International Scientific Symposium: Avoiding Dangerous Climate Change

Met Office, Exeter, United Kingdom
February 1 - 3, 2005

Cost and Technology Role for Different Levels of CO_2 Concentration Stabilization

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- Analysis results: Cost and technology role
  - Long-term and global aspects

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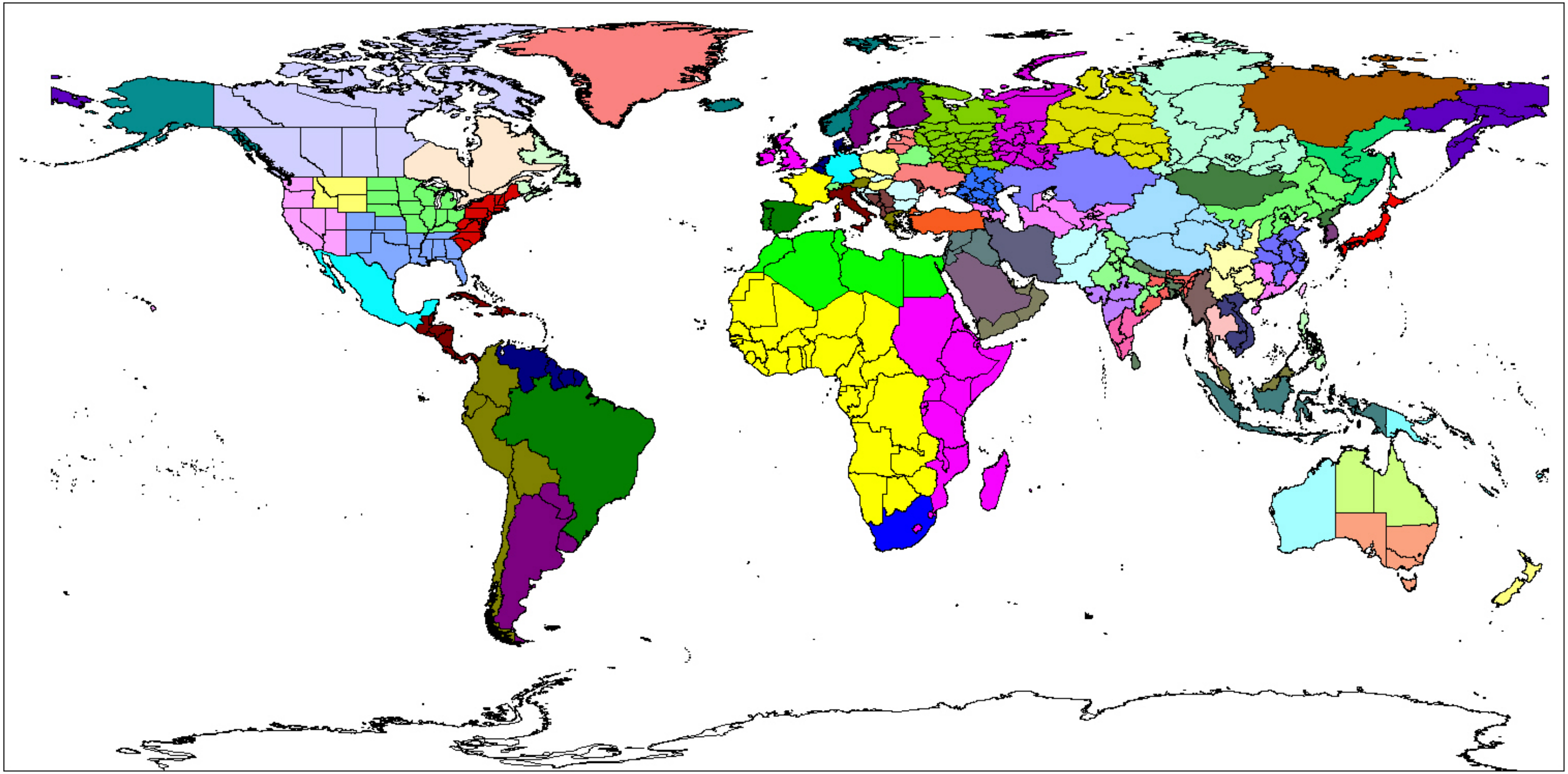
  - Middle-term aspects with focus on regional differences

    550 ppmv for SRES B2-base scenario
- Conclusion

Outline of DNE21+ Model

- Linear Programming Model (minimizing world energy system cost)
- Evaluation time period: 2000-2100 (or -2050)
- World divided into 77 regions
- Energy supply side: bottom-up, demand side: top-down
- Primary energy: coal, oil, natural gas, hydro&geoth., wind, photovoltaics, biomass and nuclear power
- Final energy demand: solid, liquid, gaseous fuels, and electricity
- Electricity demand and supply are formulated for 4 time periods: instantaneous peak, peak, intermediate and off-peak periods
- Interregional trade: coal, crude oil, natural gas, methanol, hydrogen, electricity and CO_2
- Existing facility vintages are explicitly modeled.

Model Regions in DNE21+ Model



Model Assumptions

Model Assumptions

- **Fossil fuel resource**

  Coal : 885 Gtoe
  Oil : 241 Gtoe (conventional), 2,340 Gtoe (unconventional)
  N.Gas: 243 Gtoe (conventional), 19,600 Gtoe (unconventional)

  Source: WEC, USGS, Rogner

- **Renewable energy resource**

  Cost reduction assumption: Wind power - 1.0 %/yr
  Photovoltaics - 3.4 %/yr

  Source: based on EPRI

- **Electricity generation efficiency (LHV base %)**

  Coal : 22□52 %
  Oil : 20□60 %
  N.gas : 24□62 %
  Hydrogen : 52□65 %

etc.

Assumed Cost and Potential of CO2 Capture & Storage (CCS)

	Facility cost (US$/(tC/day))	Energy requirements (MWh/tC)
CO_2 chemical recovery from coal fueled power	59,100 – 52,000	0.792 – 0.350
CO_2 chemical recovery from gas fueled power	112,500 – 100,000	0.927 – 0.719
CO_2 physical recovery on gasification plants	14,500	0.902 – 0.496
	Facility cost (US$/kW)	Generation efficiency (% LHV)
IGCC with CO_2 capture (physical recovery)	1,700 – 1,470	34.0 – 49.0

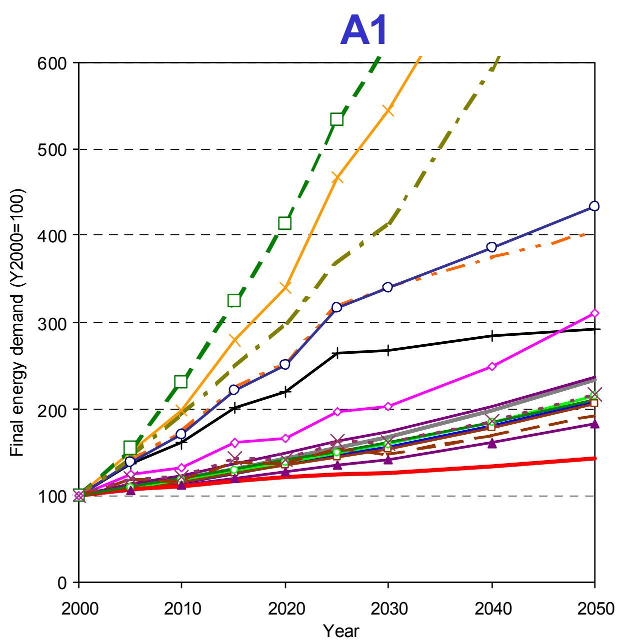
Note: Cost reduction and energy efficiency improvement are assumed to proceed with time.
Source: David et al.; Fujii et al.

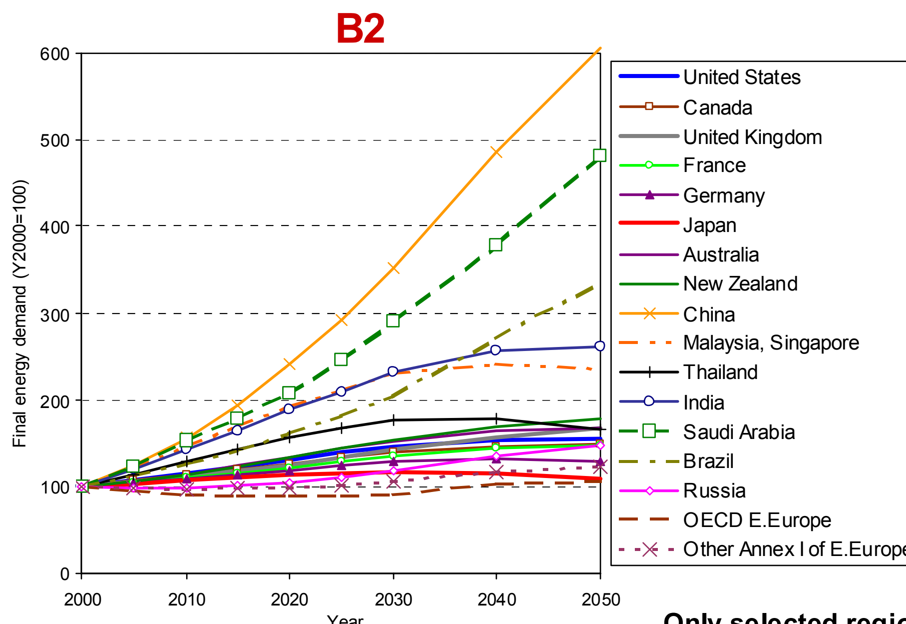
	Sequestration potential (GtC)	**Sequestration cost† ($/tC)**
Oil well (EOR)	**30.7**	**81 – 118‡**
Depleted gas well	**40.2 – 241.5††**	**34 – 215**
Coal-bed (ECBM)	**40.4**	**113 – 447‡‡**
Aquifer	**856.4***	**18 – 143**
Ocean	**–**	**36****

† Cost of CO_2 capture and interregional transportation excluded.
‡ The proceeds from recovered oil excluded.
†† 40.2 is the initial value in 2000, and the capacity increases with natural gas production.
‡‡ The proceeds from recovered gas excluded.
* The potential is the "practical" one, which is 10% and 20% of the "ideal" potentials for onshore and offshore, respectively.
** The cost includes that of CO_2 liquefaction.
Source: Hendriks, et al.; USGS; Stevens, et al.; IEA-GHG; Kotsubo et al.

Assumption of Final Energy Demand

- Population: IPCC SRES A1 and B2 (Task Group on Scenarios for Climate Impact Assessment (TGCIA))
- Growth rate of GDP per cap: IPCC SRES A1 and B2
- Growth rate of final energy per GDP for reference case: IPCC SRES A1 and B2





Only selected regions

Model Analysis Results:

Cost and Technology Role for Long-term and Global Aspects

Baseline: SRES A1- and B2-base
Stabilization Targets: 650, 550 and 450 ppmv

Simulation Cases

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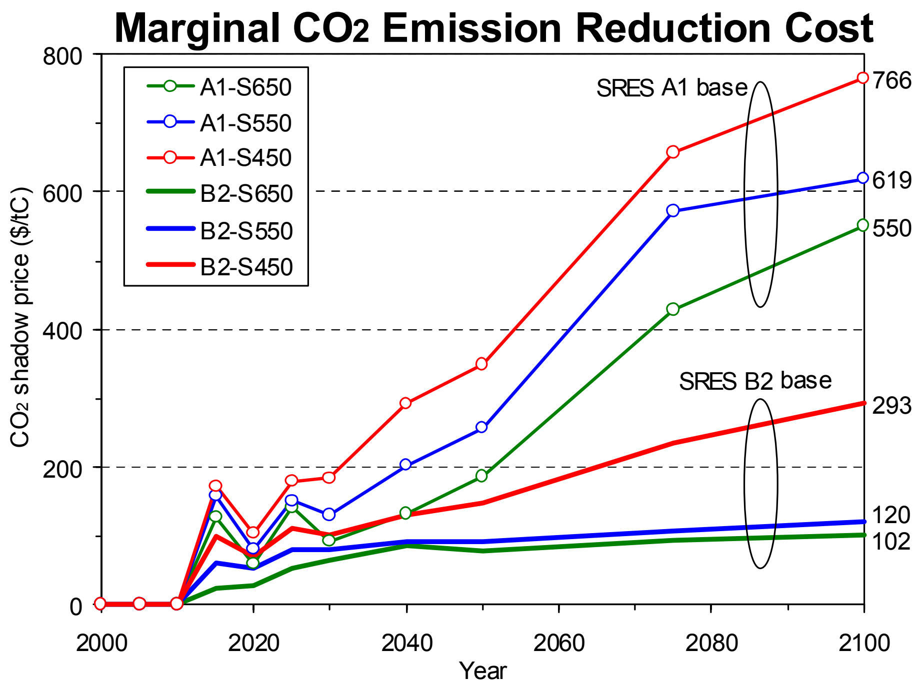
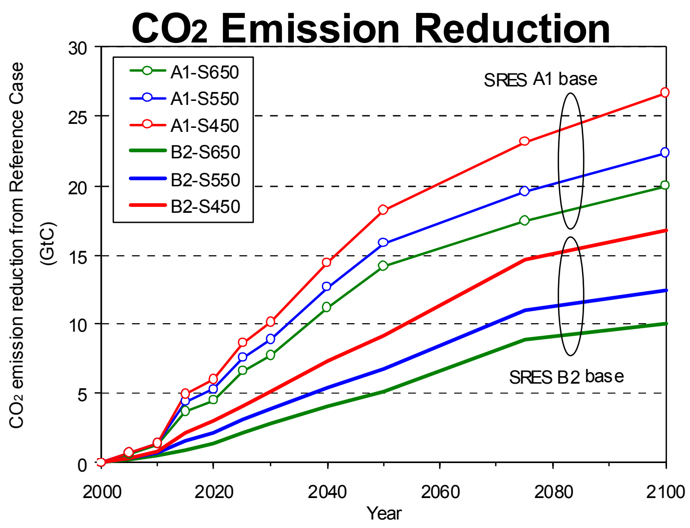
	SRES A1-base	SRES B2-base
Reference (No-constraints)	A1-Ref	B2-Ref
IPCC WGI 650 ppmv Stb.	A1-S650	B2-S650
IPCC WGI 550 ppmv Stb.	A1-S550	B2-S550
IPCC WGI 450 ppmv Stb.	A1-S450	B2-S450

SRES A1/B2 base:

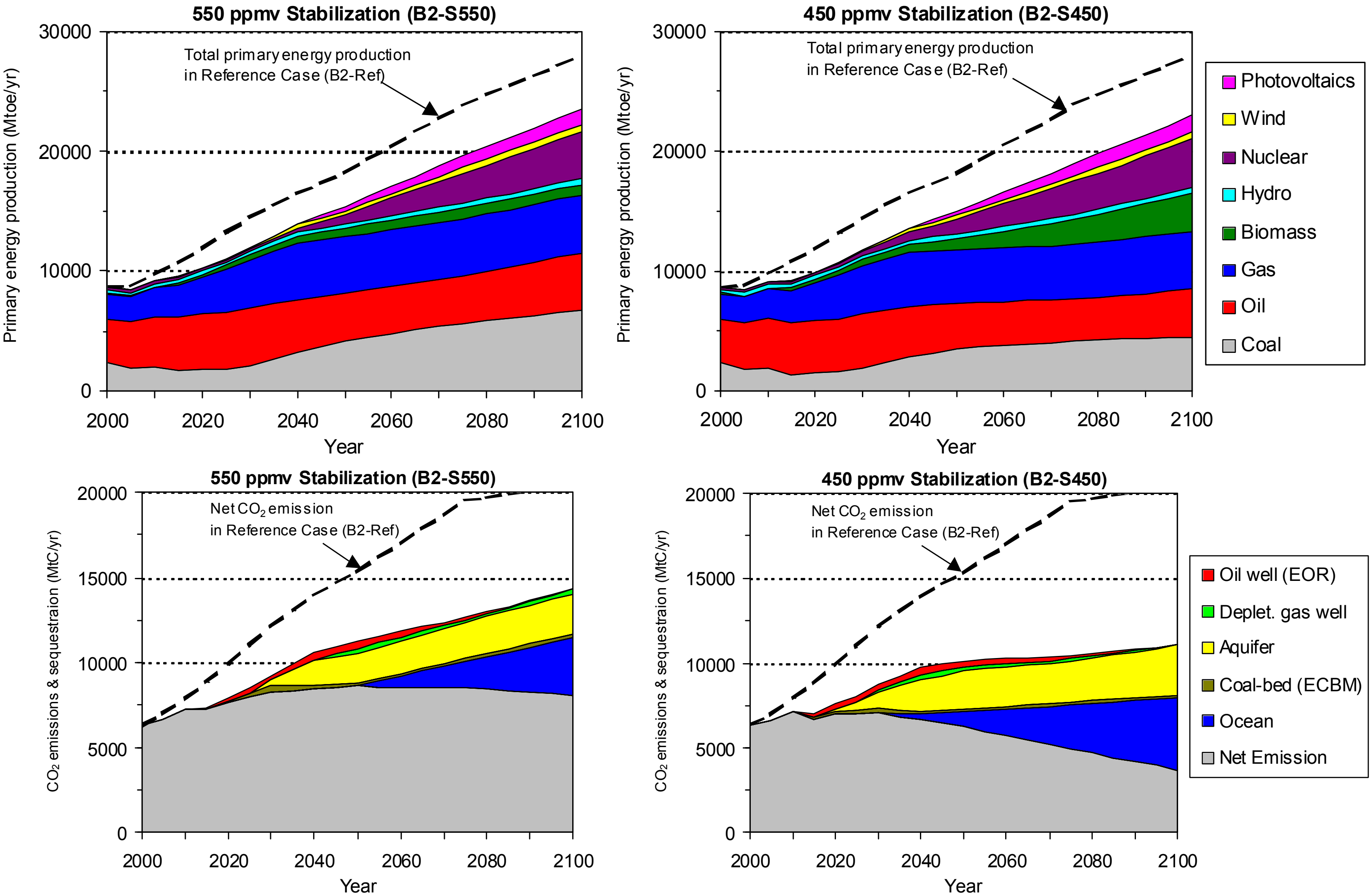
Population, GDP per capita and final energy per GDP are based on the IPCC SRES scenarios.

Marginal CO_2 Reduction Cost





Cost-effective CO_2 Emission Reduction



Remarks (1)

- Emission baselines vary greatly depending on the SRES-base scenarios and they cause larger difference in the marginal cost of CO_2 reduction for the same level of stabilization than different levels of stabilization do,

  which sheds light on:

  - Energy savings are important to lower emission baselines
  - Development and diffusion of high energy-efficiency technologies are important to promote energy savings.

- Under the SRES B2-base scenario, marginal CO_2 reduction cost rises sharply for the concentration stabilizations bellow 550 ppmv.

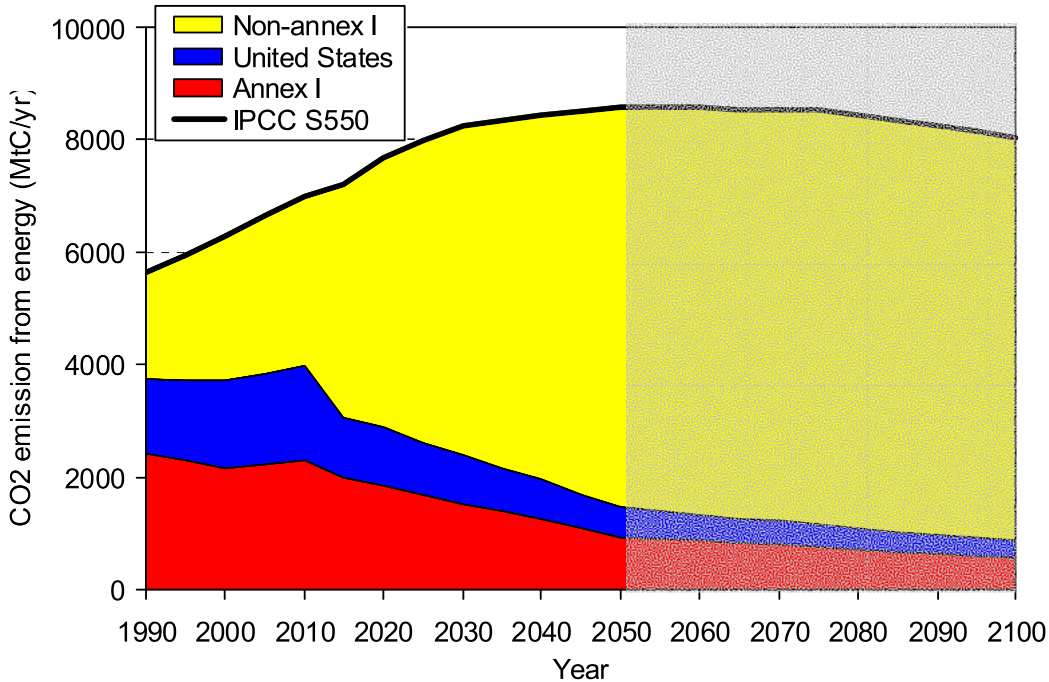
- Energy saving, switching to low carbon fuels and introduction of renewables are not sufficient, but CCS is inevitable even for the B2-S550 stabilization.

Model Analysis Results:

Cost and Technology Role for Middle-term Aspects with Focus on Regional Differences (w.o. Emission Trading)

Baseline: SRES B2-base
Stabilization Targets: 550 ppmv

Assumed Regional CO_2 Emission Limit for S550



* IPCC S550: The CO_2 concentration stabilization scenario at 550 ppmv by IPCC WG1

Year 2010: Kyoto target for Annex I countries excluding US

Per-GDP CO_2 emission reduction of 18% by 2010 for US

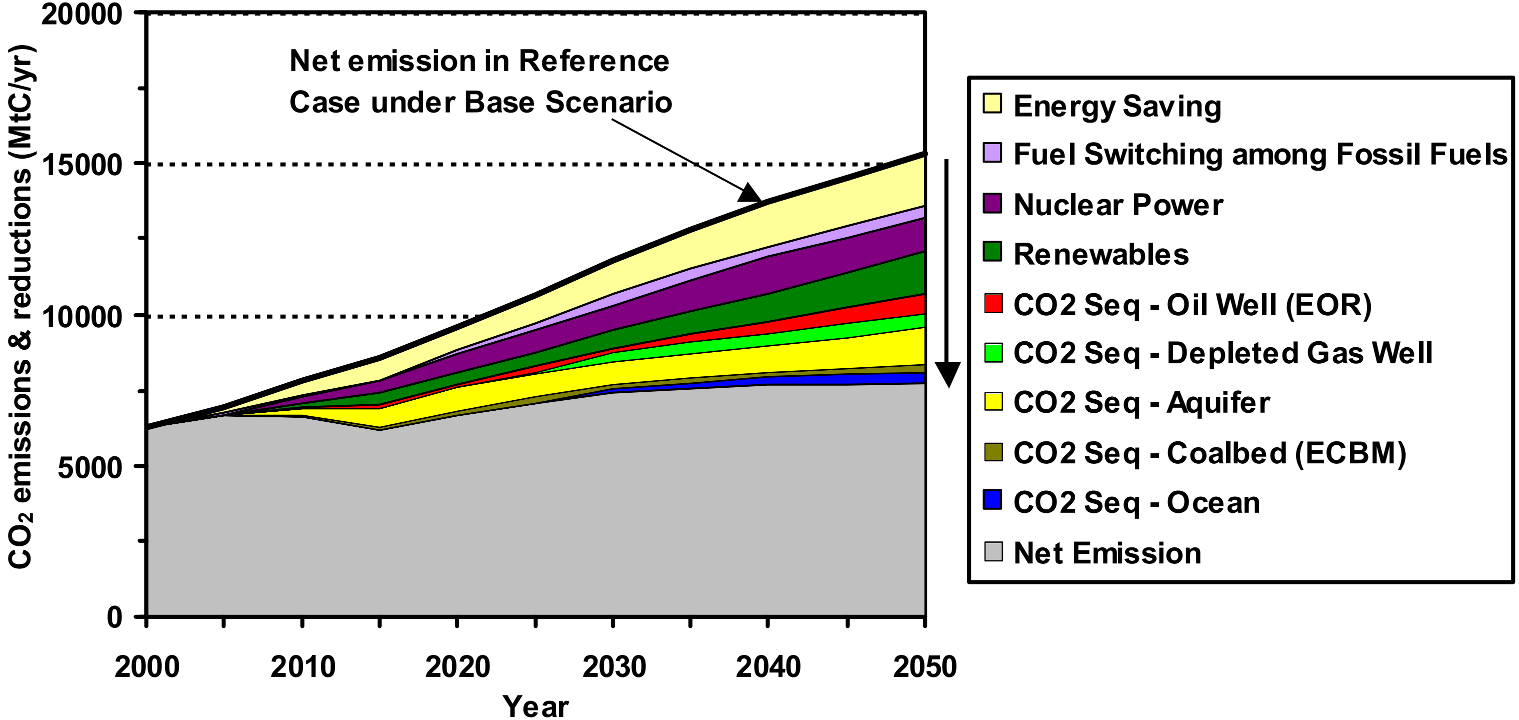
Year 2015 (Years 2013-2017) and thereafter:

UK-proposed-target for Annex I (Approximately 60% reduction in 2050 relative to in 1990)

Emission reductions for Non-Annex I countries to keep the S550 in total

CO_2 Emission Reduction Effects of Technological Options

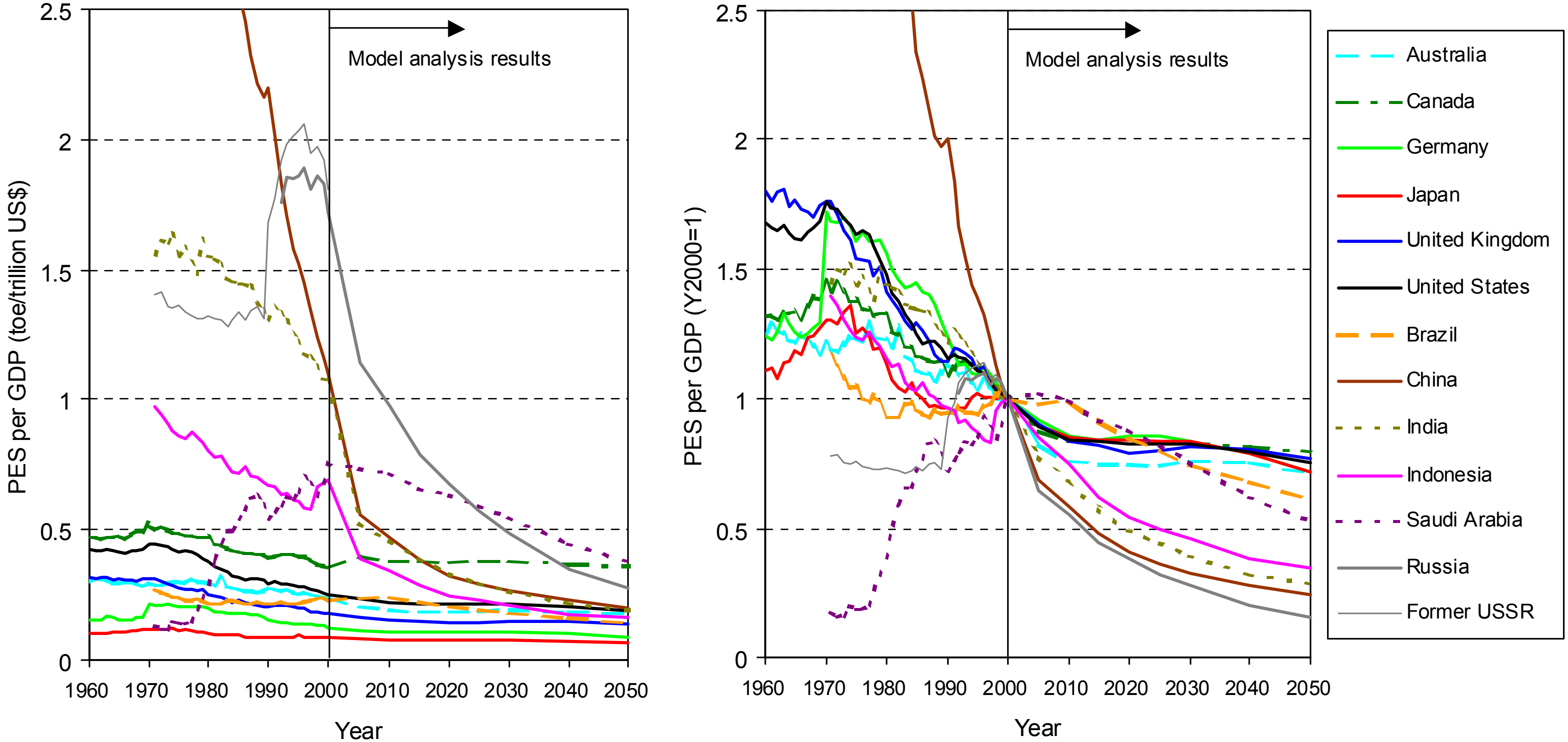
- Constraint Case (S550+KP+UK Proposal) - w.o. Emission Trading



Primary Energy per GDP

- Reference Case (No CO_2 emission constraint) -

CO_2 = (CO_2/PES) × (PES/GDP) × GDP

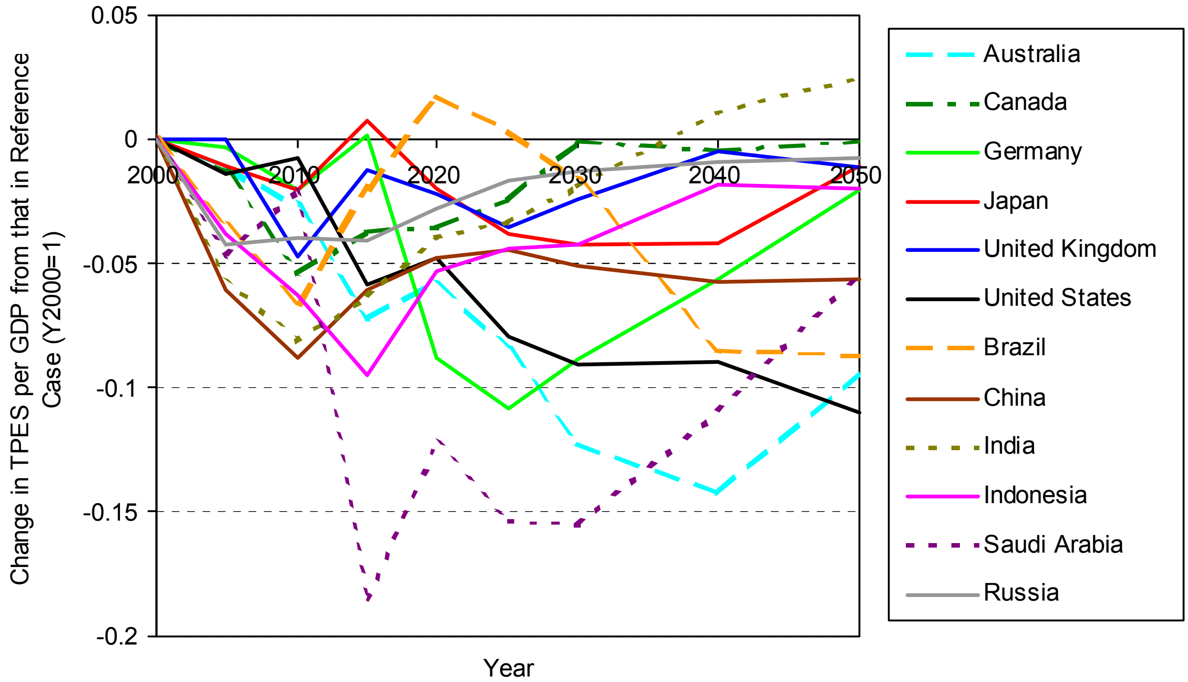


- **The energy intensity particularly in developing countries should decrease even in Reference Case from the viewpoint of achieving cost-effective energy systems regardless of CO_2 emission reduction.**

Primary Energy per GDP

- Constraint Case (S550+KP+UK Proposal) -

$CO_2 = (CO_2/PES) \times (PES/GDP) \times GDP$

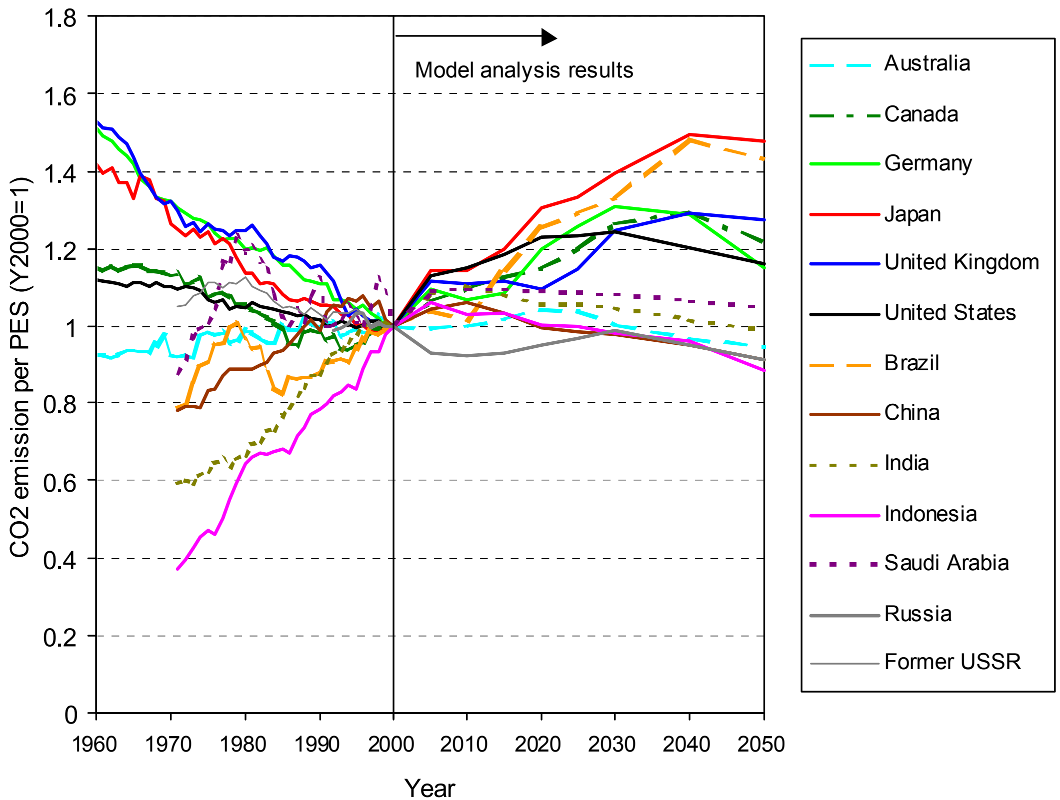


- **A moderate acceleration of the energy intensity improvement (about 10%) should be required for most regions in Constraint Case compared with Reference Case.**

CO_2 Emission Per Primary Energy

- Reference Case (No CO_2 emission constraint) -

$CO_2 = (CO_2/PES) \times (PES/GDP) \times GDP$

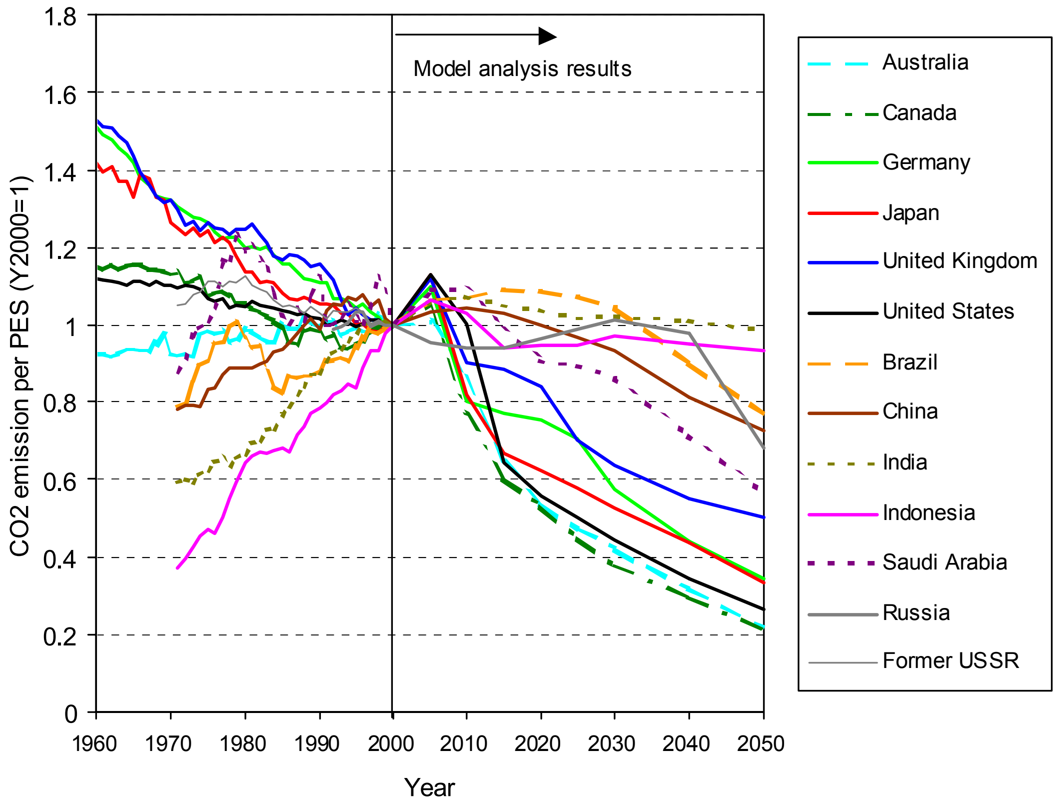


- The CO_2 intensity does NOT have to be decreased in Reference Case.

CO_2 Emission Per Primary Energy

- Constraint Case (S550+KP+UK Proposal) -

CO_2 = (CO_2/PES) × (PES/GDP) × GDP



- **The CO2 intensity should be decreased more in developed countries than in developing countries.**

Remarks (2)

- Decrease in primary energy per GDP shall induce productivity improvement.
- Decrease in CO_2 emission per primary energy shall induce less productivity improvement but cost rise.

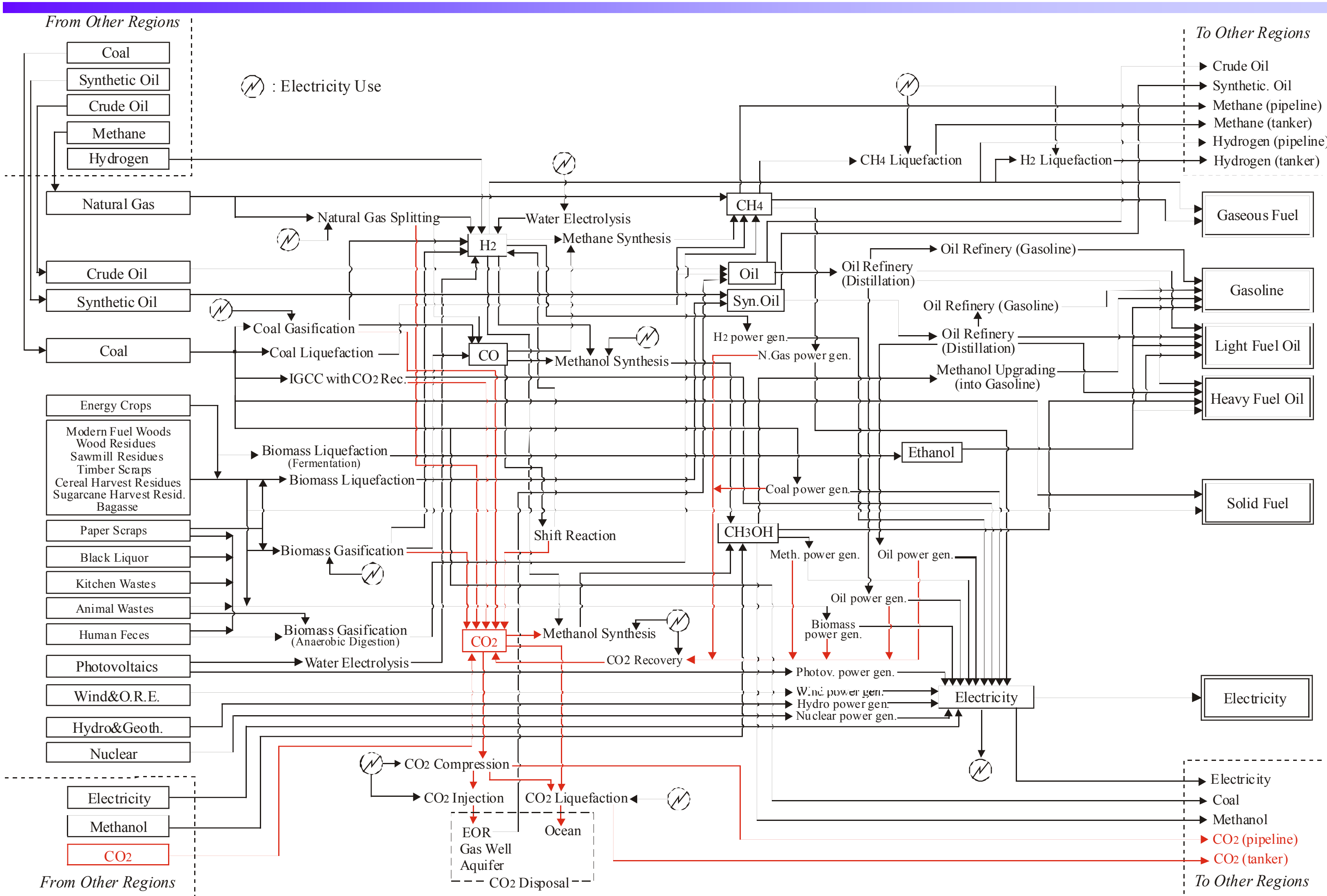
- Developing countries are required to reduce primary energy per GDP for No-CO_2 constraint case as well as for constraint case.
- Developed countries do not have much room for energy intensity improvement, and should decrease CO_2 emission per primary energy for CO_2 constraint case.

- This situation concerning CO_2 emission reduction would bring to developing countries more benefit or stronger competitiveness through the larger productivity improvement and the smaller cost rise than developed countries.

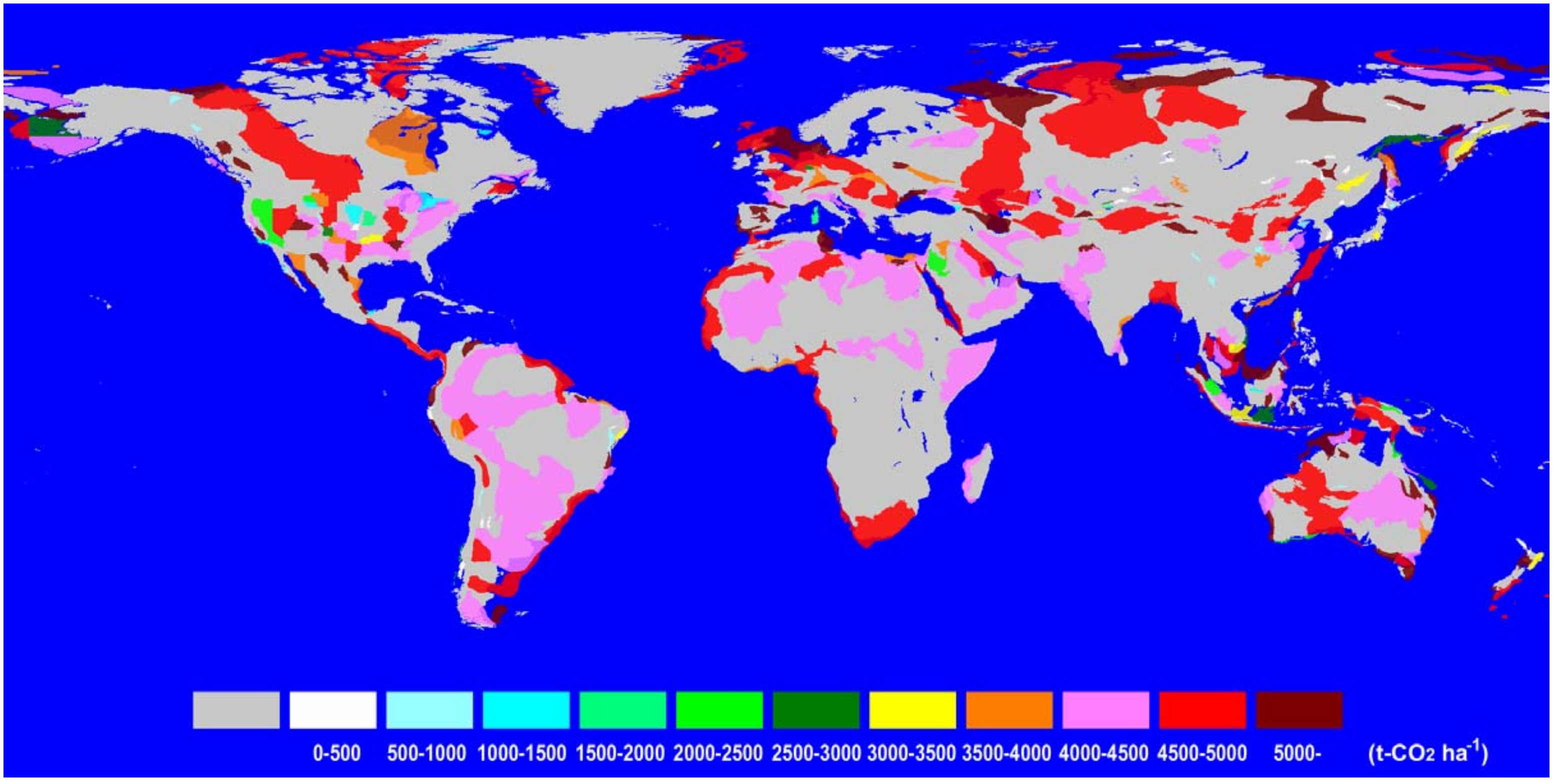
Final Remarks

- Not only stabilization levels but also future emission baselines are the key factors of emission reduction cost, and there exists large uncertainty on the emission baseline.
- Development and diffusion of high energy-efficiency technologies are recommended to lower the emission baseline as well as to reduce the emission from the baseline.
- CO_2 stabilization requires energy saving particularly for developing countries, which would bring to them more benefit or stronger competitiveness than to developed countries.
- Even to achieve moderate levels of stabilization, CCS is necessitated especially for developed countries, which lowers the carbon intensity but would bring no direct benefit to their economies.

Assumed Conversion Processes of DNE21+



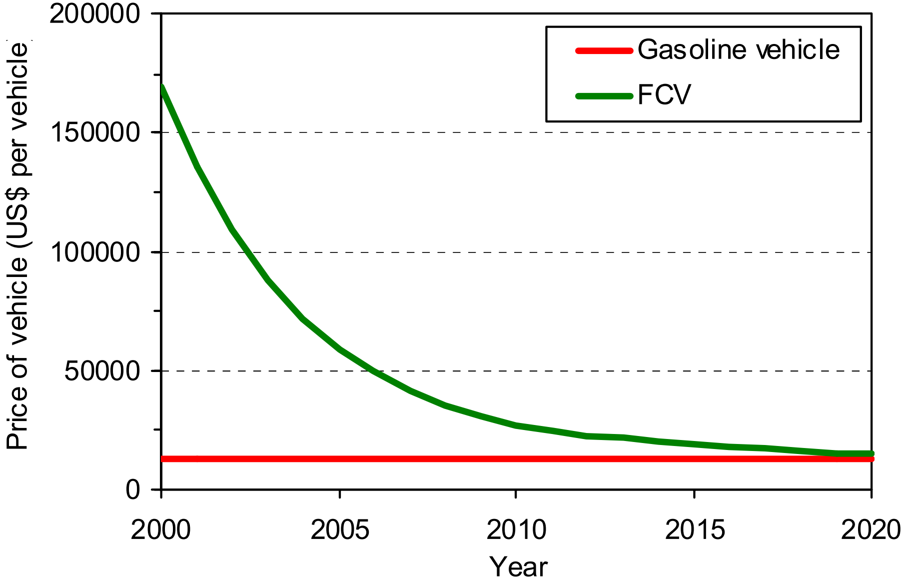
CO_2 Sequestration Potential into Aquifer



Note: The potential was estimated by RITE based on a sedimentary basin map of USGS. The "ideal" potential of aquifer sequestration is shown.

Assumption on Fuel-cell Vehicle (FCV)

- **FCV Average life: same as gasoline vehicles (150,000 km)**
- **Wheel efficiency of FCV: 3.1 times of gasoline vehicles (8km/L)**
- **Cumulative installation of FCV: 0.05 and 5.00 million vehicles in 2010 and 2020, respectively**
- **Cumulative installation of gasoline vehicles of hybrid type: 5.0 and 20.0 million vehicles in 2010 and 2020, respectively**



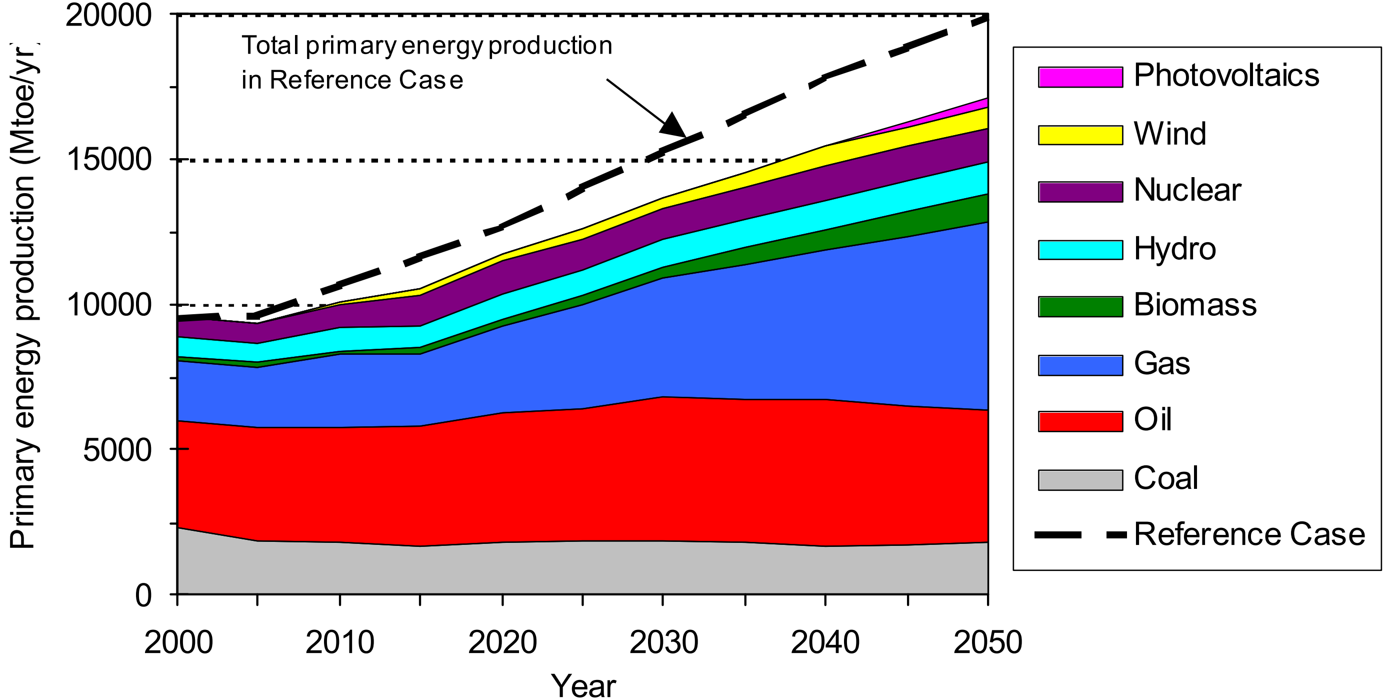
Source: WE-NET Task 1 (2003)

1US$=120Yen

- Supply costs of hydrogen are endogenously determined in the model.
- The above differences in efficiency and vehicle price are converted to the cost penalty on the supply costs of hydrogen.

World Primary Energy Production

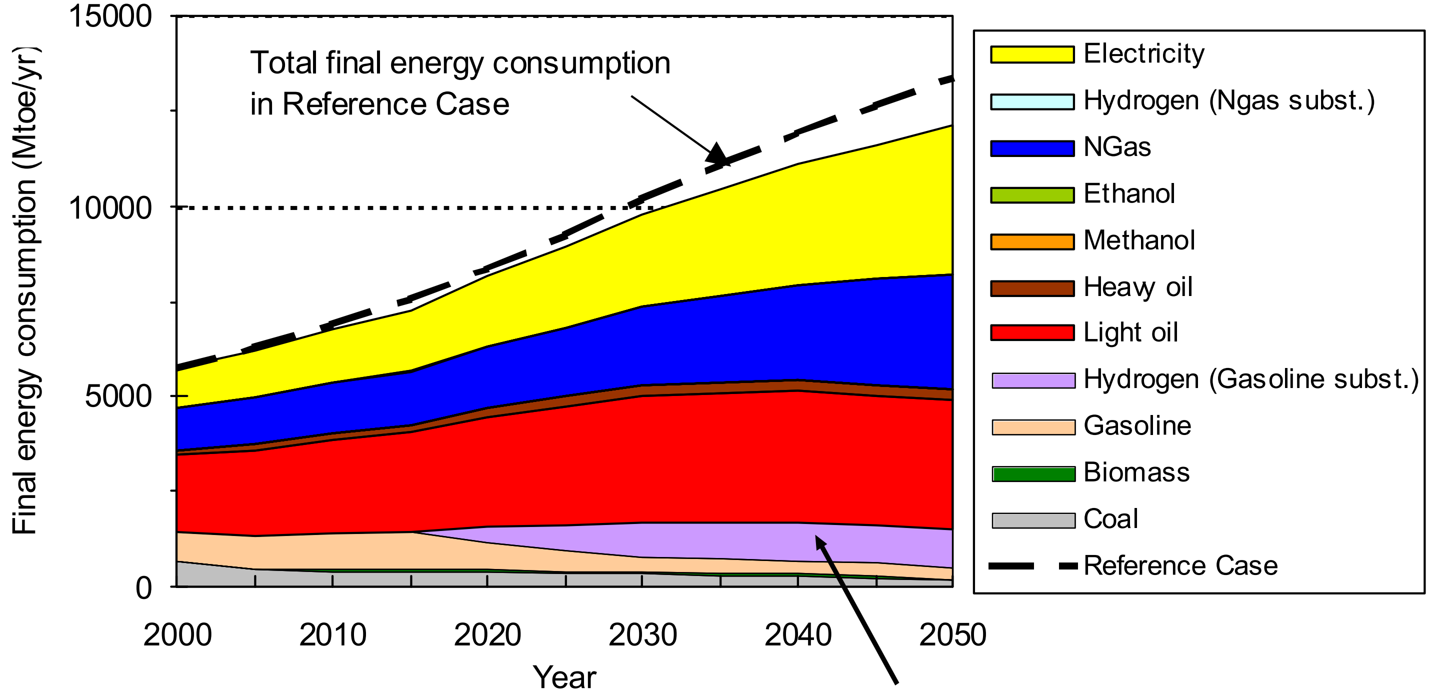
- Regulation Case w.o. Emission Trading -



Note: 1TWh=0.086/0.33Mtoe is used for primary energy conversion of nuclear, hydro, wind powers and photovoltaics.

World Final Energy Consumption

- Regulation Case w.o. Emission Trading -

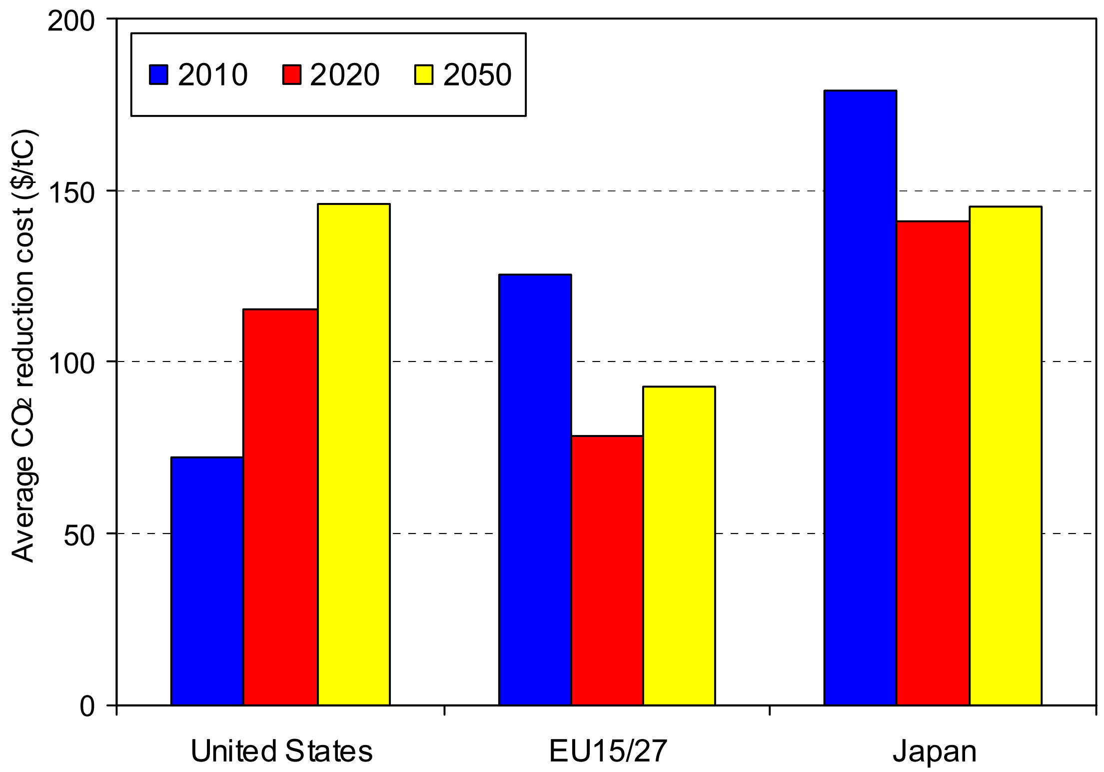


***Gasoline substituted by hydrogen for FCV* ***

*** The energy is shown as the substitution of gasoline. The hydrogen consumption is about one third of the shown energy in the figure.**

Average CO_2 Emission Reduction Cost

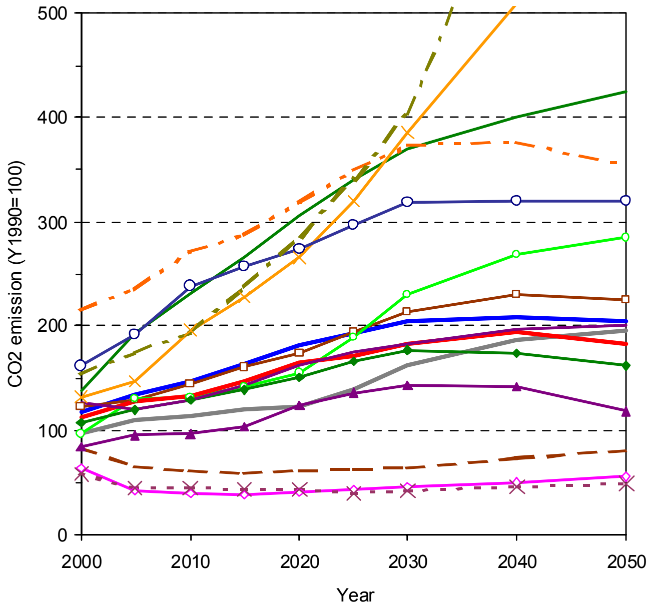
- Regulation Case w.o. Emission Trading -



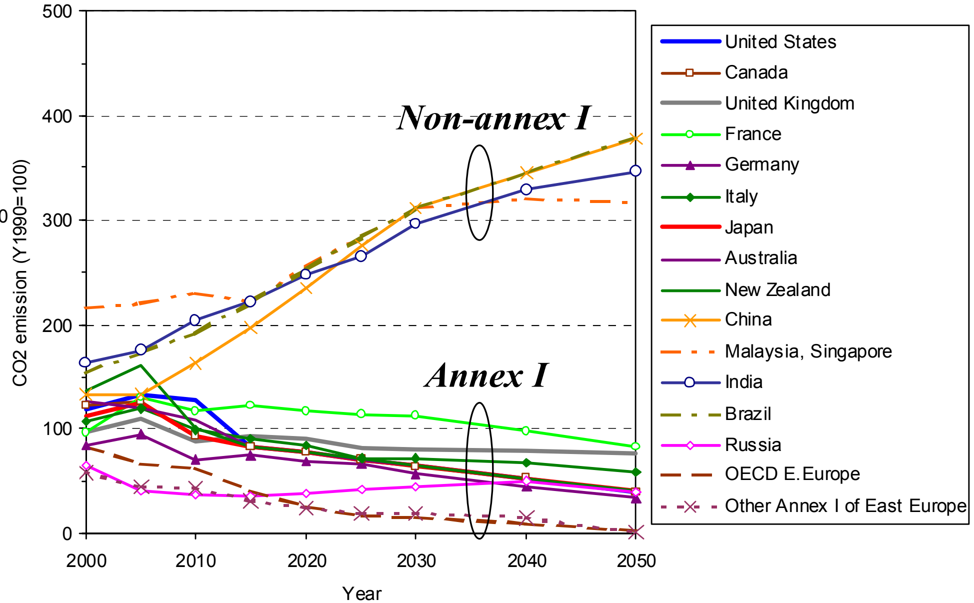
Note: The 15 and 27 countries bubble are assumed for EU in 2010 and thereafter, respectively.

CO2 Emission Profiles by Region

Reference Case



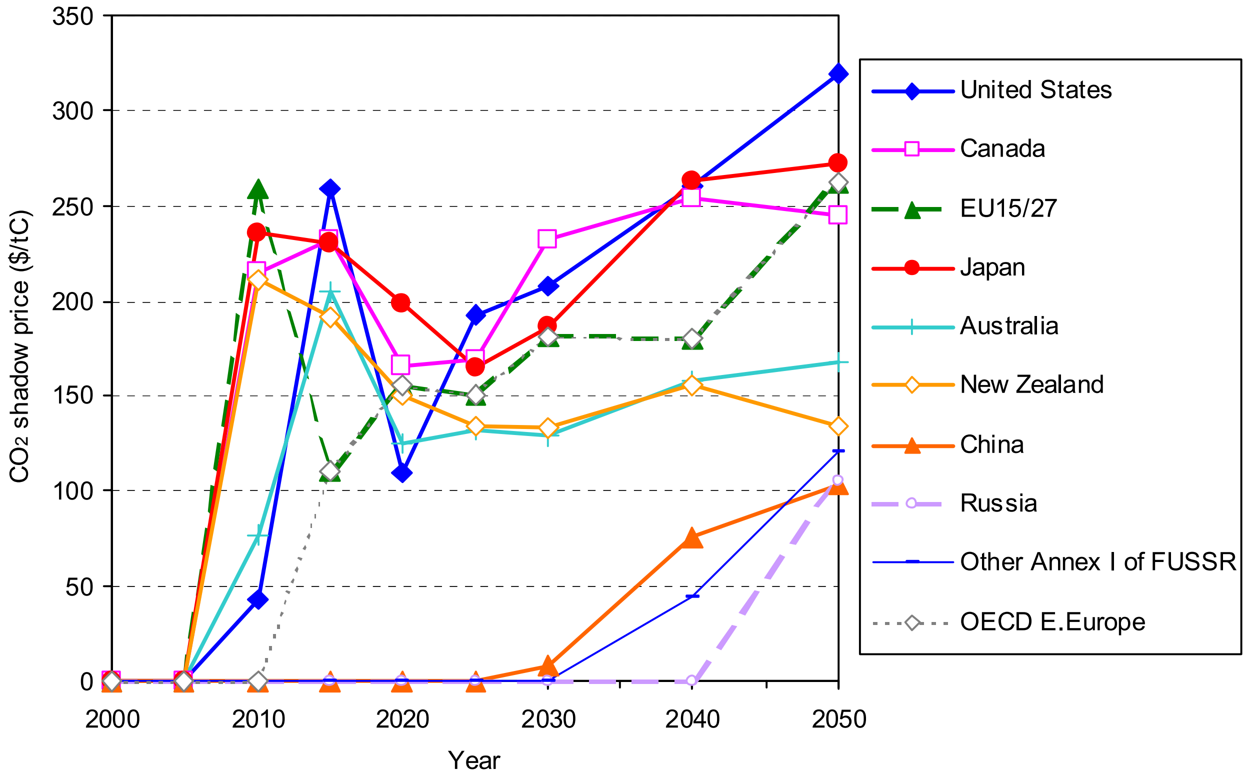
Regulation Case w.o. Emission Trading



Note: CO_2 emission from energy only.

Marginal CO_2 Emission Reduction Cost

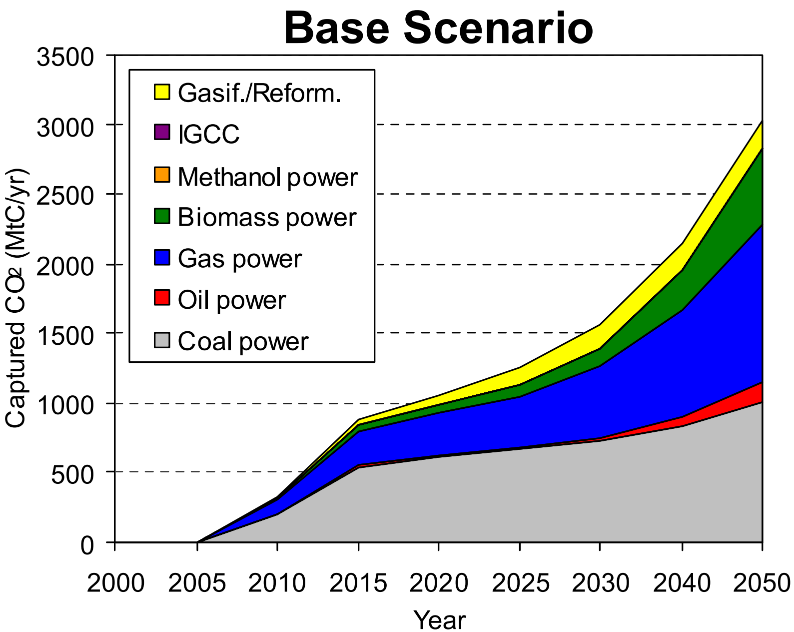
- Regulation Case w.o. Emission Trading -

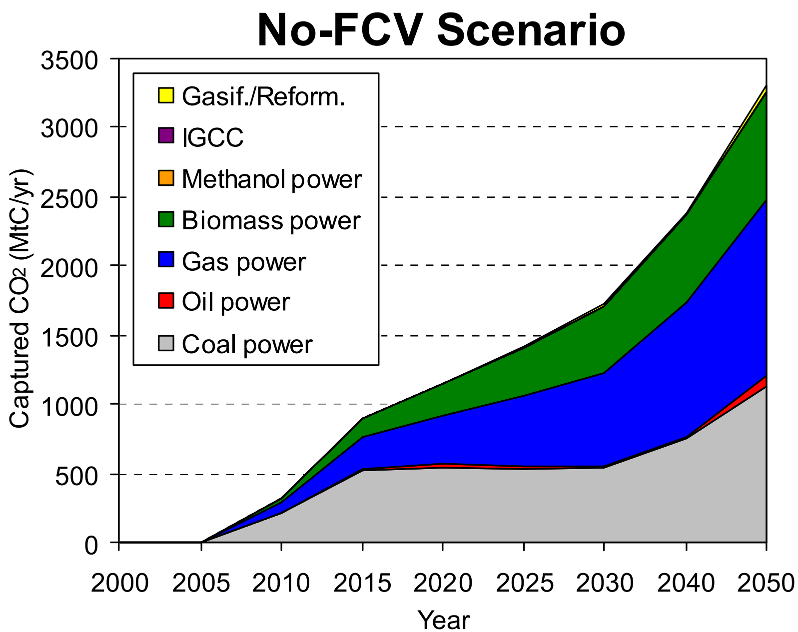


Note: The 15 and 27 countries bubble are assumed for EU in 2010 and thereafter, respectively.

World Captured CO_2

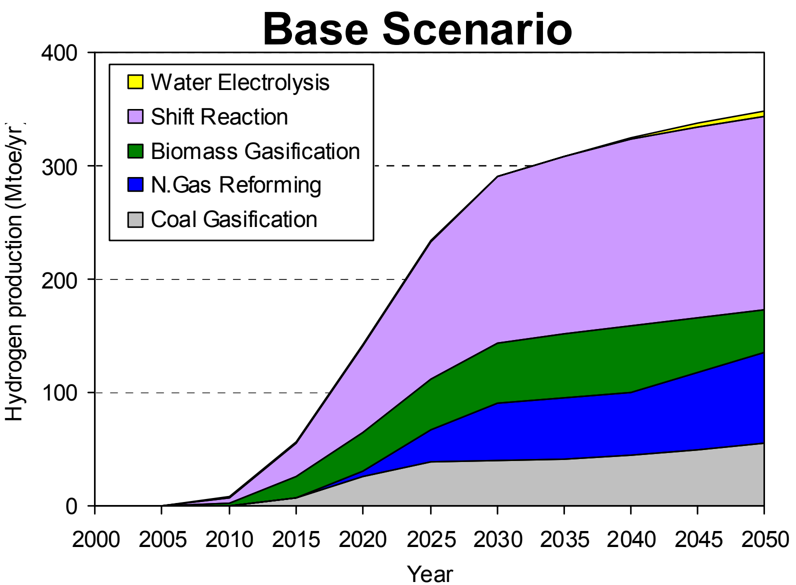
- Regulation Case w.o. Emission Trading -

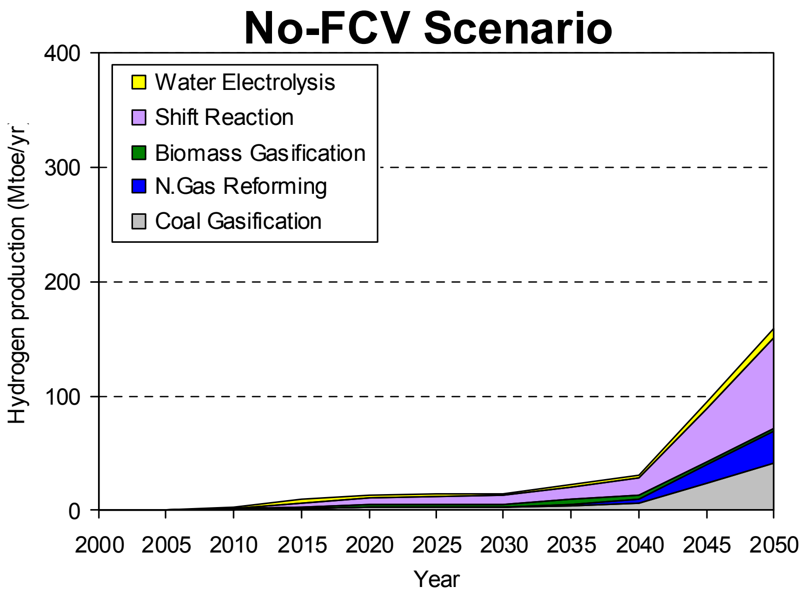




World Hydrogen Production

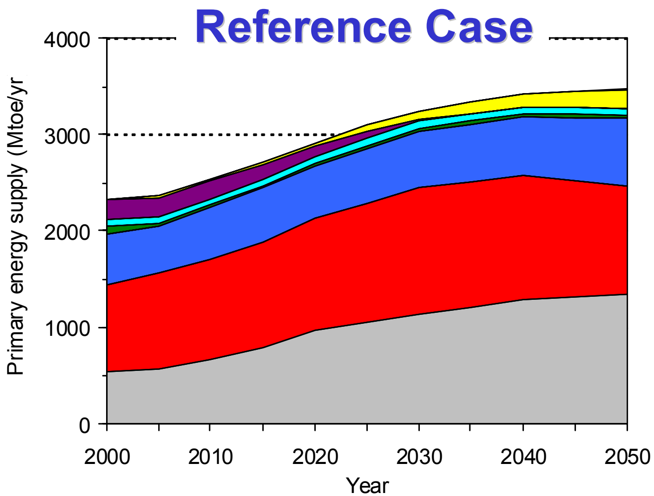
- Regulation Case w.o. Emission Trading -

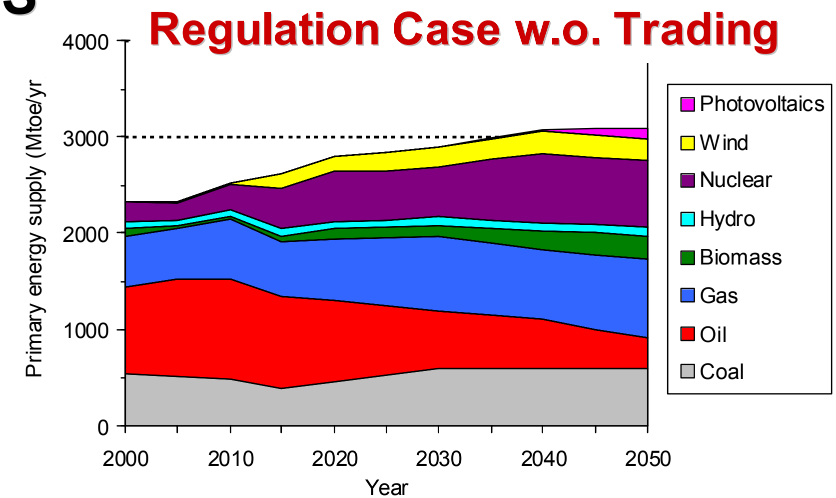




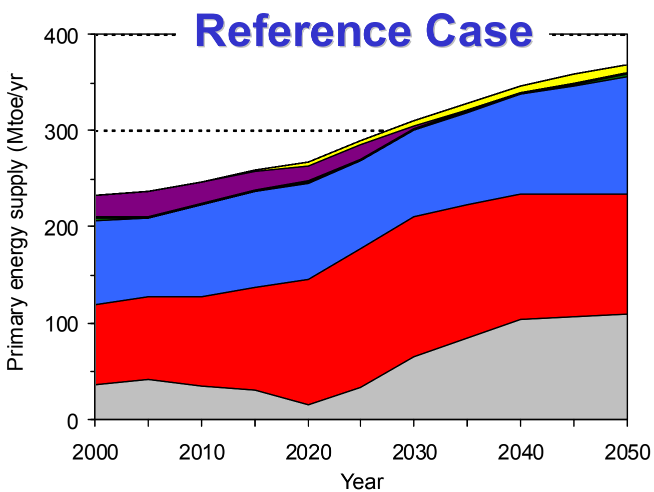
Primary Energy Consumption

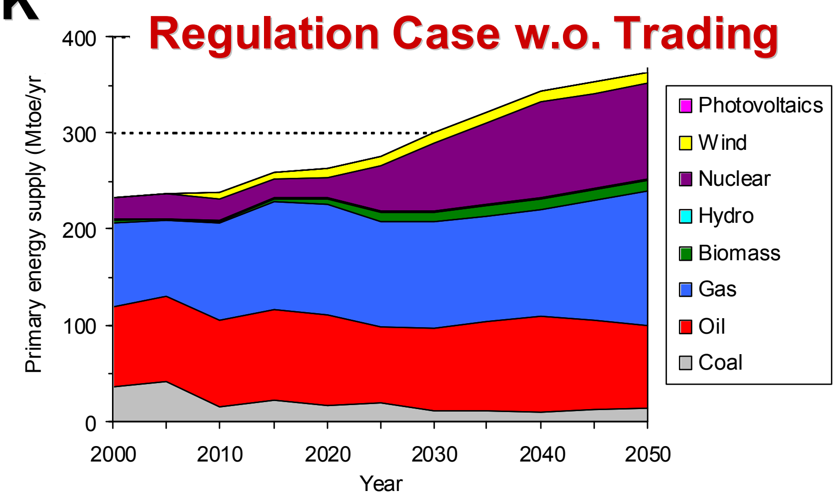
US





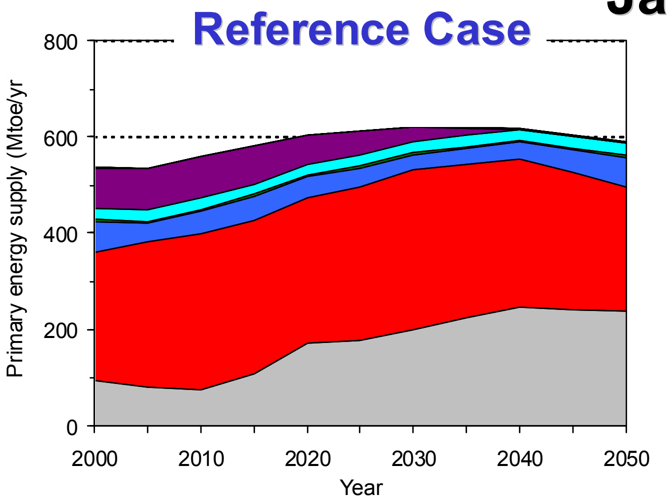
UK

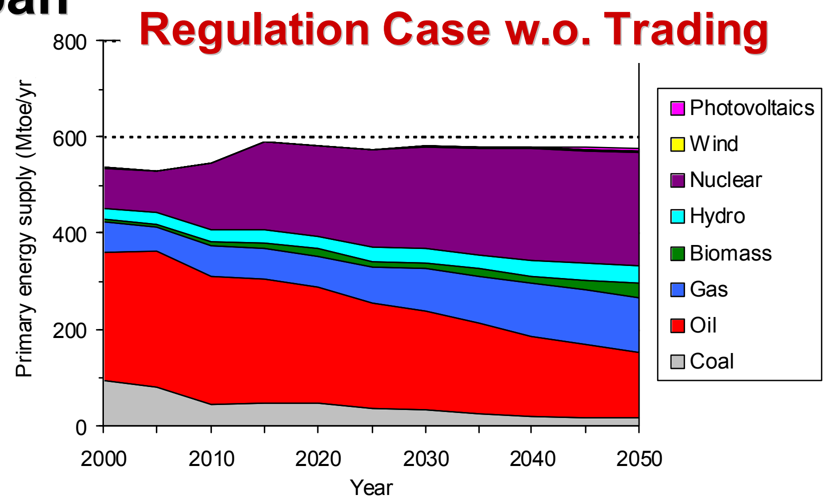




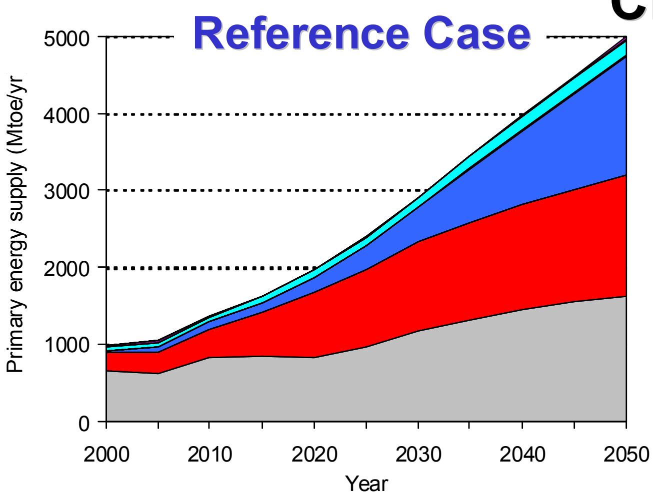
Primary Energy Consumption (Contd.)

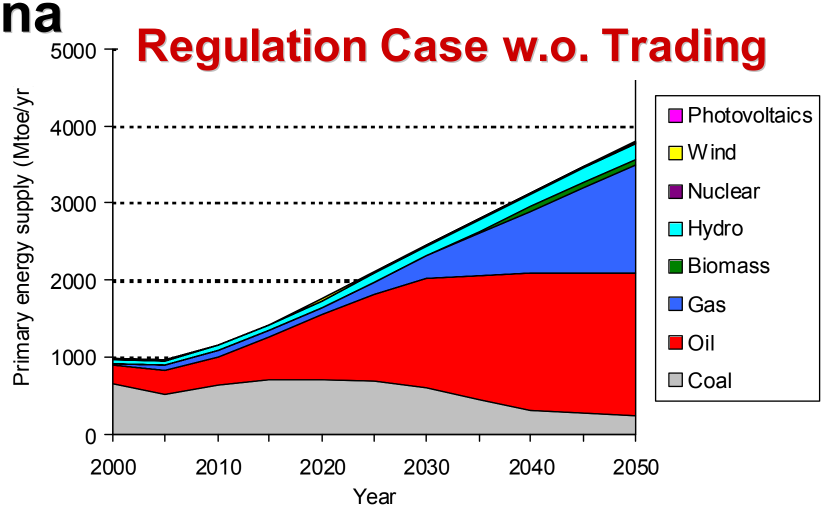
Japan





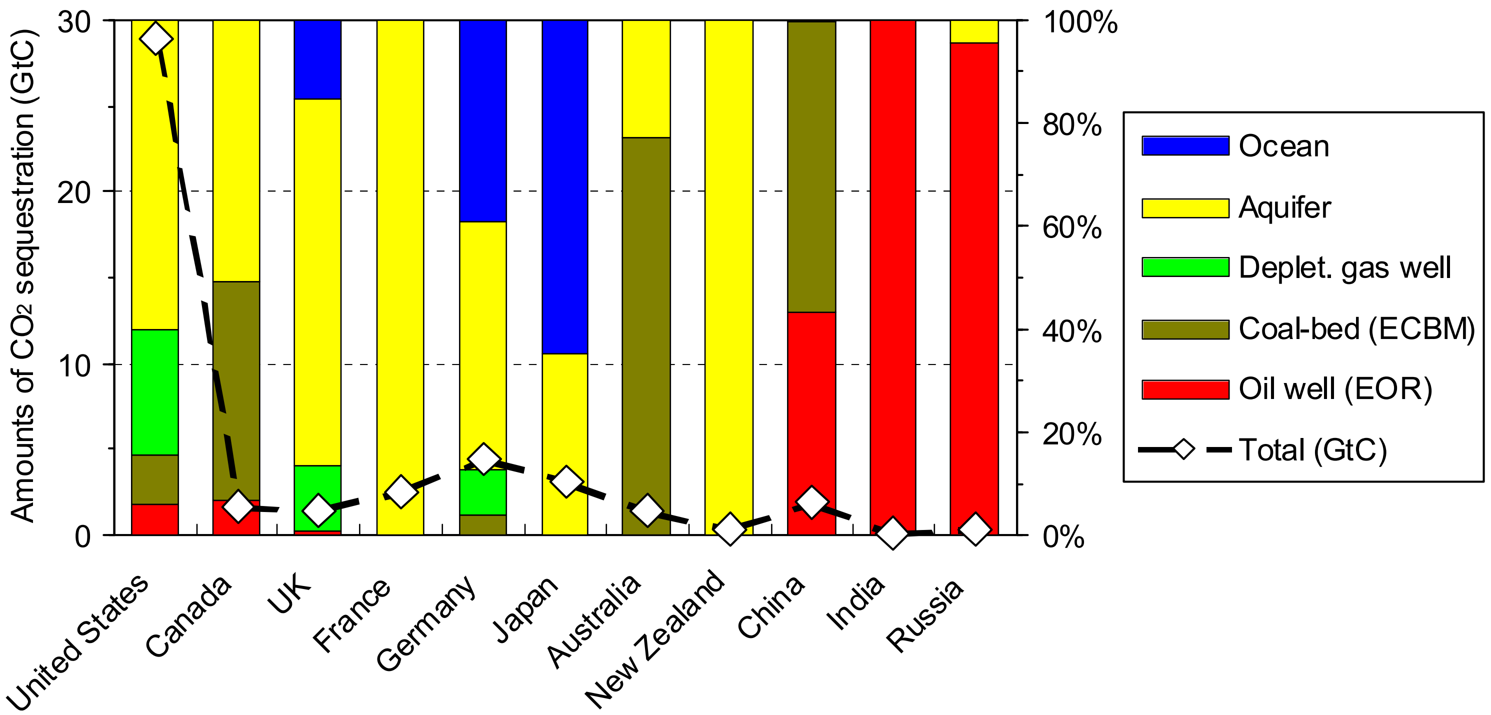
China





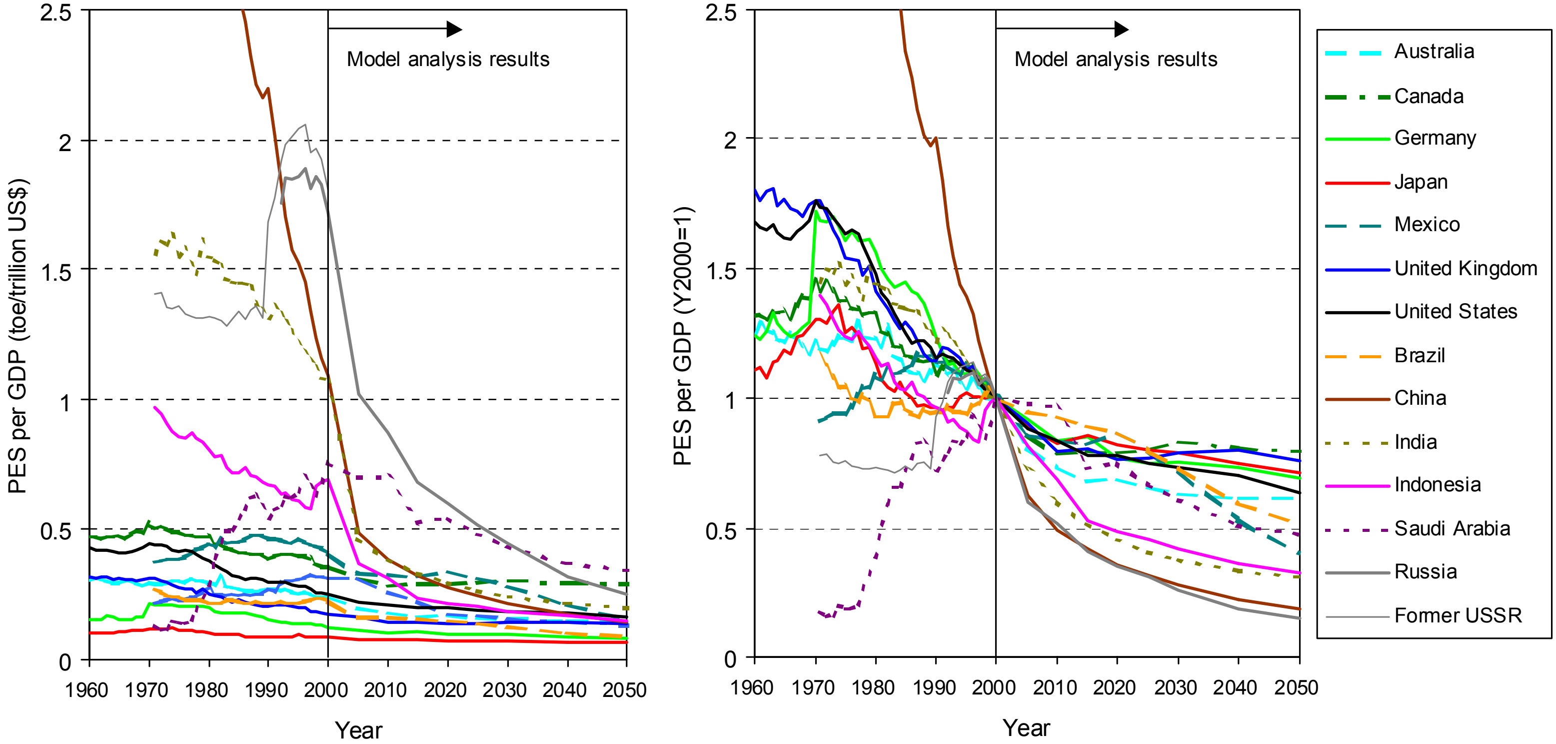
Cumulative CO_2 Sequestration between 2000 and 2050 by Region

- Regulation Case w.o. Emission Trading -



Primary Energy per GDP

- Constraint Case (S550+KP+UK Proposal) -



- **A moderate acceleration of the energy intensity improvement (about 10%) should be required for most regions in Constraint Case compared with Reference Case.**