Modeling Experience Curves in MERGE

S. Kypreos PSI

Annual Meeting of the International Energy Workshop
24-26 June 2003, Laxenburg, AUSTRIA

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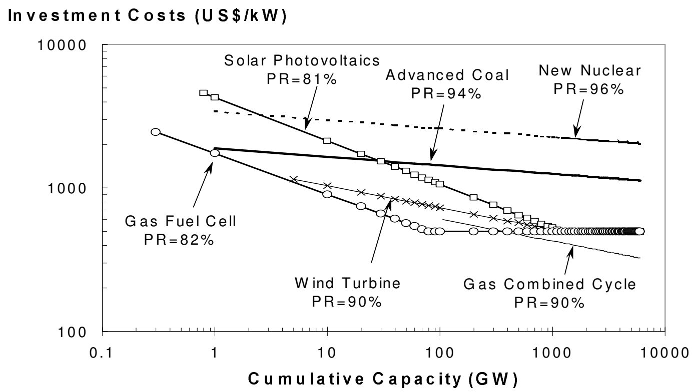
Learning curves assumed for some electricity generation technologies.



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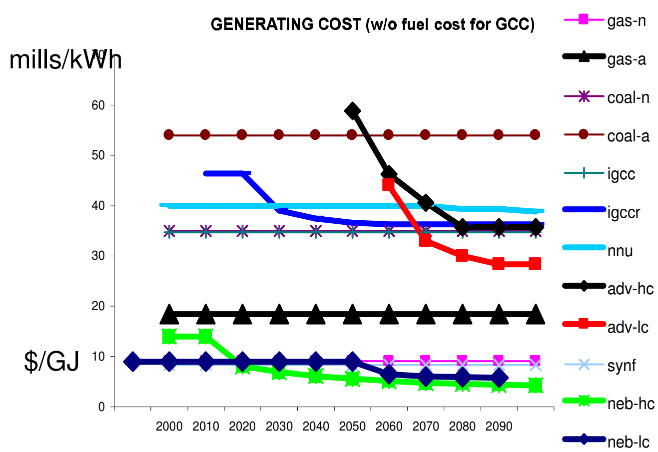
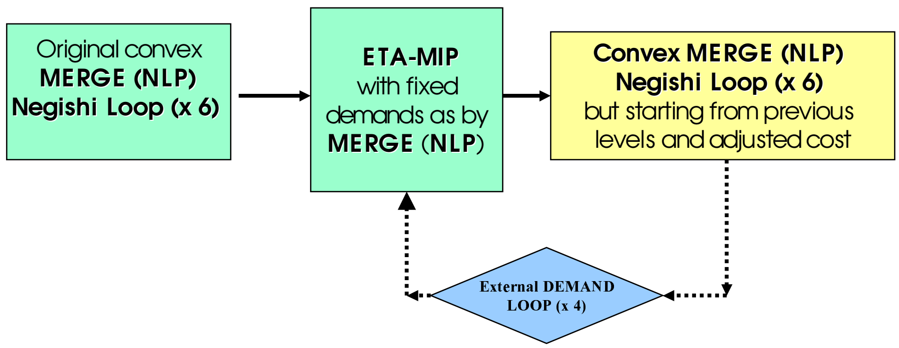


Electricity Generating Cost in the 550L Case. Here the autonomous cost reduction Is not shown; ADV-HC, ADV-LC, IGCCR, NEB-LC, NEB-HC and NNU assume cost reduction due to LBD

Solving MERGE-ETL (II)



CO_2 case studies

- **BauN (w/o LBD) and BauL (LBD) : no CO2 limits**
- **Carbon Stabilization cases under full Carbon trade and global learning for:**
  - **550 ppmv (w/o LBD) and 550 (w LBD)**
  - **500 ppmv (w/o LBD) and 500 (w LBD)**
  - **550 (w/o LBD & DT/Dt); e.g., with limits in the rate of temperature change**
- **C/B Analyses with LBD (e.g., CBL)**

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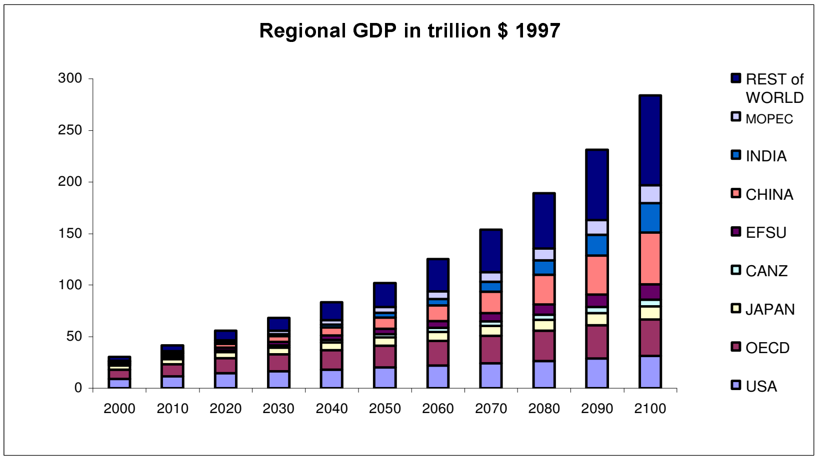
Regional GDP in the BaUN Case;

The current developing countries will produce more than 66% of the Global output late in the century while OECD contributes by only 30%.



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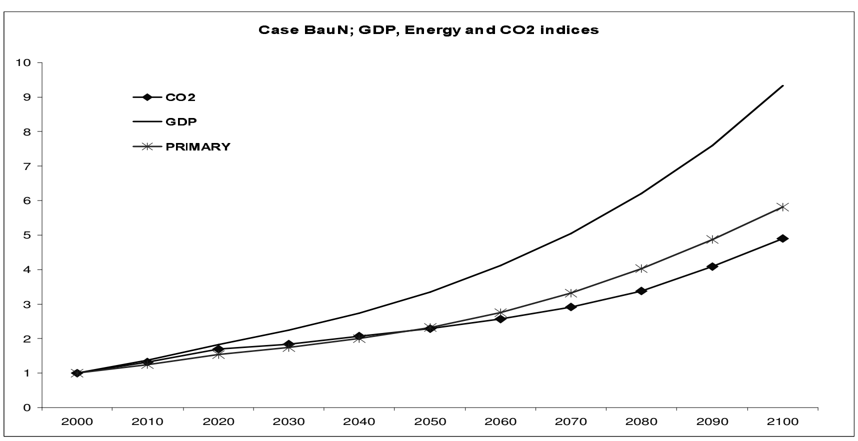
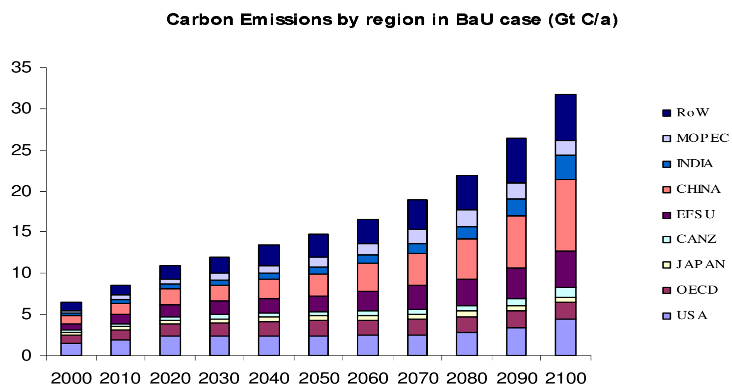
Energy and Economic Indices for the baseline case



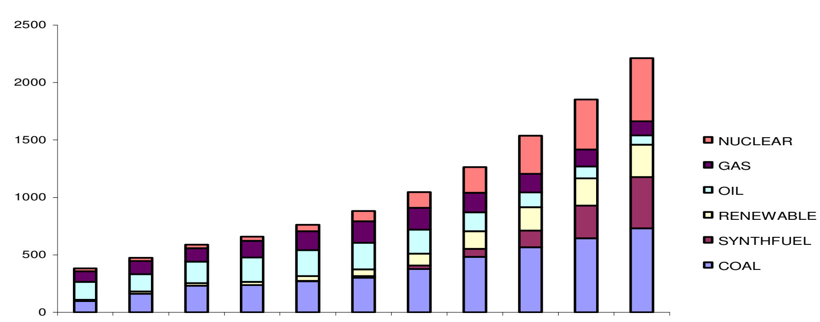
Regional CO2 Emissions in the BaUN Case;

Current less developed regions produce more than 50% of global emissions by 2050 and 60% by the end of the century



Primary Energy in BaUN Case;

The first 50 years indicate a balanced use of Oil, Gas and Coal while in the second half Coal (including synthetic fuels) and nuclear and renewables dominate



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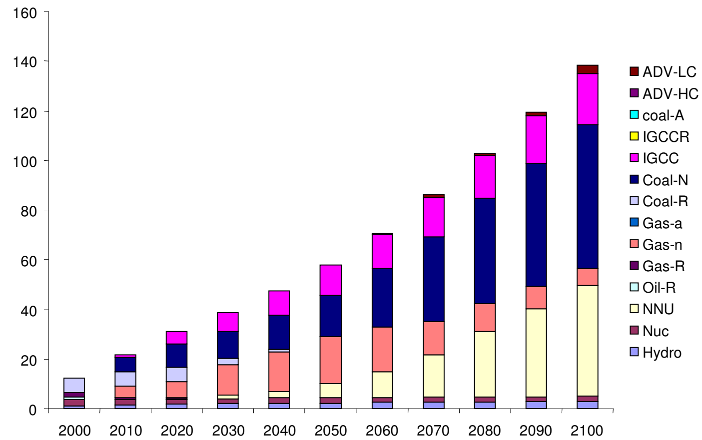
Electricity Generation in the BauN case (kTWh/yr)



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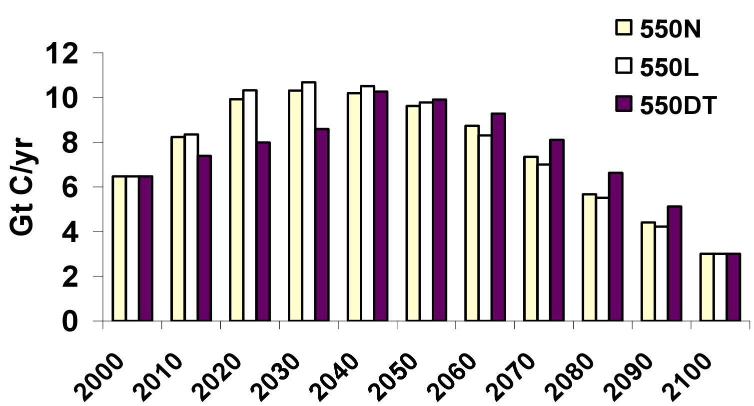
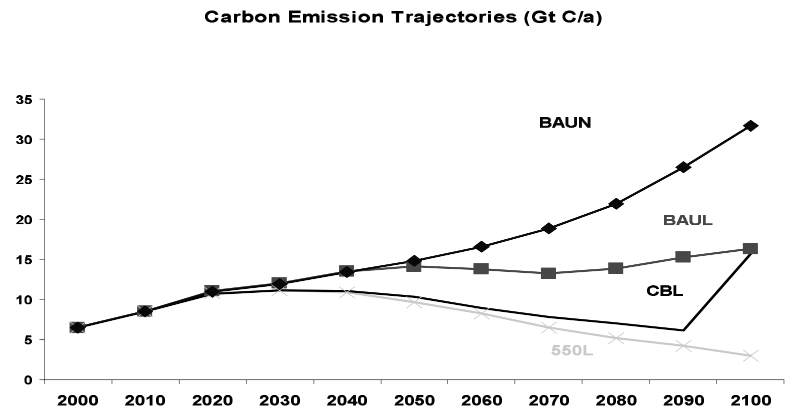
Emission Trajectories in GtC/yr;

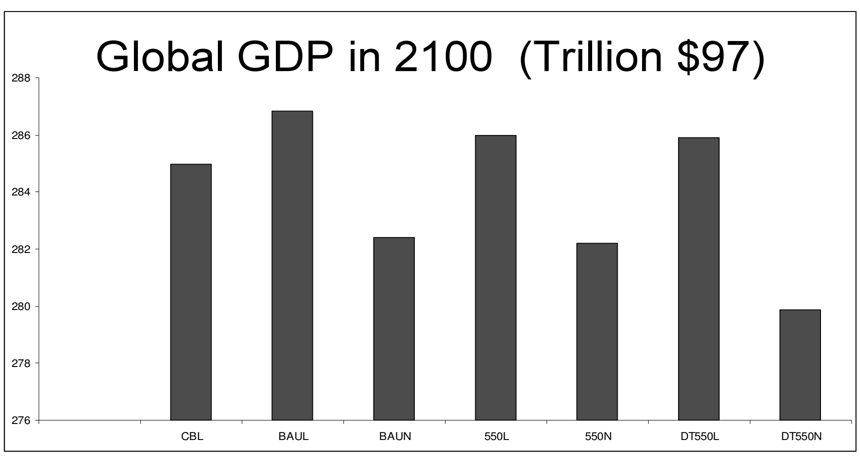
LBD is postponing actions to reduce carbon emissions; but if a constraint is imposed on the rate of temperature change (e.g., by applying a maximum temperature increase of 0.21 degree Celsius per decade, as in 550DT, actions are stronger than the Kyoto protocol



Emission Trajectories in GtC/yr;

Emissions in the C/B case with ETL policies are quite similar to the emission levels of the 550-ppmv case while the corresponding concentrations are





GDP in the year 2100 assumes always higher values in the case of LBD. The lower the carbon concentration limit the higher the GDP losses but the higher the benefit due to LBD.

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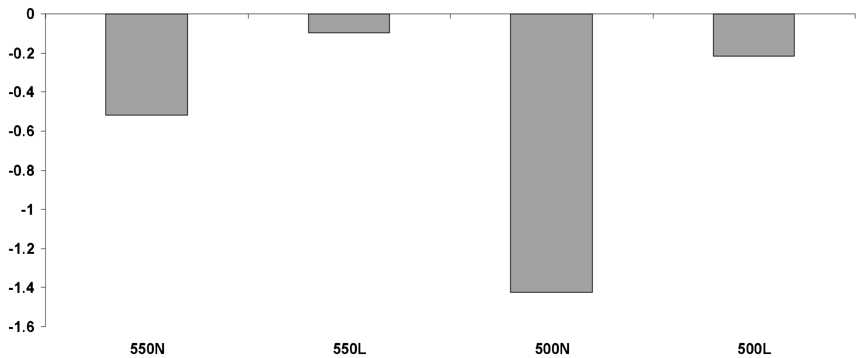
Cumulative Undiscounted GDP losses for the stabilisation cases relative to the GDP of BaUN



Losses are significantly reduced due to LBD; in the 550-ppmv-stabilisation case the cumulative losses (0.52%) are reduced to 0.1 % while in the 500-ppmv case losses are reduced from 1.42% to 0.22%, relative to the BaUN case.

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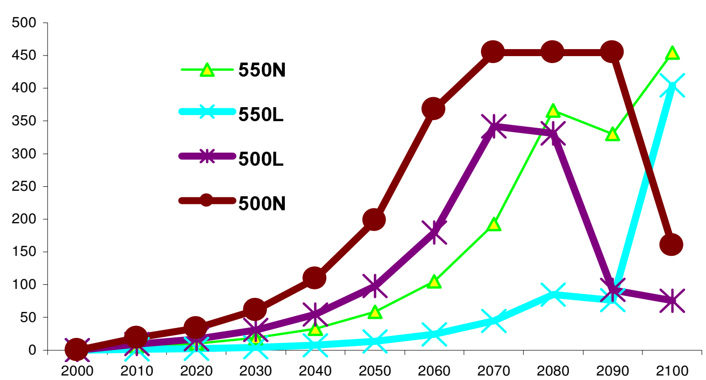
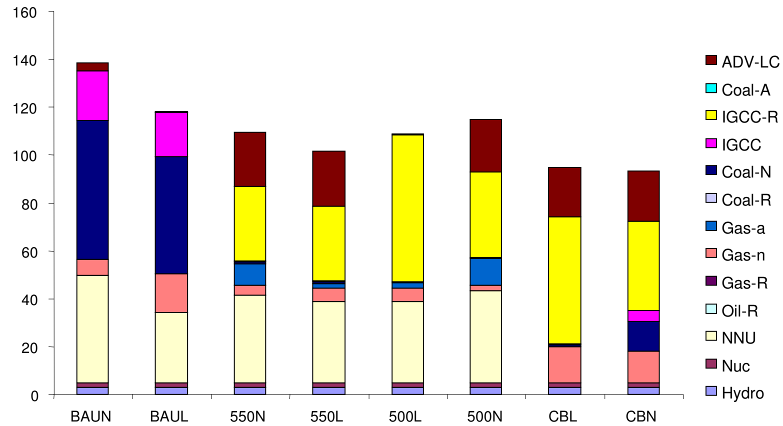
Marginal Costs in $/t C;

The marginal costs in the case of LBD are reduced well below $100 per ton of carbon by the year 2090 in the 550-ppmv cases due to the introduction of fossil fuel sequestration options and the penetration of renewables in the non-electric markets. The shape of the marginal costs reflects the price of a resource with limited cumulative availability.



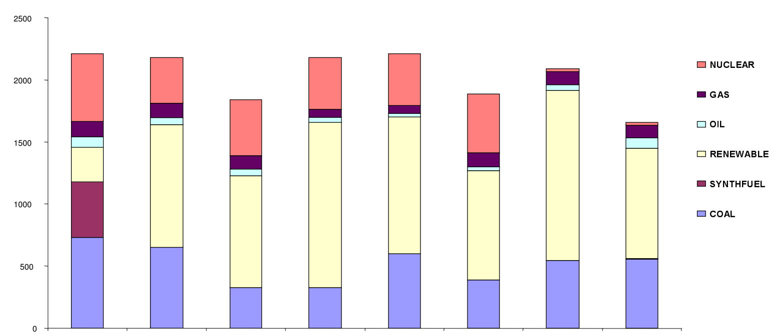
Electricity Production in 2100 (kTWh/a)



Under the carbon constraint production of coal with c-removal and sequestration, new nuclear and wind dominates. In the reference case coal and new nuclear dominate with some contribution of of wind.

Primary by fuel in 2100 (EJ/a)

With LBD energy becomes a more competitive production factor and production of advanced renewables and new nuclear designs increases. Synthetic fuels are important only for the reference case



Conclusions

- Fossil fuels dominate in the BaUN cases with high levels of carbon emissions (e.g., 33 Gt C/yr by the year 2100).
- ETL supporting policies alone reduce emissions in the BaUL case from 33 to 16 Gt C/yr.
- The marginal carbon control costs in the 550-ppmv case are below 100 $/ t C when policies in favour of learning are applied.
- Cumulative GDP losses are below 1.4% (500N) or 0.25 % (500L).
- Even in the standard C/B case emissions follow the 550-ppmv trajectory up to 2090.
- Kyoto type policies are justified if constraints on the rate of temperature change are needed to avoid catastrophic effects (550DTL).
- Most promising systems are the IGCC with carbon removal and sequestration, wind, new nuclear designs and renewables.
- Biomass and other zero-carbon emitting fuels and technologies contribute significantly to the Hydrogen Economy

Outlook

- The results presented are optimistic; the runs assume
  - the *When, Where* and *What* flexibility as given;
  - Policies supporting learning as given;
  - *Global diffusion of learning* and *know how transfer* from North to the South;
  - *High rates of learning* performance over time.
- But most of the optimism comes in the way Hydrogen as Non-Electric fuel is modelled. The cost/efficiency of end-use devices (e.g., fuel-cell, etc.) is not included in the code
- Thus, we need
  - to better model the Hydrogen-Economy by including explicitly end-use technologies for transport,
  - externalities related to regional and local pollutants and the
  - appropriate algorithms for solving such problems.
- Other points of improvement refer to the rationalization of damages, discounting, and the treatment of catastrophic effects. For that we need to link MERGE with simple GC models.

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Technologies used in MERGE-ETL and naming conventions

Technology name	Identification/Examples	
Electric Technologies		Introduction date
HYDRO	Hydroelectric, geothermal and other renewables	Existing
NUC	Remaining initial nuclear	Existing
GAS-R	Remaining initial gas fired	Existing
OIL-R	Remaining initial oil fired	Existing
COAL-R	Remaining initial coal fired	Existing
GAS-N	Advanced combined cycle	2000
GAS-A	Advanced combined cycle with sequestation and LBD	2020
COAL-N	Pulverized coal without CO2 recovery;	2000
COAL-A	Pulverized coal with CO2 recovery and LBD	2020
IGCC	Integrated gasification and combined cycle without CO2 removal	2010
IGCCR	Integrated gasification and combined cycle with CO2 removal and LBD	2020
ADV-HC	Carbon-free technologies (e.g., SPV); costs decline with LBD (high cost)	2000
ADV-LC	Carbon-free technologies (e.g., WND); costs decline with LBD (low cost)	2000
NNU	Carbon-free technologies (e.g., New nuclear); costs decline with LBD (low cost)	2010
Non-Electrict Technologies		
CLDU	Coal Direct use	Existing
OIL1-OIL10	Oil categories	Existing
GAS1-GAS10	Gas categories	Existing
SYNF	Synthetic fuels w/o Learning	Existing
RNEW	Renewables w/o Learning	Existing
NEB -HC	Renewables Back-stop High cost with LBD e.g., Hydrogen from SPV, nuclear, etc.	2010
NEB -LC	Renewables Back-stop Low cost with LBD	2010

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Technical data for systems used in MERGE-ETL

		Gen. Costs mills/kWh	Carbon Emissions Kg C/kWh	specific cost $/kW	load factor	life years	Learning rate (-)	floor cost $/kW
Electric Technologies								
HYDRO		40	0					
NUC		37	0					
GAS-R*		6.3	0.1443					
OIL-R*		6.3	0.2094					
COAL-R		20.3	0.2533					
GAS-N*		9.1	0.087					
GAS-A*		18.4	0.01	1010	0.7	25	0.11	550
COAL-N*		35	0.209	1300				
COAL-A		54	0.0068	2090	0.7	25	0.05	800
IGCC		34.7	0.193	1400				
IGCCR		46.4	0.026	1910	0.7	25	0.05	1000
ADV-HC		220	0	5000	0.25	25	0.2	1000
ADV-LC (Wind)		44	0	1000	0.25	25	0.11	400
NNU		40	0	2500	0.7	25	0.04	1000
Non-Electric Technologies								
		$/GJ	t C/GJ	$/GJ				$/GJ
CLDU		2.5	0.0241					
OIL1-OIL10	3.00-5.25		0.0199					
GAS1-GAS10	2.00-4.25		0.0137					
SYNF		8.33	0.4					
RNEW		6	0					
NEB -HC		14	0	13.3	1	20	0.15	4
NEB -LC		9	0	10	1	20	0.1	4

* Gas and oil systems do not include fuel cost