Energy system modeling

Fredrik Hedenus
Energy and Environment
Physical Resource Theory
Chalmers
hedenus@chalmers.se

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Outline

- Climate change
- Purpose of the model
- Basic model structure
- Background on energy technologies
- Results and analysis

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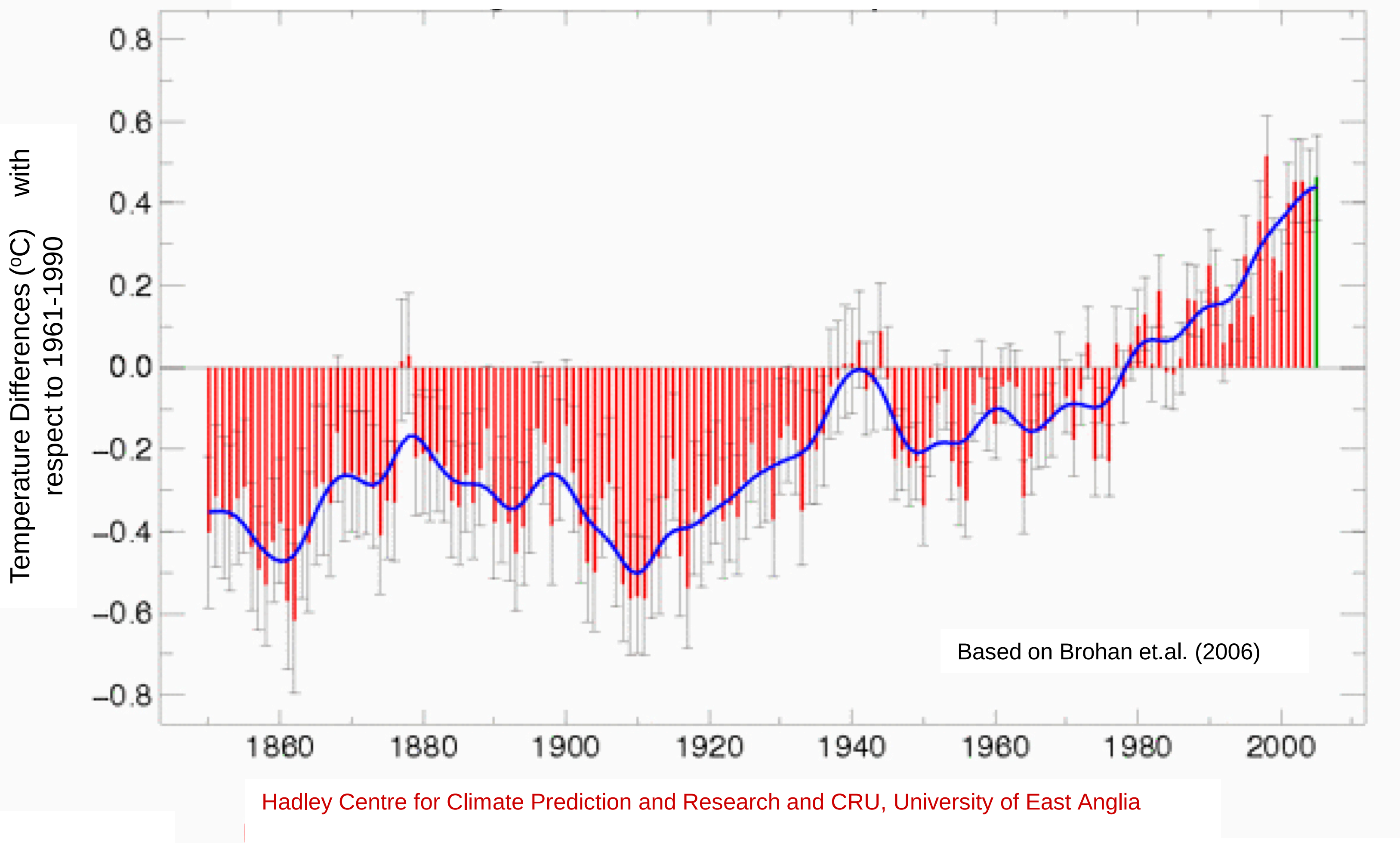
Global average surface temperature 1850-2005



Source: http://www.metoffice.gov.uk/research/hadleycentre/obsdata/globaltemperature.html

What do we know about climate change

- There are a natural greenhouse effect. (The most important natural greenhouse gases are carbon dioxide and water vapor)
- The concentration of carbon dioxide and other greenhouse gas has increased in the atmosphere.
- As the concentration of greenhouse gases increases, so does the temperature, however unceratin to which extent.
- There has been climate change, but we have still not seen the full effect of our emissions

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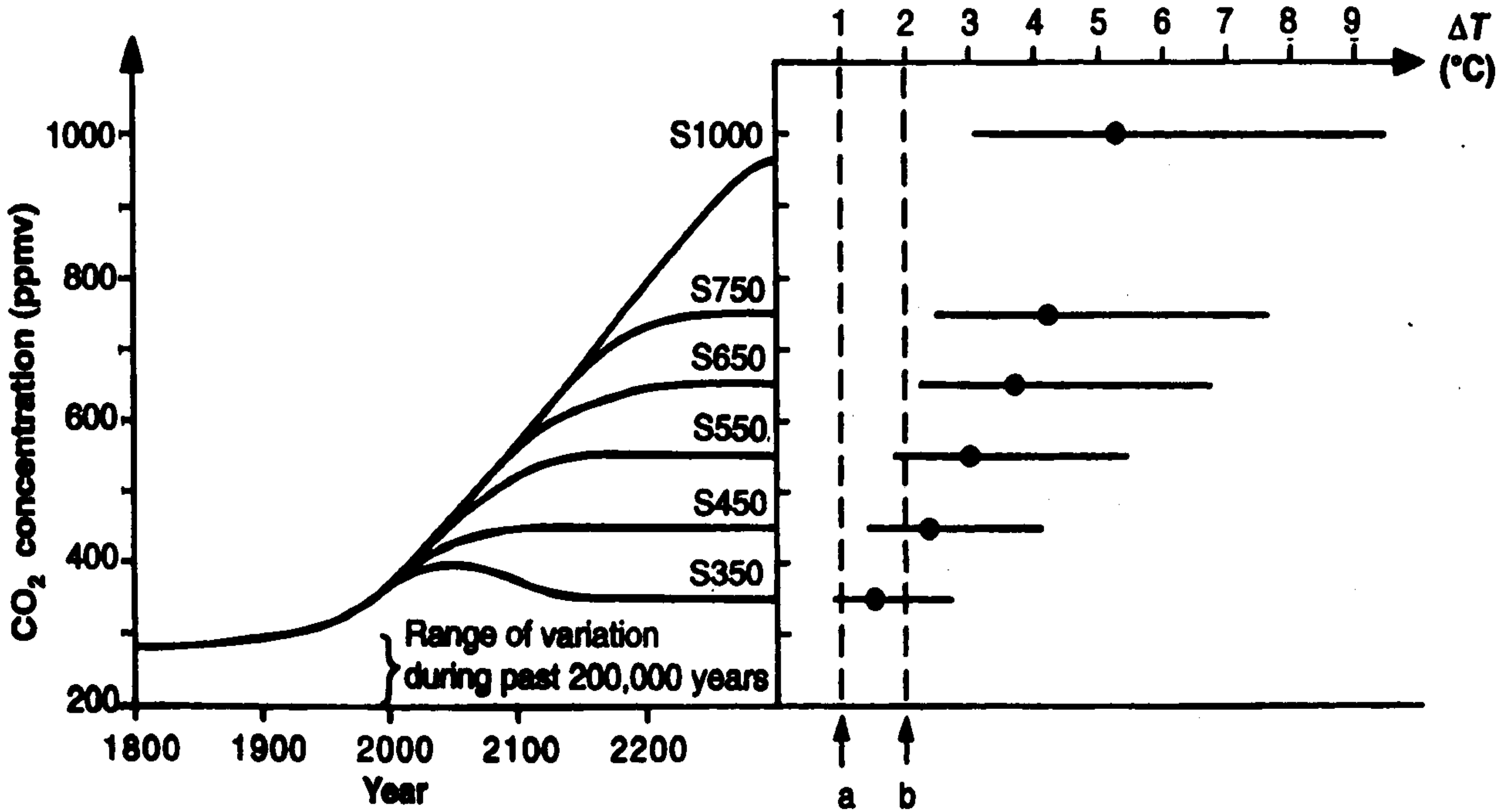
Long-term stabilization targets



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Azar & Rodhe

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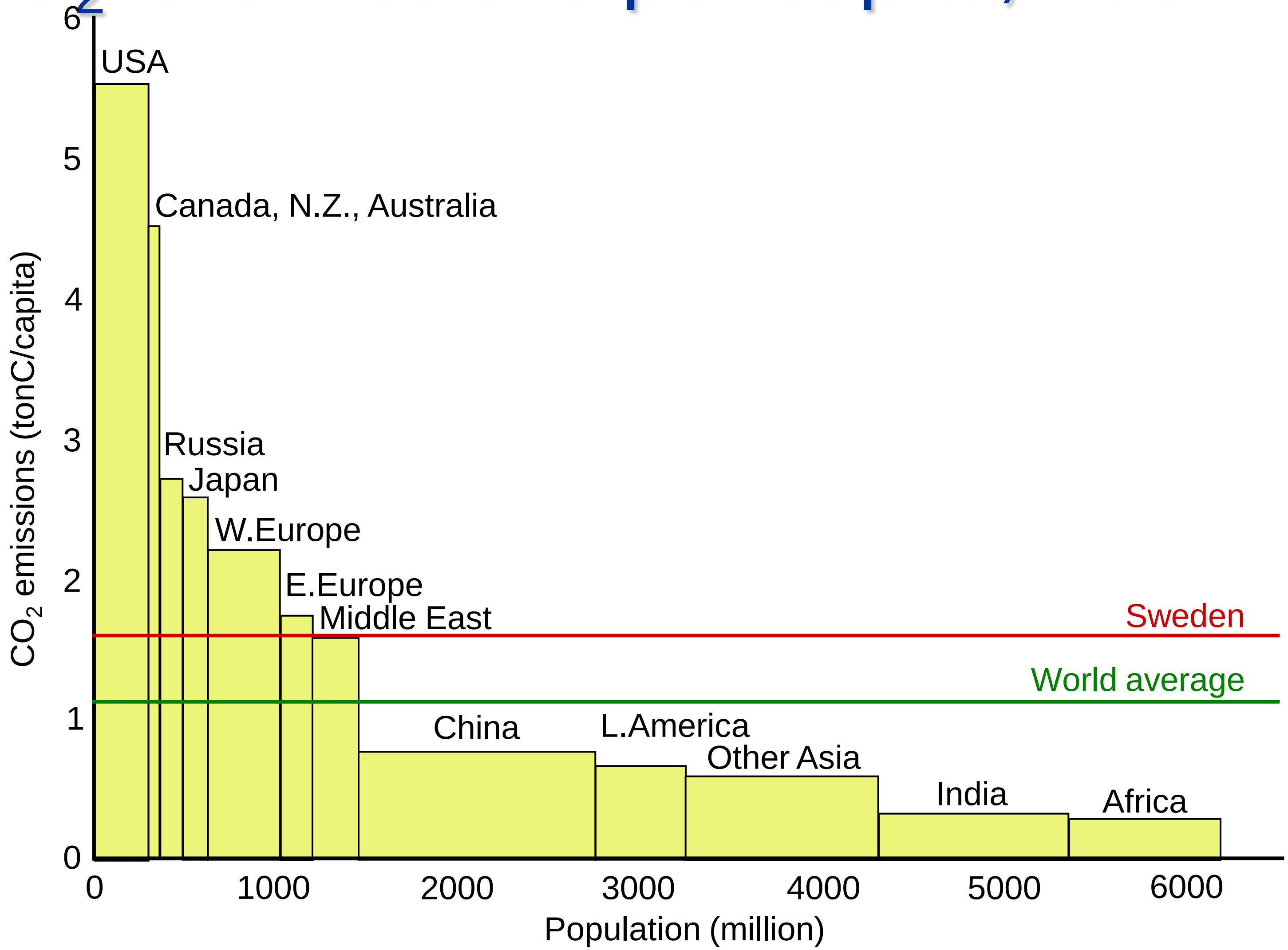
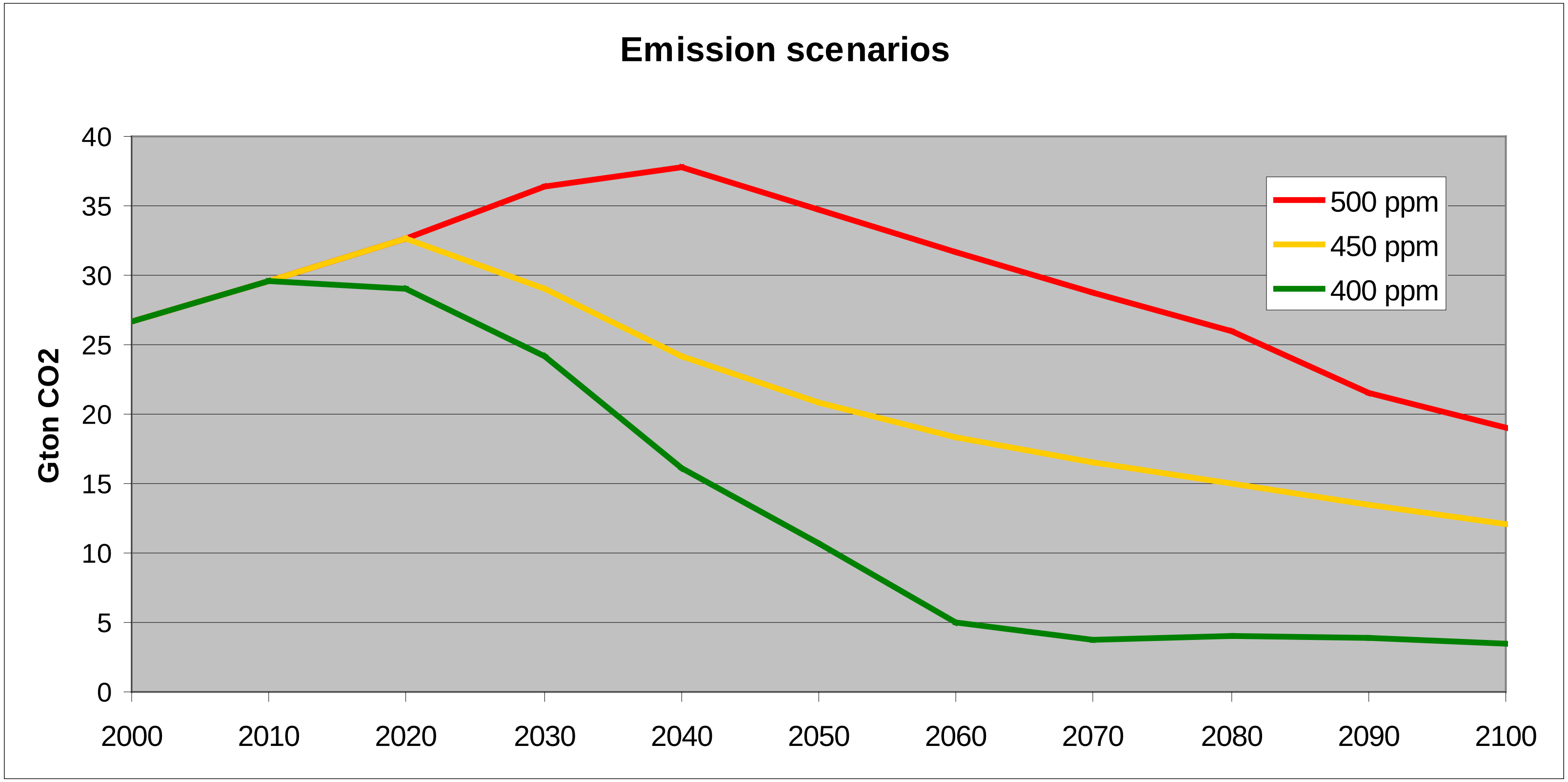
CO_2-C emissions per capita, 2002



Data from 2002. Sources: FAO, CDIAC

Emission scenarios



Research questions

- Which energy technologies are the cheapest to use?
- What is the cost of reducing the emissions?
- Which interrelations are there in the energy system?
- Where is it most cost-effective to use biomass?
- What determines the future transport system?

Objective to minimize cost

$$A(t) = \sum_{f} S(f,t)p(f) + \sum_{x,y} I(x,y,t)k(x,y)$$

- *A(t)* Annual cost of the energy system
- *S(f,t)* Energy supply
- *p(f)* Fuel cost
- *I(x,y,t)* Investments made
- *k(x,y)* Capital costs for energy conversion

Discounting

- Do you prefer the get 1000 USD today or in 10 years?

- We are richer in the future
- We get interest at the bank
- Uncertainty about the future

Objective function

$$\min C = \sum_{t=1}^{T} \frac{A(t)}{(1+r)^{t-1}}$$

- *C*, total cost, *A(t)* annual cost, *t* time
- Discount rate, *r*, 5 %

Main contraints

- Emission constraints

$$U(t) = \sum_f S(f,t)\beta(f)$$

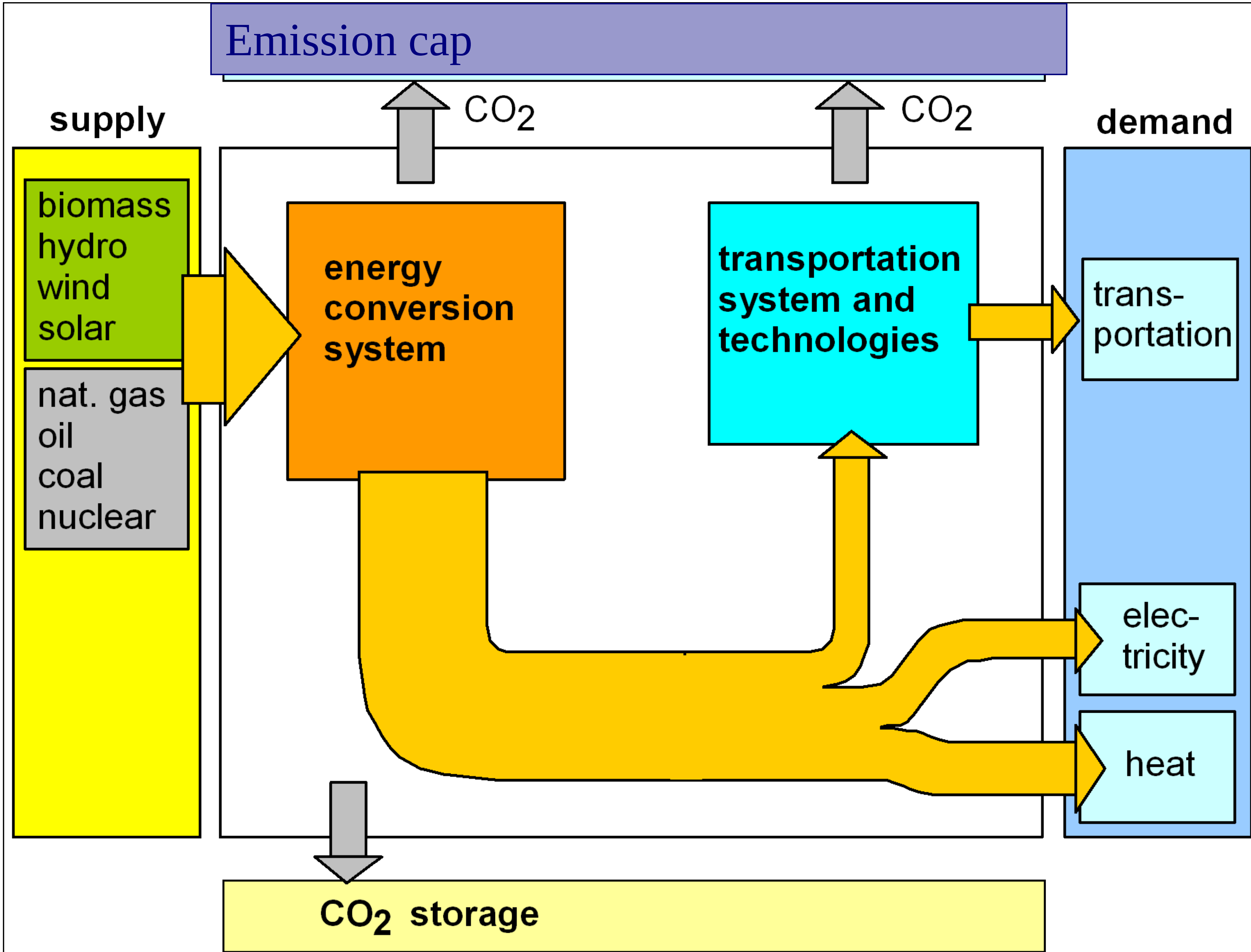
- Supply must be equal demand

$$D(t,y) + e(y,t) = \sum_x E(x,y,t)\eta(x,y)$$

$$e(\text{elec},t) = \sum_y E(\text{elec},y,t)$$

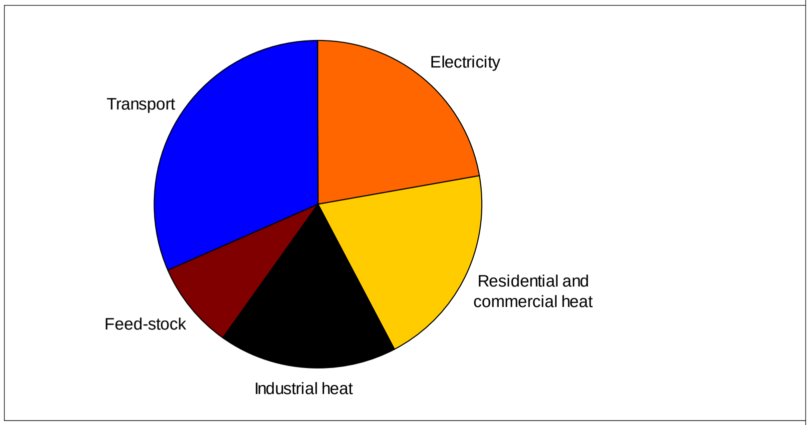
- Fossil resource constraints

$$\sum_t S(f,t)\Delta t \le R(f)$$

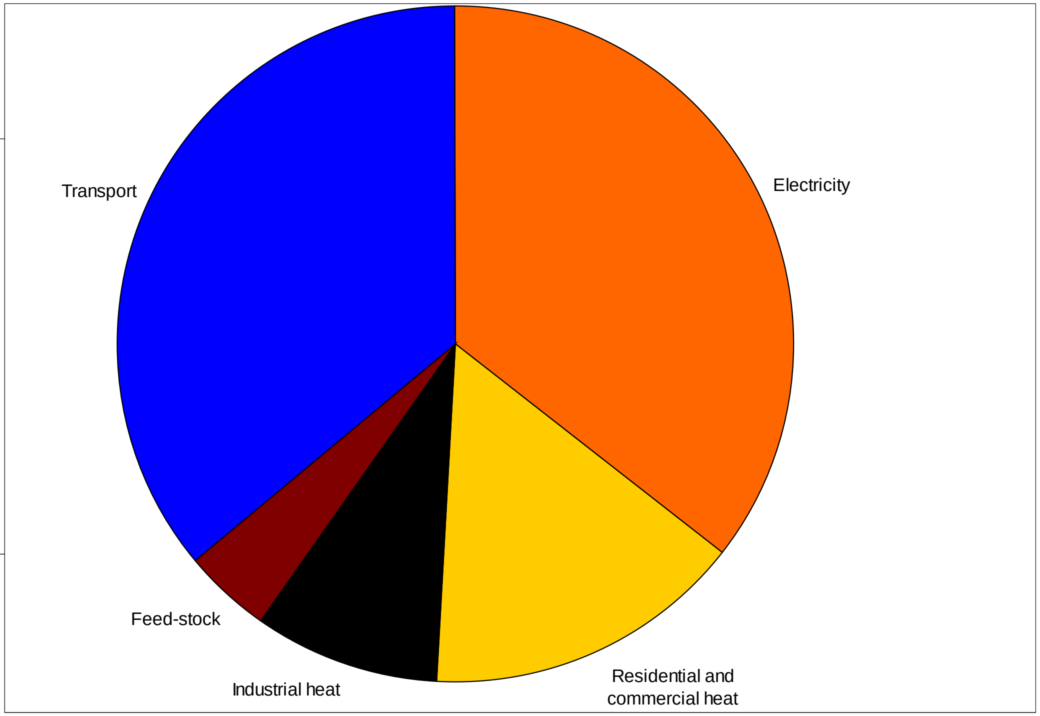

Emission cap
CO2
CO2
supply
demand
biomass
hydro
wind
solar
nat. gas
oil
coal
nuclear
energy conversion system
transportation system and technologies
trans-portation
elec-tricity
heat
CO2 storage

Energy demand

2000



2100



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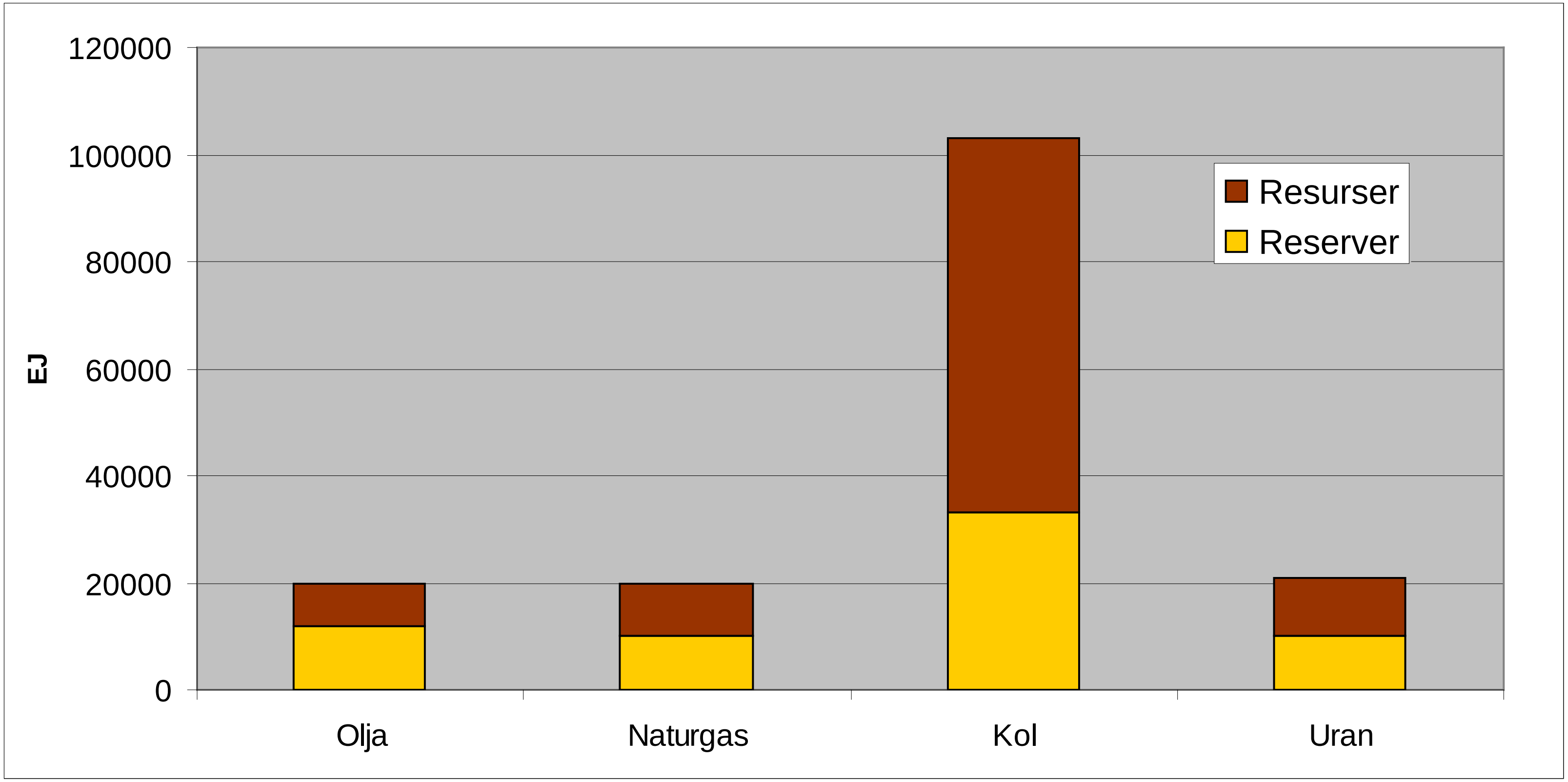
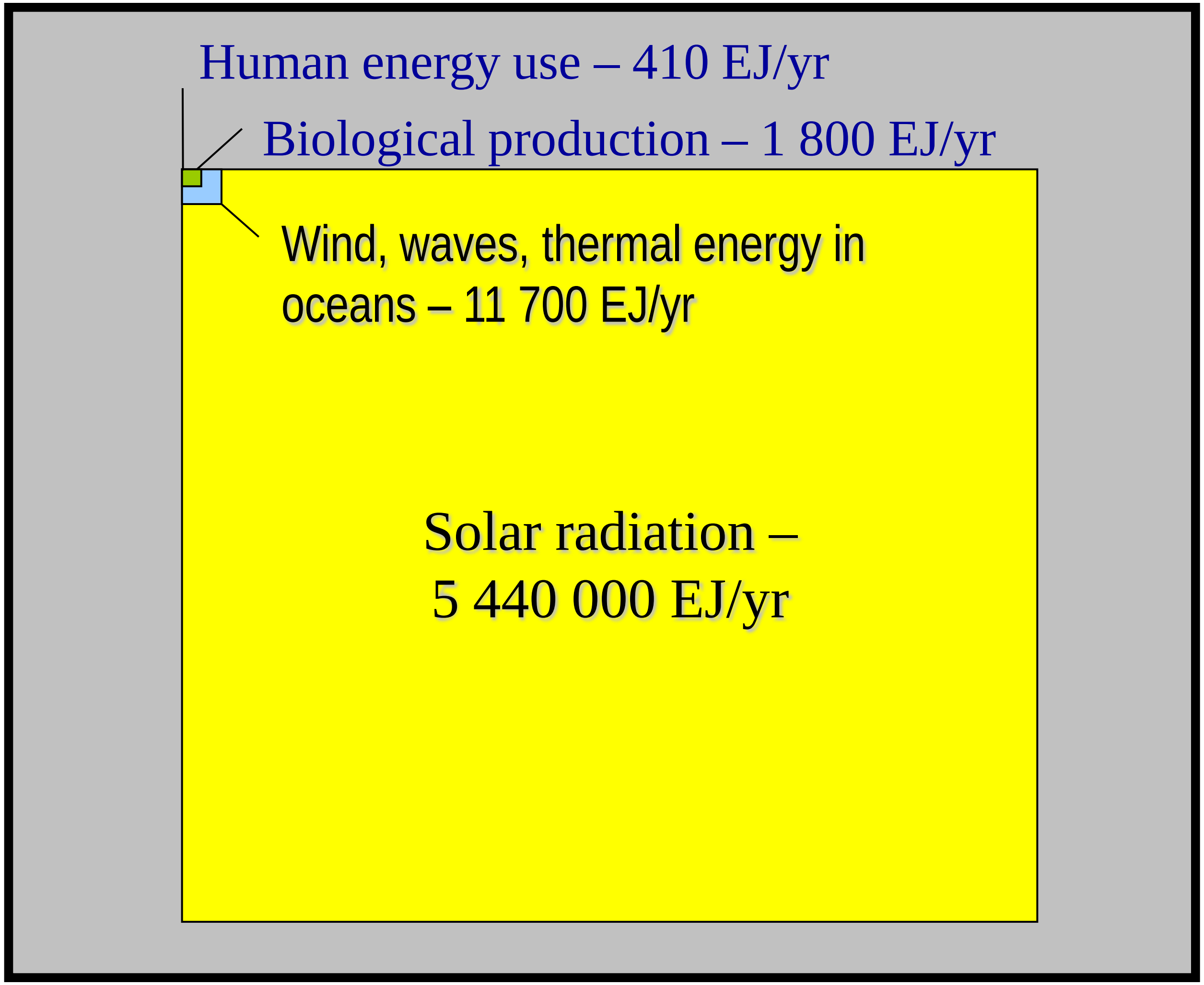
Non-renewable resources



Physical potential of renewable energy



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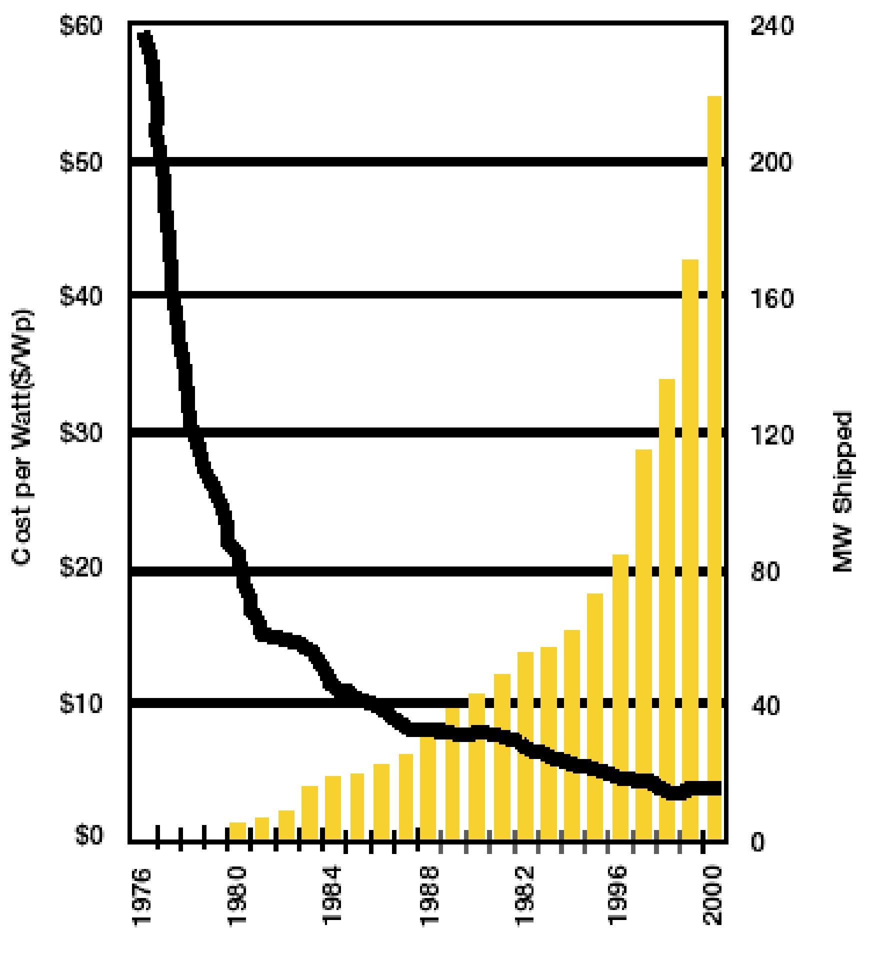
Solar energy



Solar power

Solar PV

Nuclear power

U-235 + n -> X + Y + 2-3n + E

0.7% of natural uranium is U-235, the rest is U-238.

Pros

- No CO_2 emissions
- Large resource in sea water
- Relatively cheap

Cons

- Waste
- Limited reserves
- Weapon proliferation
- Accidents

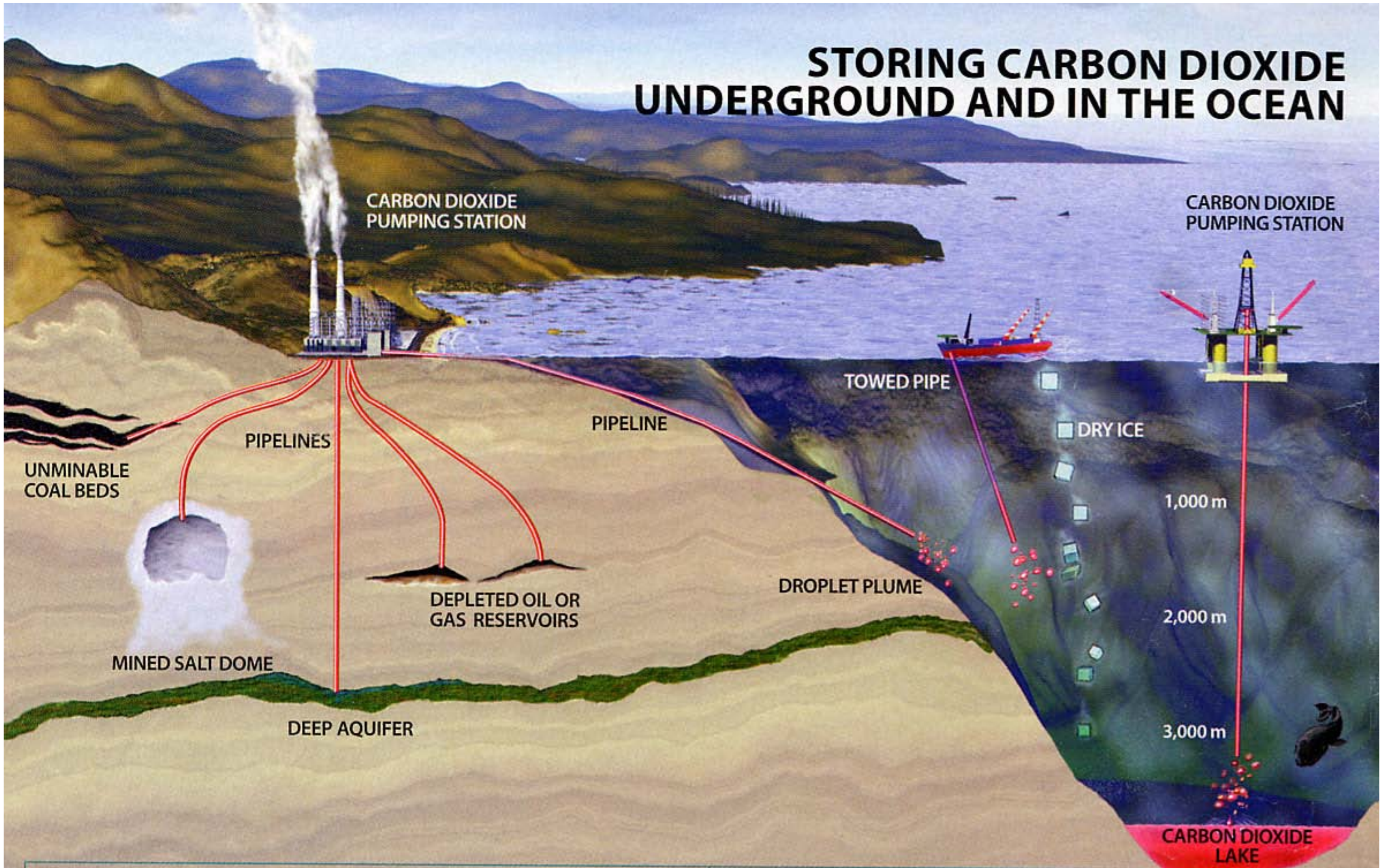
Bioenergy

Rest flows

Plantations

Grains

Carbon capture and storage (CCS)



STORAGE UNDERGROUND	ADVANTAGES	DISADVANTAGES
Coal Beds	Potentially low costs	Immature technology
Mined Salt Domes	Custom designs	High costs
Deep Saline Aquifers	Large capacity	Unknown storage integrity
Depleted Oil or Gas Reservoirs	Proven storage integrity	Limited capacity

STORAGE IN OCEAN	ADVANTAGES	DISADVANTAGES
Droplet Plume	Minimal environmental effects	Some leakage
Towed Pipe	Minimal environmental effects	Some leakage
Dry Ice	Simple technology	High costs
Carbon Dioxide Lake	Carbon will remain in ocean for thousands of years	Immature technology

Herzog et al., *Scientific American*, February 2000

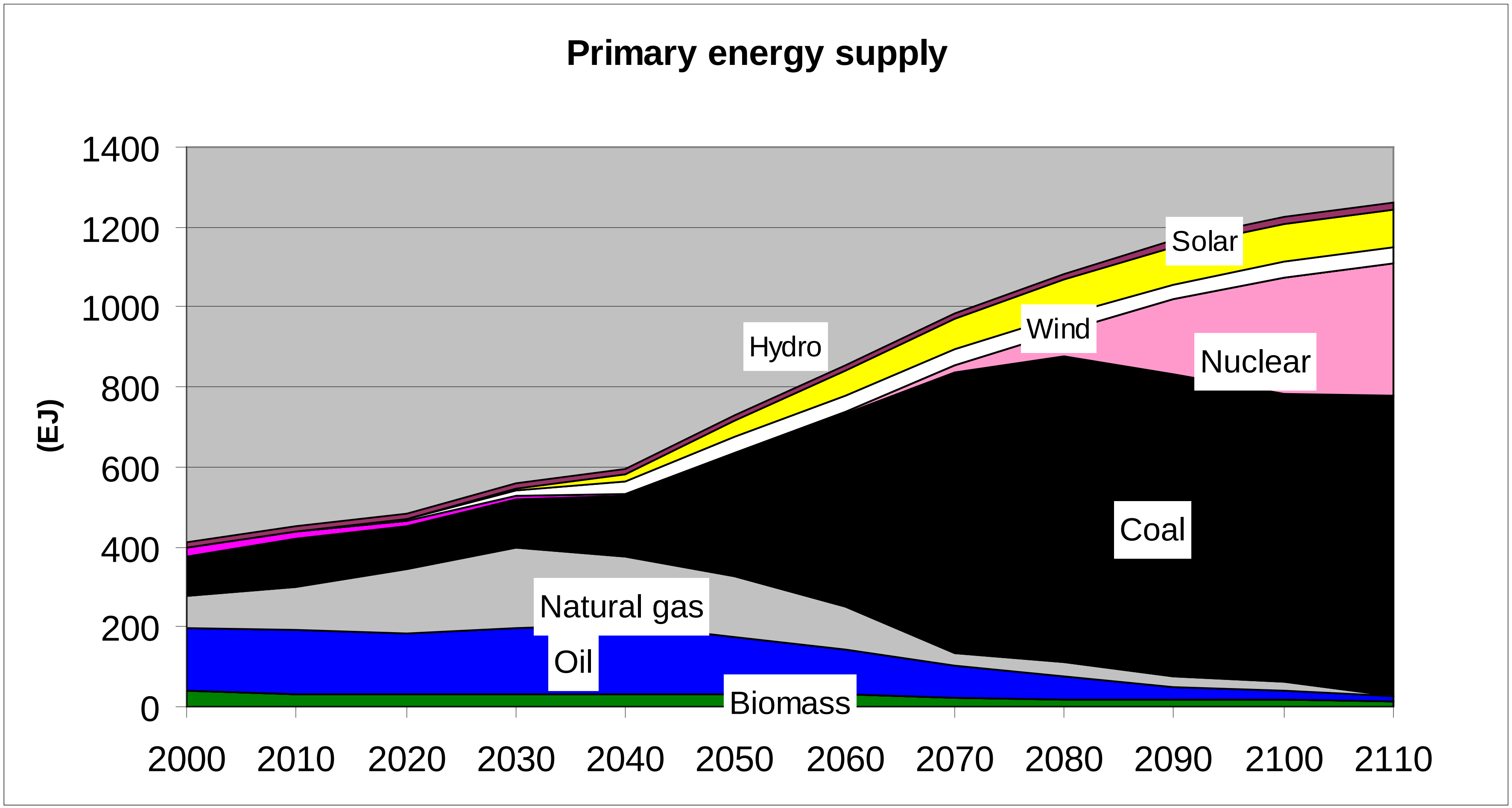
Energy carrier

- Hydrogen H2
  - Fossil fuels with CCS
  - Bioenergy (with CCS)
  - Solar energy
- Synthetic fuels CH2
  - Fossil fuels with CCS
  - Bioenergy (with CCS)
- Electricity
  - Fossil fuels with CCS
  - Nuclear power
  - Solar energy

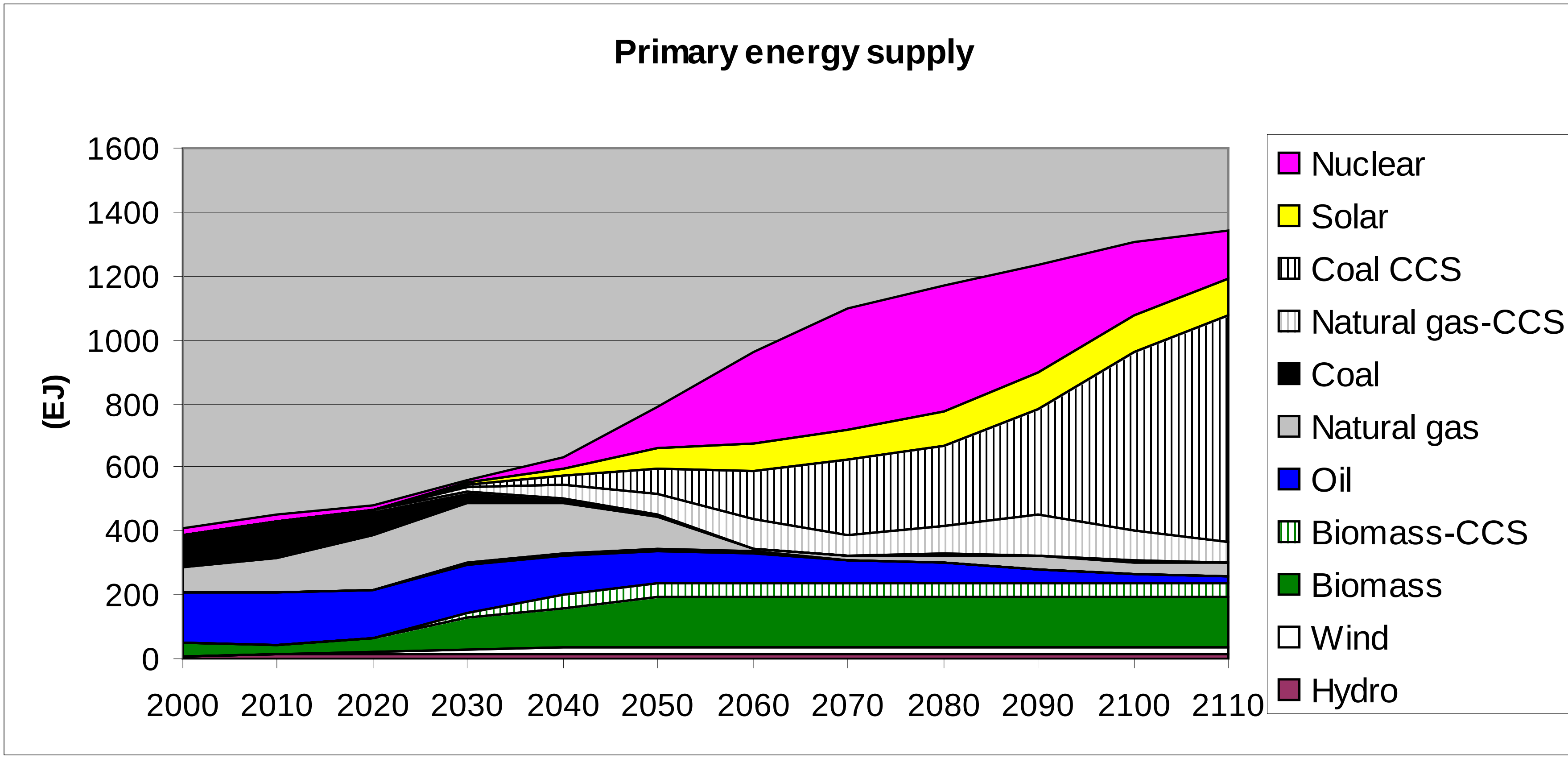
Vehicles types

- Hybrid cars
  - 35% more efficient for personal transport
- Plug-in hybrid
  - Charged from the grid
- Hydrogen fuel cells
  - 70 % more efficient

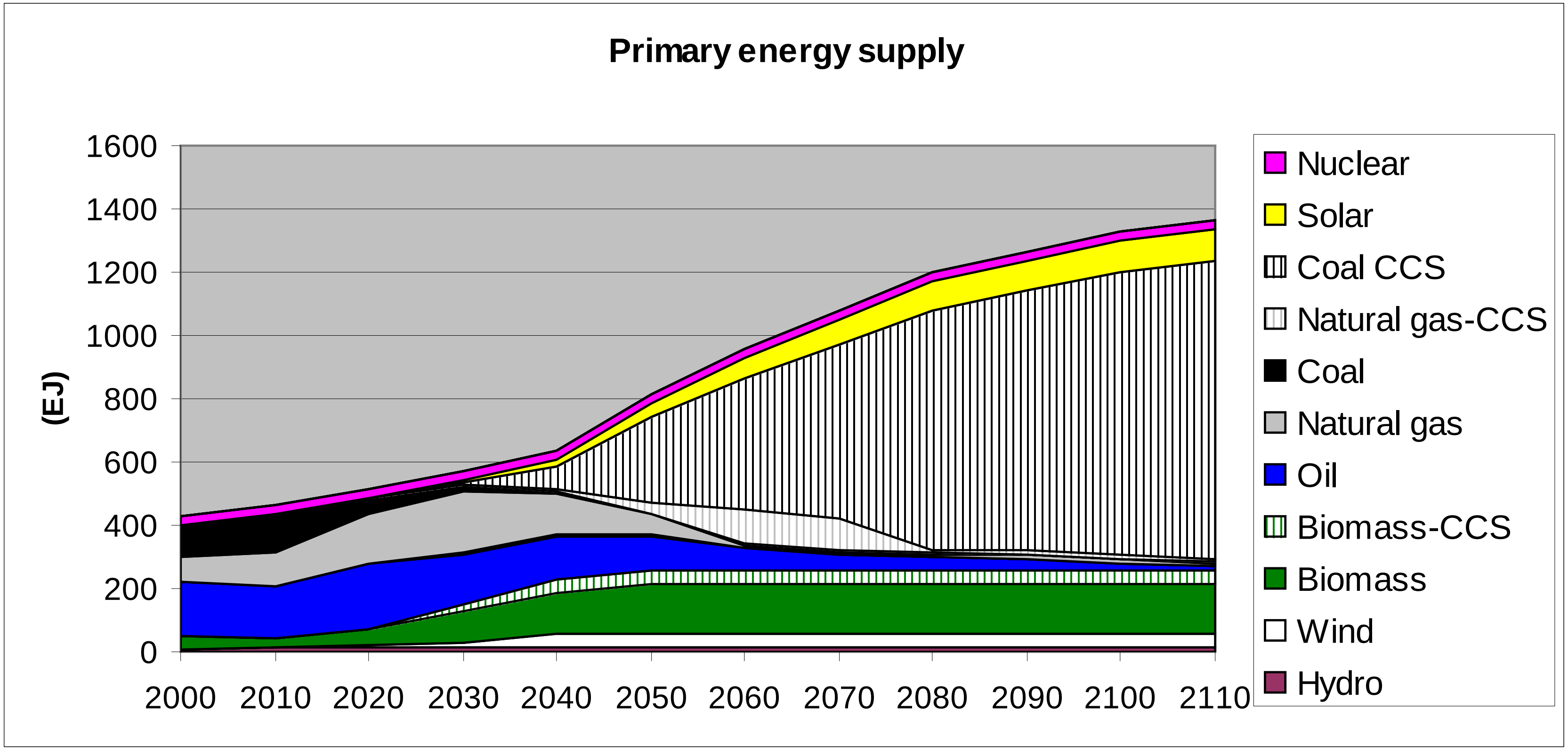
Global baseline scenario



400 ppm scenario, nuclear power and CCS allowed



400 ppm, limited nuclear, CCS allowed



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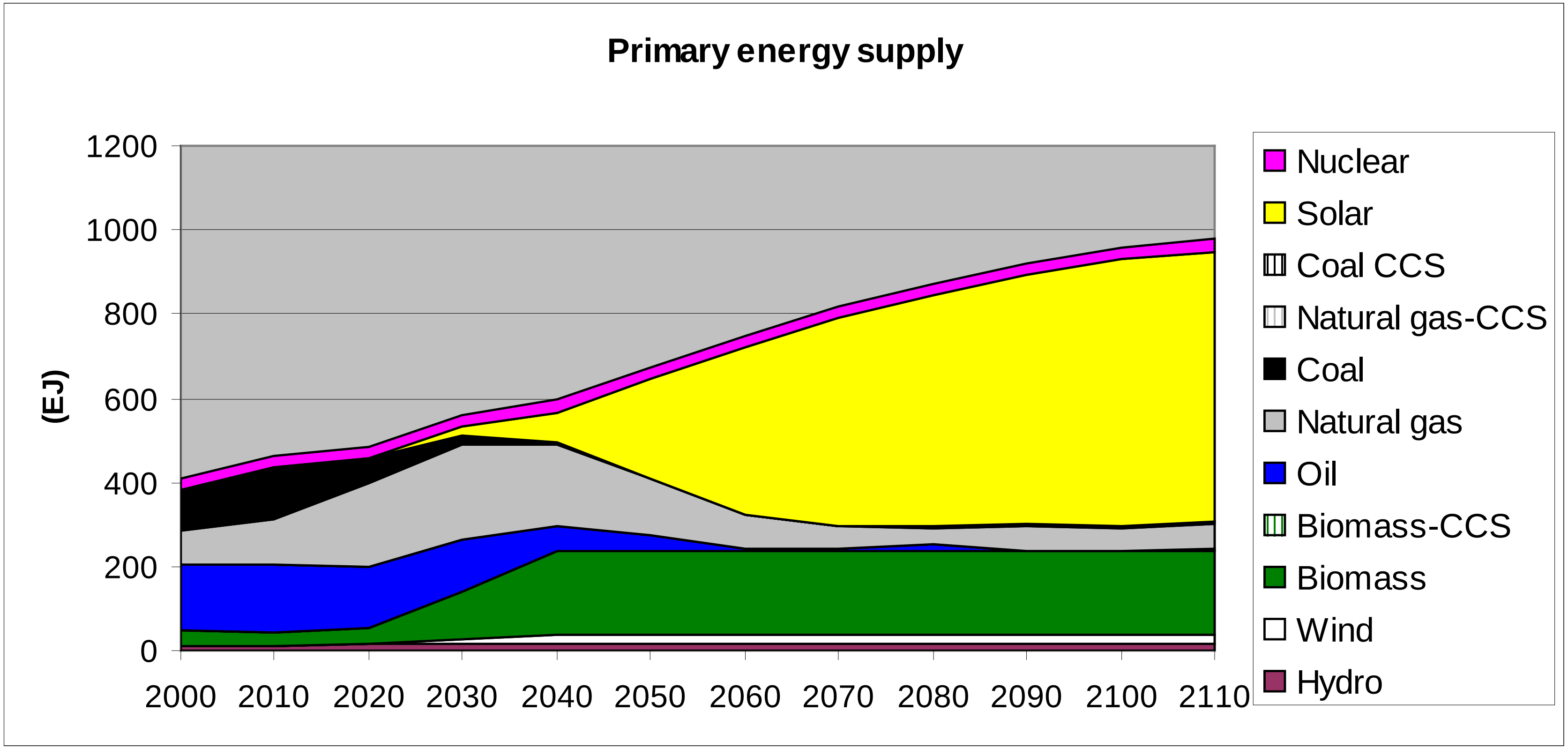
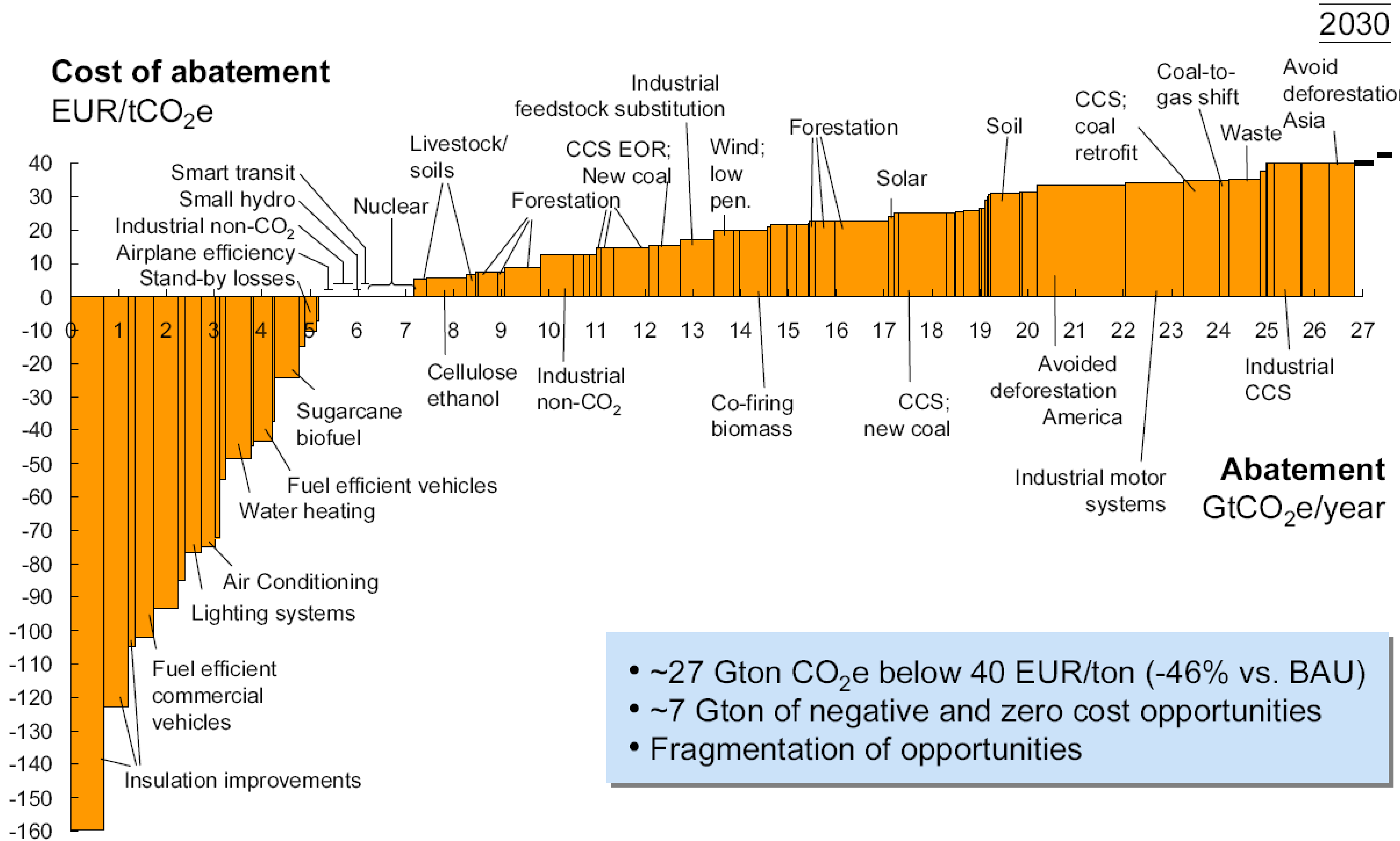
400 ppm, no nuclear and no CCS

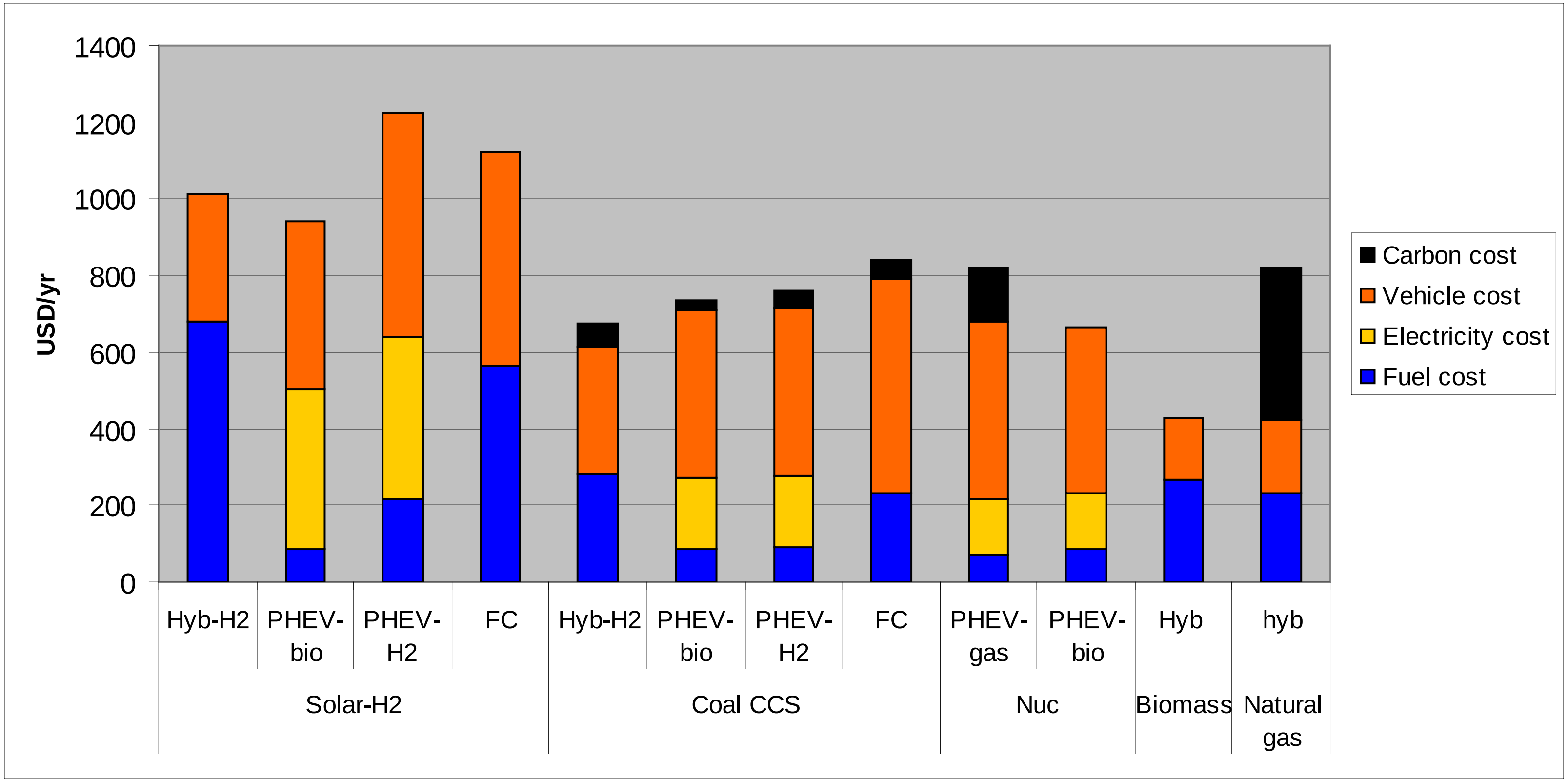


Stabilization is possible at limited costs – markets can supply

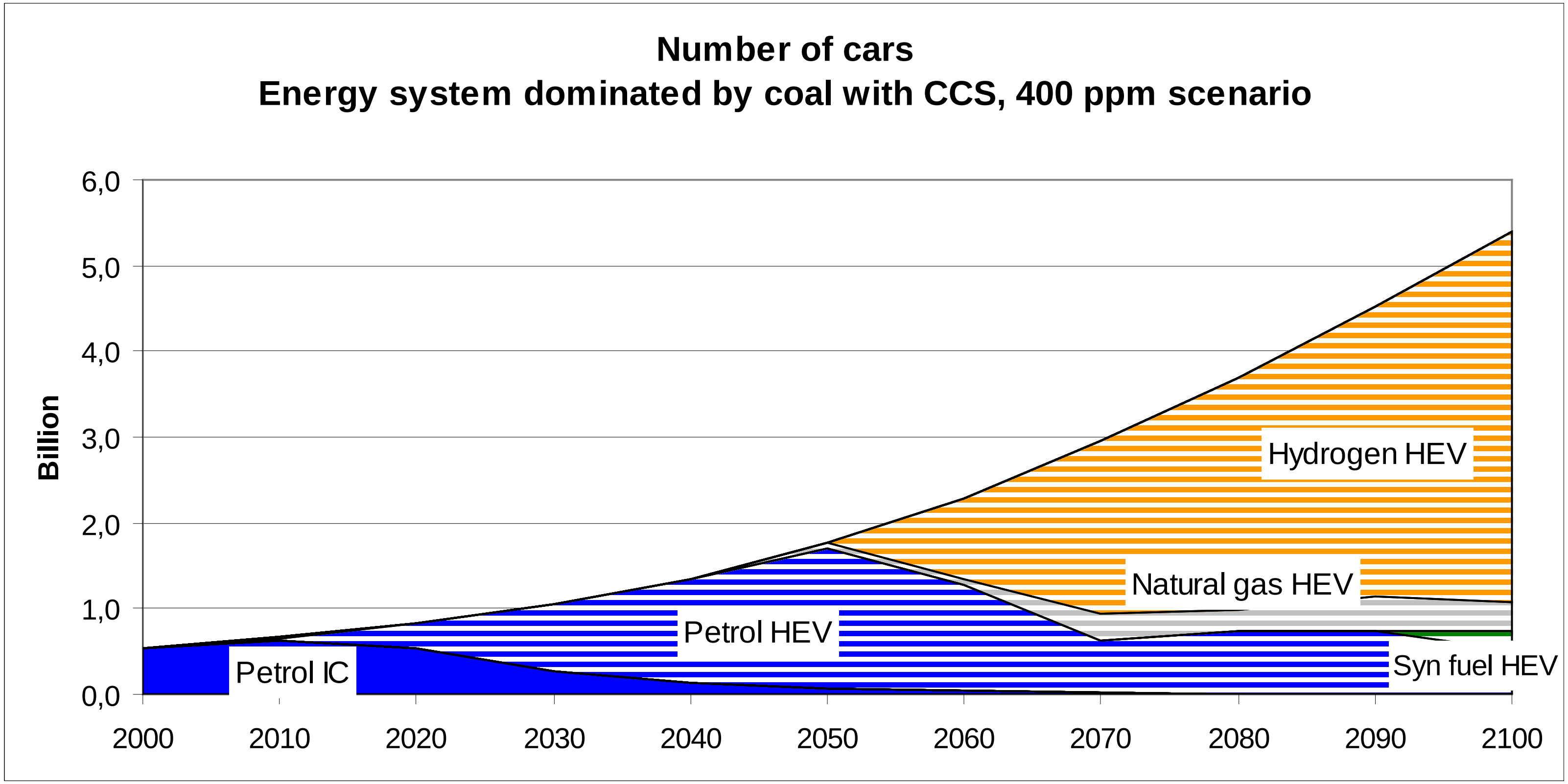


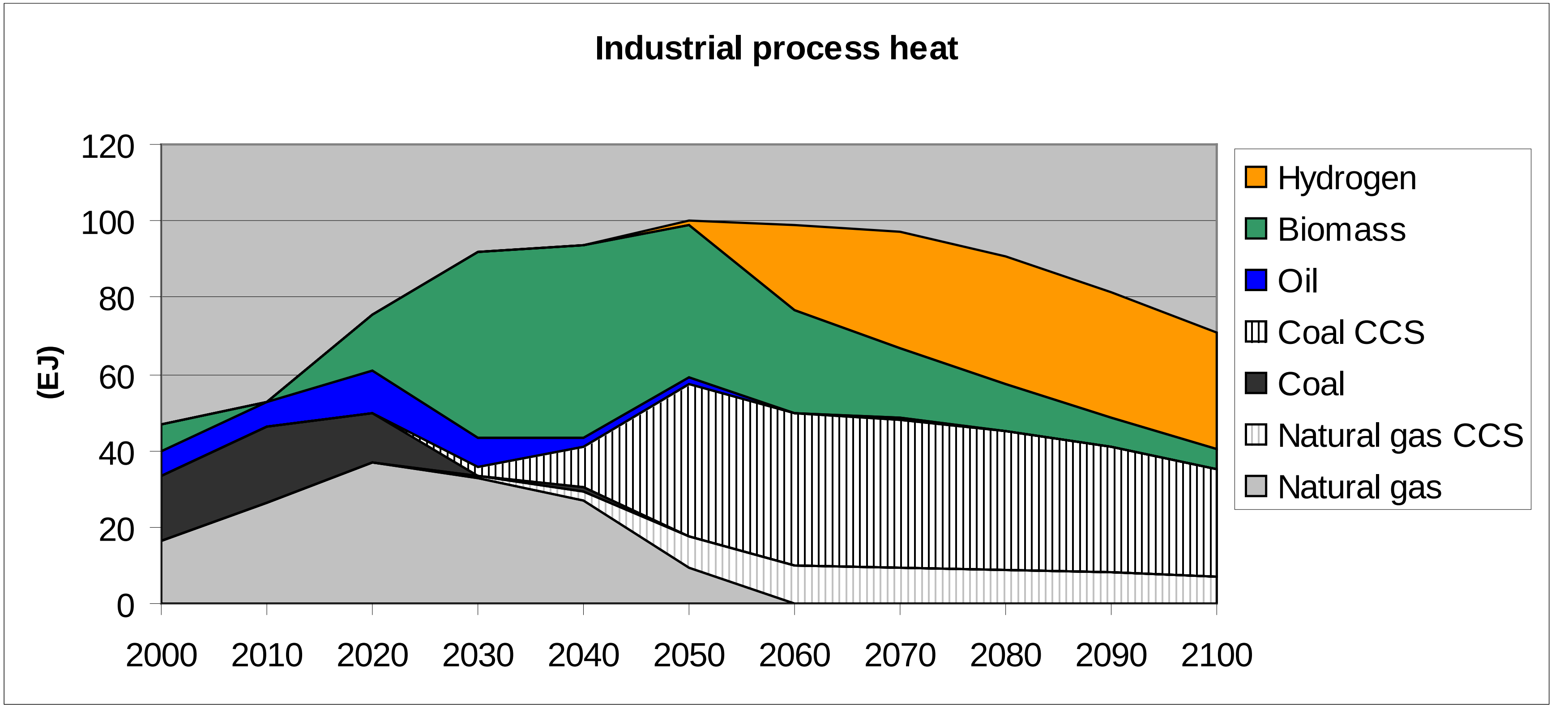
- ~27 Gton CO_2e below 40 EUR/ton (-46% vs. BAU)
- ~7 Gton of negative and zero cost opportunities
- Fragmentation of opportunities

Vehicle costs, carbon price 1000 USD/ ton C



400 ppm scenario, limited nuclear CCS allowed




Industrial process heat
(EJ)
120
100
80
60
40
20
0
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Hydrogen
Biomass
Oil
Coal CCS
Coal
Natural gas CCS
Natural gas

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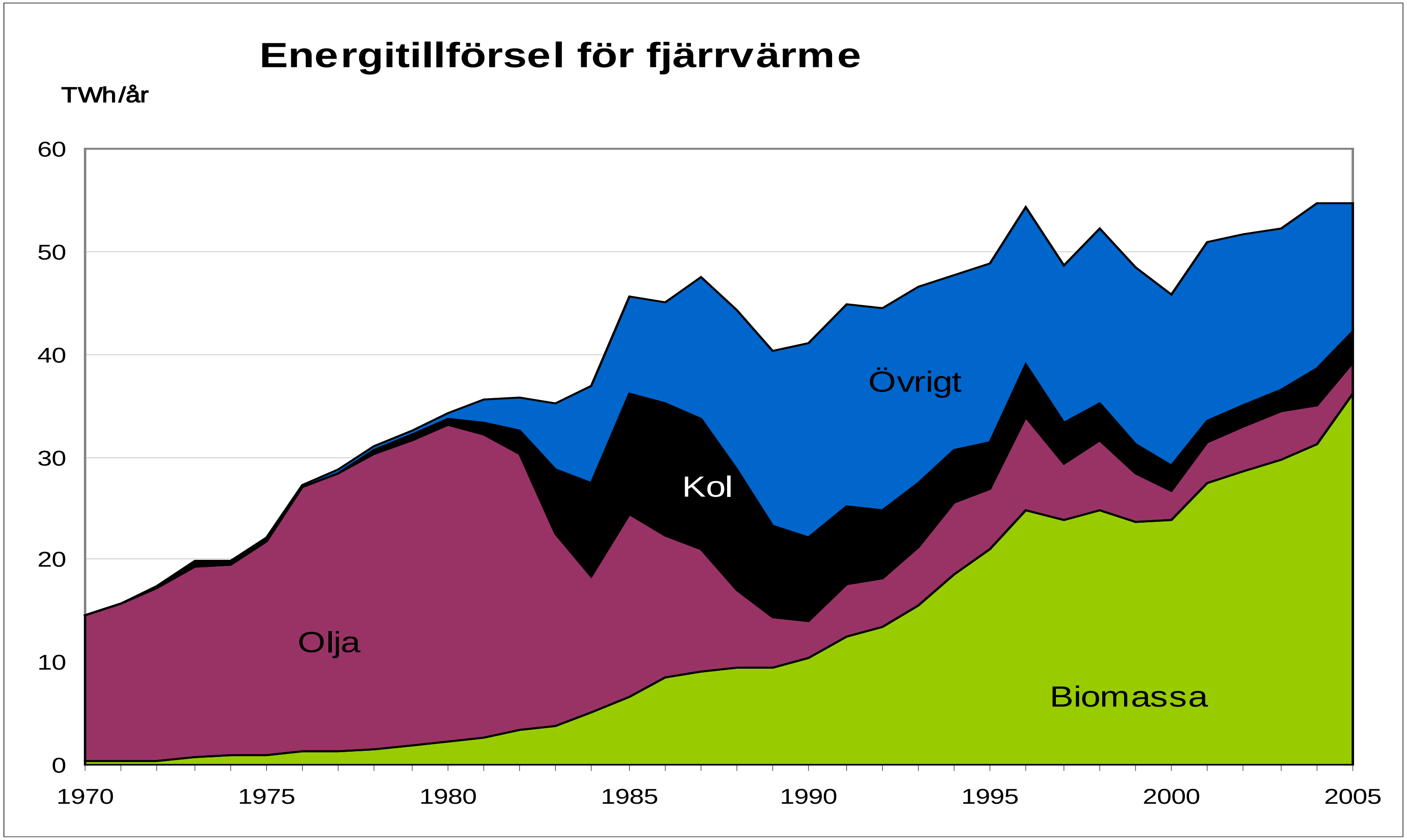
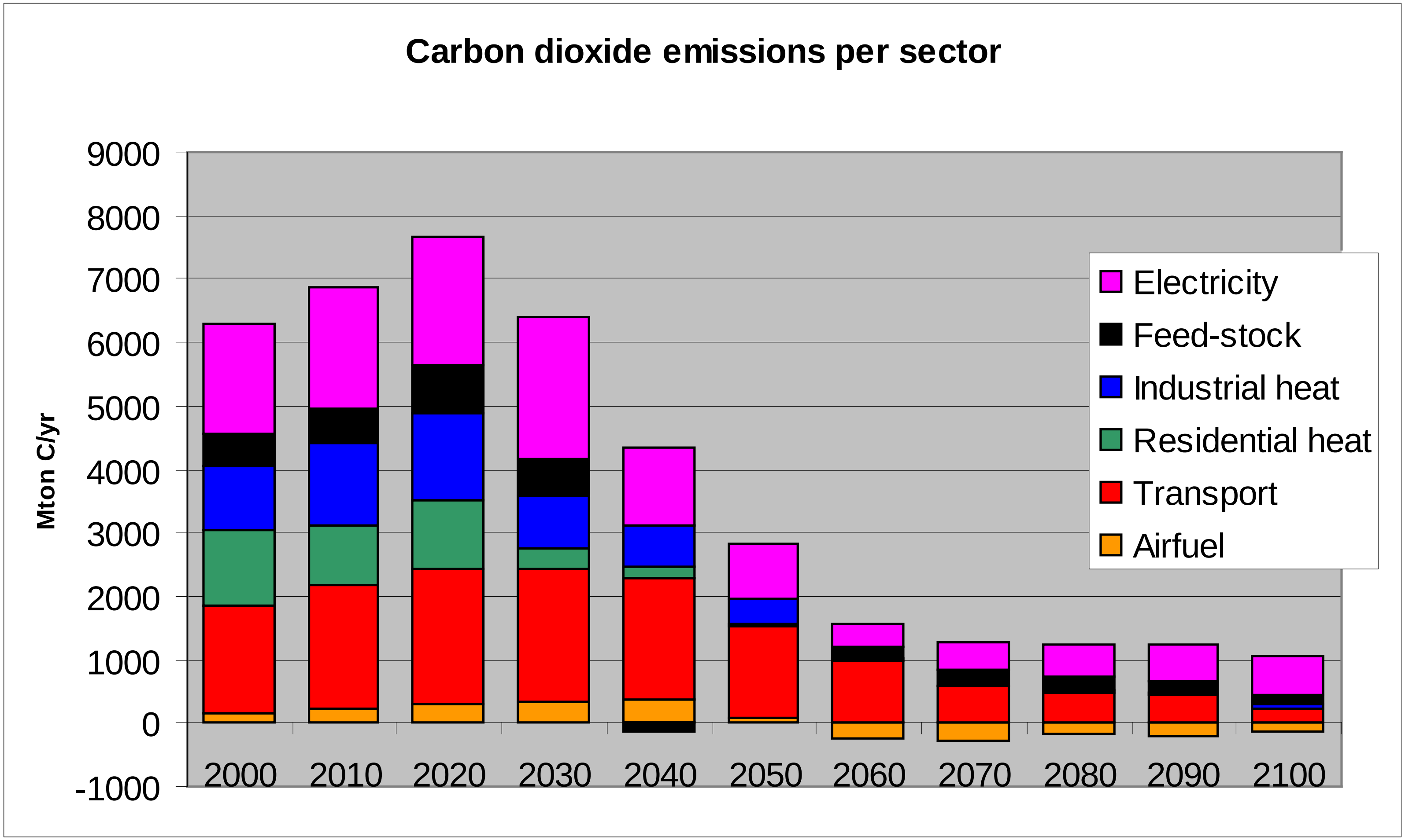
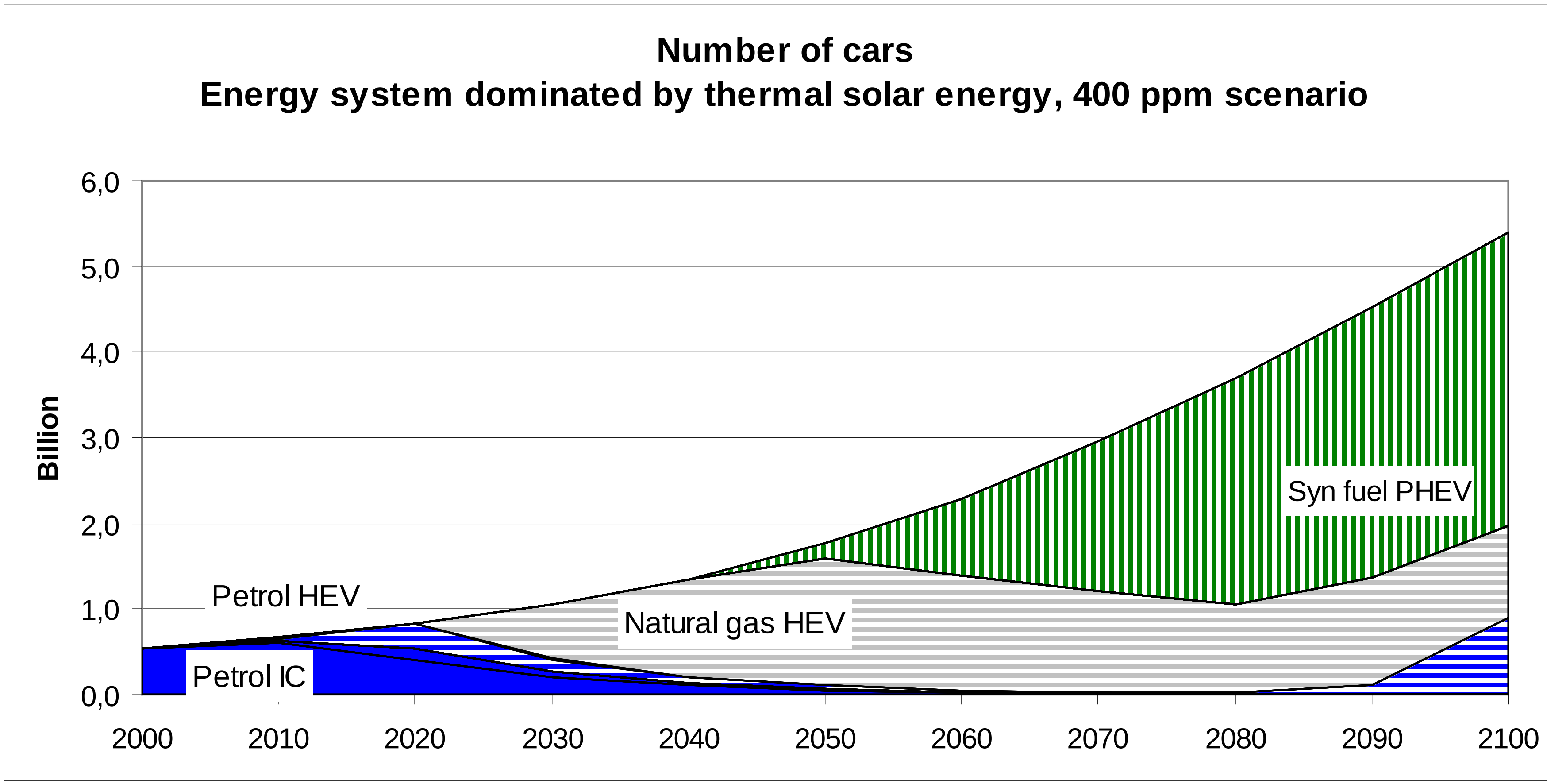
District heating in Sweden, a carbon tax since 1991



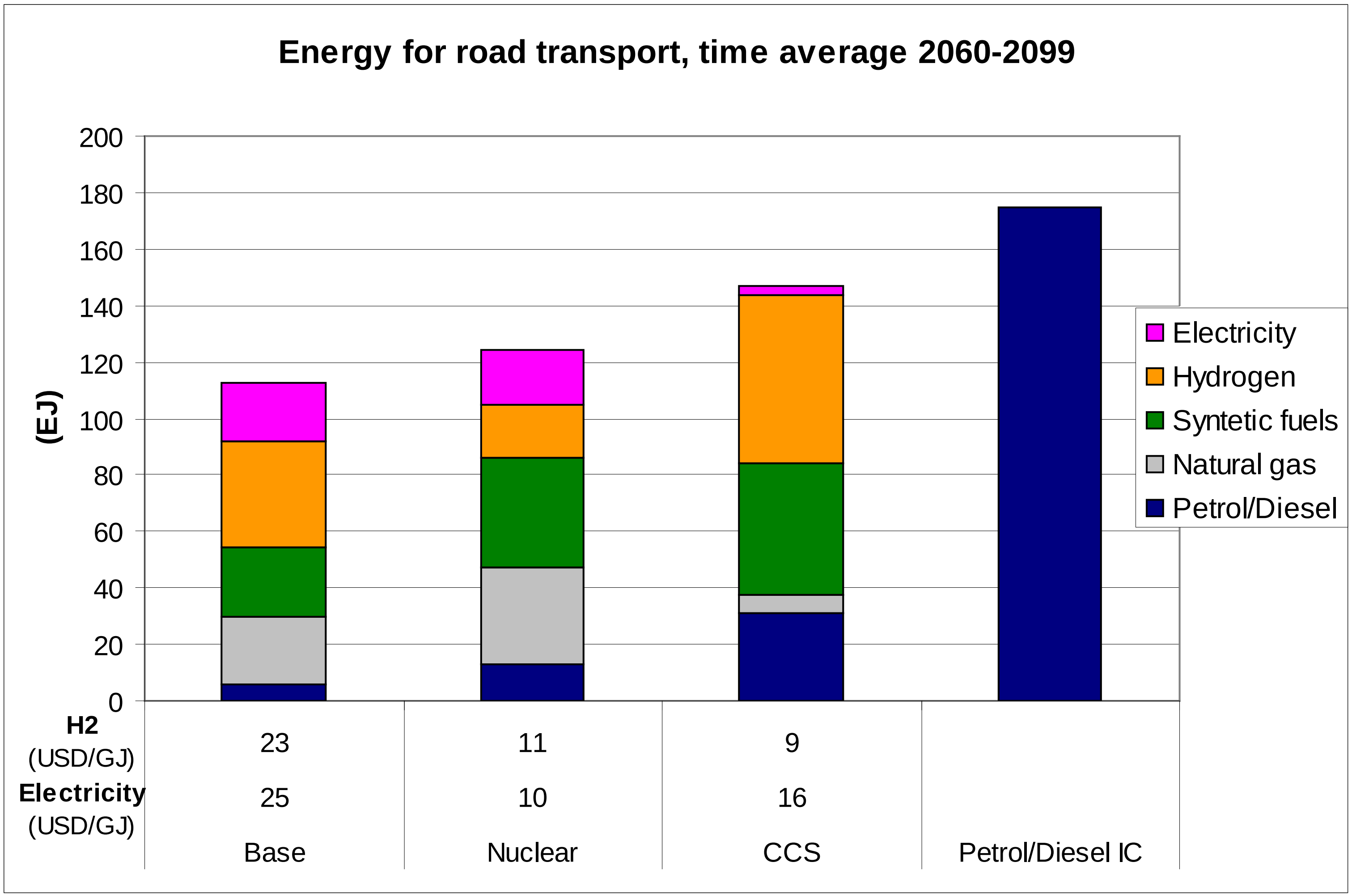
Where is it most cost-efficient to reduce emission?

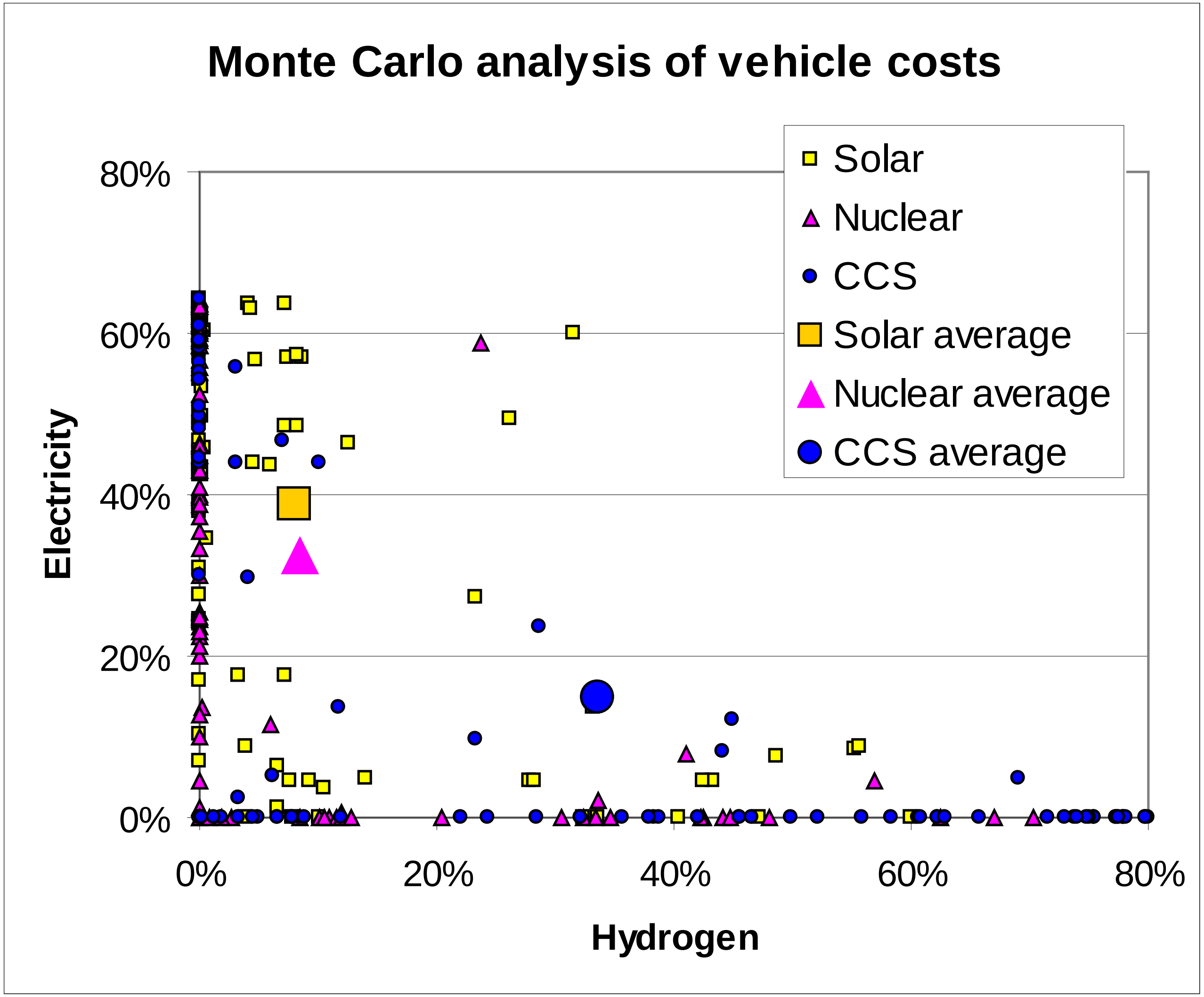




Number of cars
Energy system dominated by thermal solar energy, 400 ppm scenario
Billion
6,0
5,0
4,0
3,0
2,0
1,0
0,0
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Syn fuel PHEV
Petrol HEV
Natural gas HEV
Petrol IC

What determines which cars that are cost-effective?




Monte Carlo analysis of vehicle costs
Solar
Nuclear
CCS
Solar average
Nuclear average
CCS average
80%
60%
40%
20%
0%
Electricity
0%
20%
40%
60%
80%
Hydrogen

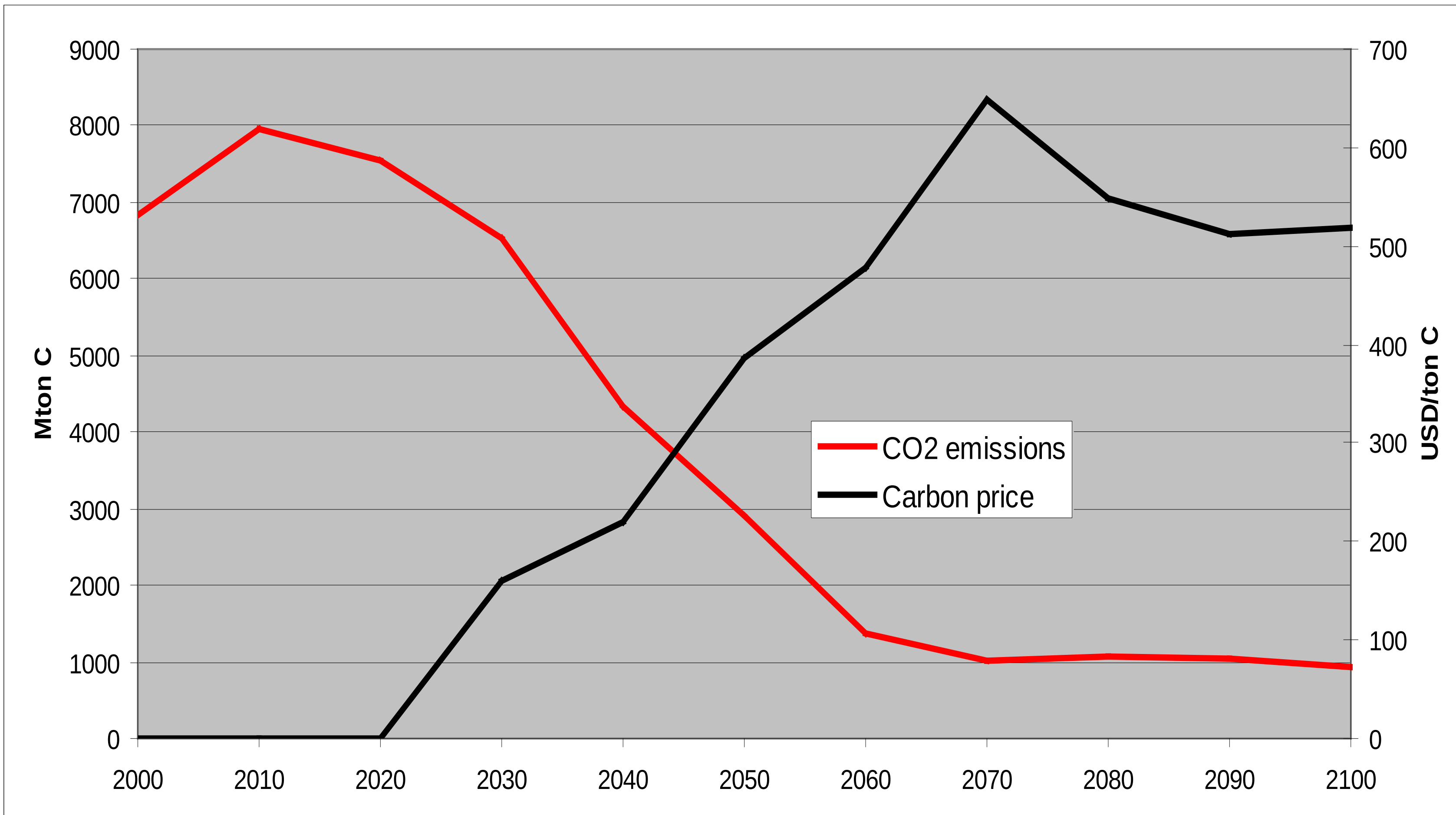
Marginal abatement cost

- Shadow price of emissions
- Inflate with discount rate

$$M(t) = m(t)(1+r)^{t-1}$$

- M(t) carbon tax in net present value
- m(t) shadow price generated in the model

Carbon emissions and carbon price



What does this model do?

- Predict (what will happen in the future)
- Prescribe (how ought the future look like)
- Describe (how does the energy system work)

Summary

- Energy system models can
  - Give guidance on how we ought to develop the energy system
  - Give better understanding of good use of scarce resources
  - Give estimates of the cost of stabilizing the carbon emissions