CHALMERS GSD

Exploring options for energy systems in a global climate perspective —

How can models be used?

Dynamics for Policy – GSD conference

The House of Lords, 2 July 2009, London

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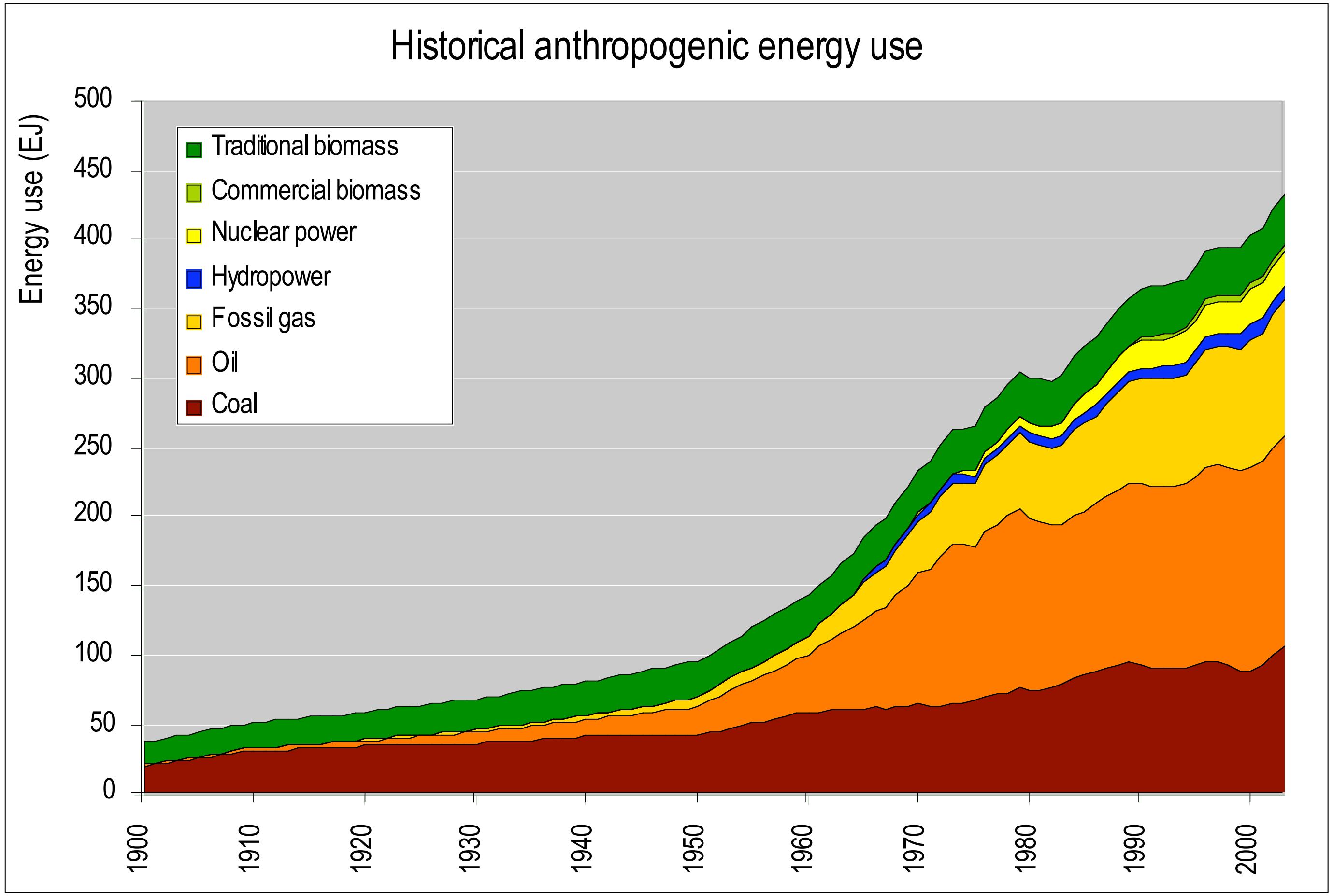
GSD: Global System Dynamics and Policies — an EU FP7 Coordination Action

An interactive web-interface

One goal with the GSD project is to improve on the communication between science and policy:

•One example of a tool to support communication of scientific insight is a web-based interface to an energy systems model: **GETOnline**

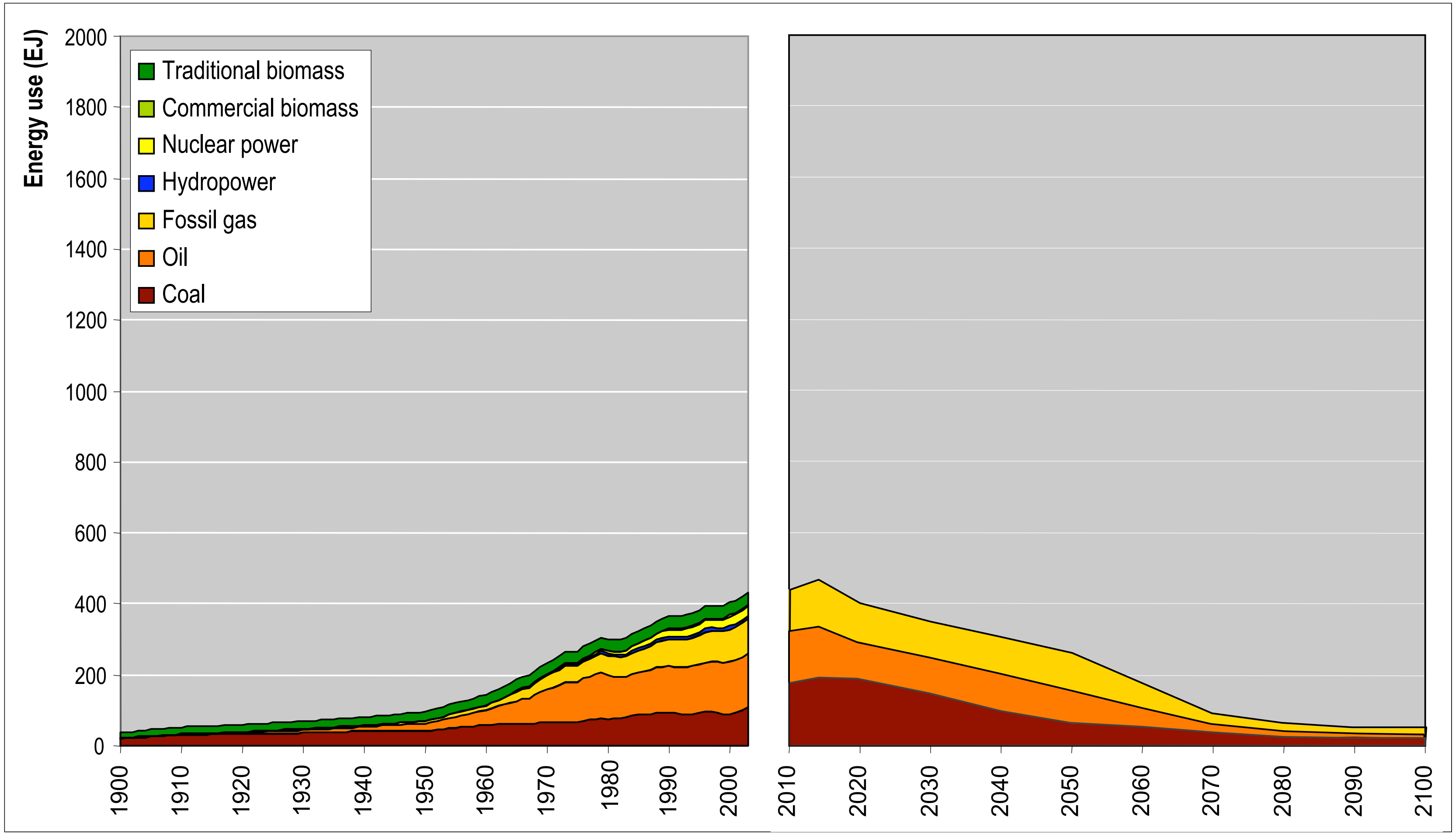
Historical global energy supply



EJ = Exa Joule = 10^{18} J

Adapted from M. Persson (2006)

Energy supply needs to be changed if high CO_2 levels must be avoided



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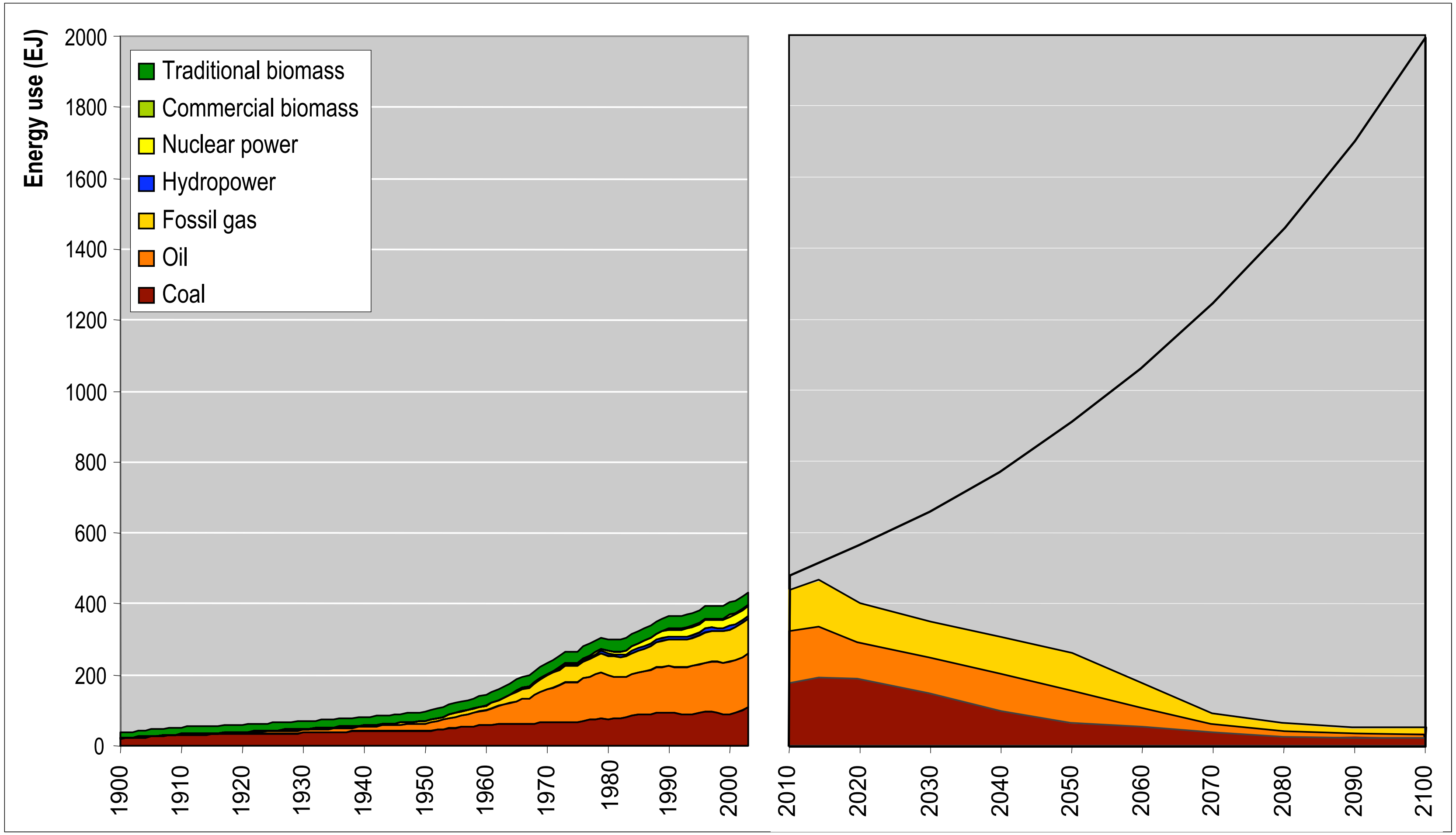

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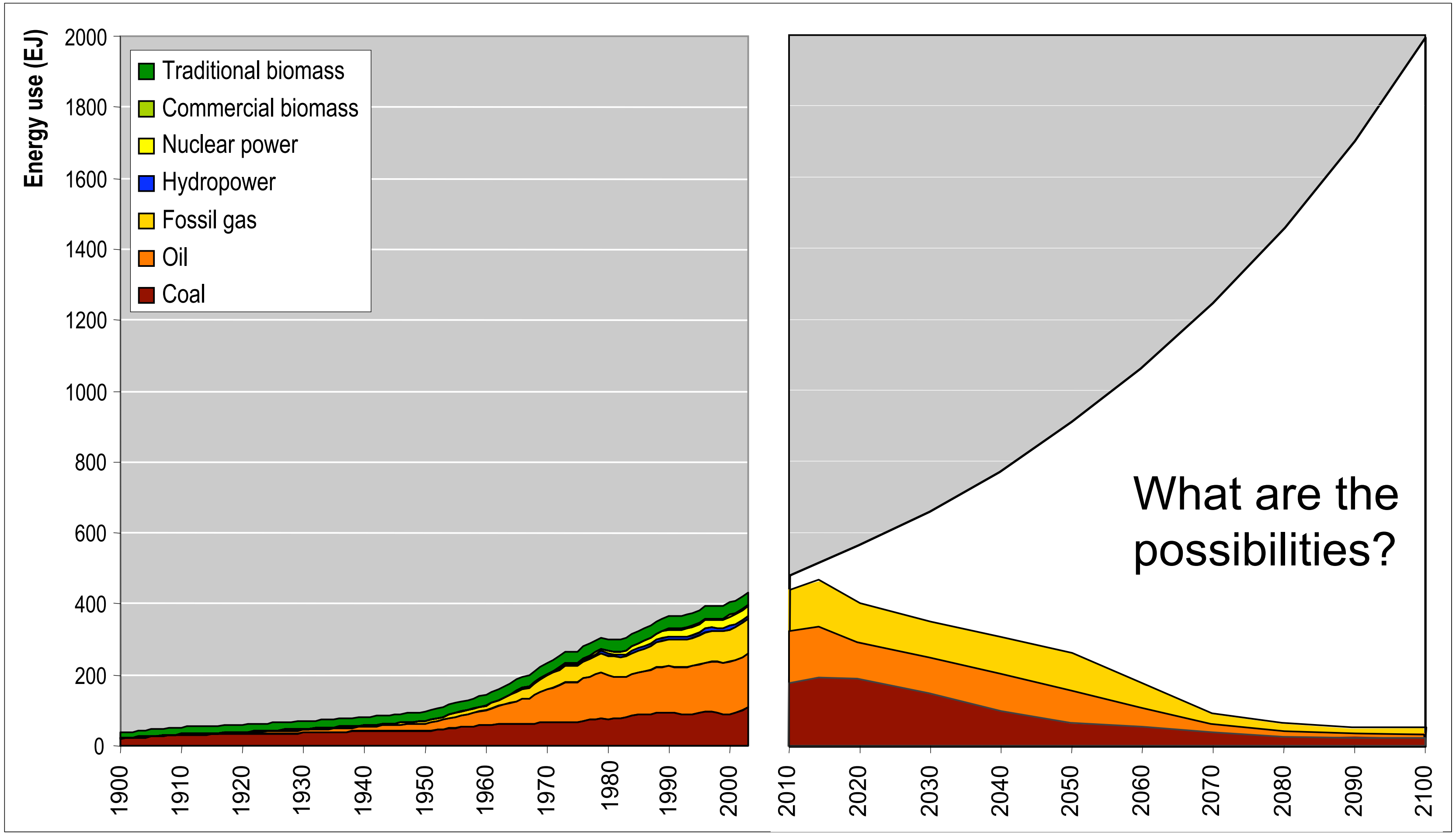

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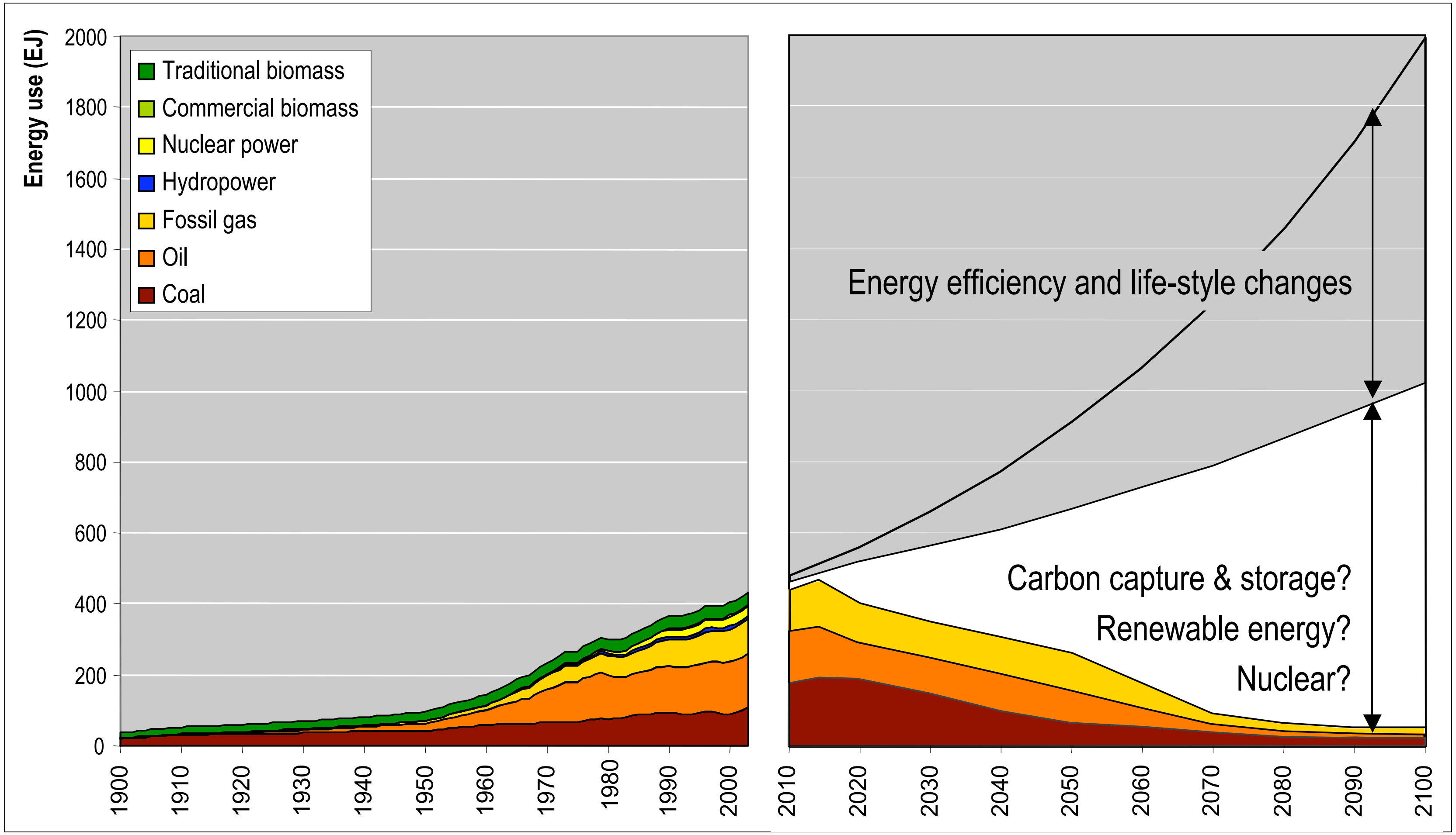

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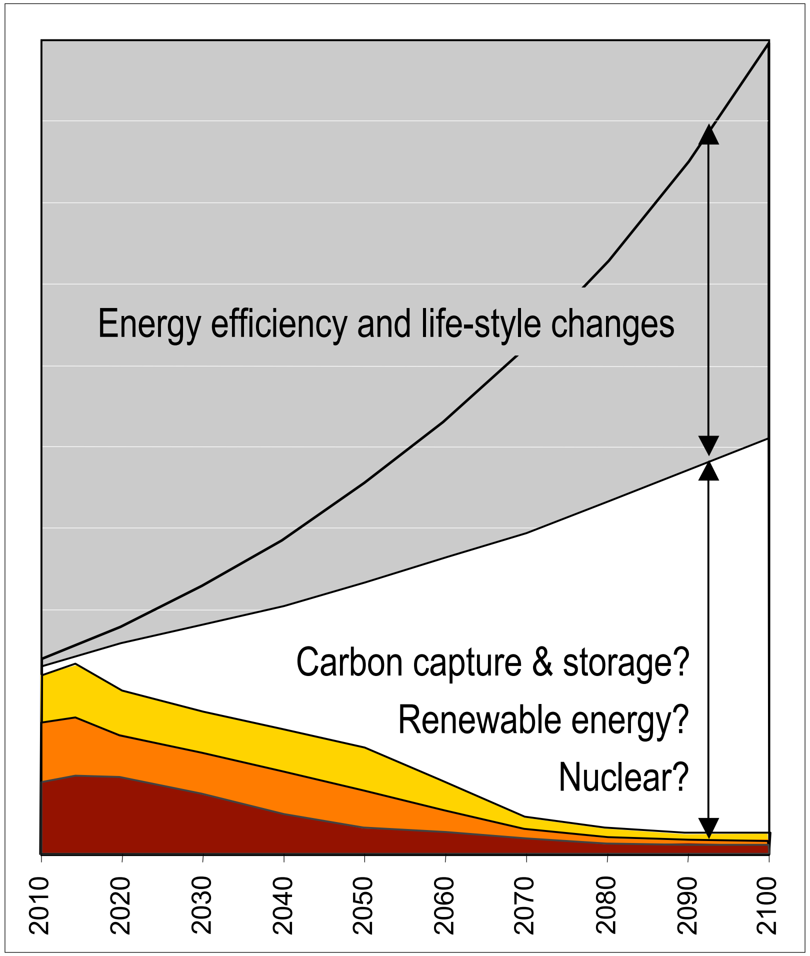
Critical issues

- Long-term vs short-term solutions
- Local/regional vs global solutions
- Costs
- Uncertainties
- Communication:
  Science – General Public –
  – Industry – Policy



In what way are energy models and scenarios for 2000-2100 useful?

Any long-term global model of the energy system (possibly also integrating climate and the economy at large) provide scenarios that must NOT be seen as predicitions.

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Any long-term global model of the energy system (possibly also integrating climate and the economy at large) provide scenarios that must NOT be seen as predicitions.

These models of the long-term development may capture

and characterize certain aspects of the energy system

•Long-term goals give implications for short-term action

•Need to distinguish what is more uncertain from what is less so: What can we agree on?

•A basis for communication between science and policy

Models in the energy and climate context

- Purpose of modelling the energy system on the global level: What are the questions?

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- Scenarios illustrating possible arrangements of the energy system to meet certain goals:
  - Identifying technology options for reaching low CO_2 targets
  - The role of different emerging technologies, e.g.,
    - CO_2 capture and storage,
    - solar power technologies,
    - plug-in hybrid vehicles vs. fuel-cell vehicles, etc.

Models in the energy and climate context

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  - The role of different emerging technologies, e.g.,
    - CO_2 capture and storage,
    - solar power technologies,
    - plug-in hybrid vehicles vs. fuel-cell vehicles, etc.
- Energy systems modelling to analyse critical mechanisms:
  - Mechanisms that connect different sectors and different regions
  - How are food prices affected by climate policies?
  - What role can biofuels play in the transportation sector?
  - Under what circumstances may electric vehicles be an important mode of transportation?

Global Energy Transition (GET) model

- Model development has been driven by a number of policy relevant issues:
  - In which sector is bio energy most efficiently used?
  - How are costs distributed between regions under strong climate polices?
  - What role can carbon capture and storage play when meeting stringent CO_2 targets?
  - Will OPEC countries gain or lose on a climate policy?
  - What are the short and long term system effects of a biofuels directive for transport in OECD countries? (Carbon leakage problem)

Global Energy Transition (GET) model

- Aim: Characterisation of energy systems development in a climate perspective
- Multi-regional global model
- Resource and climate constraints
- Exogenous demand for transport, heat, and electricity
- Energy system cost minimization (60 conversion technologies)
- Time span: 2000 - 2100

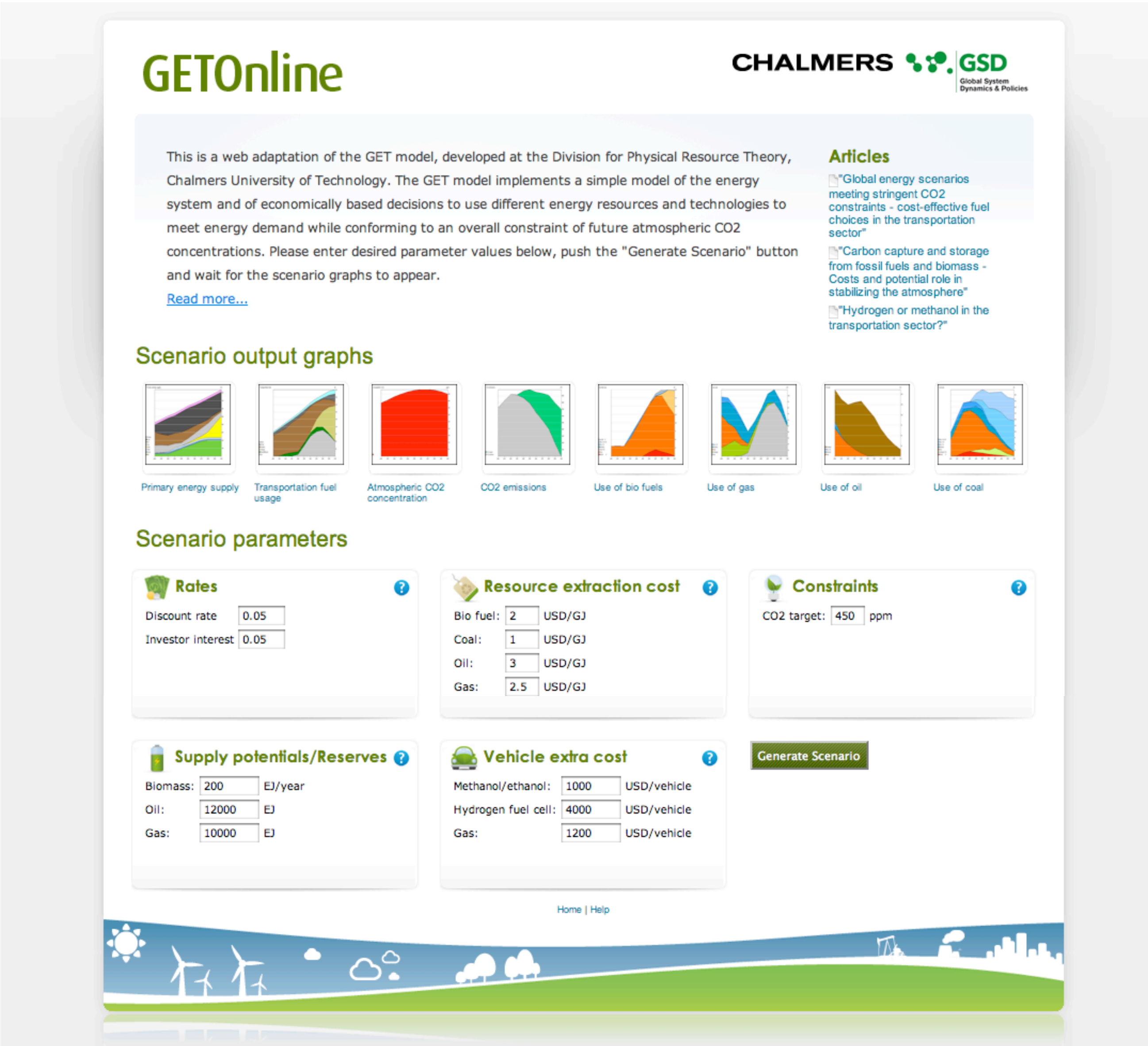
GETOnline

- Web-based model interface developed within GSD project (Claes Andersson & KL), www.chalmers.se/ee/getonline
- For controlling and running models from the GET family
  - Web interface page for setting parameters and constraints
  - Model running on a server system at Chalmers, receiving instructions from the interface page
  - Results in graphical form sent back to interface page for display
- Current implementation based on the global GET 6.0 model
  - variables and equations: ~ 5,000
- Running time:
  - new parameter settings ≈ 5 sec.
  - previously run settings ≈ immediate retrieval.

GET Online

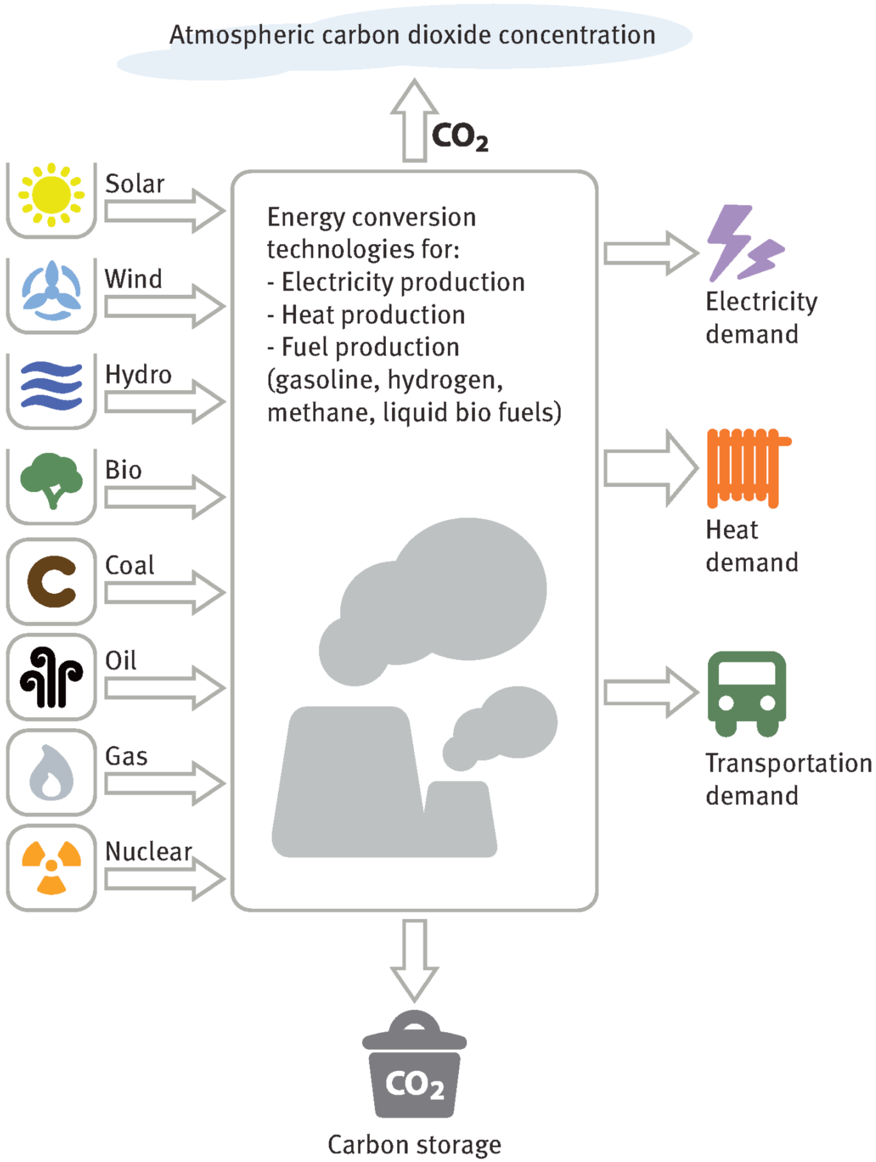
Web interface to the energy system model GET (Global Energy system in Transition):

http://www.chalmers.se/ee/getonline



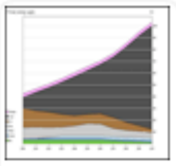
Model structure

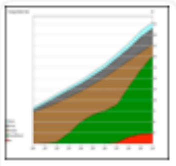
- Minimize cost for energy conversion over 21st century
- Constraints:
  - Primary energy supply
  - Demand scenarios
  - Emissions or CO_2 concentration target

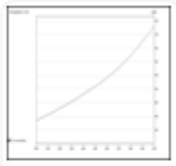


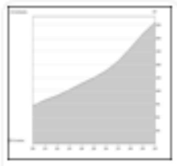
Output overview and parameter options

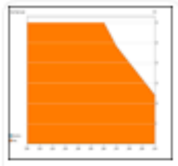
Scenario output graphs


Primary energy supply

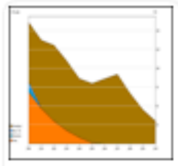

Transportation fuel usage

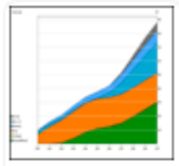

Atmospheric CO2 concentration


CO2 emissions


Use of bio fuels


Use of gas


Use of oil


Use of coal

Scenario parameters

Rates

Discount rate: 0.05

Investor interest: 0.05

Resource extraction cost

Bio fuel: 2 USD/GJ

Coal: 1 USD/GJ

Oil: 3 USD/GJ

Gas: 2.5 USD/GJ

Constraints

CO2 target: 2000 ppm

CCS capacity: 600000 Mton

Supply potentials/Reserves

Biomass: 200 EJ/year

Oil: 12000 EJ

Gas: 10000 EJ

Vehicle extra cost

Methanol/ethanol: 1000 USD/vehicle

Hydrogen fuel cell: 4000 USD/vehicle

Gas: 1200 USD/vehicle

Generate Scenario

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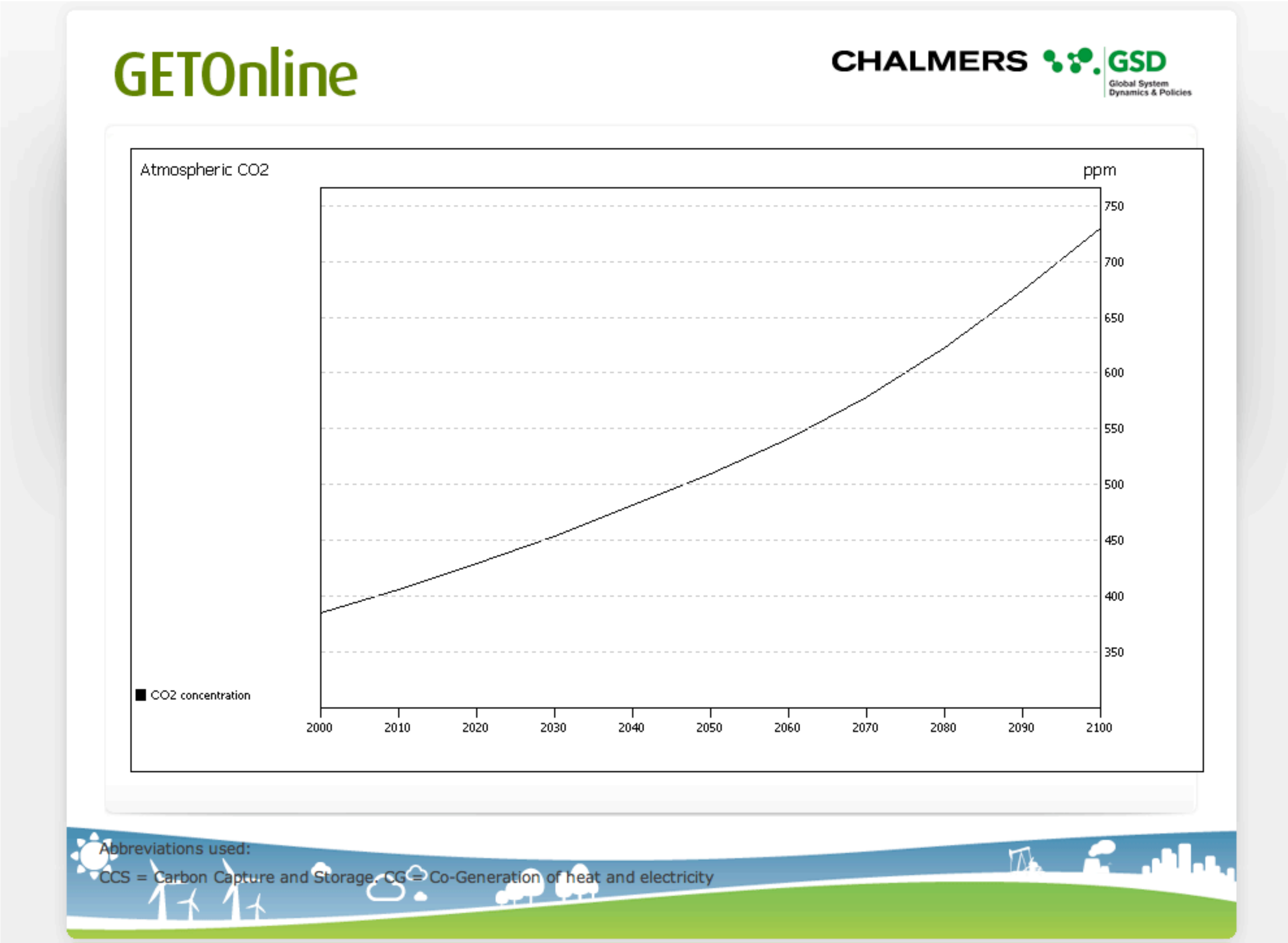
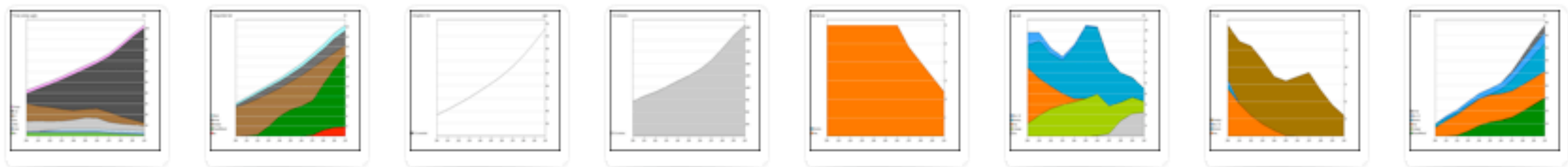
No CO_2 constraint



Output overview and parameter options

Scenario output graphs



Primary energy supply | Transportation fuel usage | Atmospheric CO2 concentration | CO2 emissions | Use of bio fuels | Use of gas | Use of oil | Use of coal

Scenario parameters

Rates

Discount rate	0.05
Investor interest	0.05

Resource extraction cost

Bio fuel:	2	USD/GJ
Coal:	1	USD/GJ
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Vehicle extra cost

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Generate Scenario

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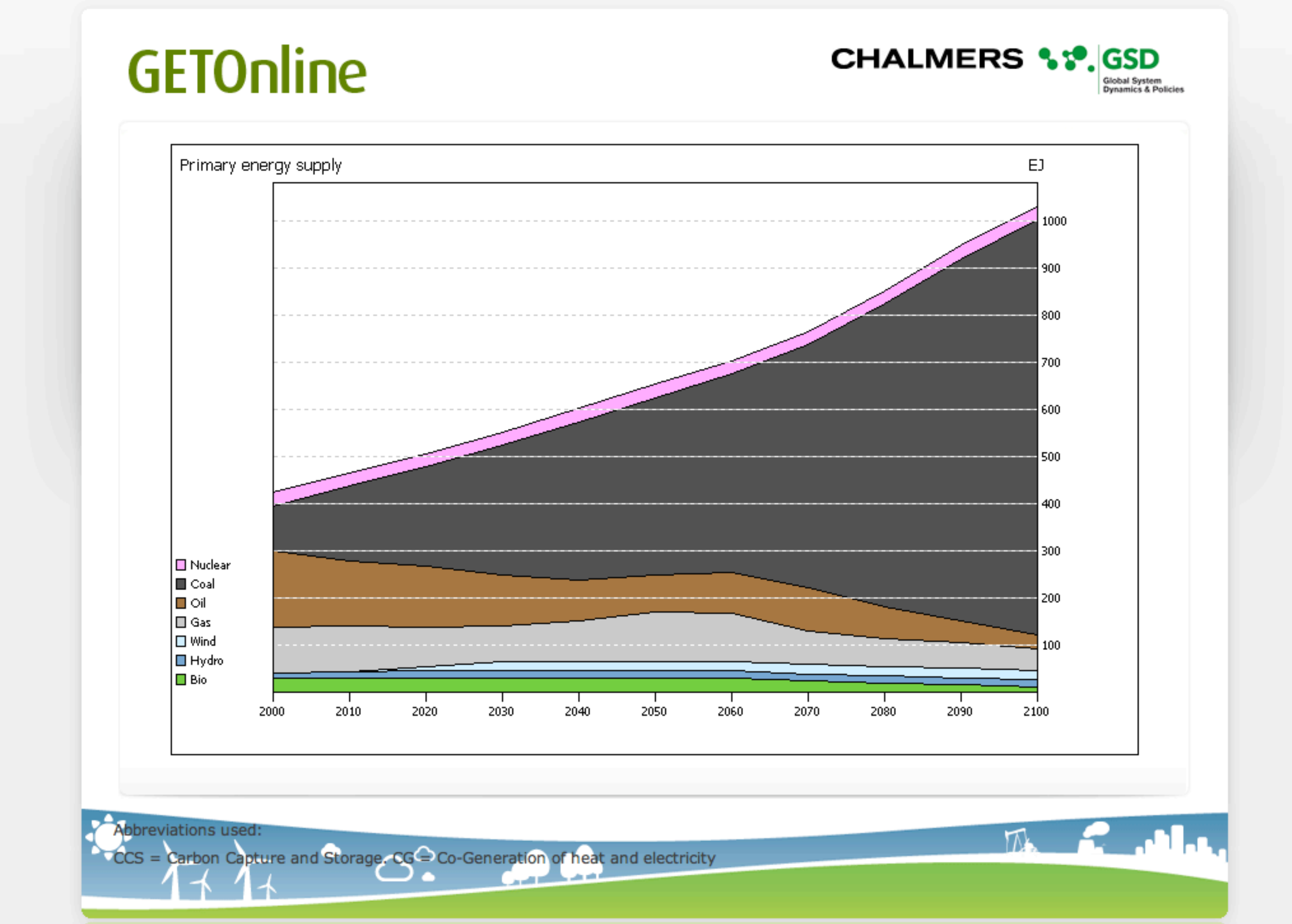
Primary energy supply when no CO_2 target



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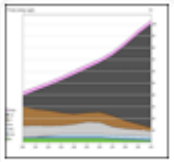
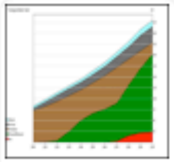
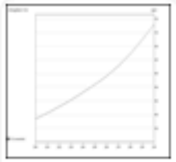
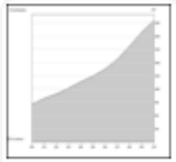
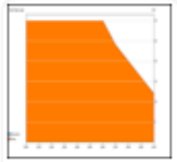
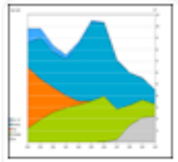

Primary energy supply

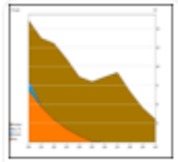

Transportation fuel usage

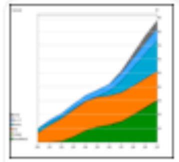

Atmospheric CO2 concentration


CO2 emissions


Use of bio fuels


Use of gas


Use of oil


Use of coal

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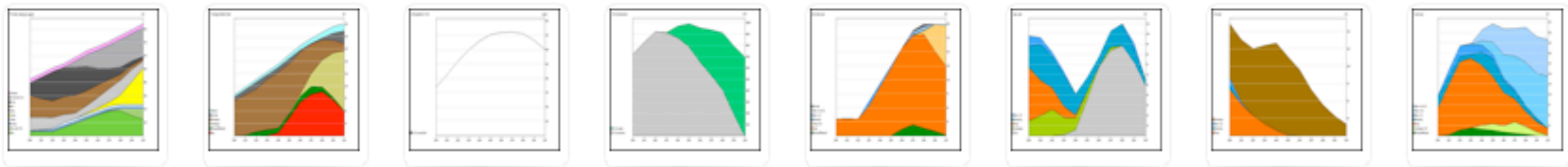
Generate Scenario

Output overview and parameter options

Scenario output graphs



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Scenario parameters

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Discount rate: 0.05

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Resource extraction cost

Bio fuel: 2 USD/GJ

Coal: 1 USD/GJ

Oil: 3 USD/GJ

Gas: 2.5 USD/GJ

Constraints

CO2 target: 450 ppm

CCS capacity: 600000 MTon

Supply potentials/Reserves

Biomass: 200 EJ/year

Oil: 12000 EJ

Gas: 10000 EJ

Vehicle extra cost

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Hydrogen fuel cell: 4000 USD/vehicle

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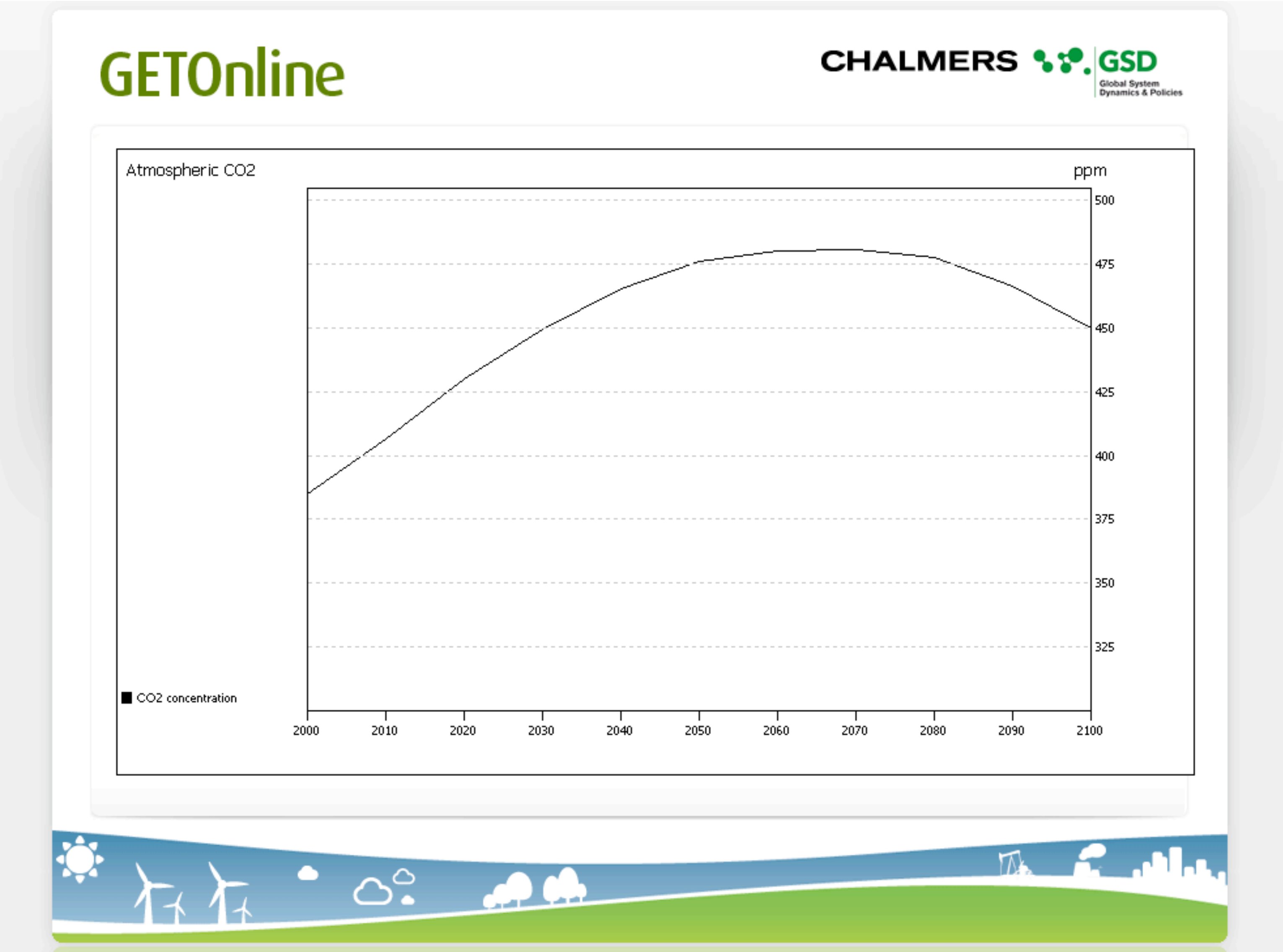
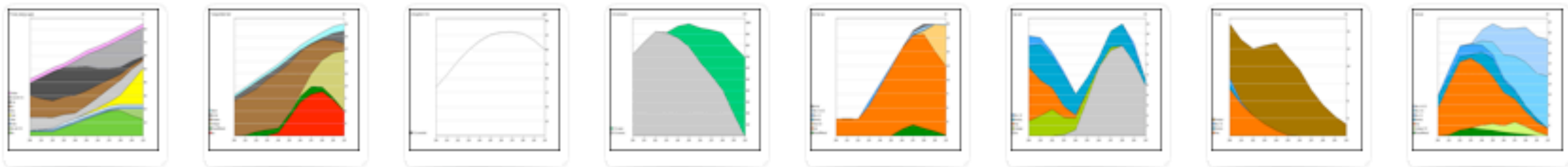
Generate Scenario

Meeting a 450 ppm CO_2 target



Output overview and parameter options

Scenario output graphs



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Scenario parameters

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Generate Scenario

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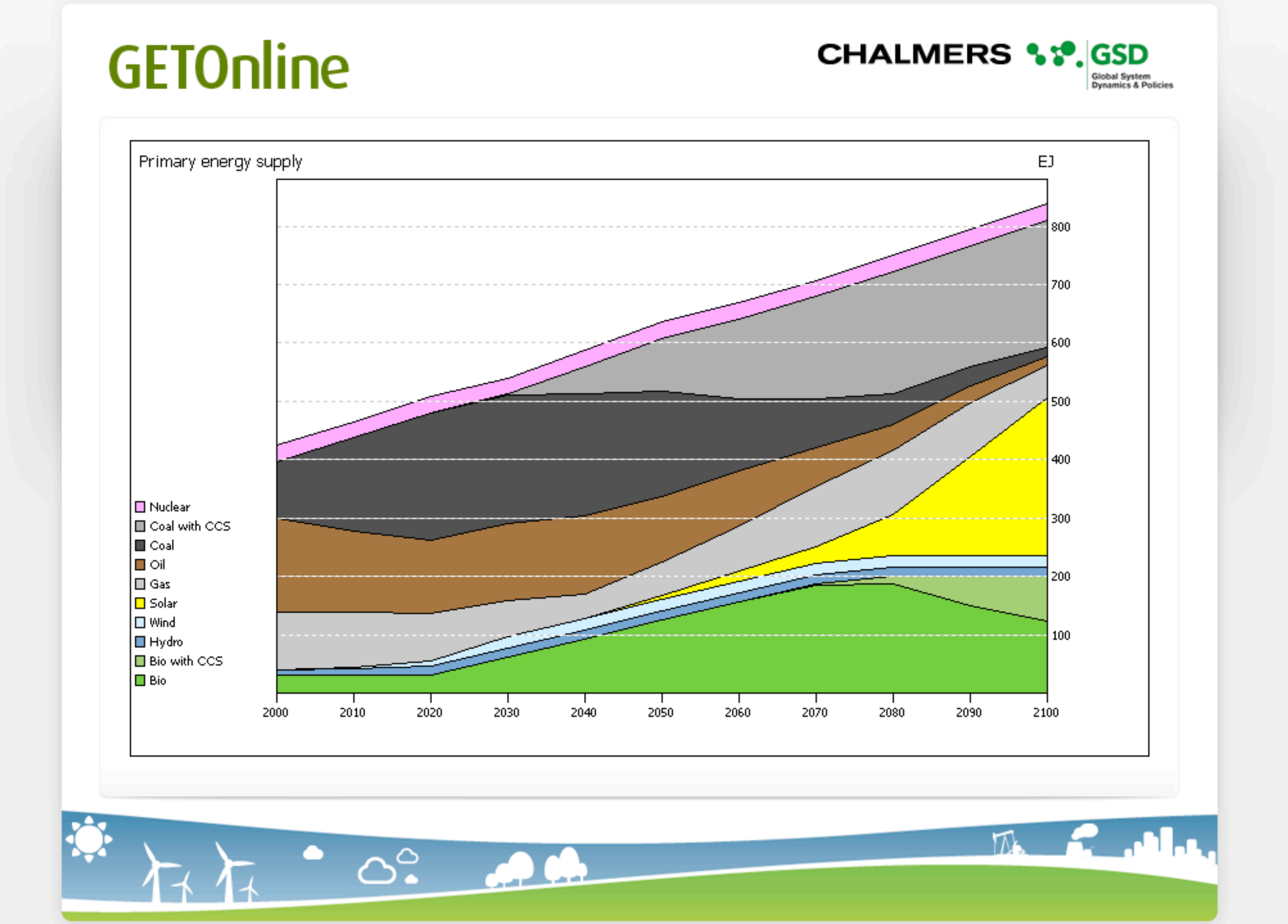
Primary energy supply in 450 ppm scenario



Further development of GETOnline

- More options to control the GET model
  - parameters
  - constraints
- More output graphs
  - cost representations (in relation to GDP)
- Regionalised version (GET 6-R)
  - based on a 6 region resolution global model

- Improvement of presentation to target a well-informed general public
  - collaboration with Ministry of Environment in Sweden
  - possibly presented at COP15 in Copenhagen

Thanks to coworkers:

<u>Energy group and Complex systems group (Chalmers)</u>

Claes Andersson
Christian Azar
Maria Grahn
Fredrik Hedenus
Daniel Johansson
Martin Persson
Tobias Persson

<u>Other groups</u>

Bert de Vries (PBL)
Eric Larson (Princeton)
Michael Obersteiner (IIASA)
Björn Sandén (Chalmers)
Kenneth Möllersten (STEM)

References

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Other web-based activities in GSD

- Web-based multi-player games for exploring human behaviour in Tragedy-of-the-commons situations are under development
  - multi-regional energy-economy-climate game
  - *eFish* – a multi-player dynamic game (pre-prototype stage)

Discussion on uncertainties and limitations

How to distribute cost over time (discounting) and how to dstribute emission rights regionally are critical questions for the global energy system (both in reality and in a model).

The global optimisation model results in a scenario that must NOT be seen as a predicition, but that can serve as a benchmark.

Uncertainties in parameters (supply potentials, costs and efficiency changes, new technologies, etc): some of this may be quantified by generating scenarios using randomised variations.

Uncertainties due to choice of model and model limitations are more difficult to quantify: compare with other model approaches; necessary to explain results in terms of basic mechanisms (simpler model)

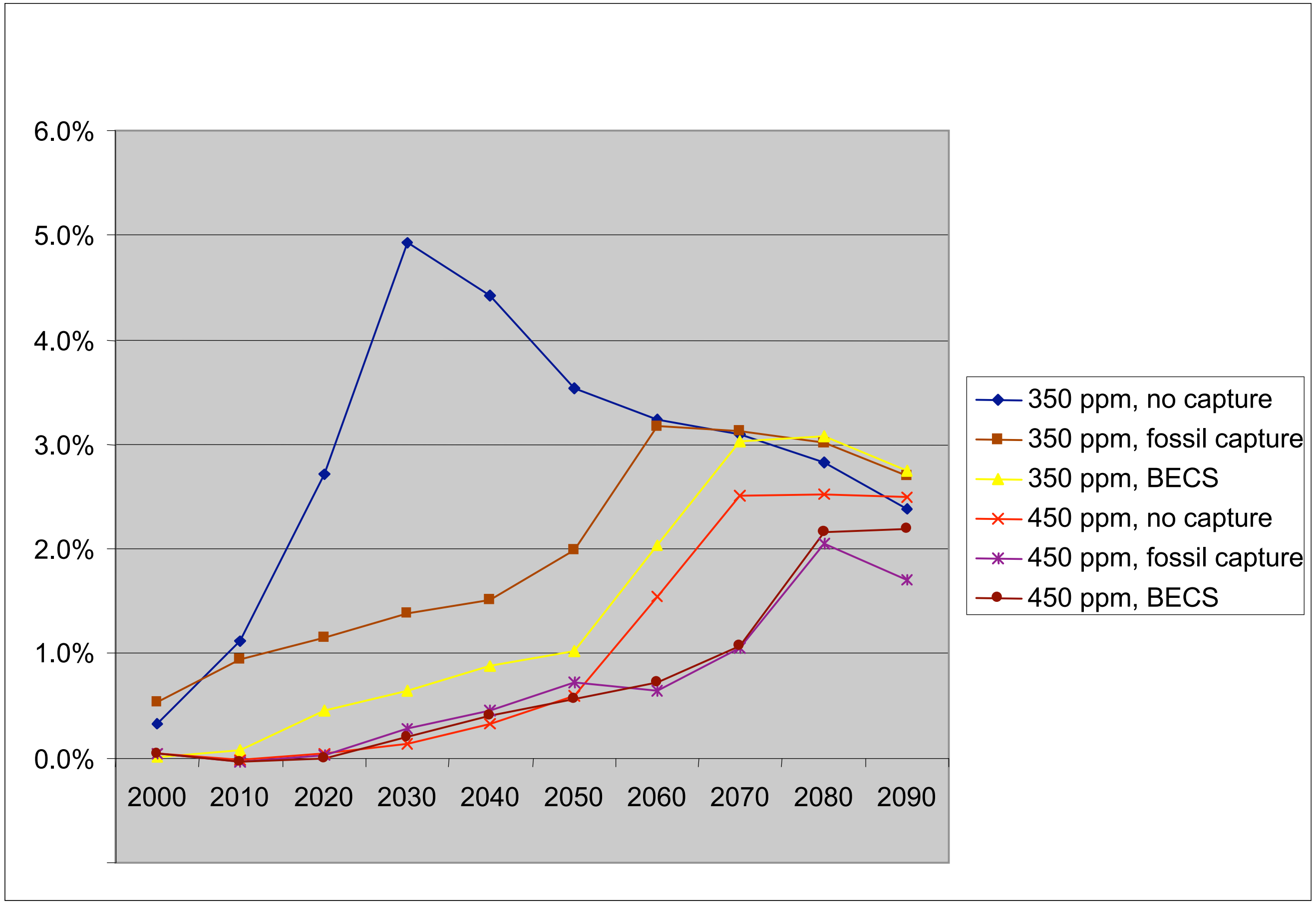
Agent-based modelling

- What role can agent-based modelling play?
  - Decisions taken at different levels, in different situations, and with different goal functions…
  - Investigation of possible conflicts of interest, like we in general have in ”tragedy of the commons” situations.
  - Agents equipped with more of realistic behaviour than what is typically assumed in economics (utility maximisation) may reveal possible solutions not directly seen from economic optimisation.

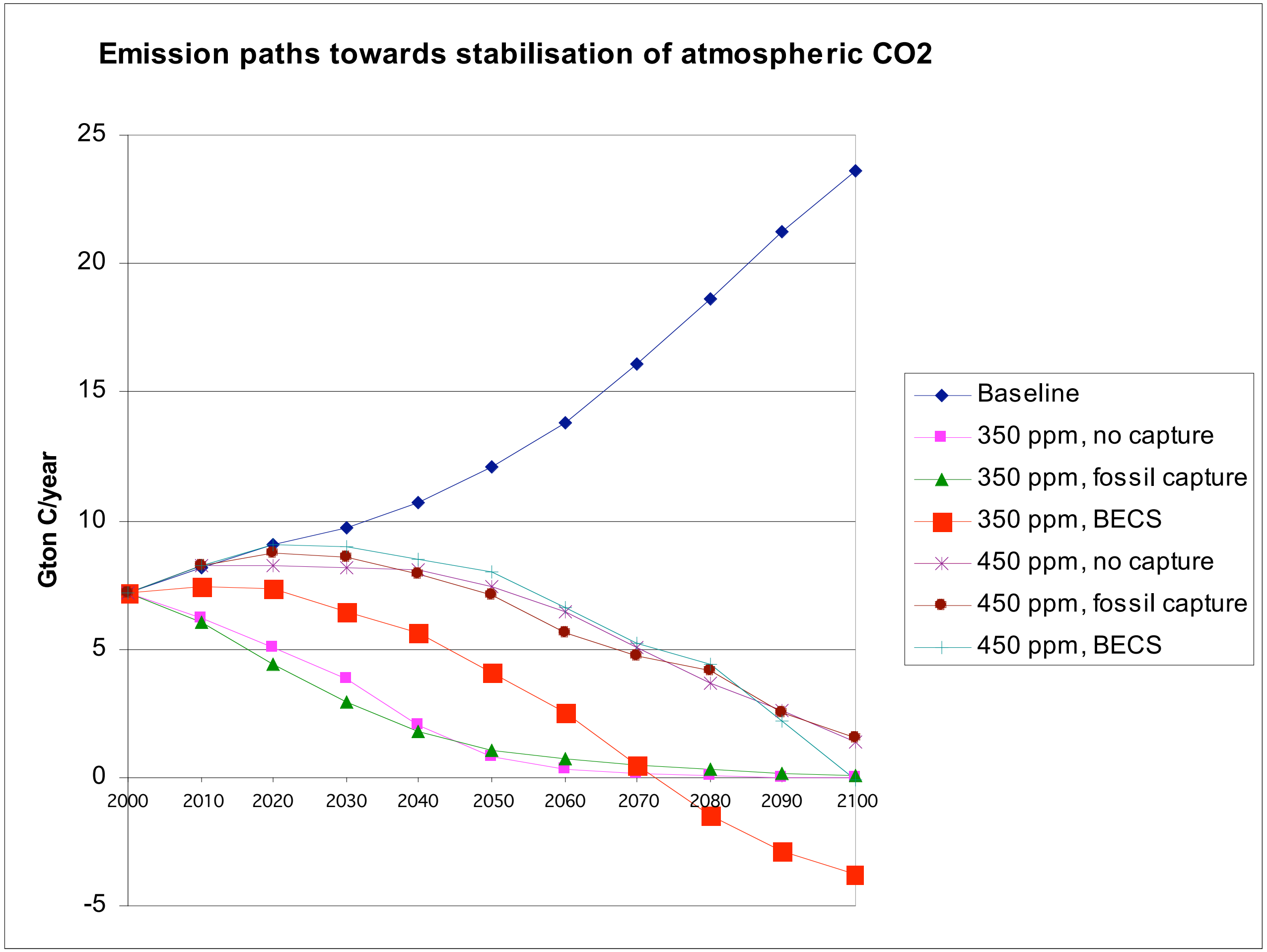
Perfect vs limited forsight

- In the global optimisation model there is full information on all parameters over the entire period. When using the scenarios as benchmarks, this may be reasonable.
- In order to bring the scenarios closer to real planning with a limited time horizon, one can do the optimisation over shorter consequtive overlapping periods. This type of model allows for an endogenous technology improvement without introducing nonlinear terms in the goal function.

Annual extra costs as fractions of GDP



Emission profiles – all scenarios



Plant efficiencies and investment costs

Table 1. Assumed efficiencies and capital.[a]

	Electricity Production[b,f]				Hydrogen Production[c]				Heat Production[d]				Methanol production[e)]	
	No C capture		With C capture		No C capture		With C capture		No C capture		With C capture		No C capture	
	Eff	$/ kW_e	Eff	$/ kW_e	Eff	$/ kW_{H2}	Eff	$/ kW_{H2}	Eff.	$/ kW_{th}	Eff.	$/ kW_{th}	Eff.	$/ kW_{MeOH}
Coal	45%	1100	35%	1500	65%	700	60%	900	90%	300	80%	500	60%	1000
Oil[f)]	50%	600	40%	1000	75%	400	70%	600	90%	100	80%	300		
Natural Gas	55%	500	45%	900	80%	300	75%	500	90%	100	80%	300	70%	600
Biomass[f)]	40%	1200	30%	1700	60%	800	55%	1000	90%	300	80%	500	60%	1000
Hydrogen[f)]	55%	500							90%	100				

Potential for carbon storage underground

Underground storage	Storage capacity (Gton C)	Retention (years)
Deep aquifers with structural traps	30-650	>100,000
Deep aquifers without structural traps	<14000	>100,000
Depleted oil and gas fields	130-500	>100,000
Coalbeds	80-260	>100,000
Enhanced oil recovery	20-65	tens

Source: Grimston *et al* (2001).

Cost for CO_2 transport and storage

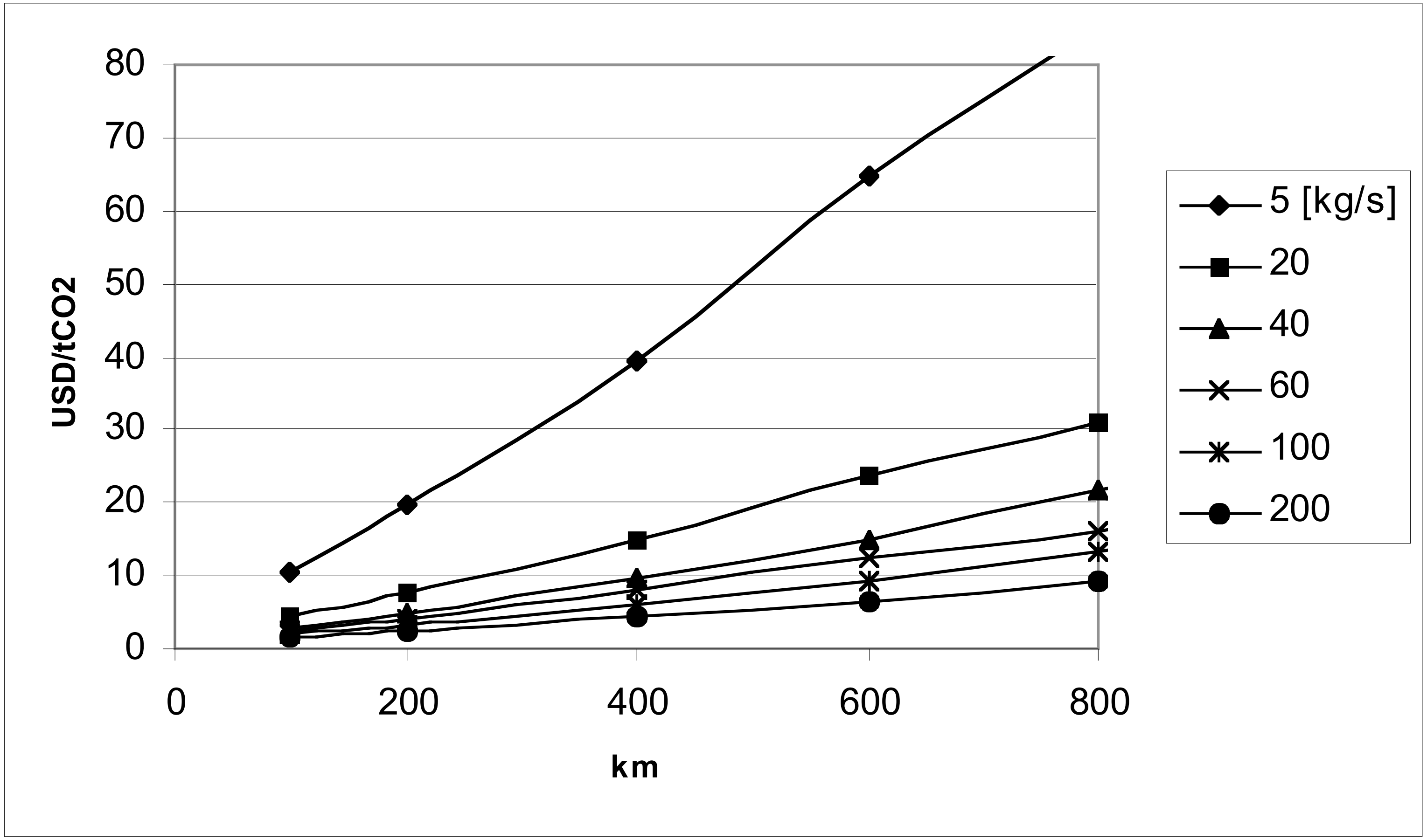


Figure. 2. Cost of CO_2 transportation and storage for on-shore injection wells.