Impacts of RD&D on Carbon Mitigation Cost

International Energy Workshop, Paris, France
22-24 of June 2004

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Modeling Experience Curves

$$EC_t / EC_0 = (CP_t / CP_0)^{-\beta} \cdot (KS_t / KS_0)^{-\gamma}$$

EC	**The Specific Energy Cost of a technology in time t**
CP	**The Cumulative Production (represents LB-Doing)**
KS	**The Knowledge Stock (represents LB-Searching)**
β	**The learning by doing elasticity**
γ	**The learning by searching elasticity**

The above relation is solvable with CONOPT3 if only one technology per market assumes LBD and if local optimal solutions are excluded by the use of bounds (Manne and Barreto, 2001). In the case of many technologies assuming LBD a heuristic approach could be used based on MIP and the separation of ETA from MERGE (Kypreos, 2000) .

Modeling Experience Curves-II

$$Y = C + I + EC + DC + AR\ \&\ D \qquad \text{Use of Output}$$

$$CP_{k,t} = CP_{k,t-1} + PE_{k,t} \cdot ypp_t \qquad \text{Cum. Product.}$$

$$KS_{k,t} = KS_{k,t-1} \cdot (1-s) + AR\&D_{k,t} \cdot ypp_t \qquad \text{Knowledge Stock Definition}$$

Y	**Economic Output**
C	**Consumption**
I	**Investments**
EC	**Energy Cost**
DC	**Damages**
AR&D	**Annual R&D for energy backstop technology**
CP	**Cumulative production; year t technology k**
PE	**Annual production; year t technology k**
KS	**The knowledge stock; year t technology k**
AR&D	**Annual R&D spending; year t, technology k**
ypp	**years per period**
s	**depreciation rate of Knowledge**

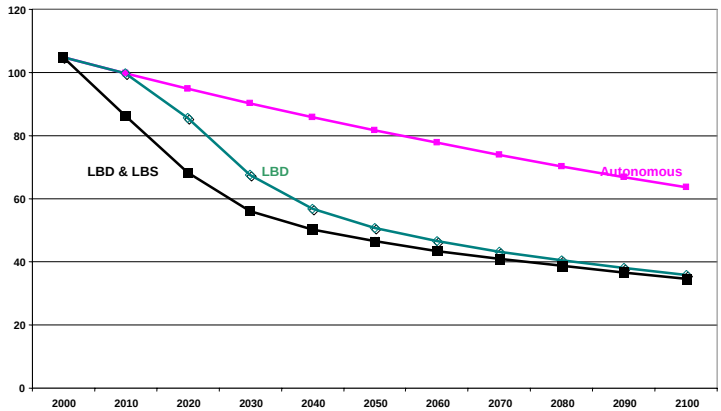
Technical data for systems used in MERGE-ETL

Electric	**technologies**	Introduction date	Gen. Cost mills/kWh	Carbon Emissions kg C/kWh
HYDRO	Hydroelectric, and other renewables	Existing	40.	0.0
NUC	Remaining initial nuclear	Existing	50.	0.0
GAS-R	Remaining initial gas fired	Existing	35.7	0.1443
OIL-R	Remaining initial oil fired	Existing	37.8	0.2094
COAL-R	Remaining initial coal fired	Existing	20.3	0.2533
GAS-N	Advanced combined cycle (AGC)	2000	30.3	0.0935
GAS-A	Gas-Fuel Cell with removal	2020	47.7	0.0
COAL-N	Pulverized Coal	2000	40.6	0.1955
COAL-A	Coal-FC with CO2 recovery	2020	55.9	0.0068
IGCC	IGCC with CO2 removal	2020	62	0.024
ADV-HC	Carbon-free technologies, high cost	Existing	95	0.0
LBDE*	Generic back-stop with LBD	2010	95	0.0
Non-Electric	**technologies**		US$/GJ	tons C/GJ
CLDU	Coal direct use	Existing	2.5	0.0241
OIL1-OIL10	Oil categories	Existing	3-5.25	0.0199
GAS1-GAS10	Gas categories	Existing	2-4.25	0.0137
SYNF	Synthetic fuels	Existing	8.33	0.04
RNEW	Renewables	Existing	6.	0.0
NEB -HC	Renewables Back-stop, high cost.	Existing	14.	0.0
LBDN*	Generic back-stop with LBD	2010	14.	0.0

*) The two technologies with LBD become available in 2005 once sufficient RD&D investments will be made, otherwise are not available at all. Also, their penetration rates increases and their production cost is assumed to reduced due to RD&D spending.

Generating Cost; Electric-Backstop; 450 ppmv

A significant cost reduction over time is shown when LBD applies.
RD&D policies are important in the early stage of introducing a new technology.
β=0.2; γ=0.15; AR&D =1E-5GWP; CP0= 8E-5GWP; s=0.03; gr=0.05

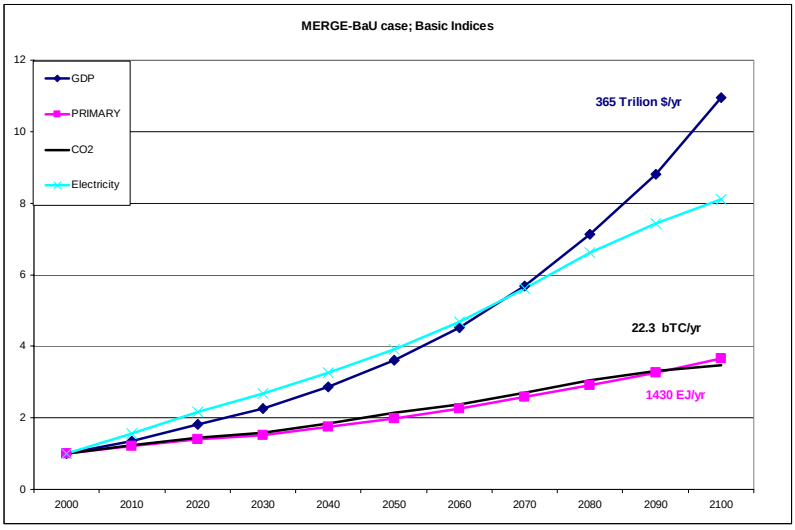


CO_2 case studies

- **BaU-N; BaU-L (w LBD) and BaU-S (w TFLC): no CO2 limits**

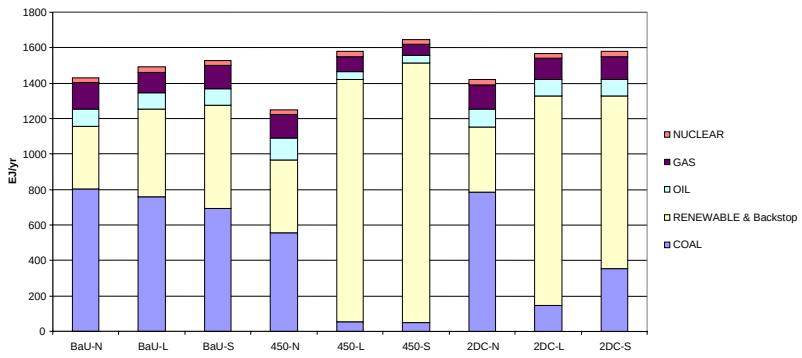
- **Carbon Stabilization cases under full participation and trade, all gases and global spillovers of learning and knowledge for:**
  - **550 ppmv, w/o LBD (550-N), 550-L and 550-S**
  - **450 ppmv, w/o LBD (550-N), 550-L and 550-S**
  - **2DC after 2000, w/o LBD (2DC-N), 2DC-L and 2DC-S**

Baseline: GDP, Energy and Carbon Indices

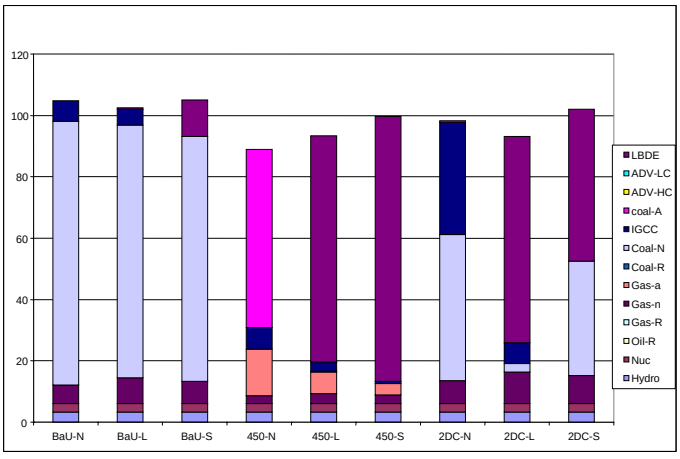


Primary by fuel in 2100 (EJ/a)

With LBD energy becomes a more competitive production factor.
LBD& LBS increases the output of renewables and back-stop technology

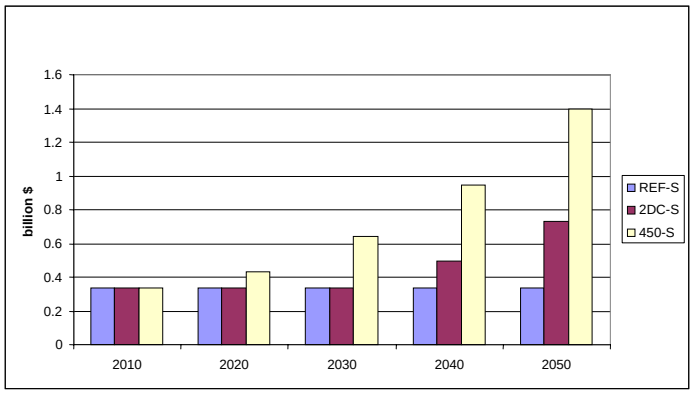


Electricity Production in 2100 (kTWh/a)



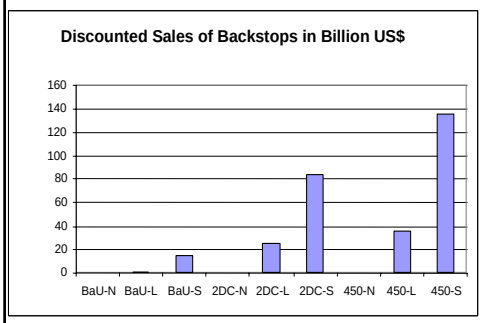
Under the carbon constraint either Coal-A or LBDE dominate. In the BaU case advanced Coal-N, and IGCC or LBDE

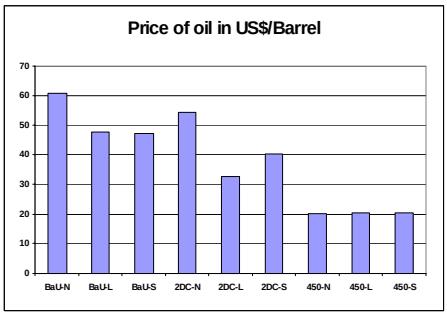
R&D Investments



Significant increase of R&D investments for electric-backstop takes place in the 450-S case

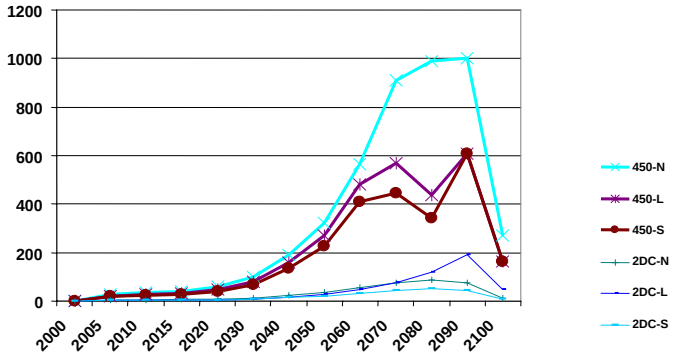
R&D Indices





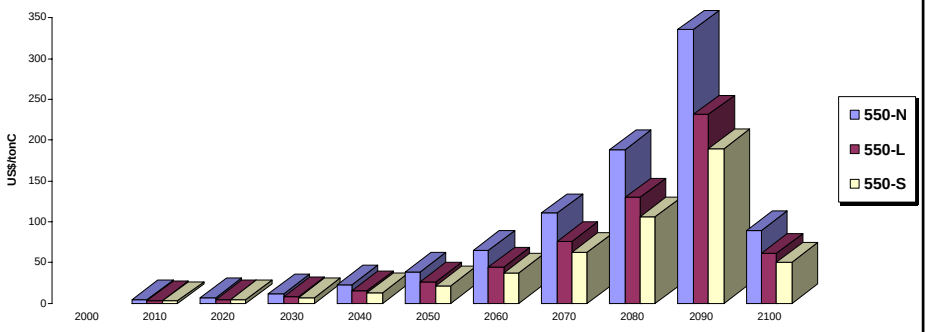
The induced R&D learning reduces cost and increases penetration of backstop technology.
Climate mitigation and RD&D policies reduce use of fossil fuels and the maximum oil and gas price

Marginal Costs in $/t C

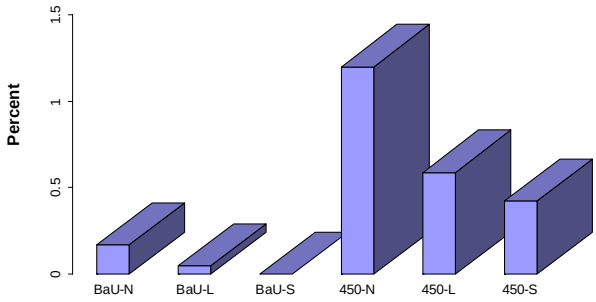


With LBD & LBS the carbon price is reduced well below $100 per ton while in the 2° Celsius case (i.e., ΔT after 2000) to be around to 500 US$/tC in the 450 case.

MERGE-TFLC; Carbon Price in US$/tC in the 550 ppmv



Cumulative and Discounted GWP losses Relative to BaU-S in Percent



Conclusions

- ***RD&D Support of new low-carbon technologies*** **reduces the overall cost in carbon mitigation significantly. These policies act in favour of energy back-stop technologies like renewables (e.g., wind, and biomass) and carbon sequestration.**
- **With endogenous learning options active in the model the Carbon Price can be reduced below $500 per ton of carbon in the 450-ppm case while the cumulative and discounted GWP losses relative to the baseline below 0.5%**
- **The analysis assumes full *"When", "Where" and "What"* flexibility, and *global spillovers* of learning and knowledge.**
- **RD&D policies is a prerequisite to establish expensive backstop systems in the energy markets while R&D is cost efficient under the circumstances analyzed**
- **Real world markets will not support this development to the extend needed, as**
  - **RD&D is a costly and long term commitment for technologies that are not yet competitive**
  - **R&D has positive externalities (spillovers) and private investors are de-motivated**
  - **Local pollution creates negative externalities that are not yet addressed**
- **Policy intervention is needed to correct for market failures**

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