Energy system modeling

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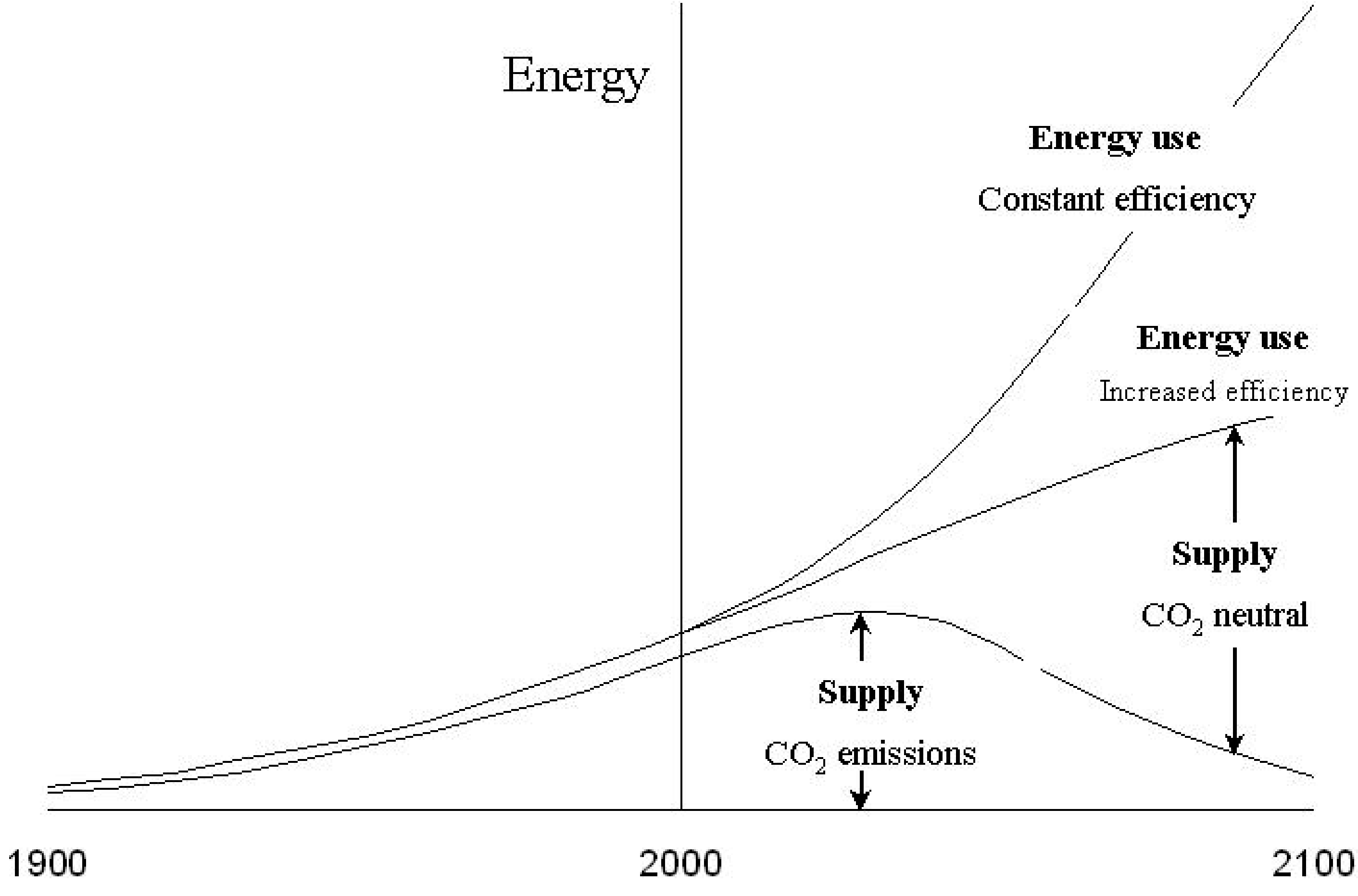
Outline

- Structure of energy system models
- Background on energy technologies
- Results and analysis

Strategies to reduce carbon dioxide emissions



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

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

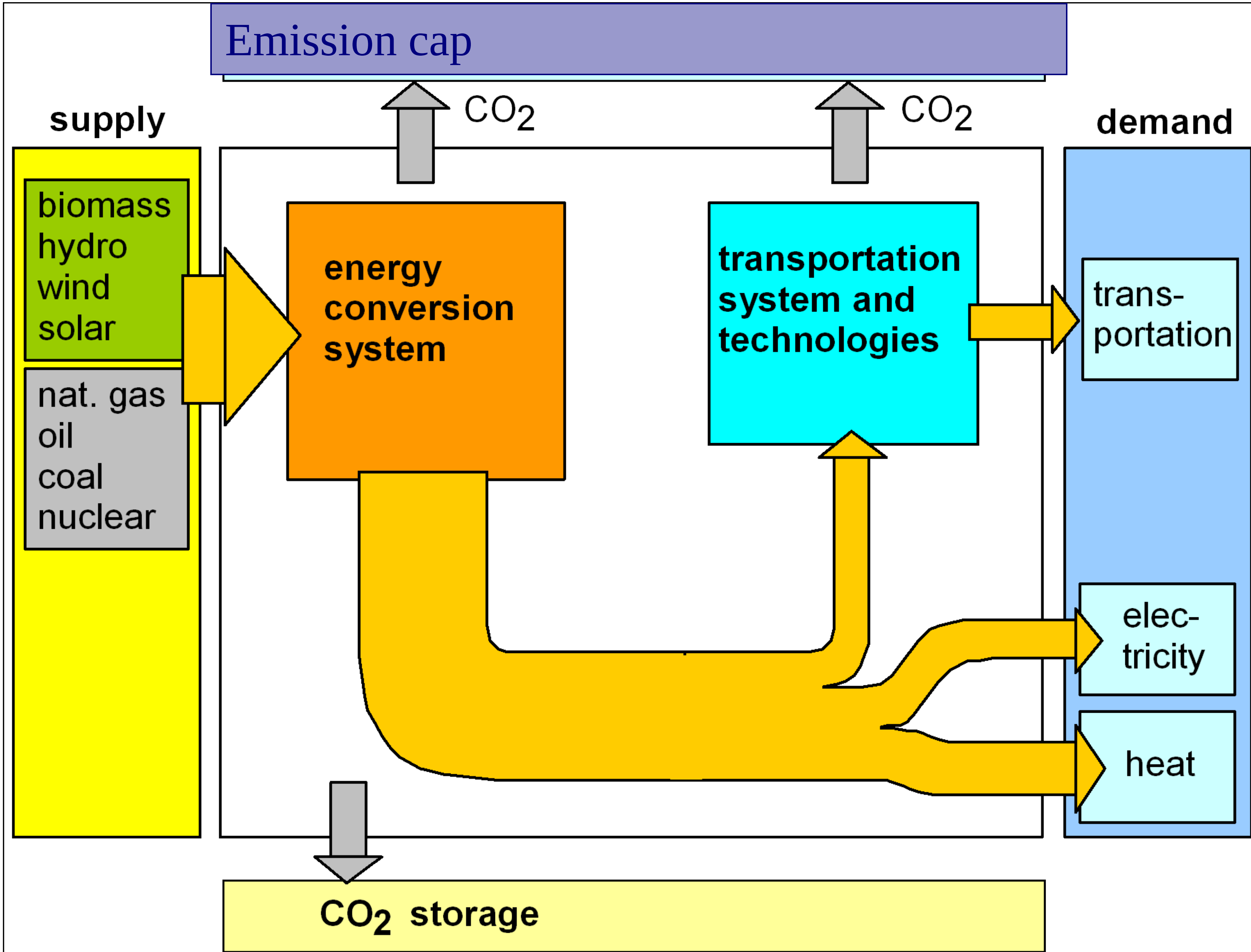
- Supply must be equal demand

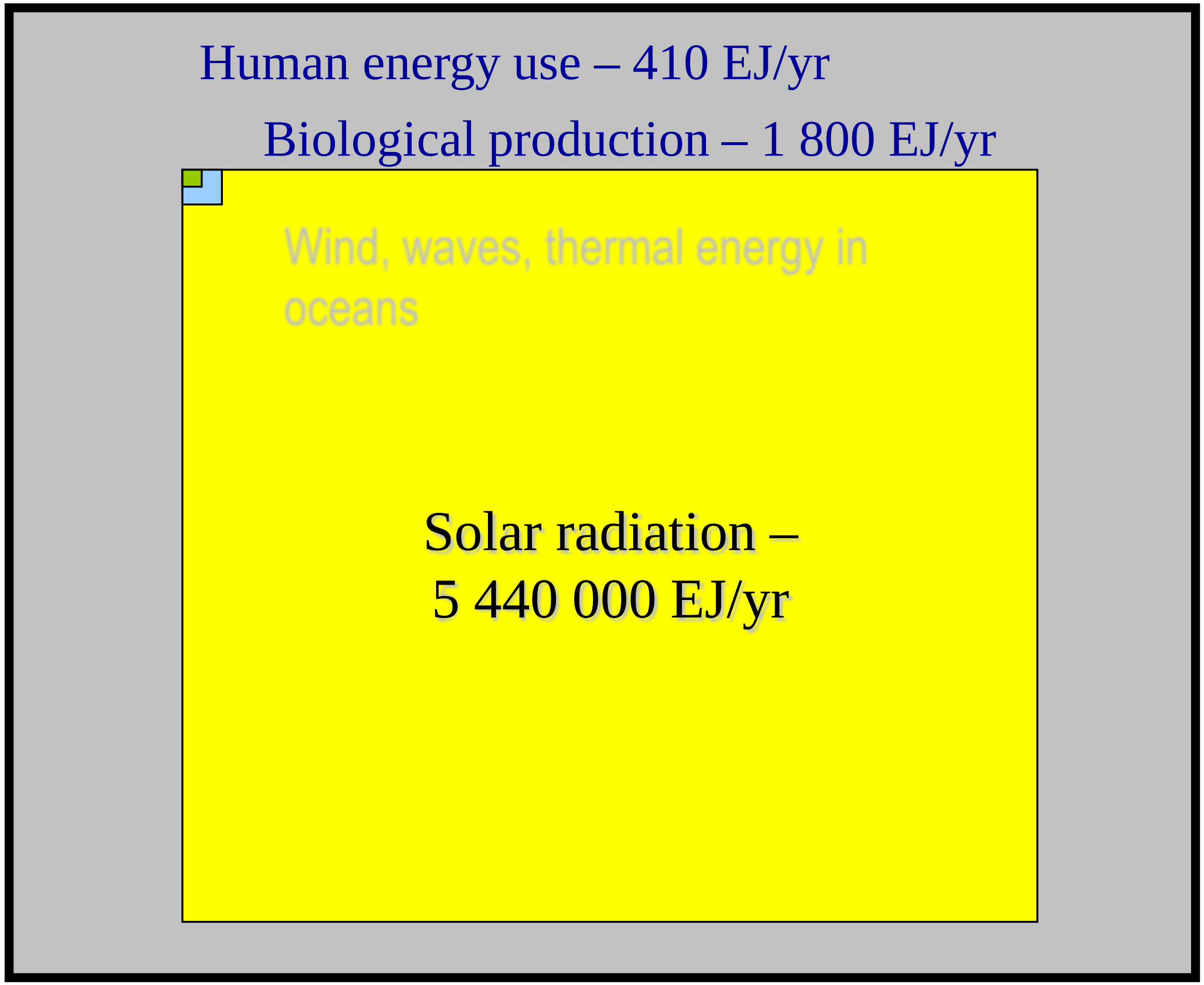
$$D(t,y) + e(y,t) = \sum_x E(x,y,t)\eta(x,y)$$

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

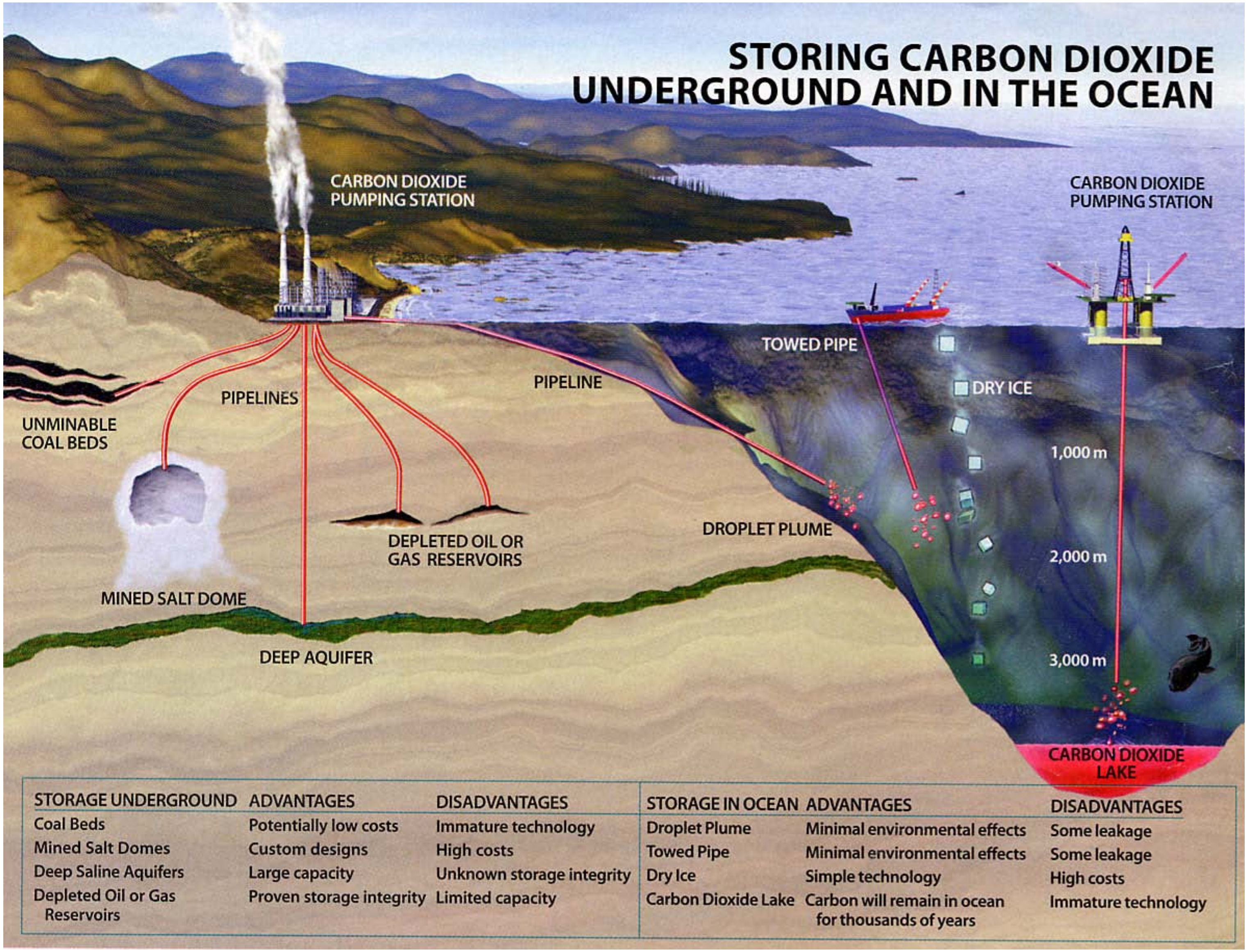
- Fossil resource constraints

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


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


Human energy use – 410 EJ/yr
Biological production – 1 800 EJ/yr
Wind, waves, thermal energy in oceans
Solar radiation – 5 440 000 EJ/yr

Carbon capture and storage (CCS)



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

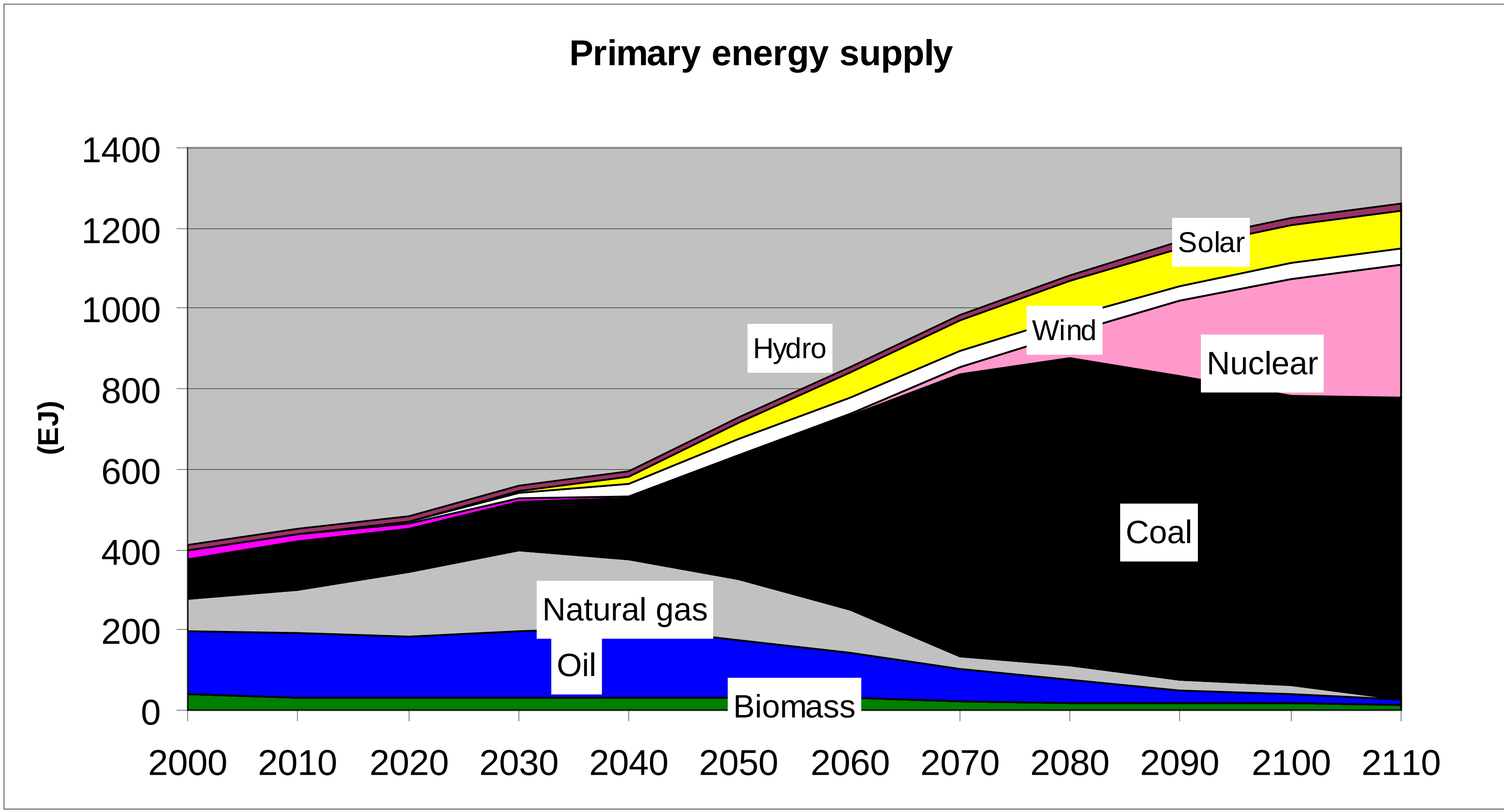
Energy carrier

- 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

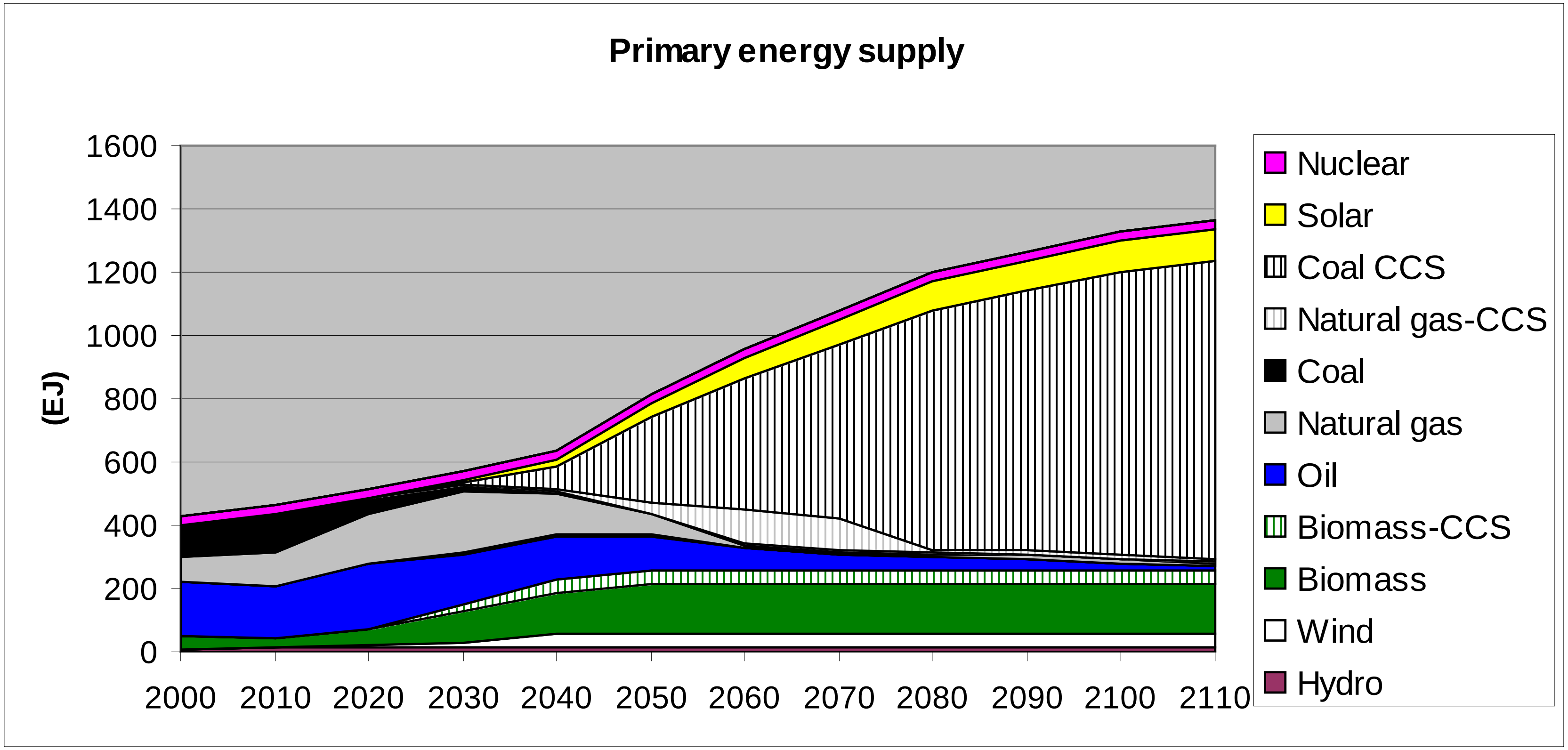
Vehicles types

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

Global baseline scenario



400 ppm, limited nuclear, CCS allowed



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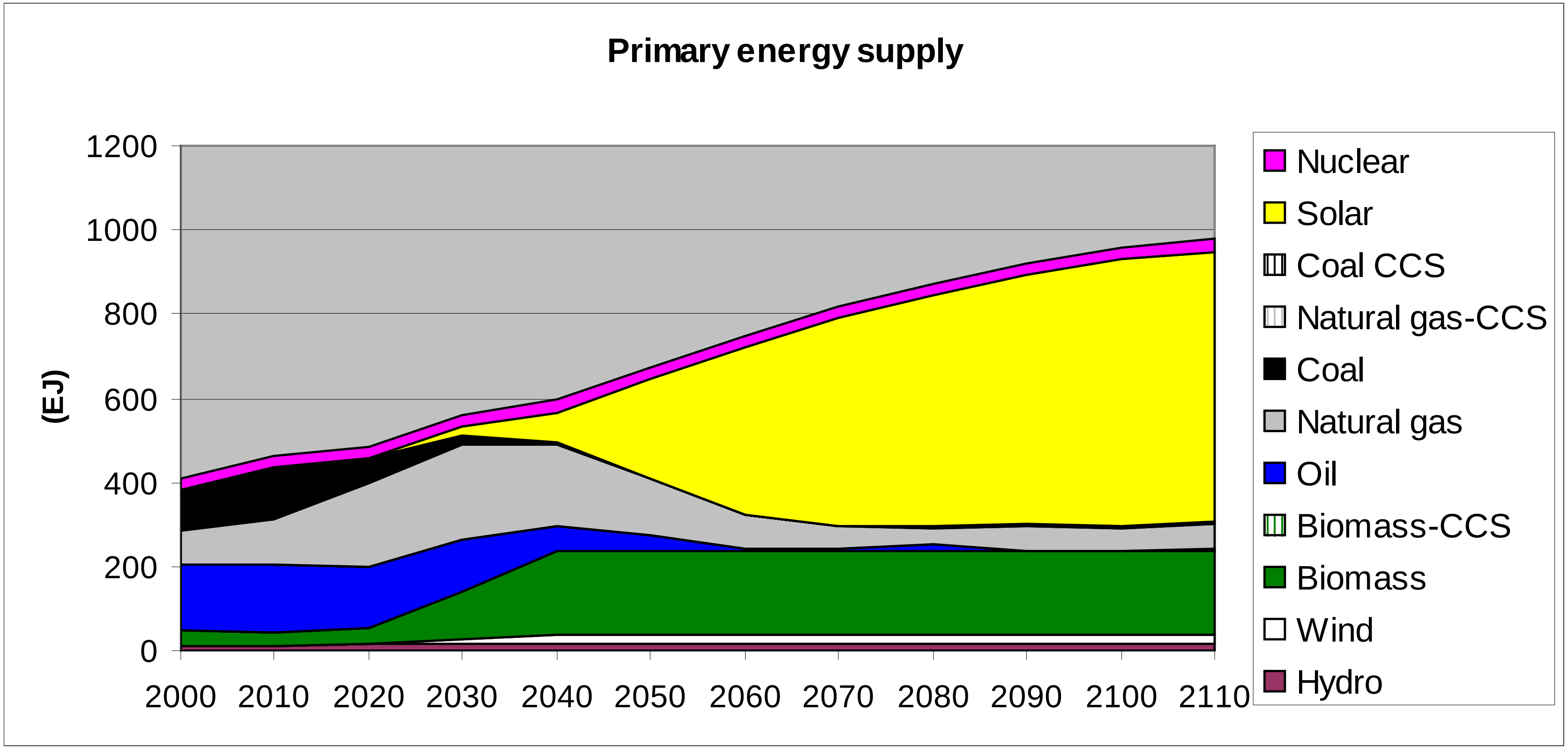
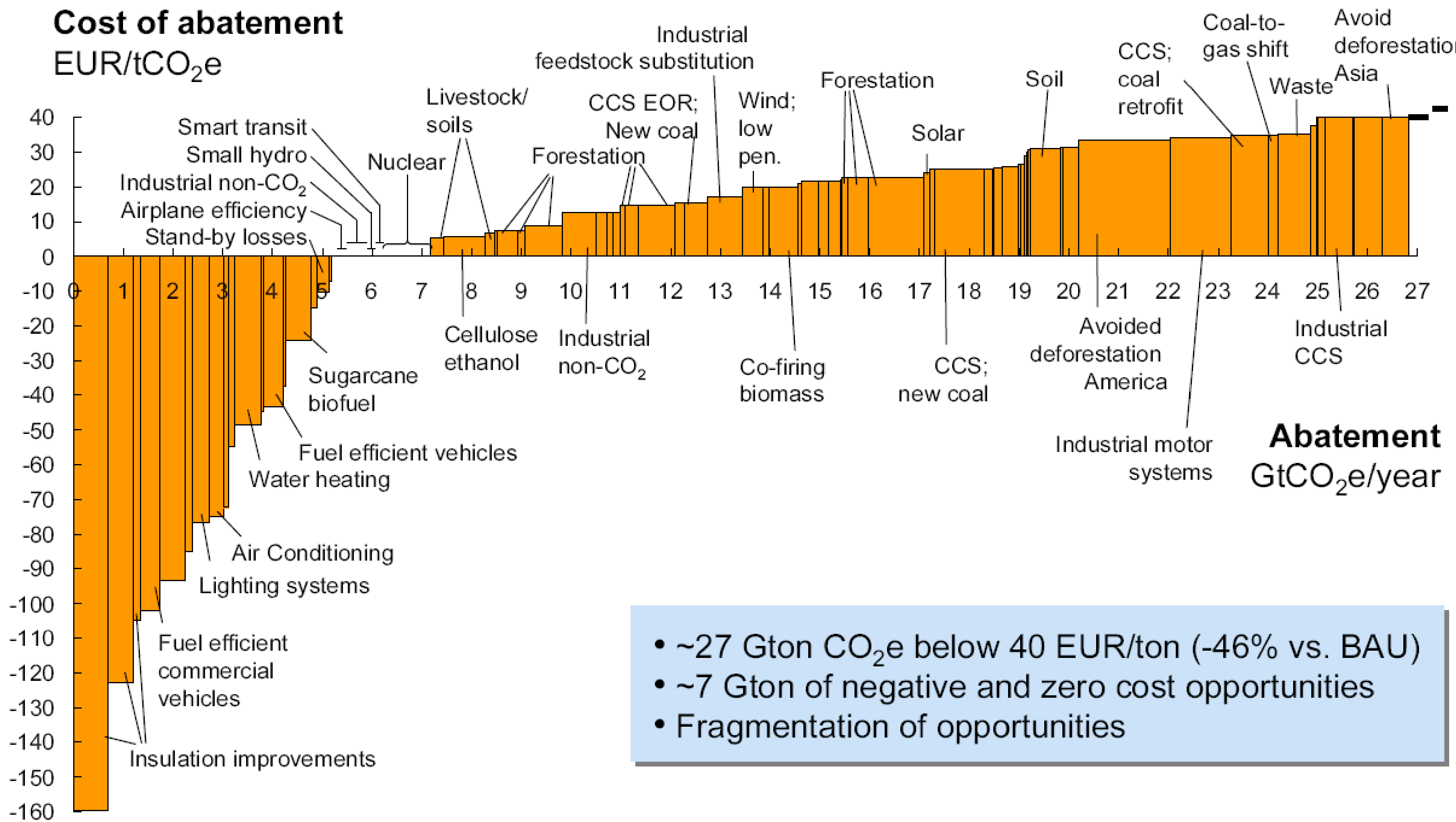
400 ppm, no nuclear and no CCS



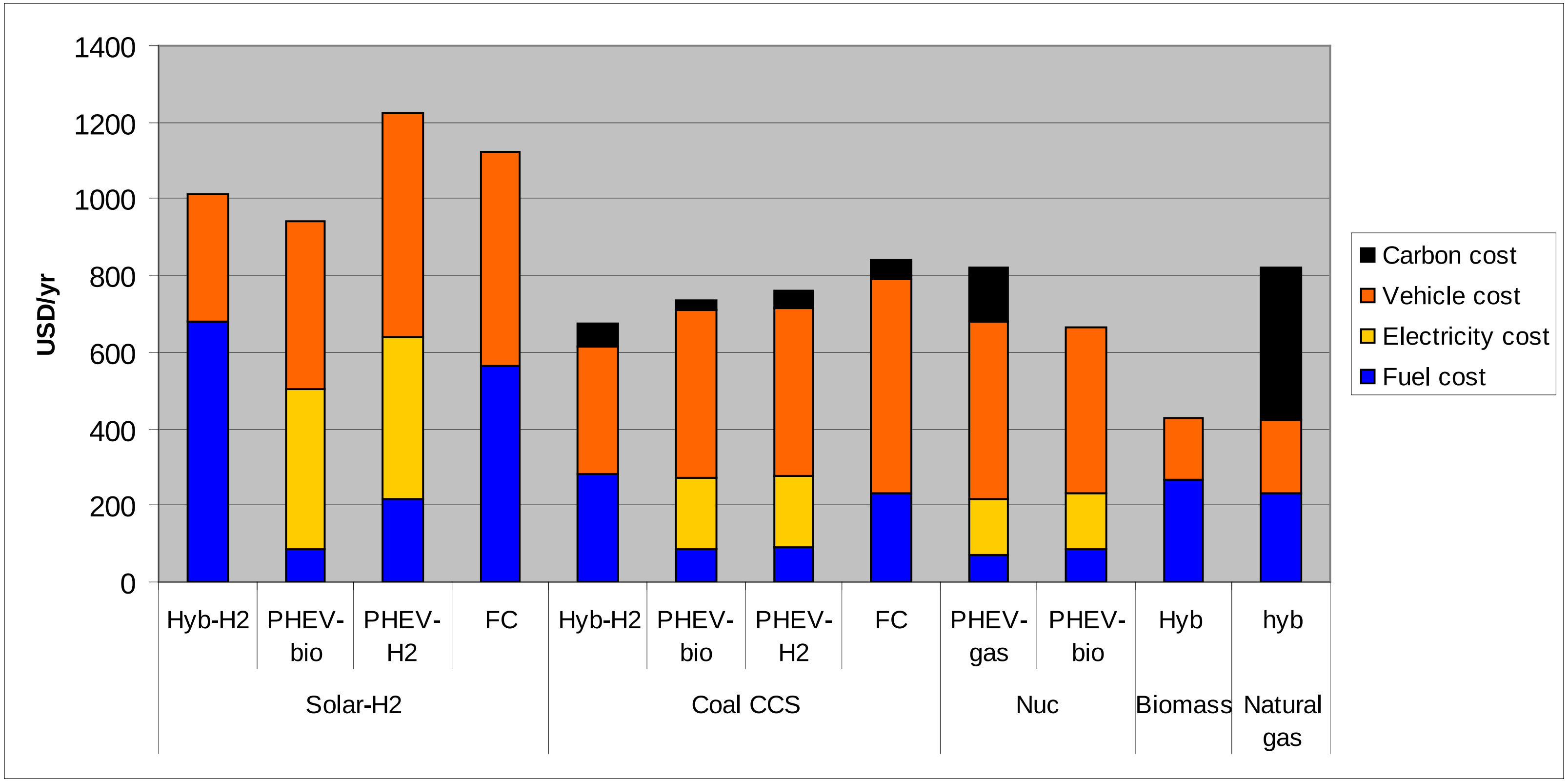
Stabilization is possible at limited costs – markets can supply

2030

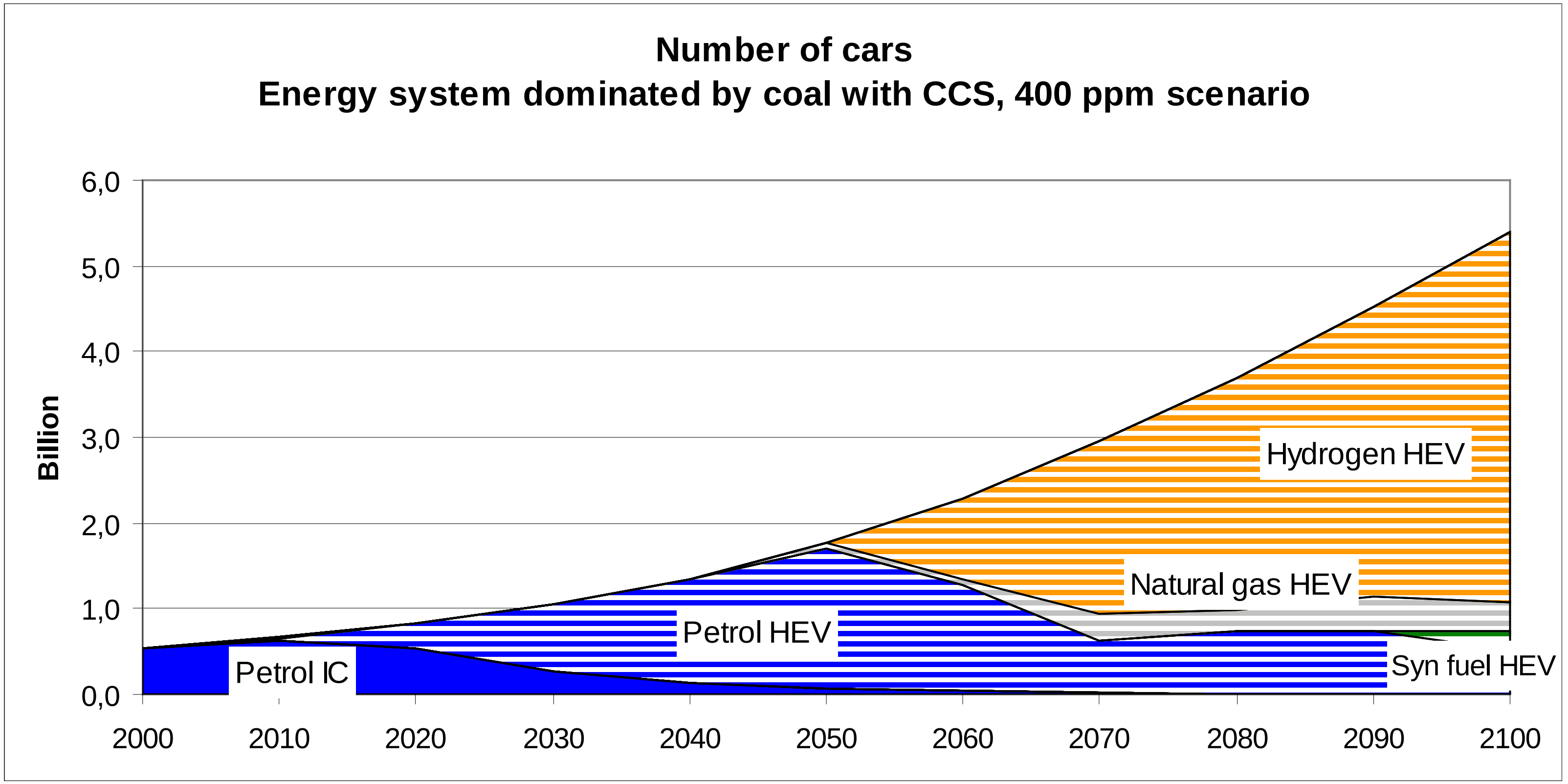


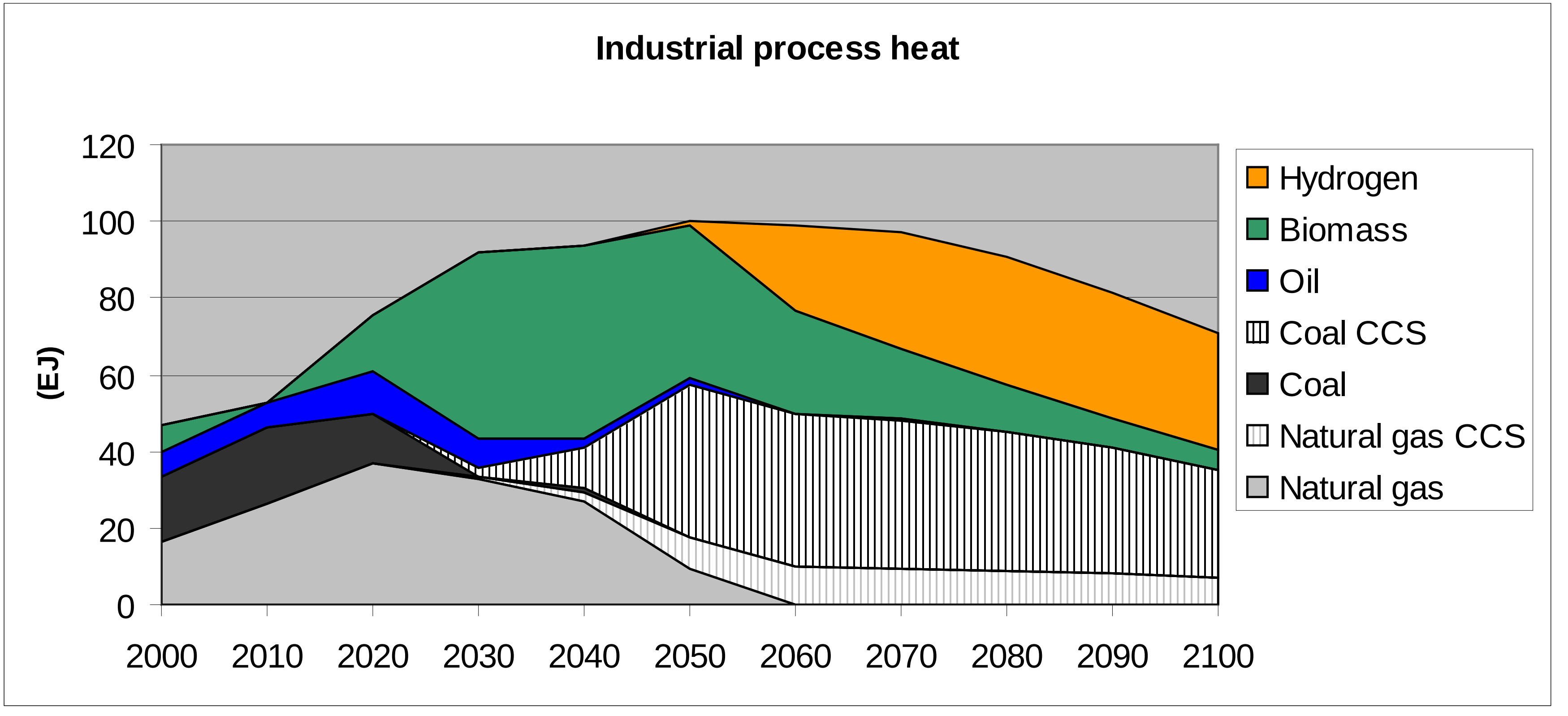
- ~27 Gton CO_2e below 40 EUR/ton (-46% vs. BAU)
- ~7 Gton of negative and zero cost opportunities
- Fragmentation of opportunities

Vehicle costs, carbon price 1000 USD/ ton C

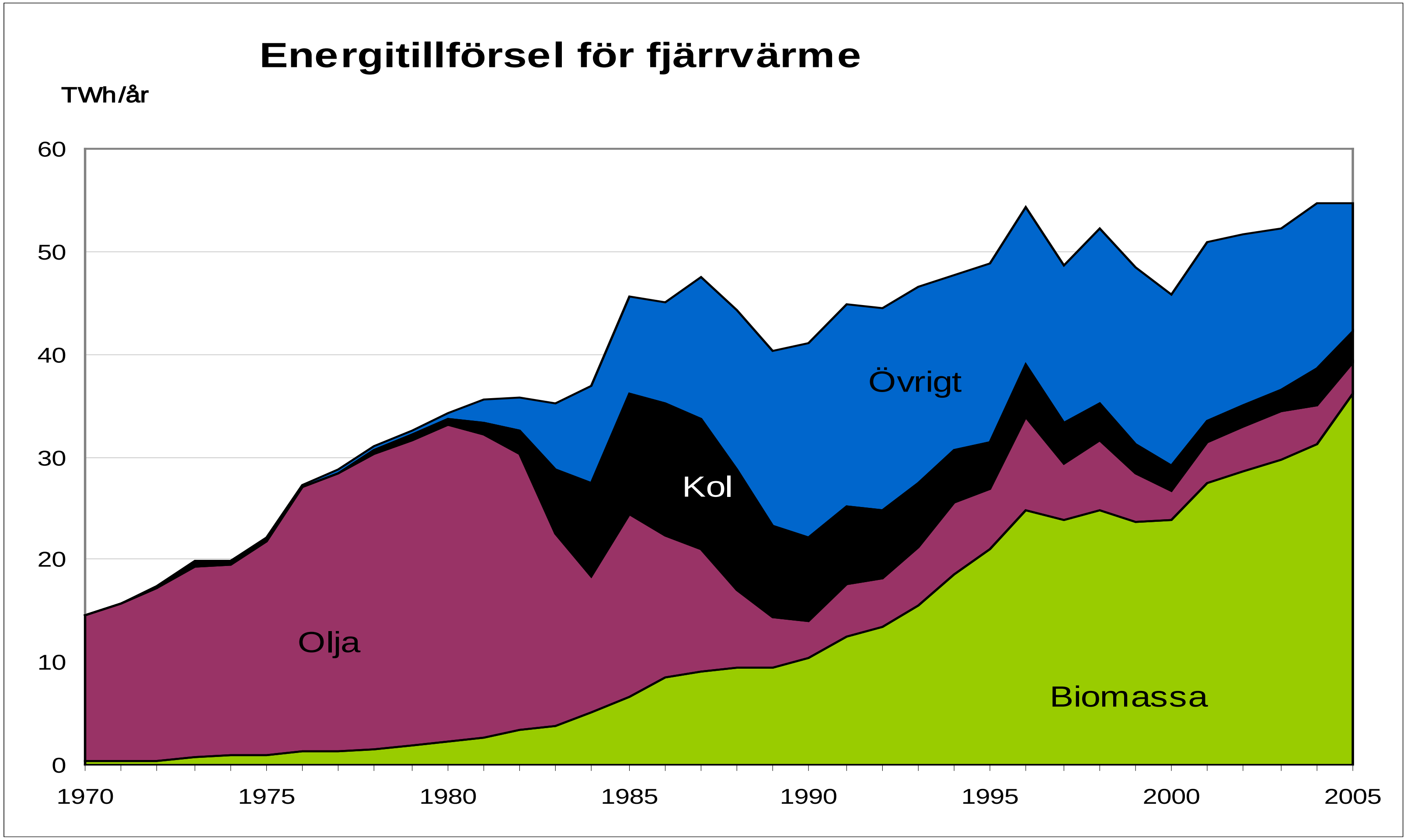


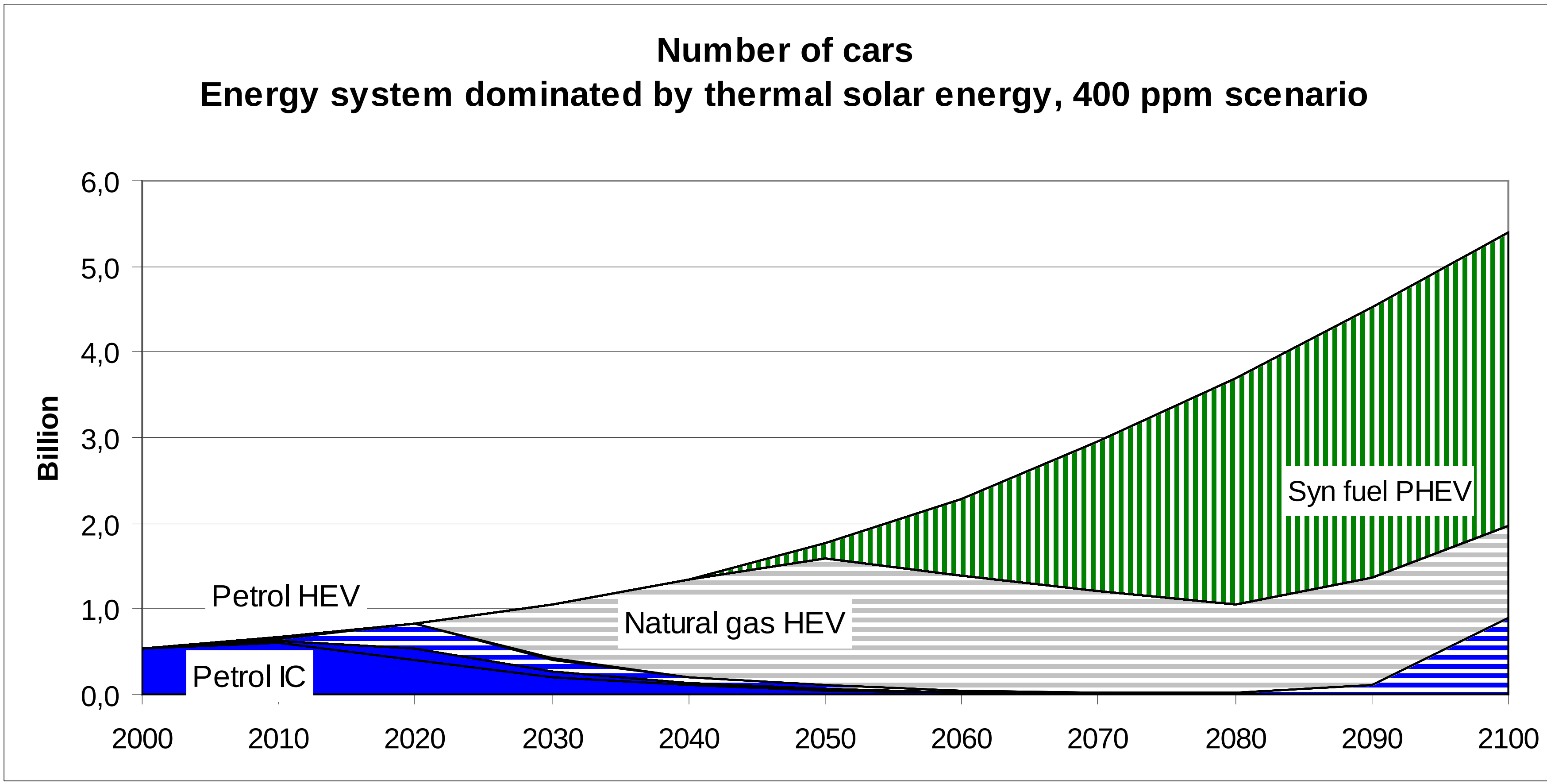
400 ppm scenario, limited nuclear CCS allowed



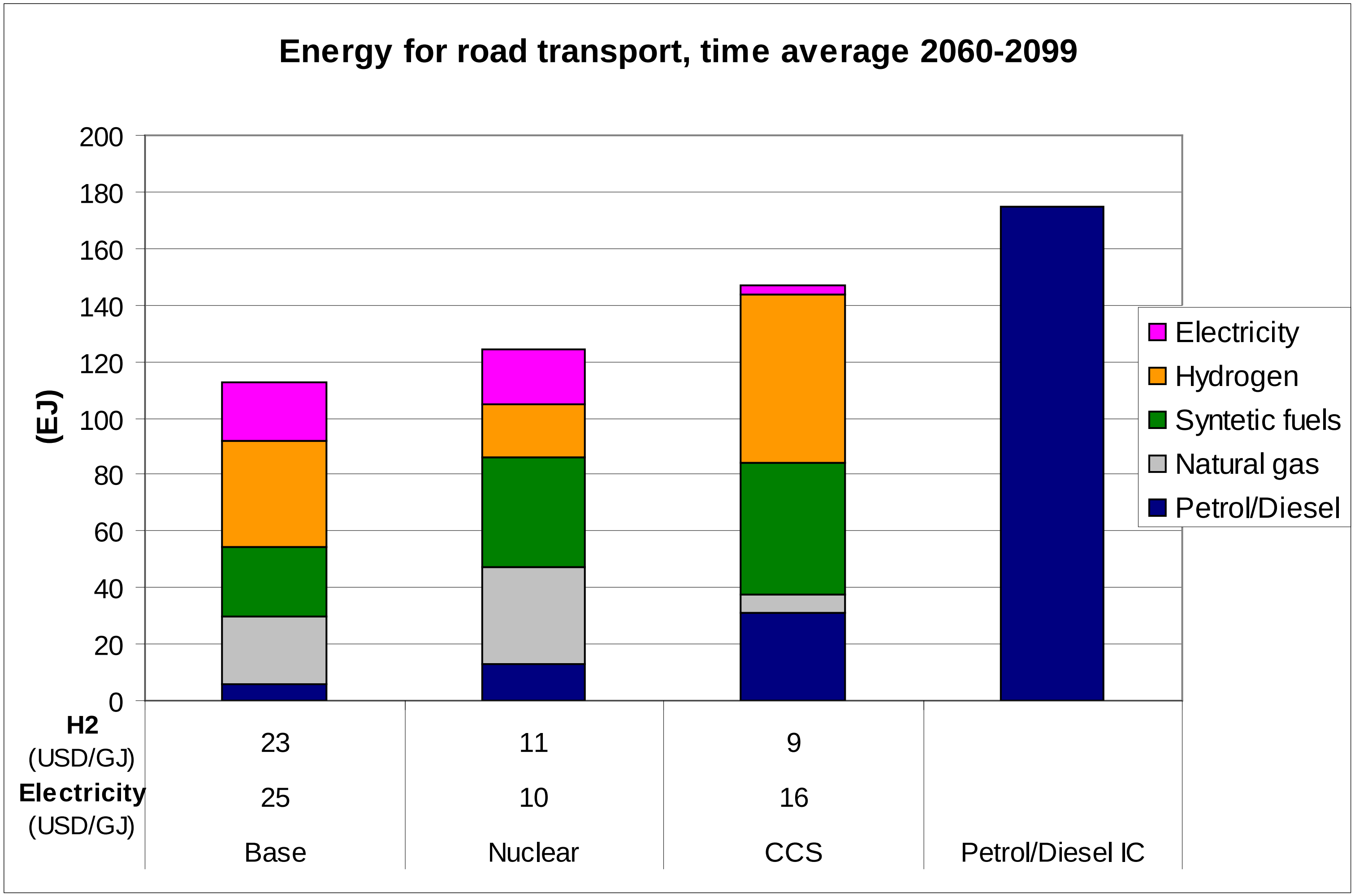

Industrial process heat
(EJ)
120
100
80
60
40
20
0
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Hydrogen
Biomass
Oil
Coal CCS
Coal
Natural gas CCS
Natural gas

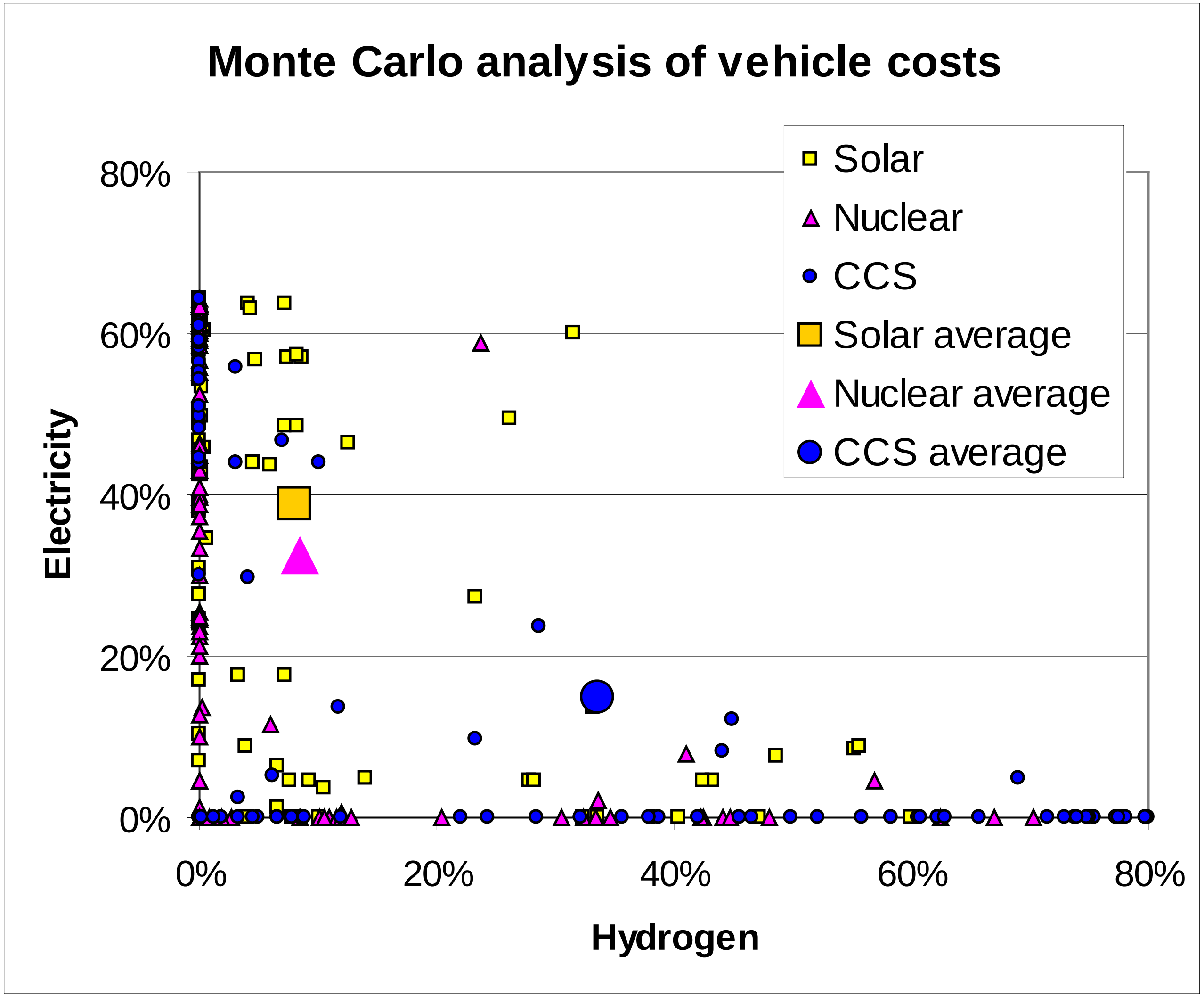
District heating in Sweden




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

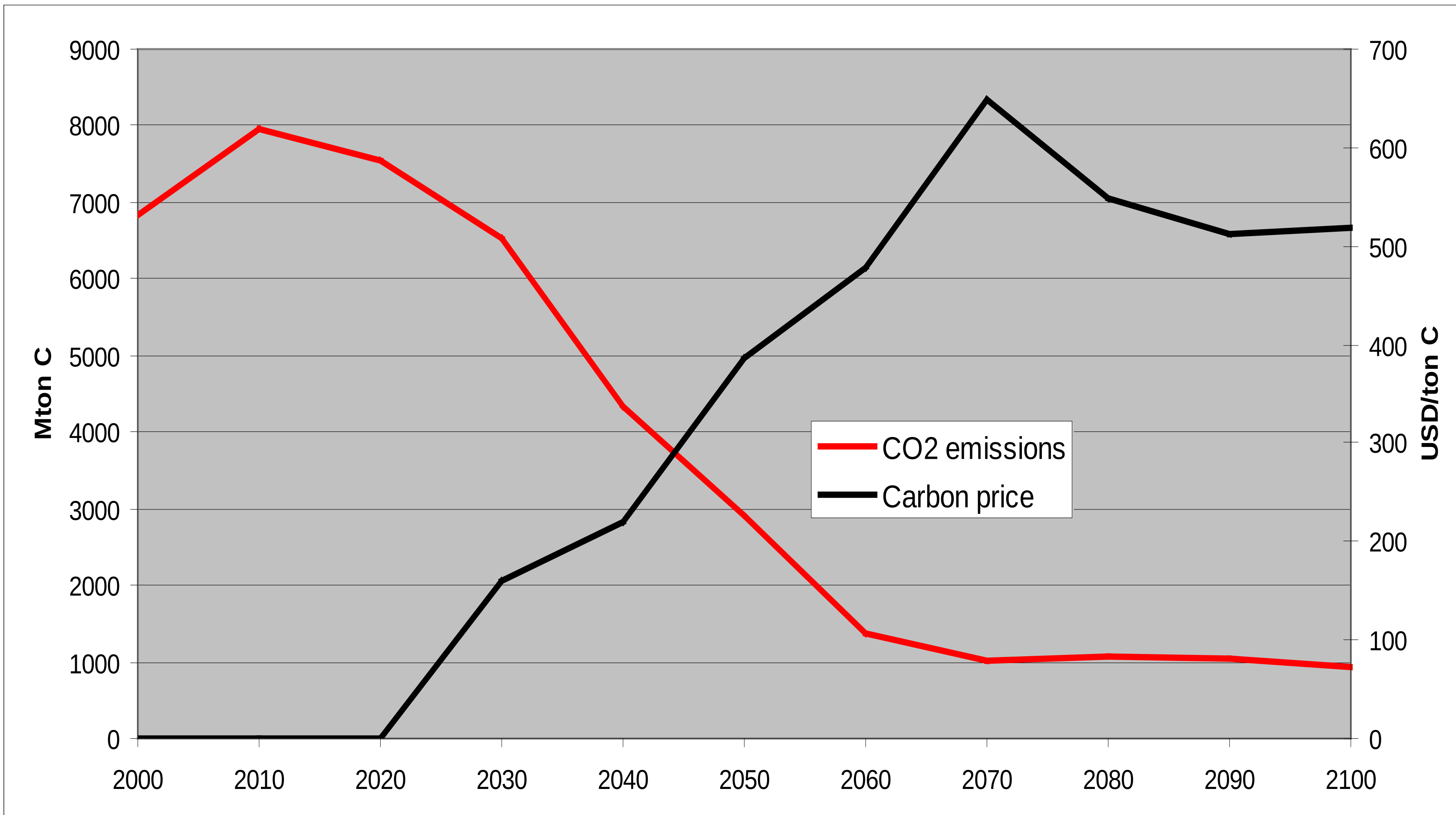
Marginal abatement cost

- 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