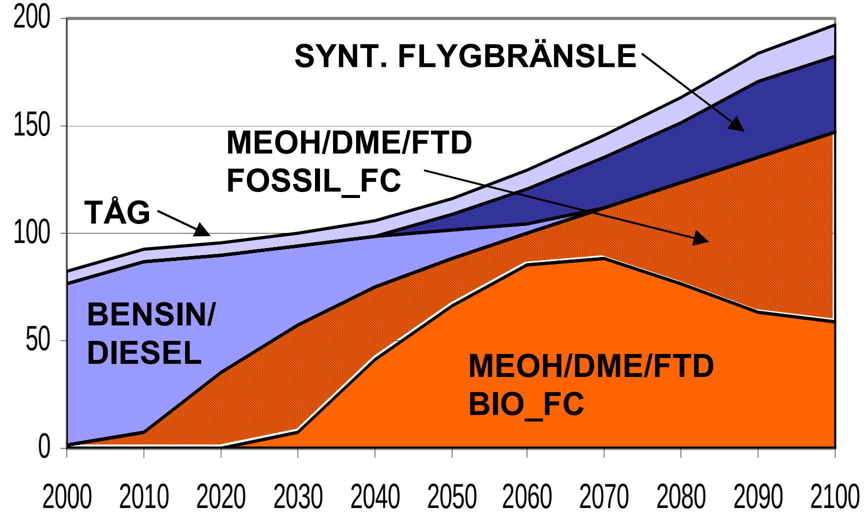
Biomass is most cost-effectively used in the heat sector

Fuel choices in the global transportation sector at 450 ppm

Transportation fuels (EJ/yr)

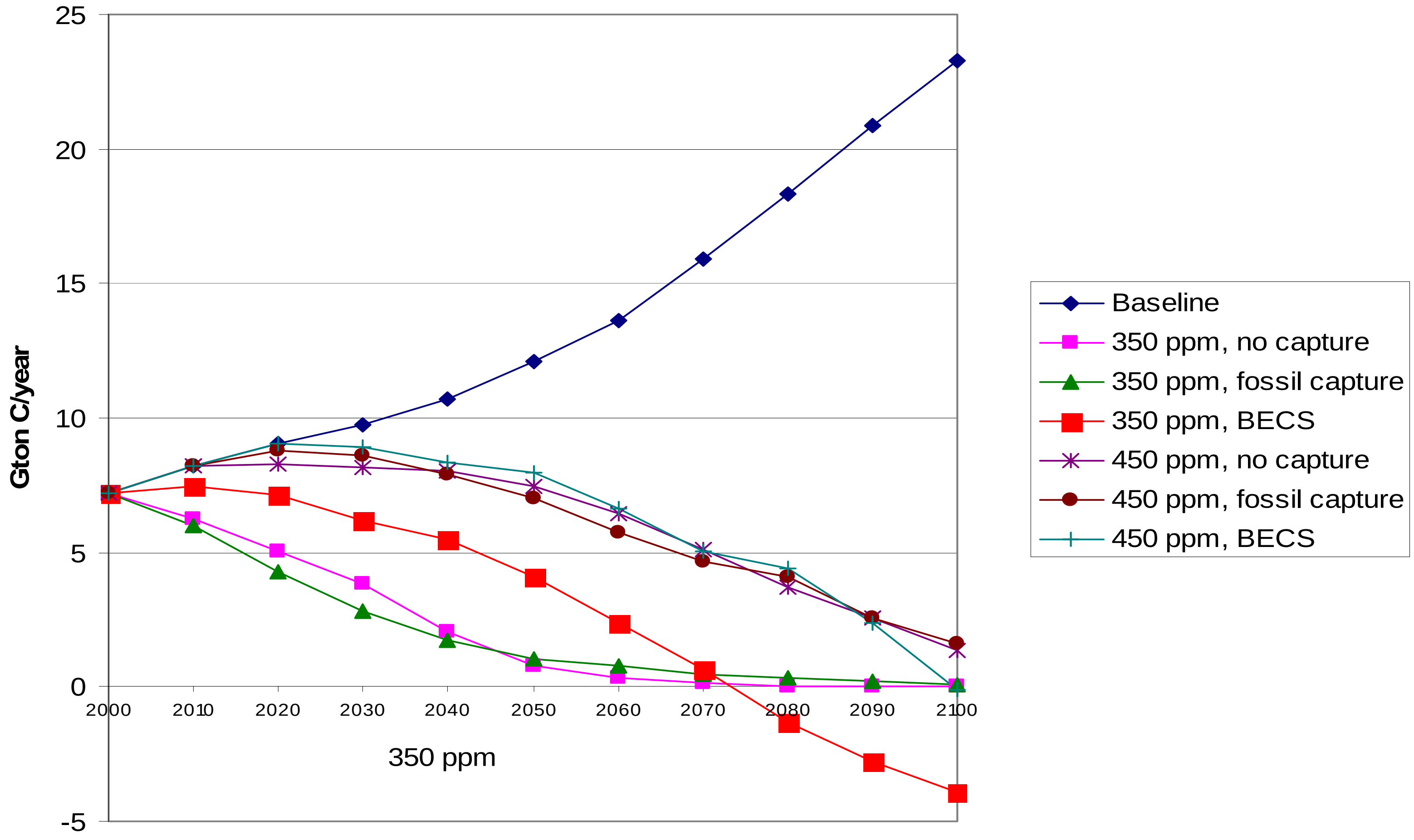


Transportation fuels when adding an assumption that hydrogen will not be available for the transportation sector (EJ/år)



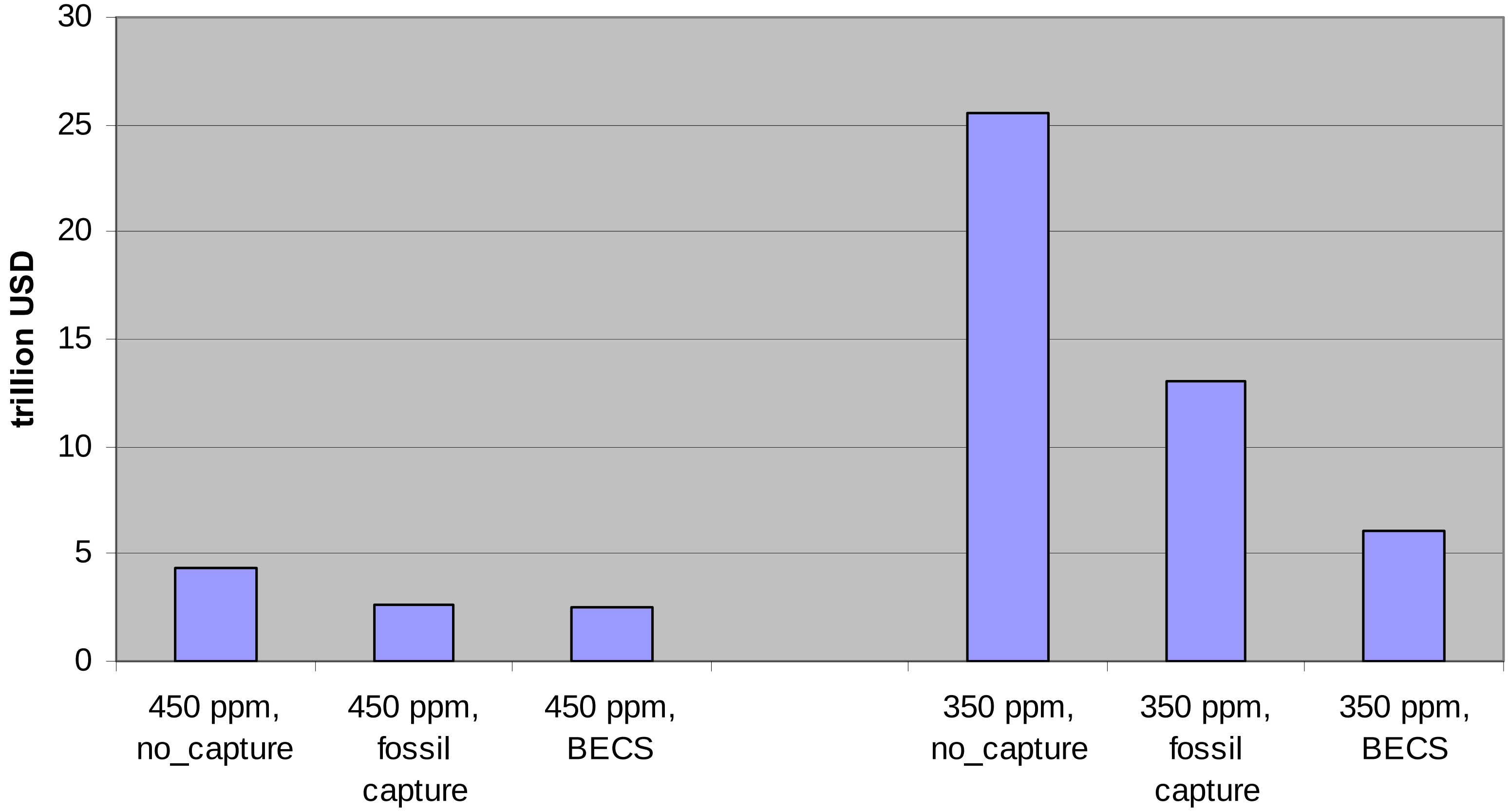
Biofuels becomes an important tool to meet stringent CO_2-concentration goals if hydrogen is excluded from the transportation sector.

Emission paths towards stabilization of atmospheric CO_2

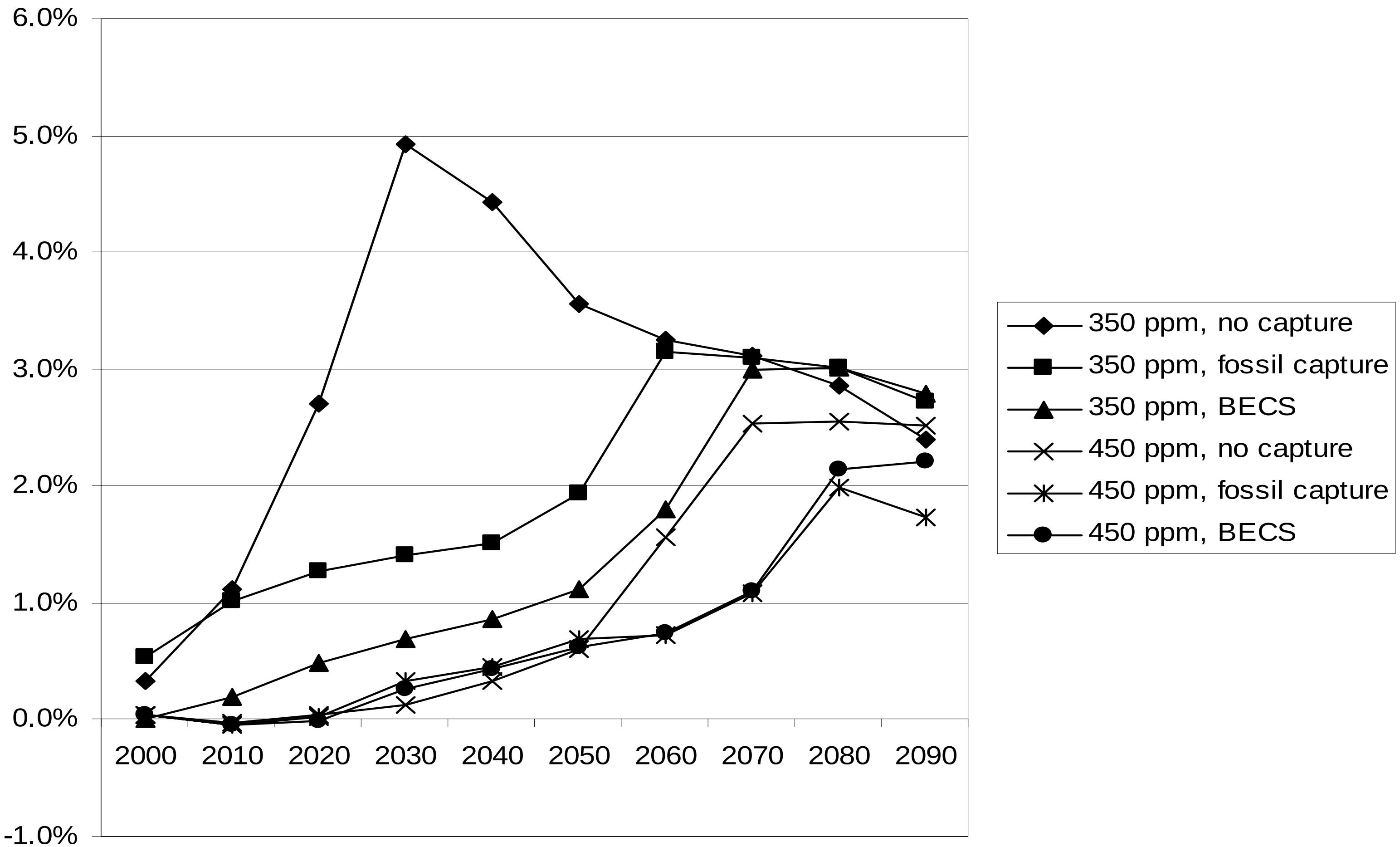


Net present value costs to stabilize the atmosphere over the period 2000-2099

compared to a baseline scenario with no CO_2 constraints.
The discount rate is 5% per year.



Extra cost for meeting targets as a fraction of GDP



It is possible
to combine ambitious climatic goals
with an increasing demand
for energy services.

Energy system costs are minimised
if CO_2-emissions first of all are reduced
in electricity and heat production.

Exercise:
List your argument

- advantages and disadvantages by using biomass for heat production
- advantages and disadvantages by using biomass for the production of transportation fuels

Some arguments	For	Against
Bio-heat	▪High energy conversion rate ▪Efficient biomass use ▪Low cost ▪Available technology	▪Solid fuels always less comfortable than fluid or gaseous fuels ▪Infrastructure is a barrier if large scale bio-heat
Biofuels	▪Energy security ▪Agriculture benefits ▪Industry benefits ▪Policy feasible ▪Available technology	▪Expensive way to reduce CO_2 ▪ Some bio-fuels does not reduce much CO_2 ▪Limited supply potential

Discussion:
Biomass for heat or as transportation fuels?

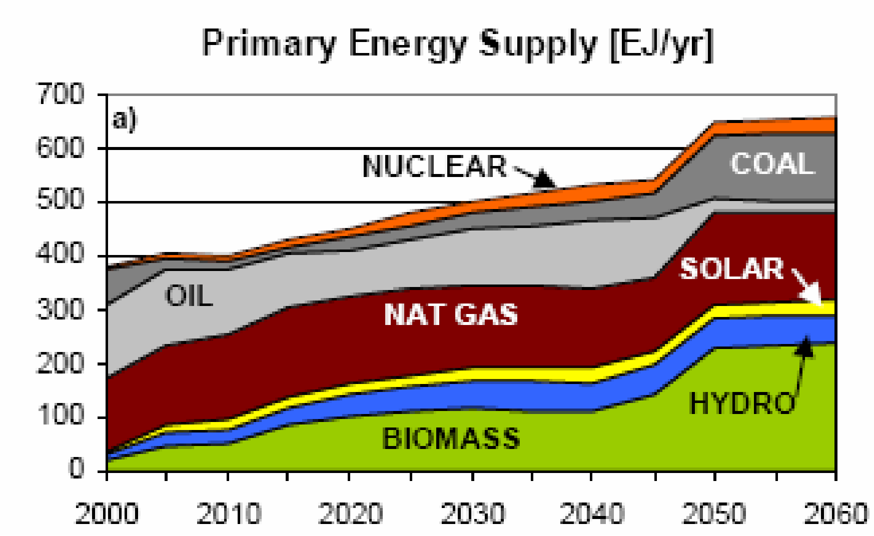
What is your opinion?

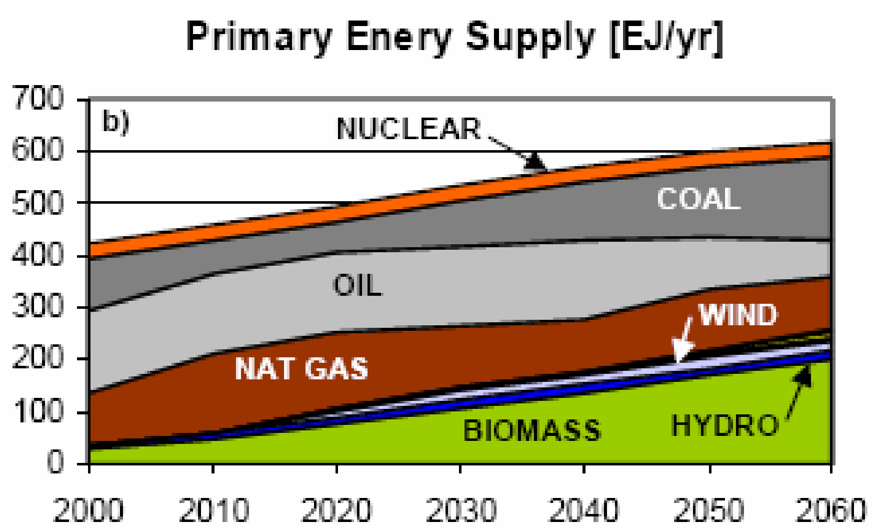
Why two similar models reach different results

Biomass for heat or as transport fuel? – a comparison between two model based studies

Maria Grahn, Christian Azar, Kristian Lindgren,
Göran Berndes, Dolf Gielen, Per Kågeson

BEAP och GET 400 ppm scenarios





BEAP

GET

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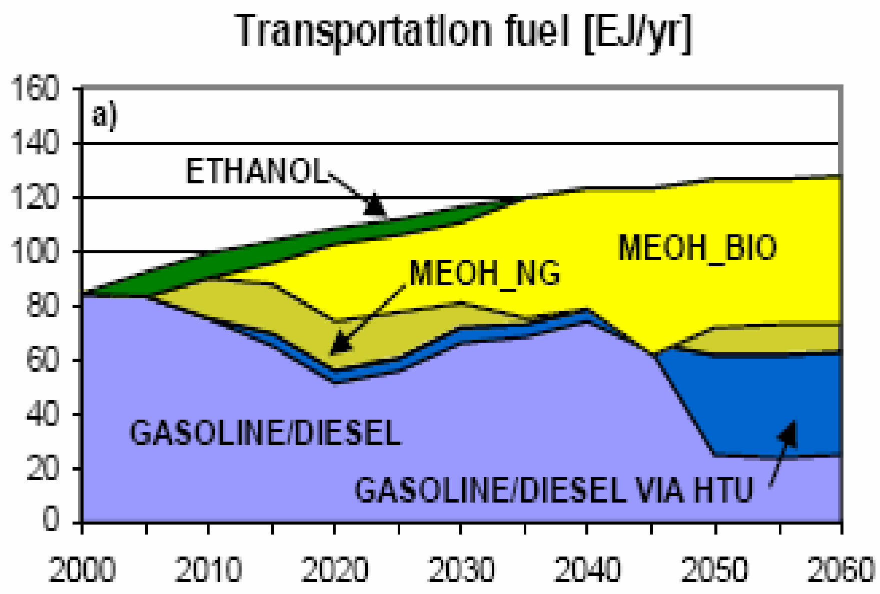
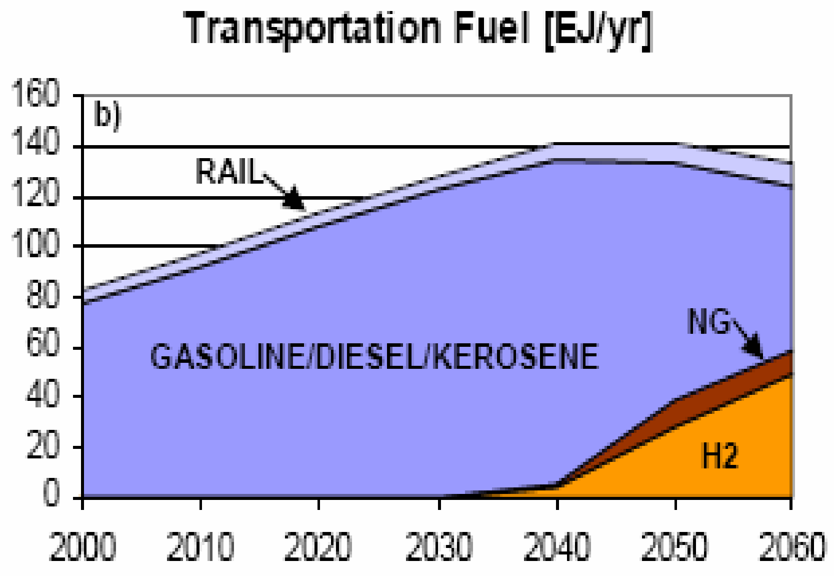


BEAP



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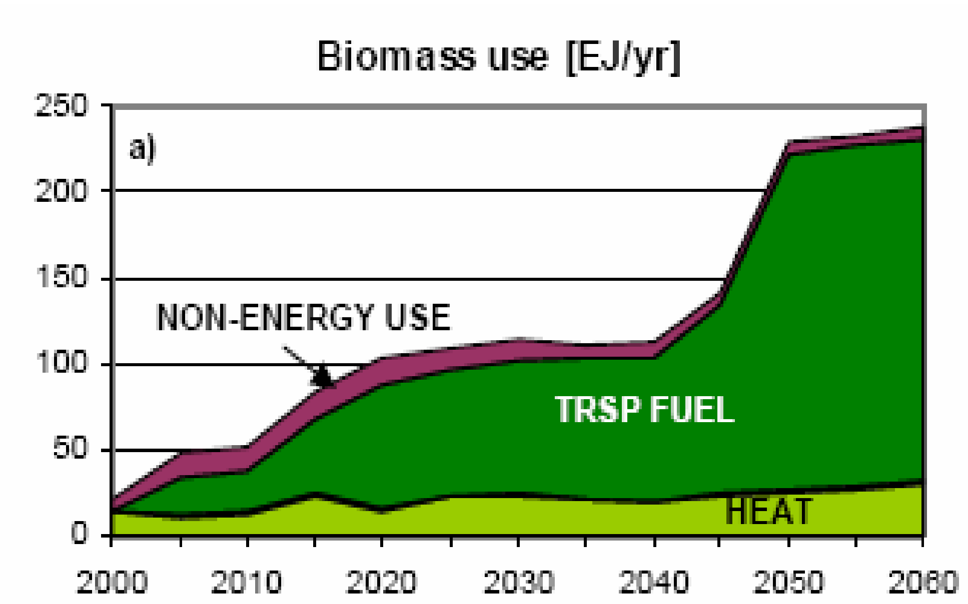
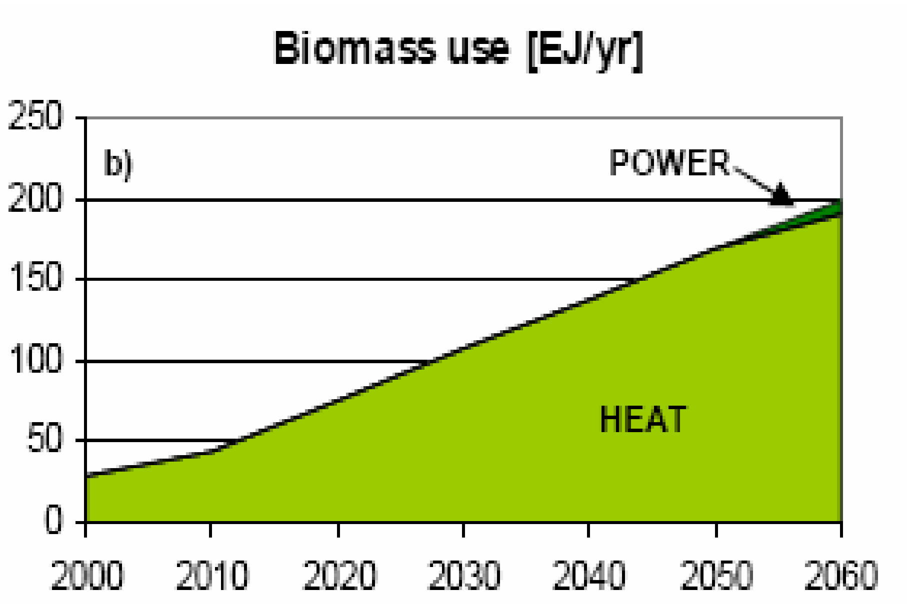


BEAP



GET

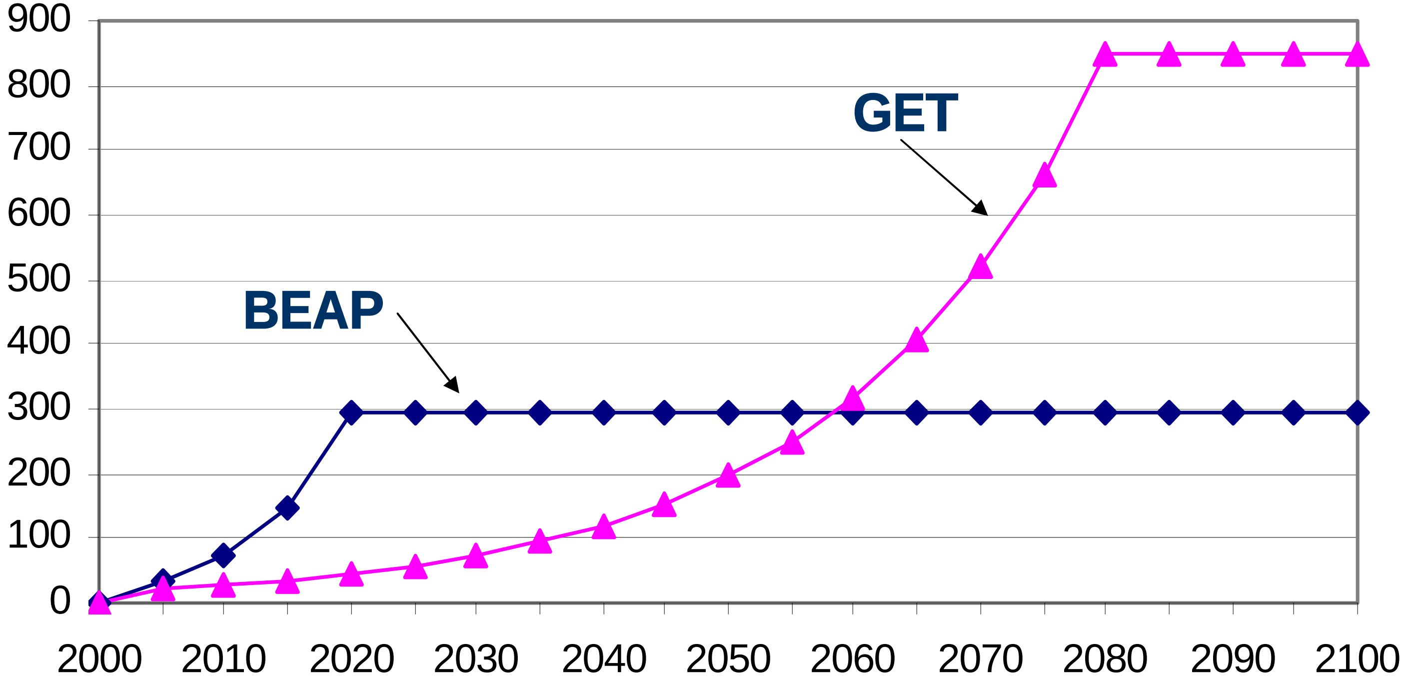
Identified four differences that impacts the biomass use

- data input error on industrial heat investments in the BEAP-model (a faktor 100 too high)

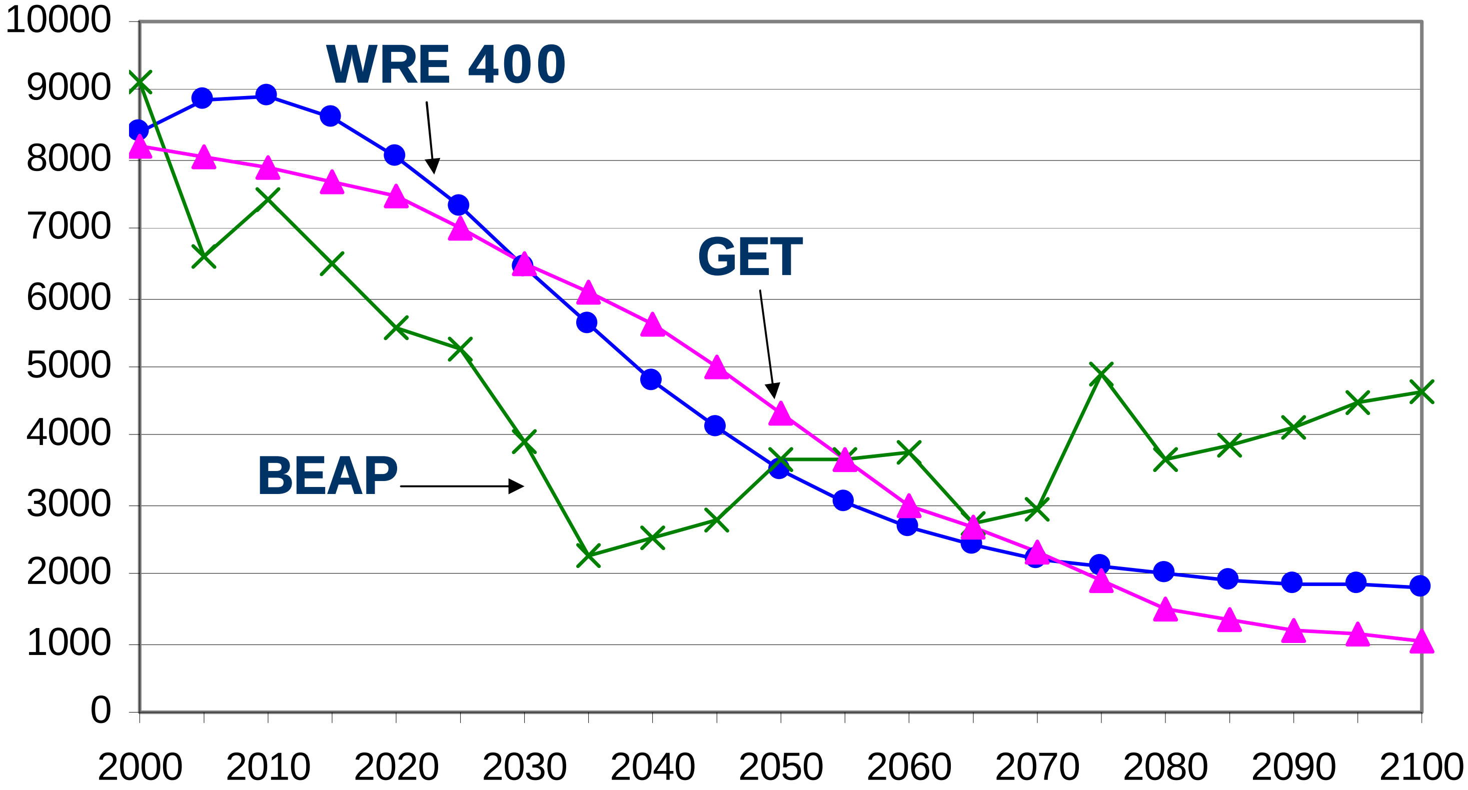
Identified four differences that impacts the biomass use

- data input error on industrial heat investments in the BEAP-model (a faktor 100 too high)
- the methods to constrain carbon dioxide emissions (different tax profile)

Carbon Taxes [USD/tC]



CO2 emissions in BEAP and GET base case [MtC/yr]



Identified four differences that impacts the biomass use

- data input error on industrial heat investments in the BEAP-model (a faktor 100 too high)
- the methods to constrain carbon dioxide emissions (different tax profile)
- assumptions on the amount of biomass that can be used for heat production

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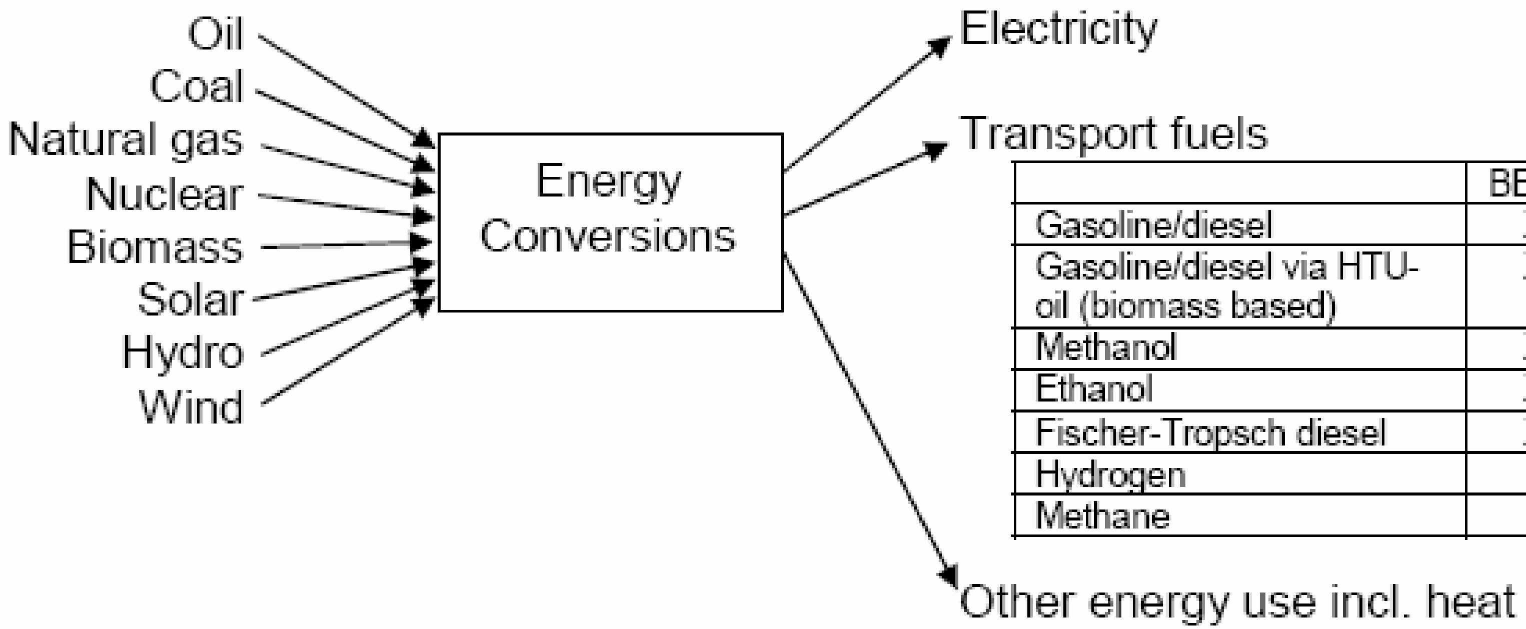
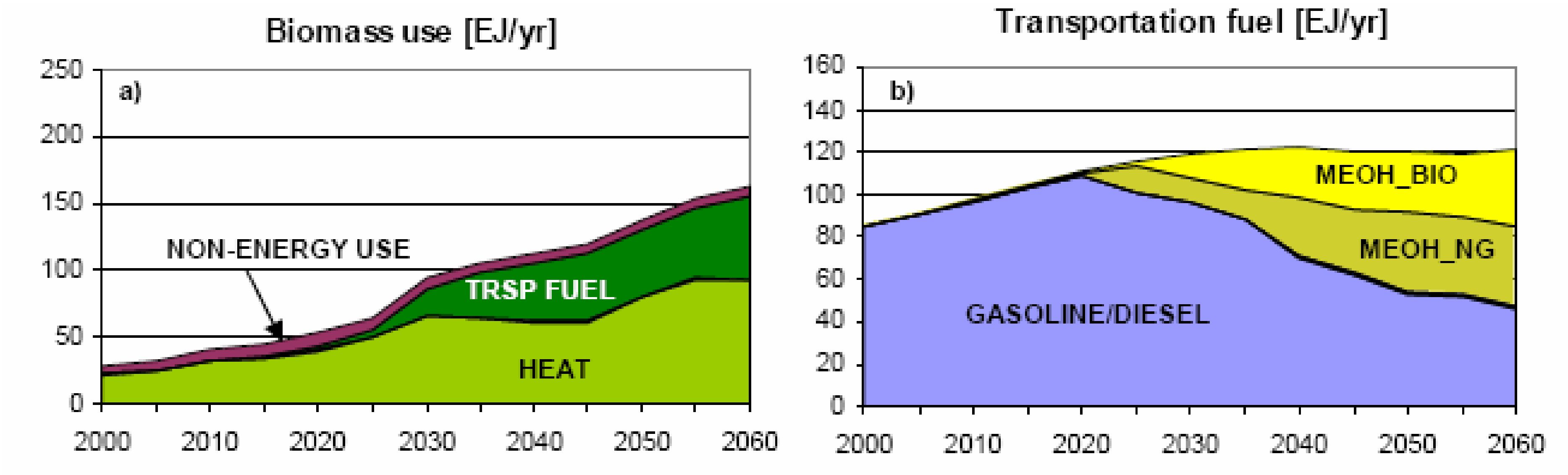
- data input error on industrial heat investments in the BEAP-model (a faktor 100 too high)
- the methods to constrain carbon dioxide emissions (different tax profile)
- assumptions on the amount of biomass that can be used for heat production
- the long run fuel options for the transportation sector (no C2-neutral H2 or natural gas in BEAP)

Energy flows in both models

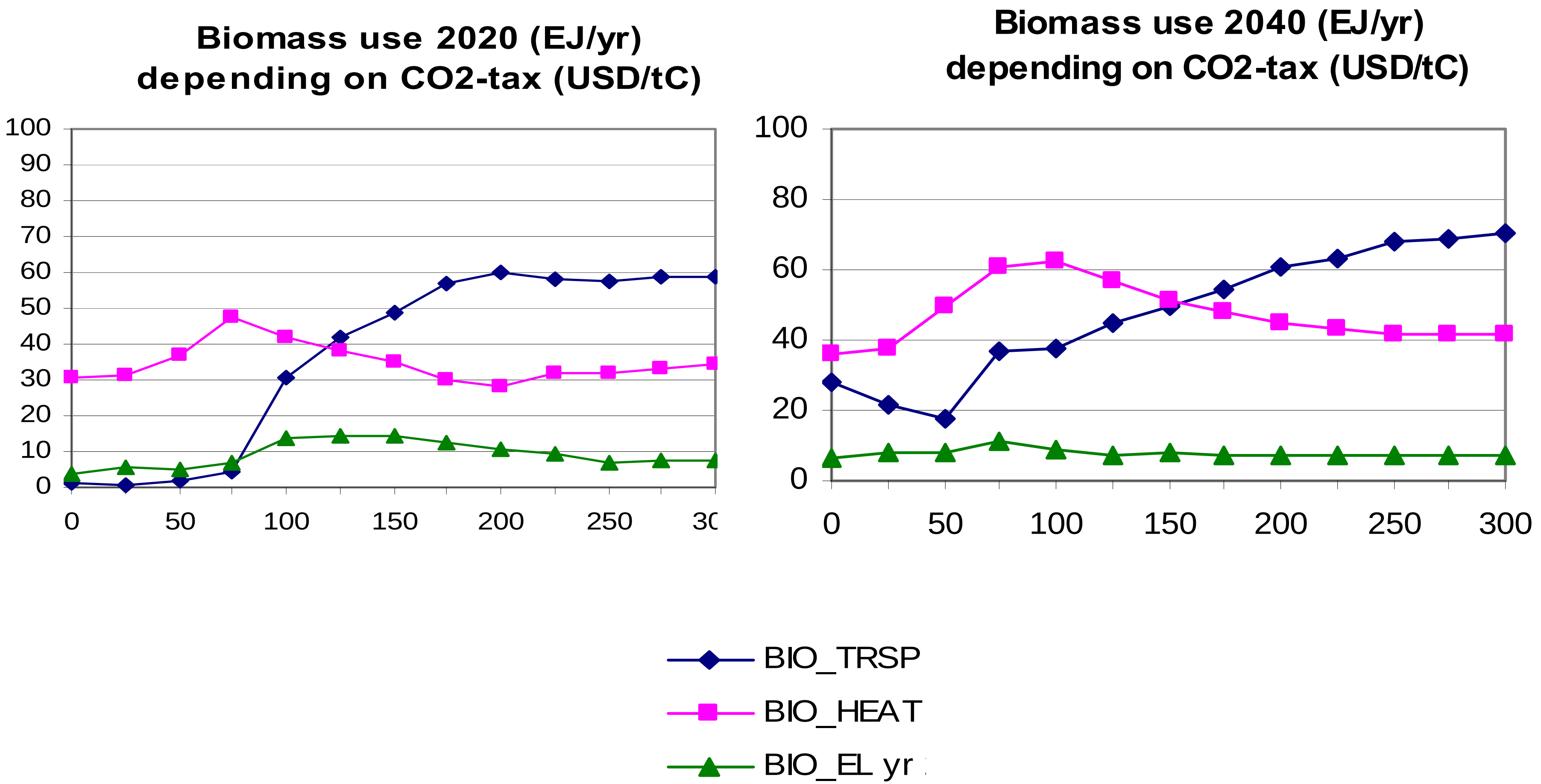


	BEAP	GET
Gasoline/diesel	X	X
Gasoline/diesel via HTU-oil (biomass based)	X	-
Methanol	X	X
Ethanol	X	-
Fischer-Tropsch diesel	X	-
Hydrogen	-	X
Methane	-	X

BEAP all changes combined



Biomass use as a function of CO_2-tax, yr 2020 and 2040



Explanation for the differing result

- It is found that both models suggest that biomass is most cost-effectively used for heat production for low carbon taxes
- But for higher carbon taxes the cost effective choice reverses in the BEAP model, but not in the GET model.
- The reason for that is that GET includes hydrogen from carbon free energy sources as a technology option, whereas that option is not allowed in the BEAP model.
- In all other sectors, both models include carbon free options. Thus with higher carbon taxes, biomass will eventually become the cost-effective choice in the transportation sector in BEAP, regardless of its technology cost parameters.

How to interpret model results?

Difficult to communicate results

- Results in absolute numbers can never be presented
- Results should not be presented as predictions of the future
- Model results illustrates the most cost-effective solution to supply the energy demand under given pre-requisites and constraints.
- Try to present your model structure and assumptions as clear as possible. The audience must be able to judge for them selves.
- Remember that linear models always gives the optimal solution (least costly) no matter how close another solution might be.

Cost-efficiency might not be the main reason when decisions are taken in reality

More important could be how political viable a change is. Often things very difficult to include in a model, for example

- Comfortability
- Public acceptance for new technologies
- Agriculture and industry policy - employment
- The impact of lobby groups
- Local pollution
- Energy security
- Consumers willingness to pay
- Political instabilities - war

How can optimisation models be useful?

The model should give general insights about how the energy system works under different pre-requisites.

The model could be seen as an experimental box where you can understand relations which otherwise not are obvious.

Important is that insights also must be able to be explained without using the model (through other calculations or logical discussion).

Sensitivity analysis on parameter assumptions as well as on model structure are crucial to value model results.

Summary of todays lecture

- It is possible to decrease carbon dioxide emissions at the same time as the demand for energy services increases.
- To reach low climate targets, a radical change of the energy system is needed. In a near future are energy efficiencies and increased use of biomass two important tools.
- Biomass replaces fossil fuels at lower costs when used for heat and power production compared to when used as for transportation fuels.
- Biofuels for transport becomes an important tool if hydrogen will not be possible to use in the transportation sector.

Summary cont.

- No matter fuel choice it is important to develop energy-efficient vehicles.
- Large transitions takes time, so to be able to introduce new technologies in about 30 years, large committments and investments are needed today.
- Optimisation models are useful and important tools for insights, but model results should be treated careful and verified by other methods too.

Tack you
for your attention!