# Emission Constraints and Induced Technical Change in the Energy Sector:

# simulations with the POLES model

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# LEPII: research on Energy, and Environmental Policies

**Axe 1: International Energy Markets and Industries**

1. Fundamentals of the oil gas and coal markets (demand, supply and prices)
2. ...

industries (liberalisation, ...

reregulation)

**Axe 2: Economic Analysis of Climate Policies**

1. Economic instruments for environmental policies (Carbon ...

negociation for the post-2012 ...

(concentration stab scenarios ...

**Axe 3: Energy Technologies for Sustainable Development**

1. Energy R&D policies and technology ...

energy technologies: Niche markets, Learning by Doing, Increasing Return ...

**The POLES world energy model :**

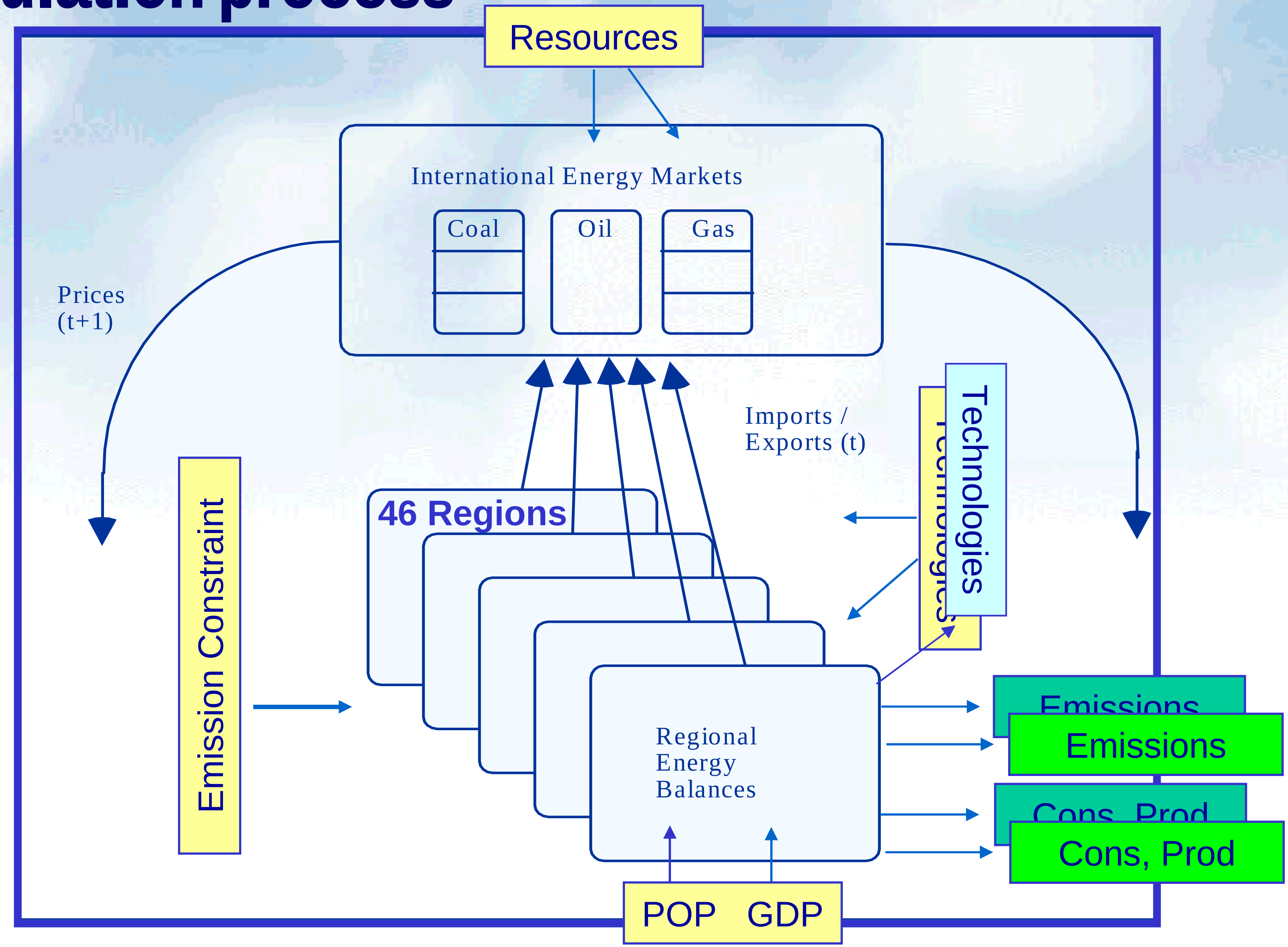
**Reference** | **Constraints** | **ITC**

**Markets under environmental constraints**

**Environmentally induced technical change**

- **POLES V.5 : inputs, outputs, model structure**
- **Technical change: TECHPOL and the exogenous approach**
- **Technical change: Two Factor Learning Curves and the endogenous approach**
- **Endogenous TC with Increasing Returns to Adoption in MENGTECH**

# The POLES model year-by-year recursive simulation process



# The POLES model regional disagregation (47)

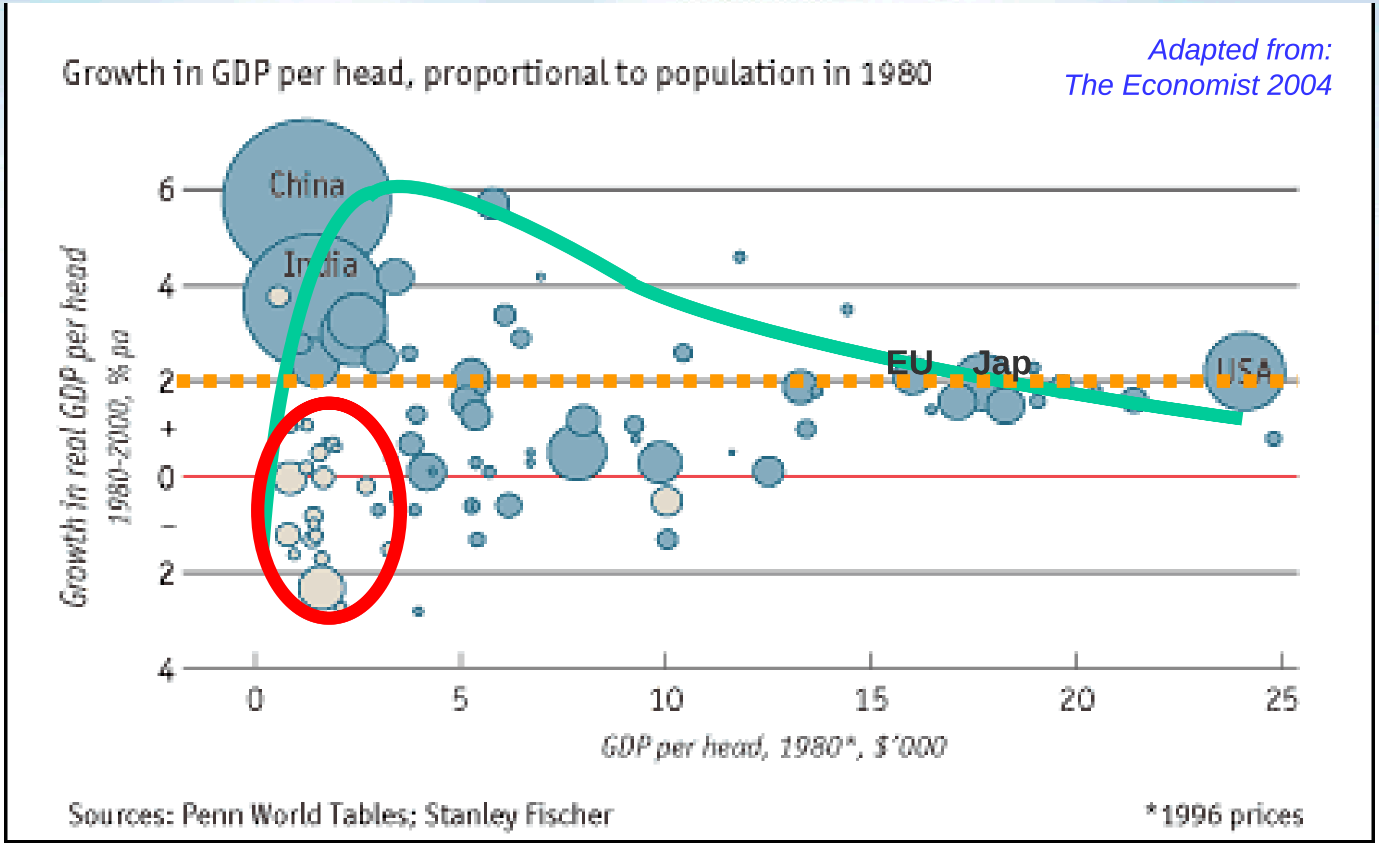
| Region | Sub-Region | Countries |
|---|---|---|
| North America | | Unites States, Canada |
| Europe | EU-15<br>EU-25<br>EU-27 | Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, UK, Turkey<br>Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovak Republic |
| Japan – South Pacific | South Pacific | Japan, Australia & New Zealand |
| CIS | | Russia, Ukraine |
| Latin America | Central America<br>South America | Brazil, Mexico |
| Asia | South Asia<br>South-East Asia | India, South Korea, China |
| Africa / Middle-East | North Africa<br>Sub-saharian Africa<br>Middle-East | Egypt |

# POLES : Energy demand modules

| | Substituable Fuels | Electricity | Transport Fuels |
|---|---|---|---|
| **Industry** | | | |
| Steel industry | X | X | |
| Chemical industry | X | X | |
| Non Metallic Mineral | X | X | |
| Other industries | X | X | |
| **Transport** | | | |
| Road / passenger | | | X |
| Road / goods | | | X |
| Rail / passenger | | X | |
| Rail / goods | | X | |
| Air transport | | | X |
| Other | | | X |
| **Tertiary** | X | X | |
| **Residential** | X | X | |
| **Agriculture** | X | X | |

# A view on economic growth & convergence

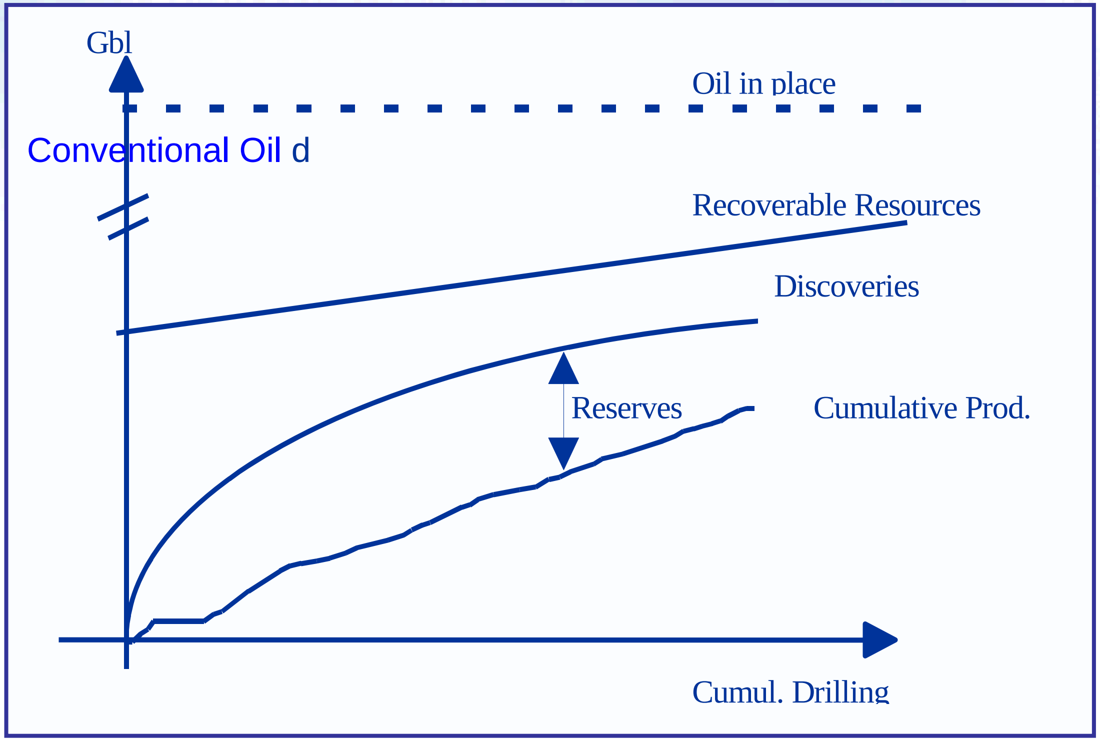
- ◆ **Exogenous scenarios from CEPII or CIRED reflect a process of "conditional convergence in per capita GDP growth" :**
  - **Economic growth is extremely rapid in the emerging countries that come out of the "poverty trap", but then slows down when their economy becomes mature**



# POLES : simulation of Oil & Gas discovery

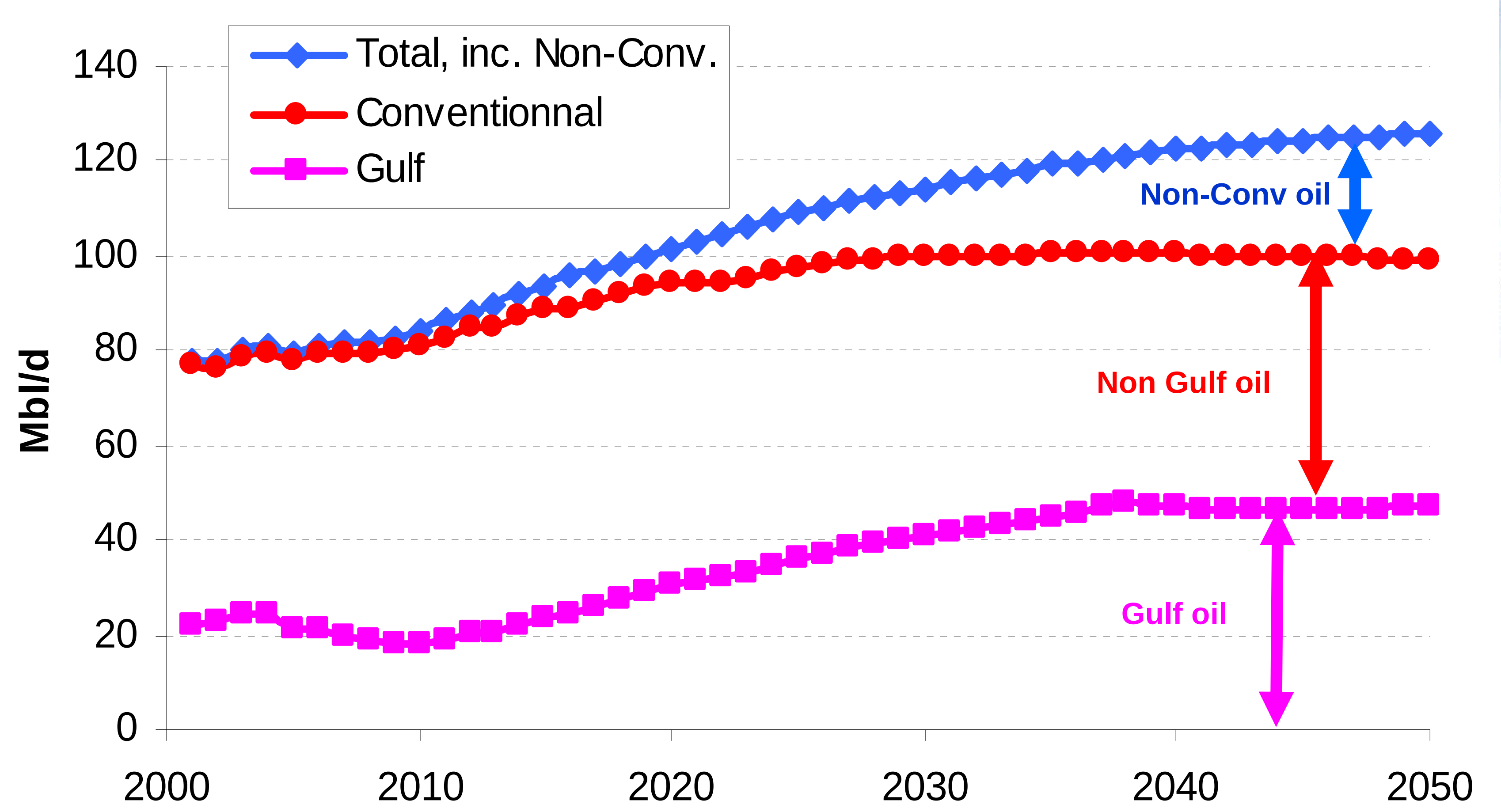
- Recoverable Resources = Oil in Place * Recovery Rate$_t$
- Discoveries increase with cumul. drilling (diminishing returns)
- Reserves = Discoveries - Cumulative Production
- Oil Price = f(Capacity Utilisation, Reserve/Production)
- Non Conventional Oil development = f(oil price)

**Country-by-country « Creaming Curve » models**

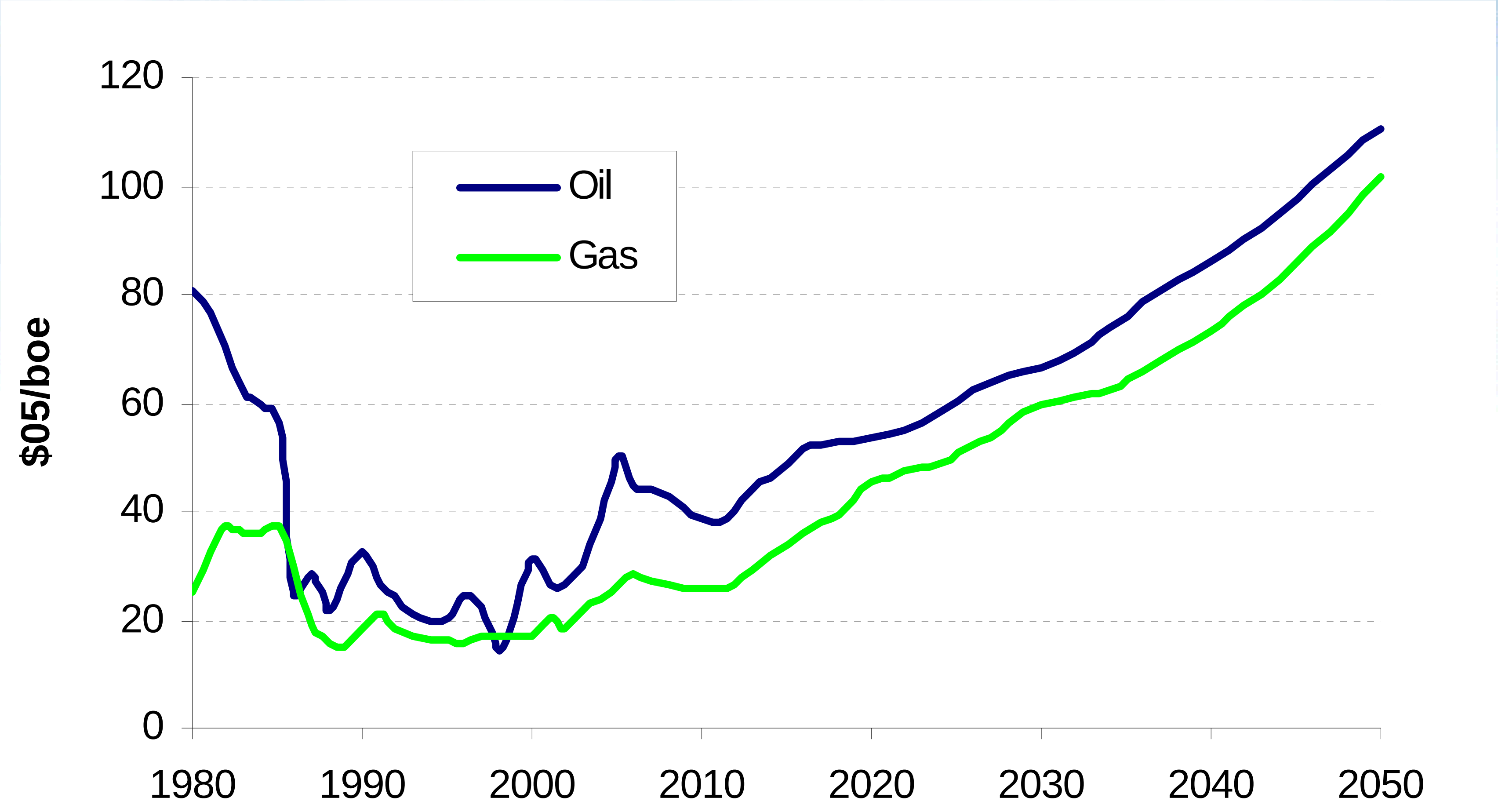


# The endogenous « oil plateau » in WETO-H2

- After 2030, the increase in oil consumption has to rely on « manufactured » non-conventional oil



# Endogenous oil and gas price simulation in WETO-H2



# POLES : Large scale power technologies

| | Large Scale Power Generation | |
|---|---|---|
| | | |
| | Advanced Thermodynamic Cycle | ATC |
| | Super Critical Pulverised Coal | PFC |
| | Integrated Coal Gasif. Comb. Cycle | ICG |
| | Coal Conventional Thermal | CCT |
| | Lignite Conventional Thermal | LCT |
| | Large Hydro | HYD |
| | Nuclear LWR | NUC |
| | New Nuclear Design | NND |
| | Gas Conventional Thermal | GCT |
| | Gas Turbines Combined Cycle | GGT |
| | Oil Conventional Thermal | OCT |
| | Oil Fired Gas Turbines | OGT |

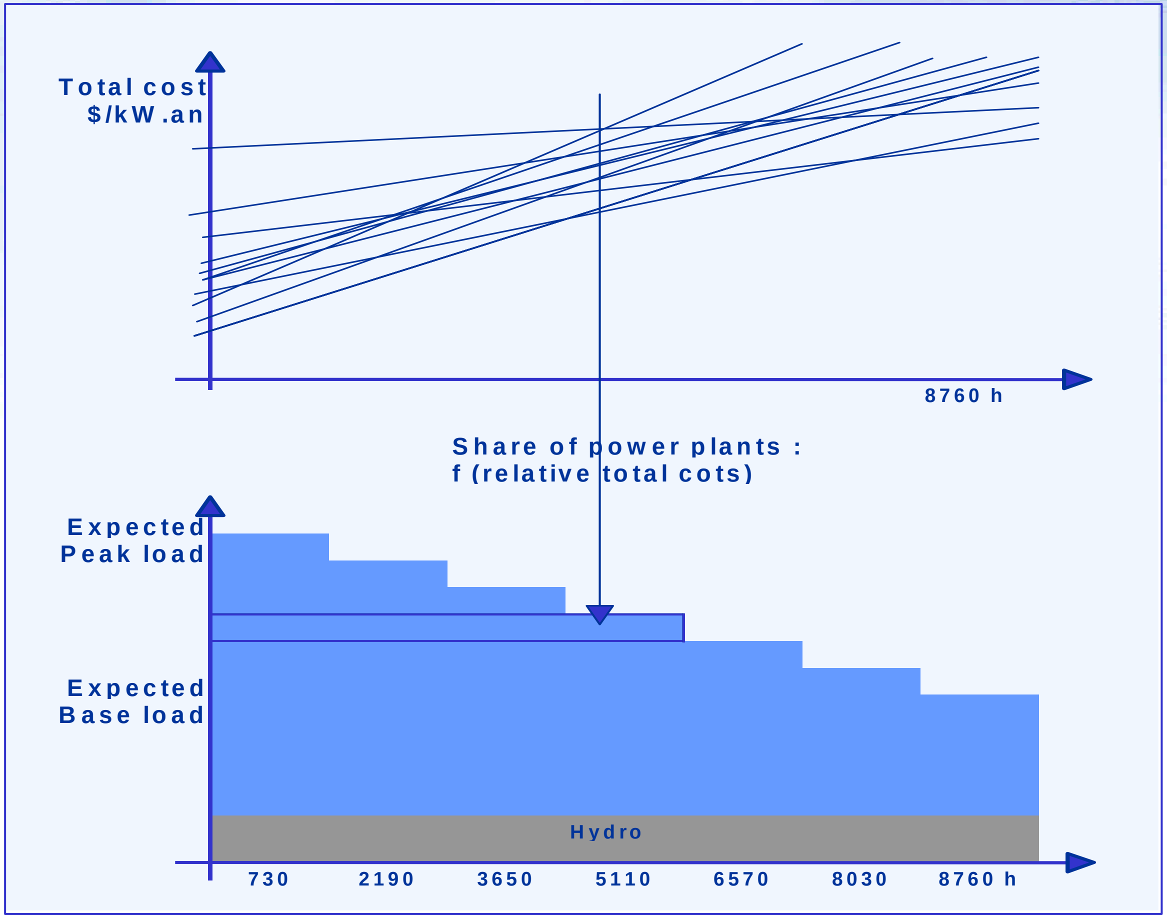
**+ CCS technologies**

- PFC + CCS => PSS Pulverized fuel Supercritical with CCS
- ICG + CCS => CGS Integrated Coal Gasification with CCS
- GGC + CCS => GGS Gas powered Gas turbine in combined cycle with CCS

# POLES : Power generation capacity planning

- Investment costs from CTS E3DB database
- Fuel costs endogenous to the model

**Country-by-country « Screening Curve » models**



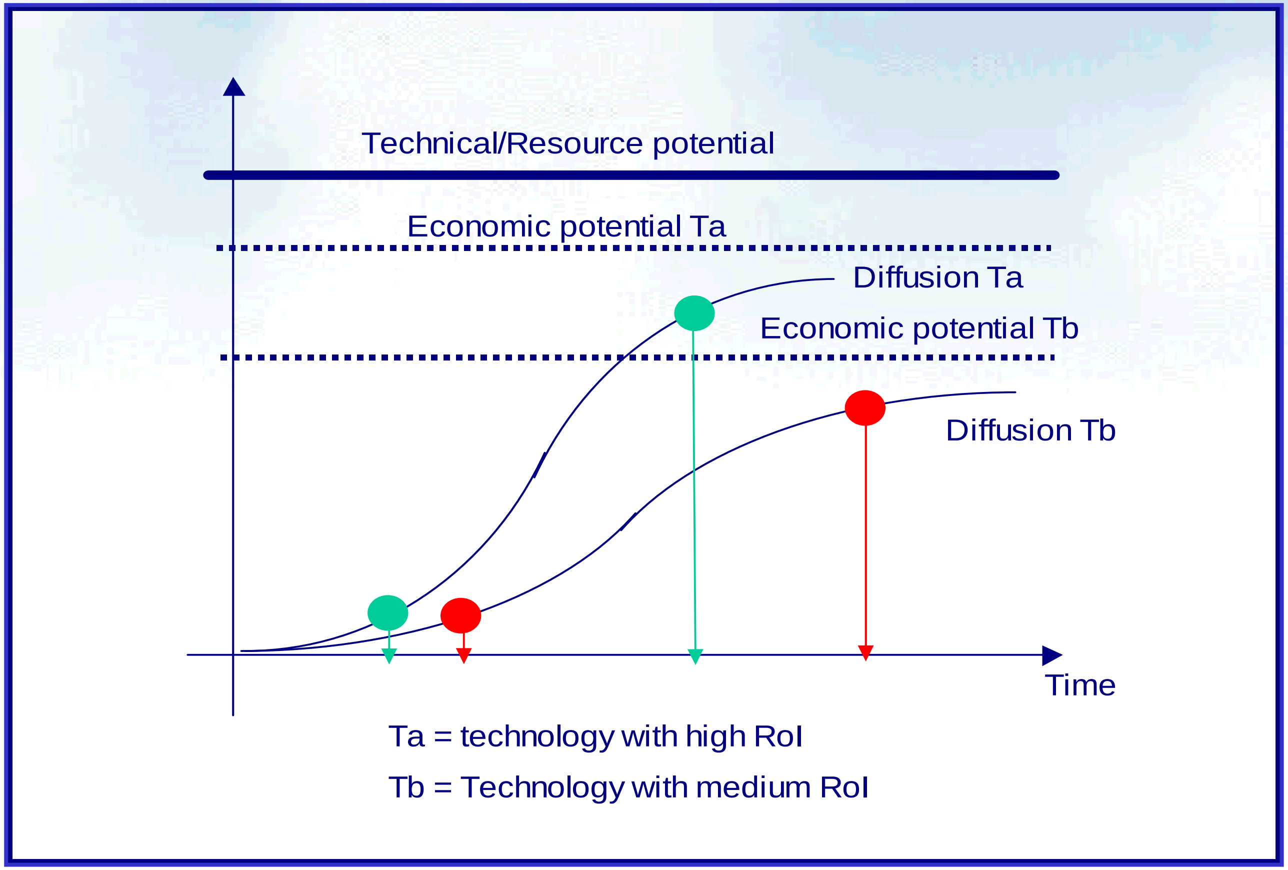
# POLES : New and Renewable technologies

| New and Renewable Technologies | |
|---|---|
| | |
| Waste Incineration CHP | BF2 |
| Biomass Gasif. with Gas Turbines | BGT |
| Combined Heat and Power | CHP |
| Photovoltaics (windows) | DPV |
| Proton Exch. Membr. Fuel Cell (Fixed) | MFC |
| Solid Oxide Fuel Cell (Fixed Cogen.) | SFC |
| Rural Photovoltaics | RPV |
| Solar Thermal Powerplants | SPP |
| Small Hydro | SHY |
| Wind Turbines | WND |
| Biofuels for transport | BF3 |
| Fuel Cell Vehicle (PEM) | FCV |

# POLES : New energy technology diffusion

- **Market potential and speed of diffusion increase with cost-competitiveness**

**Country-by-country Improved « Fisher-Pry » models**



# WETO-H2 production technologies

| | | |
|---|---|---|
| 1 | Hydrogen from Gas Steam Reforming | GSR |
| 2 | Gas Steam Reforming with CCS | GSS |
| 3 | Heavy Fuel Oil Partial Oxidation | OPO |
| 4 | Coal GAsification | CGA |
| 5 | Coal Gasification with CCS | CGS |
| 6 | Biomass GAsification | BGA |
| 7 | Biomass Gasification with CCS | BGS |
| 8 | Biomass PYrolysis | BPY |
| 9 | Solar Methane Reforming | SMR |
| 10 | Solar thermal High-temperature Thermolysis | SHT |
| 11 | Nuclear thermal High-temperature Thermolysis | NHT |
| 12 | Electrolysis dedicated Nuclear power plant | WEN |
| 13 | Electrolysis dedicated Wind power plant | WEW |
| 14 | Electrolysis baseload electricity from Grid | WEG |

# ULCOS: Ultra Low CO2 Steel-making, key technologies

| | |
|---|---|
| OPen Hearth furnace | OPH |
| Blast Oxygen Furnace | BOF |
| Blast Oxygen Furnace Advanced | BOFA |
| Blast Oxygen Furnace with CCS | BOFS |
| Smelting Reduction Process | SRP |
| Smelting Reduction Process with CCS | SRPS |
| Smelting Redution Process, H2 based | SRPH |
| Electric Arc Furnace, conventional | EAF |
| Electric Arc Furnace, Advanced | EAFA |
| Direct Reduction Process | DRP |
| Direct Reduction Process, H2 | DRPH |

# Low Emission Vehicles

- **Diversified technological options for Hydrogen in road transport, with biofuels mixed to gasoline for the residual liquid fuel demand:**
  - Conventional ICE vehicle — ICE
  - Pluggable hybrid vehicle (100km) — HYB
  - Battery electric car — BEC
  - Direct H2-ICE vehicle — HCE
  - Methanol Fuel-Cell Vehicle — FCVM
  - Hydrogen Fuel-Cell Vehicle — FCVH

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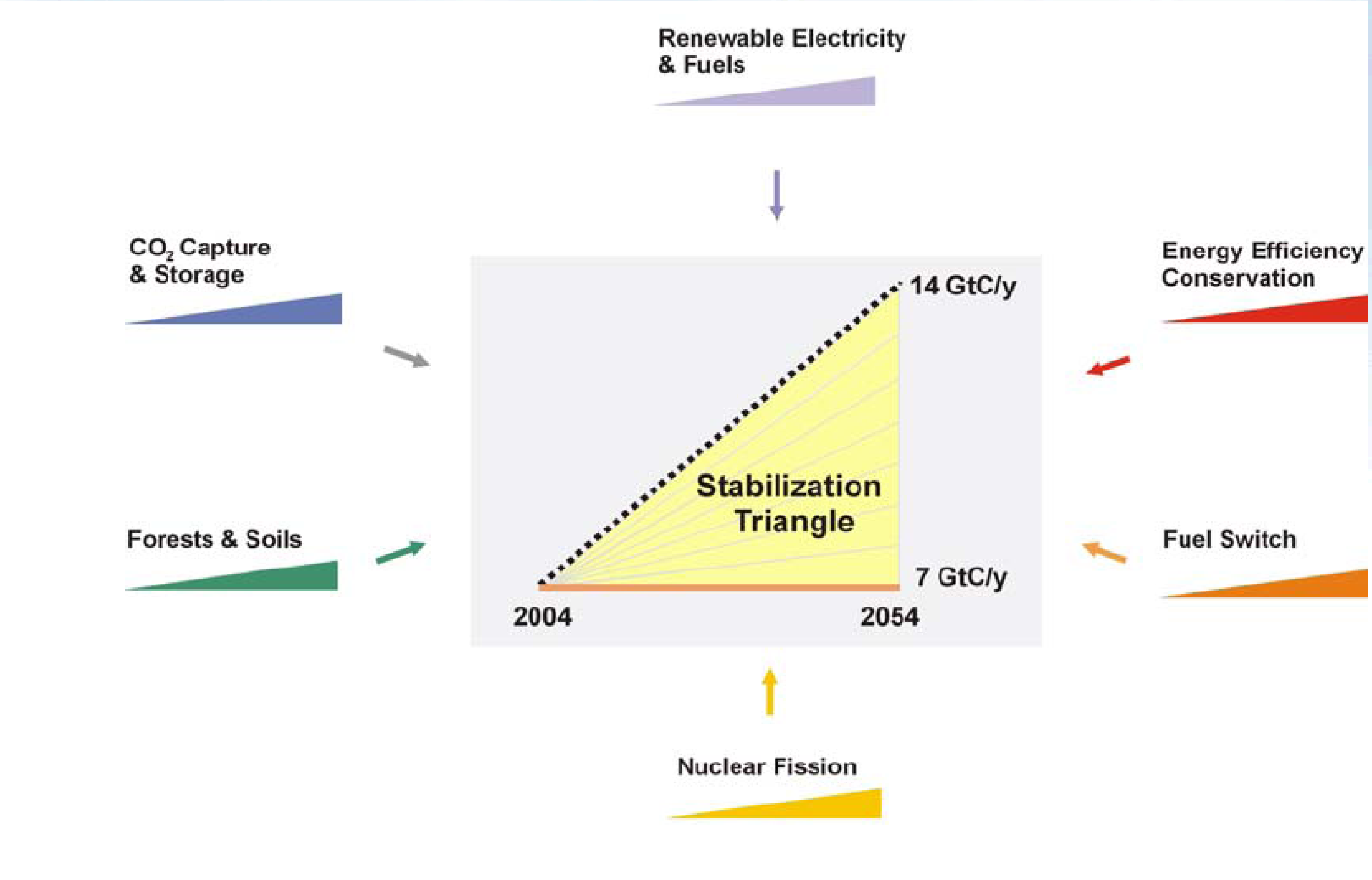
# 6 wedges: Pacala & Socolow (Science, V305 2004)




gure 2: Filling the Stabilization Triangle with seven "wedges." Six broad categories are identified.

# The TECHPOL database

- **Content :**
  - 50 technologies : centralised power plants, decentralised and renewable power plants, H² production technologies … with and without $CO_2$ capture
  - 6 main attributes : overnight investment costs, electrical efficiency, load factor, VOM, FOM, lifetime, floor cost … + other
  - More than 300 different time-series for past and projected costs / performance plus a large number of selected data for specific projects or technologies
- **Organisation :**
  - Four different files – Centralised, Decentralised, Hydrogen, Carbon Capture and Transport Excel sheets – in which data are collected, processed and organised
  - One complementary tool providing a standardized routine for the calculation of electricity / hydrogen levelised production costs and completes the validation process within an integrated framework

# TECHPOL db: example for conventional coal plants

| Data | Countr | Designation | Designation ( | Referen | Source | Yea | data prod. | Units | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment cost | Europe | Steam boiler - coal fired | | | IEA, 2004 | 2004 | original data | $02/kW | | 1149 | 1039 | 940 | 940 | | |
| Investment cost | Belgium | Pulverised Coal | Supercritical | 600 MW | Commission Ampere, 2000 | 2000 | original data | $02/kW | | 1292,1 | | | | | |
| Investment cost | Belgium | Pulverised Coal | Ultra-supercritic | 600 MW | Commission Ampere, 2000 | 2000 | original data | $02/kW | | | | 1430 | | | |
| Investment cost | OECD | Pulverised Coal | | | David & Herzog, 2001, | 2000 | diff. Sources | $02/kW | | 1201 | 1154 | | | | |
| Investment cost | OECD | Pulverised Coal | | | David & Herzog, 2001, | 2000 | diff. Sources | $02/kW | | 1201 | 1154 | | | | |
| Investment cost | OECD | Pulverised Coal | | 500 MW | Freund & Davison, 2002, | 2002 | from IEA GHG | $02/kW | | 1066 | | | | | |
| Investment cost | OECD | Pulverised Coal | | 500 MW | Freund & Davison, 2002, | 2002 | from IEA GHG | $02/kW | | 1943 | | | | | |
| Investment cost | OECD | Pulverised Coal | | | Freund & Davison, 2002, | 2002 | from EPRI | $02/kW | | 1191 | | | | | |
| Investment cost | OECD | Pulverised Coal | | | Freund & Davison, 2002, | 2002 | from EPRI | $02/kW | | 2069 | | | | | |
| Investment cost | USA | Coal steam elec | Supercritical | 500 MW | Williams, 2004 | 2004 | original data | $02/kW | | 1194 | | | | | |
| Investment cost | USA | Coal steam elec | Supercritical | 500 MW | Williams, 2004 | 2004 | original data | $02/kW | | 2070 | | | | | |
| Investment cost | USA | Coal steam elec | Ultra-supercritic | 500 MW | Williams, 2004 | 2004 | original data | $02/kW | | 1213 | | | | | |
| Investment cost | USA | Coal Ultra-super | Ultra-supercritic | 500 MW | Williams, 2004 | 2004 | original data | $02/kW | | 2030 | | | | | |
| Investment cost | USA | Coal | | 400 MW | GENSIM, 2002 | 2002 | from DOE | $02/kW | | | | | | | |
| Investment cost | USA | Coal | | 400 MW | GENSIM, 2002 | 2002 | from Platt's | $02/kW | | | | | | | |
| Investment cost | USA | Pulverized coal | | 600 MW | EIA, 2004 | 2003 | original data | $02/kW | | | 1141 | 1106 | | | |
| Investment cost | USA | Pulverized coal | Supercritical | 600 MW | US NCEP, 2004 | 2004 | from NorthBri | $02/kW | | | | | | | |
| Investment cost | OECD | Coal, steam cycle | | | Gielen & Podkanski, 2004 | 2004 | original data | $02/kW | | | 1075 | 1025 | | | |
| Investment cost | OECD | Coal, steam cycle | | | Gielen & Podkanski, 2004 | 2004 | original data | $02/kW | | | 1850 | 1720 | | | |
| Investment cost | OECD | Coal, | Ultra-supercritical | | Gielen & Podkanski, 2004 | 2004 | original data | $02/kW | | | | 1260 | | | |
| Investment cost | OECD | Coal, | Ultra-supercritical | | Gielen & Podkanski, 2004 | 2004 | original data | $02/kW | | | | | 1675 | | |
| Investment cost | OECD | Standard coal pow er plant | | | Riahi et al., 2004 | 2000 | diff. Sources | $02/kW | | 958 | | | | | |
| Investment cost | OECD | Standard coal pow er plant | | | Riahi et al., 2004 | 2000 | diff. Sources | $02/kW | | 1676 | | | | | |
| Investment cost | UK | Pulverized coal | Supercritical | 1600 MW | RAE, 2004 | 2004 | original data | €99/kW | | | | | | | |
| Investment cost | UK | Fluidized bed co | Circulating FBC | 150 MW | RAE, 2004 | 2004 | original data | €99/kW | | | | | | | |
| Investment cost | Germany | Coal steam pow er production | | 600 MW | Ikarus, 2003 | 2000 | original data | €99/kW | | 894 | 889 | 904 | 894 | | |
| Investment cost | France | Pulverized coal | Supercritical | 2 x 800 MW | MINEFI, 2003 | 2003 | original data | €99/kW | | | 1153,8 | | | | |
| Investment cost | France | Circulating fluidized bed | | 400 MW | MINEFI, 2003 | 2003 | original data | €99/kW | | | 1135 | | | | |
| Investment cost | EU 15 | Pulverized coal | | > 500 MW | IPTS | 2000 | average | €99/kW | 1205 | 1037 | 1037 | 1037 | 1037 | | |
| Investment cost | EU 15 | Coal | Supercritical | 650 MW | IPTS | 2000 | average | €99/kW | 1647 | 1015 | 1033 | 1037 | 1040 | | |
| Investment cost | EU-15 | Coal conventional - CCT | | | EPE - Sapientia | 2004 | original data | €99/kW | | 1250 | 1210 | 1170 | 1130 | 1090 | 1050 |
| Investment cost | EU 15 | Pulverised coal | Supercritical | | EPE - Sapientia | 2004 | original data | €99/kW | | 1500 | 1380 | 1260 | 1160 | 1080 | 1000 |
| Investment cost | Belgique | Pulverised coal | Ultra-supercritic | | Markal - BEL, 2001 | 2001 | original data | €99/kW | 1172 | 939,73 | | | | | |
| Investment cost | EU 15 | Pulverised coal | Ultra-supercritical | | ECN, 1997 | 1997 | original data | €99/kW | 1429 | 1429,3 | *1429* | 1429 | *1429* | 1429 | |

# TECHPOLdb: powergen

| HYP | | 2000 | 2025 | 2050 |
|---|---|---|---|---|
| Nat Gas | $/MBTU | 3 | 8 | 12 |
| Oil | $/bl | 25 | 50 | 75 |
| Coal | $/t | 40 | 80 | 120 |
| Carbon | €/tCO2 | 0 | 25 | 50 |

- **Total investment decreases by 25 % in 2050, but CCS is an extra investment of 50 %**
- **Fuel costs are multiplied by almost 3 between 2000 and 2050**
- **In the no-CCS option, carbon costs represent almost half of 2050 cost**
- **Supercritical coal with CCS in 2050 is still about twice the current generation cost**

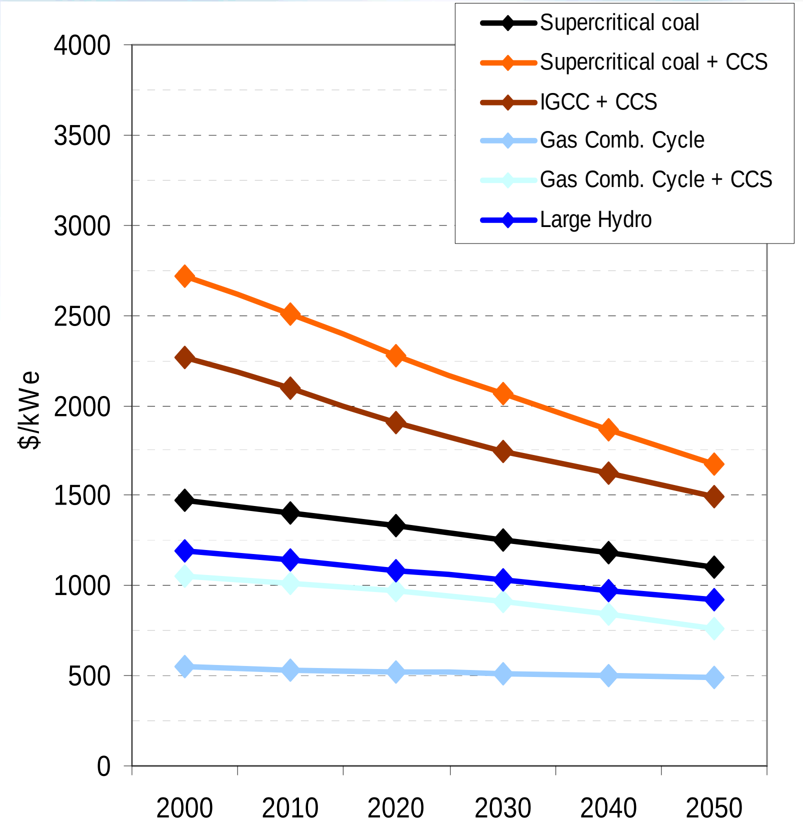
| SUPERCRITICAL COAL | | Without CCS | | | With CCS | | |
|---|---|---|---|---|---|---|---|
| 99€ - 95$ | | 2000 | 2025 | 2050 | 2000 | 2025 | 2050 |
| Overn. Inv. Cost | €/kW | 1200 | 1050 | 900 | 2153 | 1717 | 1328 |
| Technical lifetime | Years | 35 | 35 | 35 | 35 | 35 | 35 |
| Construction time | Years | 3 | 3 | 3 | 4 | 4 | 4 |
| Interest rate | % | 5% | 5% | 5% | 5% | 5% | 5% |
| Decommission share | % | 10% | 10% | 10% | 10% | 10% | 10% |
| Discount rate (%) | % | 8% | 8% | 8% | 8% | 8% | 8% |
| **Total investment Cos** | **€/kW** | **1330** | **1164** | **997** | **2443** | **1948** | **1507** |
| **Fixed annual cost** | **€/kWy** | **114** | **100** | **86** | **210** | **167** | **129** |
| FOM cost | €/kWy | 40 | 38 | 36 | 47 | 44 | 42 |
| Load. Factor | % | 85% | 85% | 85% | 85% | 85% | 85% |
| **Uncertainty 1** | | | | | | | |
| **Fixed cost** | **€/MWh** | **21** | **19** | **16** | **34** | **28** | **23** |
| **Fuel price** | **€/toe** | **57** | **114** | **171** | **57** | **114** | **171** |
| Carbon content | tCO2/toe | 4 | 4 | 4 | 4 | 4 | 4 |
| **Carbon price** | **€/tCO2** | **0** | **25** | **50** | **0** | **25** | **50** |
| Fuel efficiency | % | 44% | 48% | 50% | 35% | 40% | 42% |
| Fuel input | toe/kW | 1,5 | 1,3 | 1,3 | 1,8 | 1,6 | 1,5 |
| C&C rate | % | | | | 85,0% | 88,0% | 90,0% |
| CO² emitted **Uncertainty 2** | tCO²/MWh | 0,8 | 0,7 | 0,7 | 0,1 | 0,1 | 0,1 |
| **Fuel cost** | **€/MWh** | **11** | **20** | **29** | **14** | **25** | **35** |
| **Carbon cost** | **€/MWh** | **0** | **18** | **34** | **0** | **3** | **4** |
| VOM cost **Uncertainty 3** | €/MWh | 3,0 | 3,0 | 2,0 | 3,5 | 3,5 | 2,5 |
| **Variable cost** | **€/MWh** | **14** | **41** | **66** | **17** | **31** | **41** |
| Capture cost | €/tCO² | | | | 27 | 24 | 21 |
| **Production cost** | **€/MWh** | **35** | **60** | **82** | **52** | **59** | **64** |

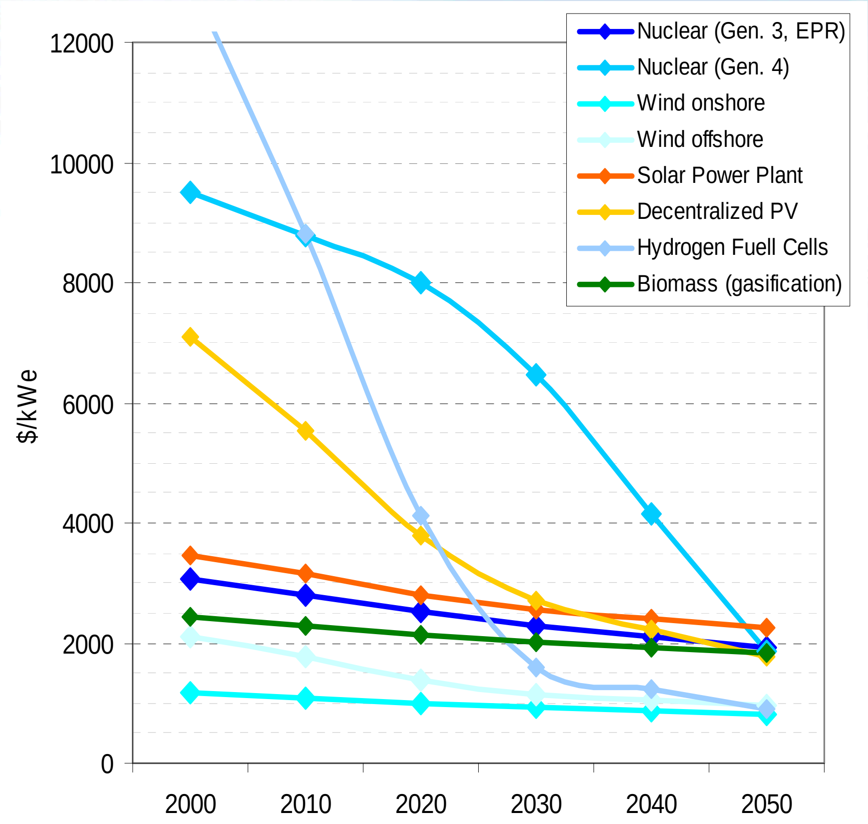
# TECHPOL db: some fundamentals of H2 production

| Hydrogen Technologies | | Steam Methane Reforming + CCS | | | Coal Partial Oxydation + CCS | | | Biomass Pyrolysis | | | Electrolysis - dedicated nuclear | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| € 2 000 | | 2000 | 2025 | 2050 | 2000 | 2025 | 2050 | 2000 | 2025 | 2050 | 2000 | 2025 | 2050 |
| Floor costs | | | 40 | | | 60 | | | 30 | | | 200 | |
| Overn. Inv. Cost | €/M3d | 70 | 61 | 59 | 181 | 166 | 123 | 112 | 98 | 70 | 1114 | 935 | 299 |
| Other costs | €/M3d | | | | | | | | | | | | |
| Technical lifetime | Years | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 25 | 25 | 25 |
| Construction time | Years | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 8 | 8 | 8 |
| Interest rate | | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% |
| Decommission share | | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,7 | 0,7 | 0,7 |
| Discount rate (%) | | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% |
| **Total investment Cos** | **€/M3d** | **79** | **69** | **67** | **205** | **188** | **139** | **124** | **108** | **77** | **1510** | **1267** | **405** |
| **Annualised inv. cost** | **€/M3d/y** | **7** | **6** | **6** | **18** | **16** | **12** | **11** | **9** | **7** | **141** | **119** | **38** |
| FOM cost | €/M3d/y | 0,66 | 0,57 | 0,48 | 1,68 | 1,45 | 1,21 | 1,31 | 1,05 | 0,79 | 5 | 4 | 4 |
| Load. Factor | % | 80% | 83% | 85% | 80% | 83% | 85% | 80% | 83% | 85% | 80% | 85% | 85% |
| **Fixed cost** | **€/toe** | **99** | **83** | **78** | **257** | **226** | **165** | **159** | **133** | **93** | **1947** | **1544** | **528** |
| **Fuel price** | **€/toe** | **120** | **200** | **400** | **57** | **71** | **100** | **150** | **170** | **190** | **20** | **22** | **25** |
| Carbon content | tCO2/toe | 0,4 | 0,4 | 0,4 | 0,7 | 0,7 | 0,7 | | | | | | |
| **Carbon price** | **€/tCO2** | **0** | **25** | **50** | **0** | **25** | **50** | | | | | | |
| Fuel efficiency | % | 63% | 68% | 73% | 28% | 37% | 47% | 65% | 65% | 65% | 31% | 36% | 37% |
| **Fuel cost incl. Carbo** | **€/toe** | **190** | **311** | **579** | **204** | **237** | **285** | **231** | **262** | **292** | **64** | **61** | **67** |
| VOM cost | €/toe | 24 | 23 | 22 | 85 | 75 | 65 | 35 | 35 | 35 | 20 | 20 | 20 |
| **Variable cost** | **€/toe** | **214** | **334** | **601** | **289** | **312** | **350** | **266** | **297** | **327** | **84** | **81** | **87** |
| **Production cost** | **€/toe** | **314** | **417** | **678** | **546** | **537** | **515** | **425** | **429** | **420** | **2031** | **1625** | **616** |
| Production cost | €/GJ | 8 | 10 | 16 | 13 | 13 | 12 | 10 | 10 | 10 | 49 | 39 | 15 |

# Exogenous technology cost projections in WETO-H2

- The **TECHPOL database** provides harmonised data for conventional and new energy technologies



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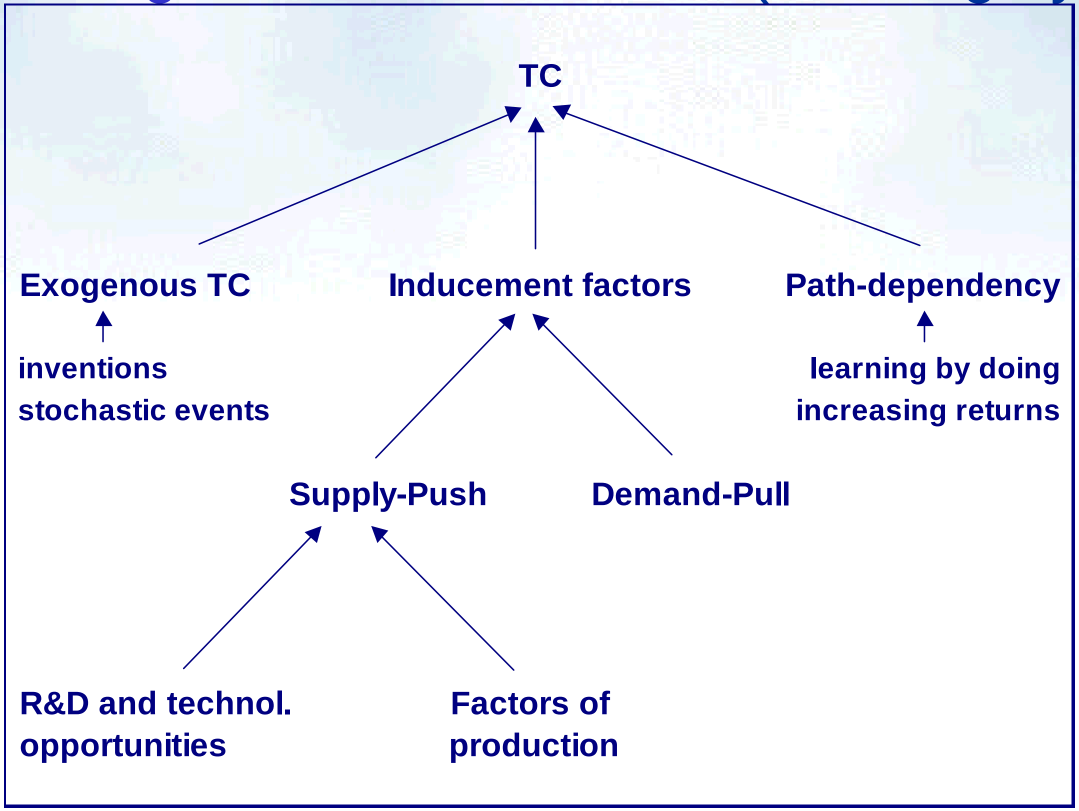
# The sources of Technical Change

- **Technical Change is the complex result of :**
  - exogenous events (scientific discoveries)
  - inducement factors (R&D investment, relative prices…)
  - and endogenous mechanisms (learning by doing ...)

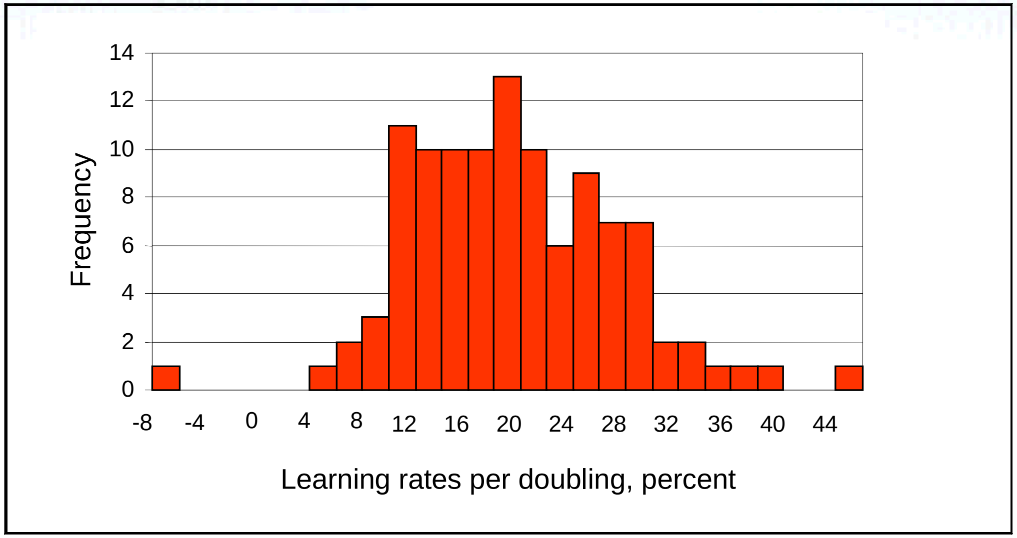


# Endogenous technical change: learning rates

- Analyses of the experience effect show a link between cumulative production or capacities and costs:

$$COST = A * CUMCAP^{-b}$$

- The learning rate measures the cost decrease for each doubling of capacities: $LR = (1 - 2^{-b})$
- Field studies show the bulk of learning rates ranging from 10% to 30 %:



# POLES : Endogenous technological progress

- In POLES Reference case, a « Two Factor Learning Curve », simulates cost decrease with cumulative installed capacities and cumulative R&D spending (public and private)

$$COST = A * CUMCAP^{-b} * CUMRD^{-c}$$

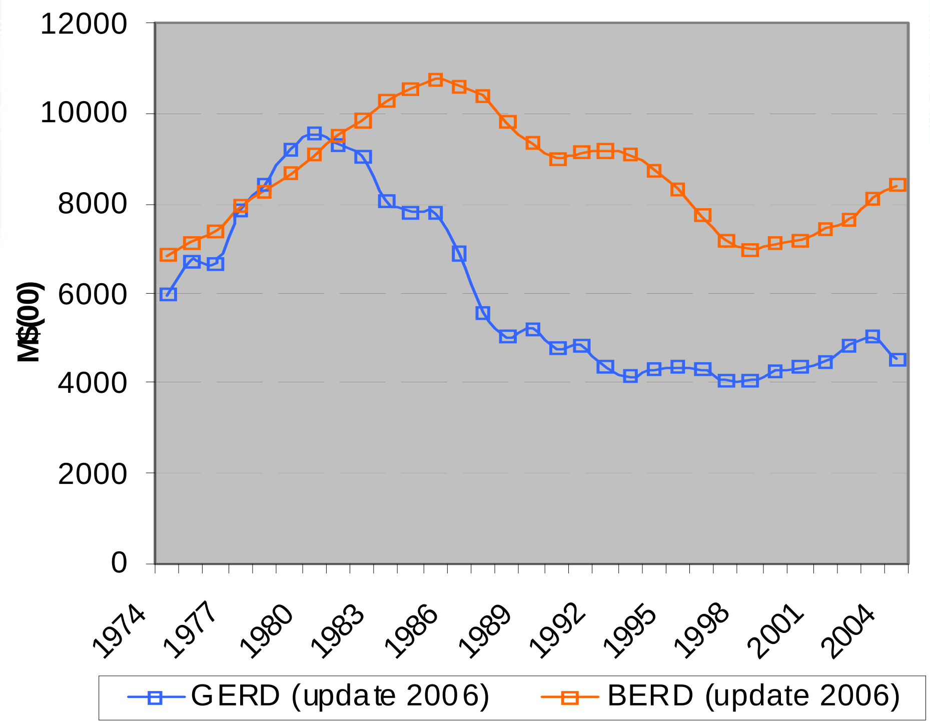
with: CUMRD = Government Energy R&D
+ Business Energy R&D

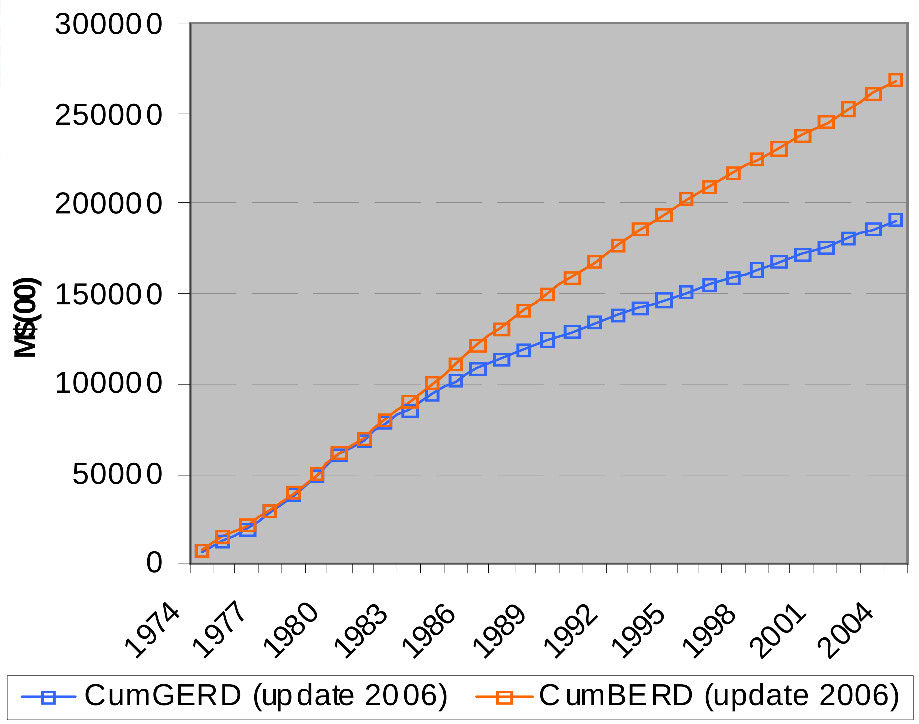
- Later definitions of the TFLC also include a « floor cost », because no technology goes down to zero cost

# TECHPOL R&D db: Total expenditures

- Between 1974 and the late 80s GERD has been more than halved, while BERD was kept at a higher level

Figure 1: Total and cumulative GERD and BERD

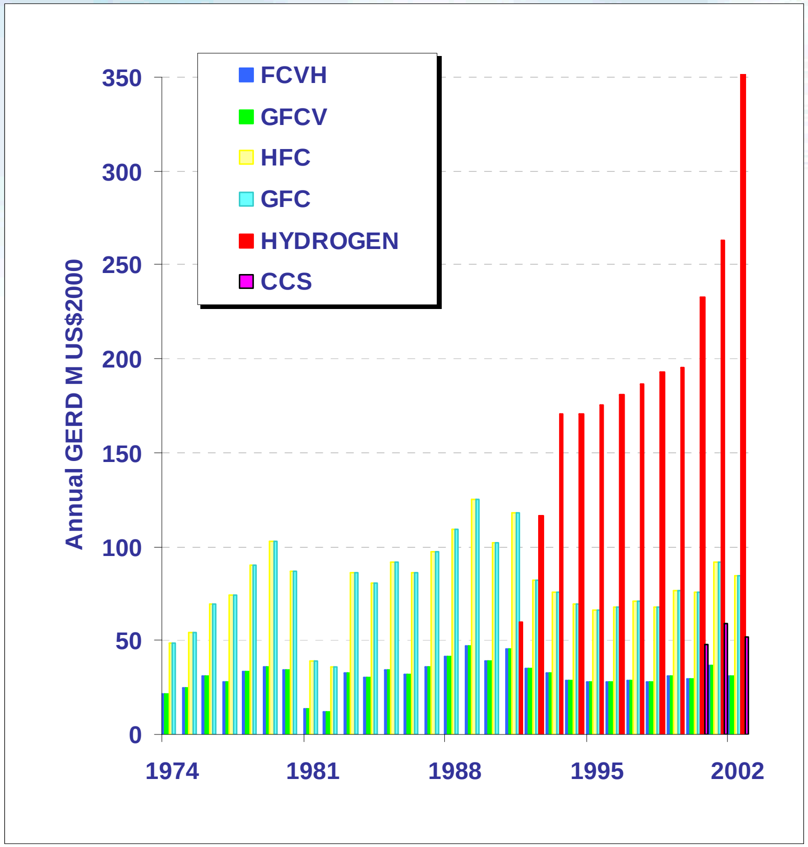


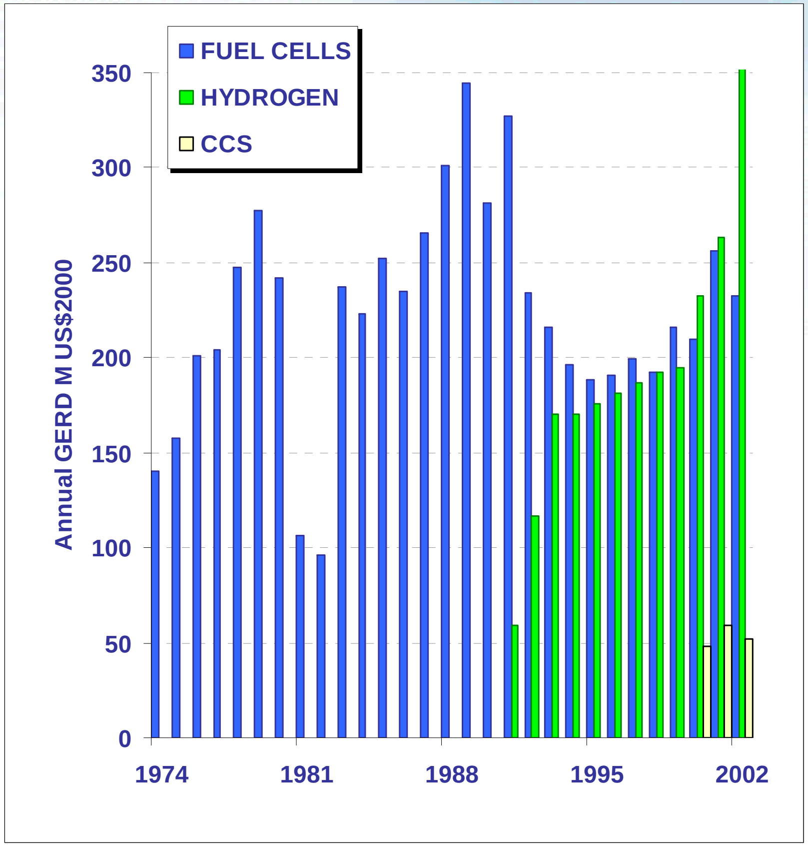




1. *Source: TECHPOL database, 2008*

# TECHPOL R&D db: GERD for hydrogen

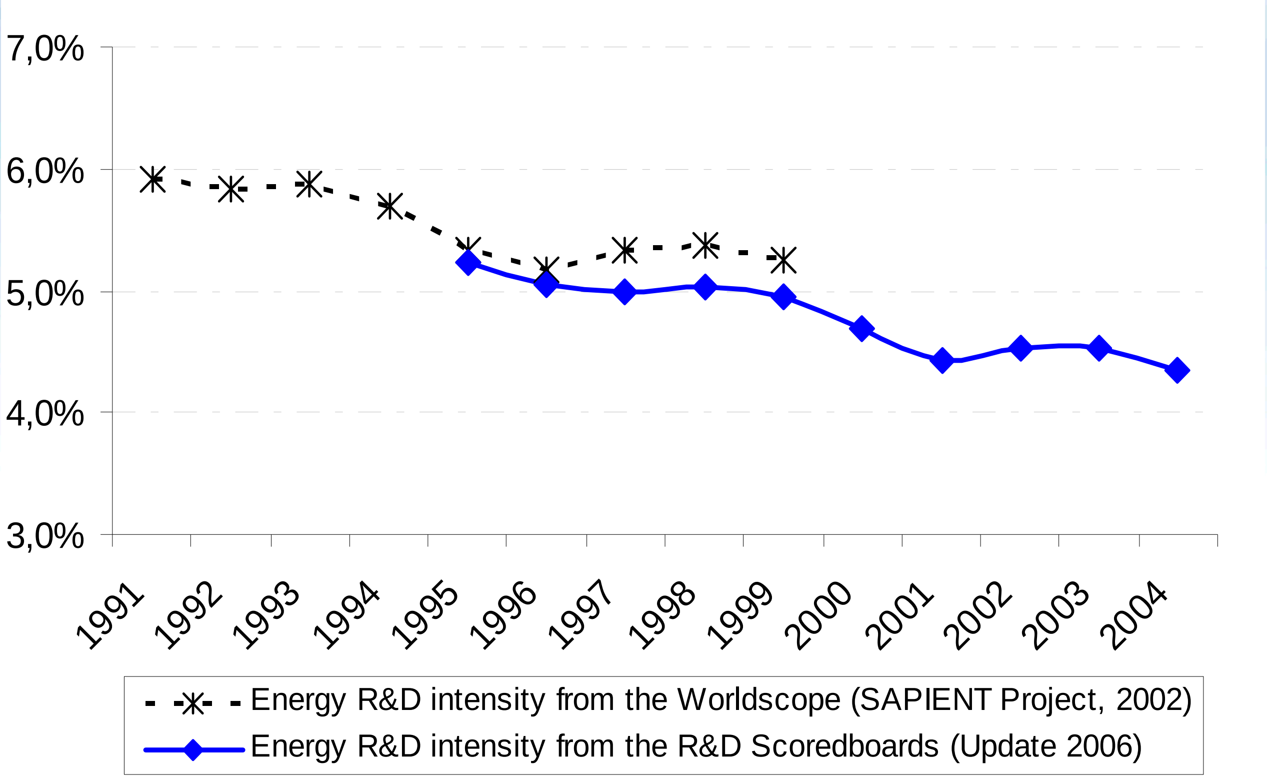
- Fuel-cells have benefitted of high amounts public of R&D earlier than H2
- Strong increase in H2 research in recent years
- R&D for CCS is just starting



# TECHPOL R&D db: Business E R&D expenditures

Figure 1: Energy R&D intensity of industry (R&D / net sales)




**Source: TECHPOL database, 2008**

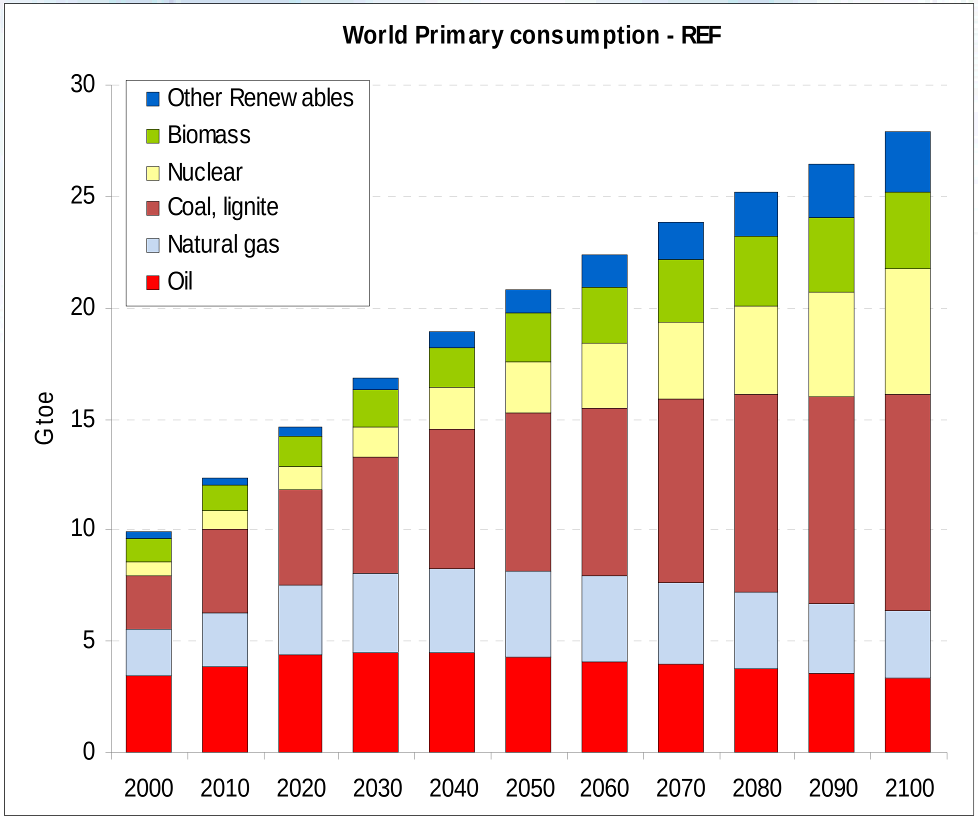
- **POLES V.5 : inputs, outputs, model structure**
- **Technical change: TECHPOL and the exogenous approach**
- **Technical change: Two Factor Learning Curves and the endogenous approach**
- **Endogenous TC with Increasing Returns to Adoption in MENGTECH**

# Induced Technical Change scenarios in the MENGTECH project

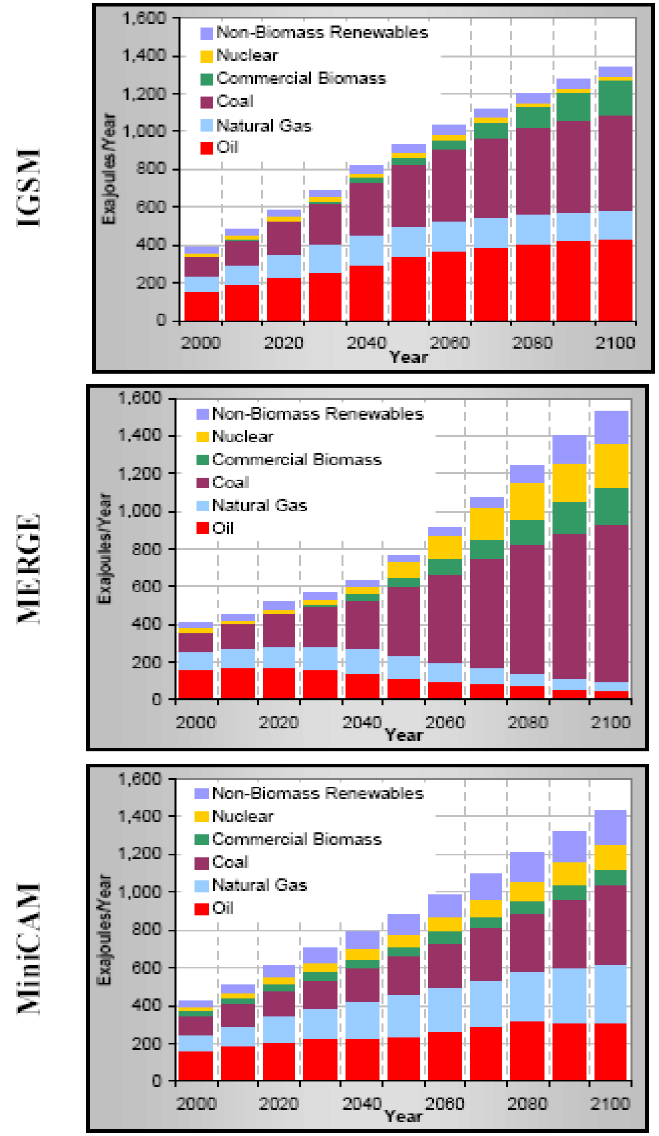
- The goal of the MENGTECH project (with NTUA, KUL, PSI …) has been to extend the modelling framework in order to account for Increasing Returns to Adoption and irreversibilities in TC
- This was in particular in order to avoid the « mixed-basket » effect in the results of incremental TC simulations
- New specifications have been introduced for the diffusion functions of new techs (network effects) and breakthroughs are simulated through reductions of the technology floor costs in the TFLC

# The POLES 2100 Reference compared to US-CCSP

- POLES2100 28 Gtoe = 1200 EJ




Global Primary Energy Consumption (EJ/y)



# US - Climate Change Science Program (2003-2008)

| | Total Radiative Forcing from | Approximate Contribution to Radiative Forcing | Approximate Contribution to Radiative | Corresponding $CO_2$ |
|---|---|---|---|---|
| Leve | | | | |
| Leve | | | | |
| Leve | | | | |
| Leve | | | | |
| Year I | | | | |
| Preindustri | | | | |

CCSP Product 2.1, Part A Draft for Public Comment: Do Not Cite or Quote

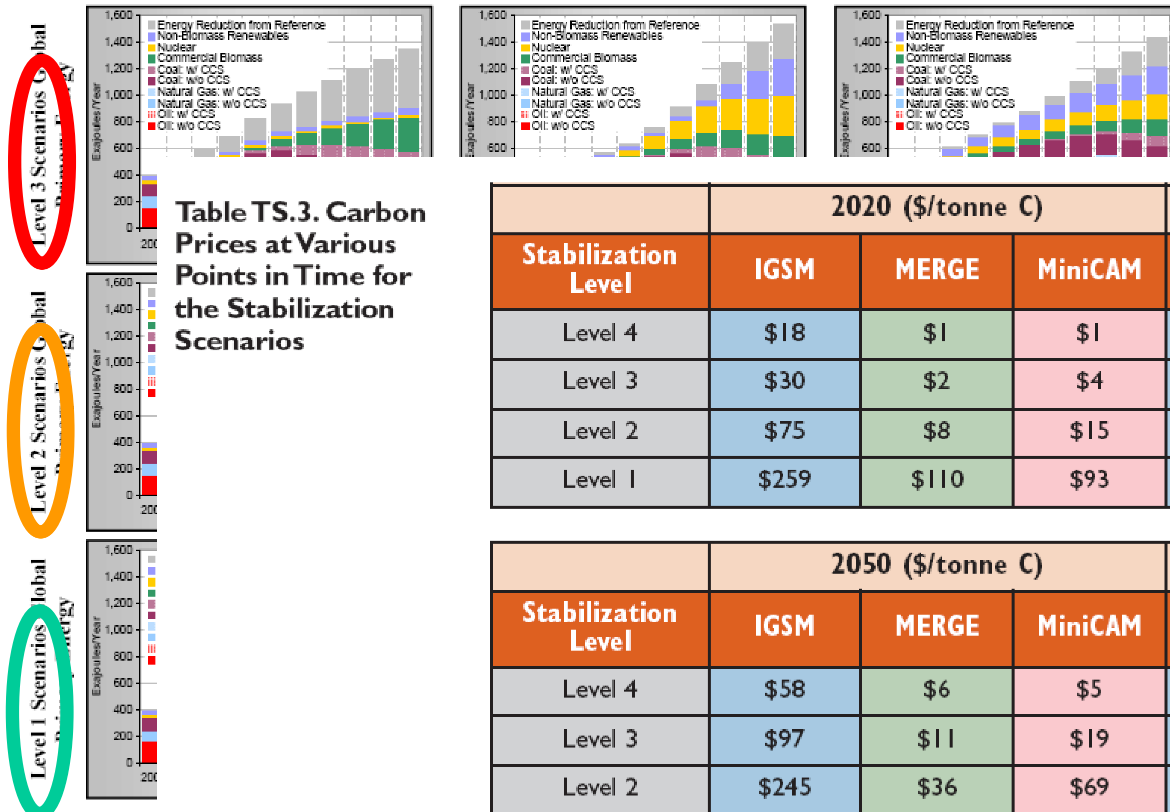



**Table TS.3. Carbon Prices at Various Points in Time for the Stabilization Scenarios**

| Stabilization Level | 2020 ($/tonne C) IGSM | 2020 MERGE | 2020 MiniCAM | 2030 ($/tonne C) IGSM | 2030 MERGE | 2030 MiniCAM |
|---|---|---|---|---|---|---|
| Level 4 | $18 | $1 | $1 | $26 | $2 | $2 |
| Level 3 | $30 | $2 | $4 | $44 | $4 | $7 |
| Level 2 | $75 | $8 | $15 | $112 | $13 | $26 |
| Level 1 | $259 | $110 | $93 | $384 | $191 | $170 |

| Stabilization Level | 2050 ($/tonne C) IGSM | 2050 MERGE | 2050 MiniCAM | 2100 ($/tonne C) IGSM | 2100 MERGE | 2100 MiniCAM |
|---|---|---|---|---|---|---|
| Level 4 | $58 | $6 | $5 | $415 | $67 | $54 |
| Level 3 | $97 | $11 | $19 | $686 | $127 | $221 |
| Level 2 | $245 | $36 | $69 | $1,743 | $466 | $420 |
| Level 1 | $842 | $574 | $466 | $6,053 | $609 | $635 |

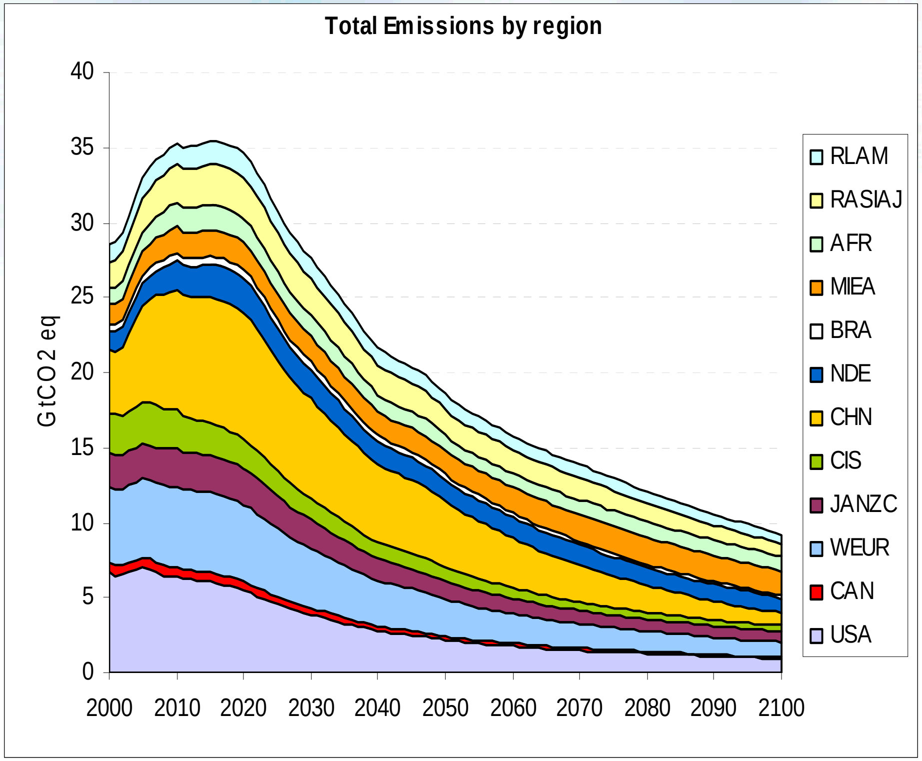
177 120 98 €/tCO2

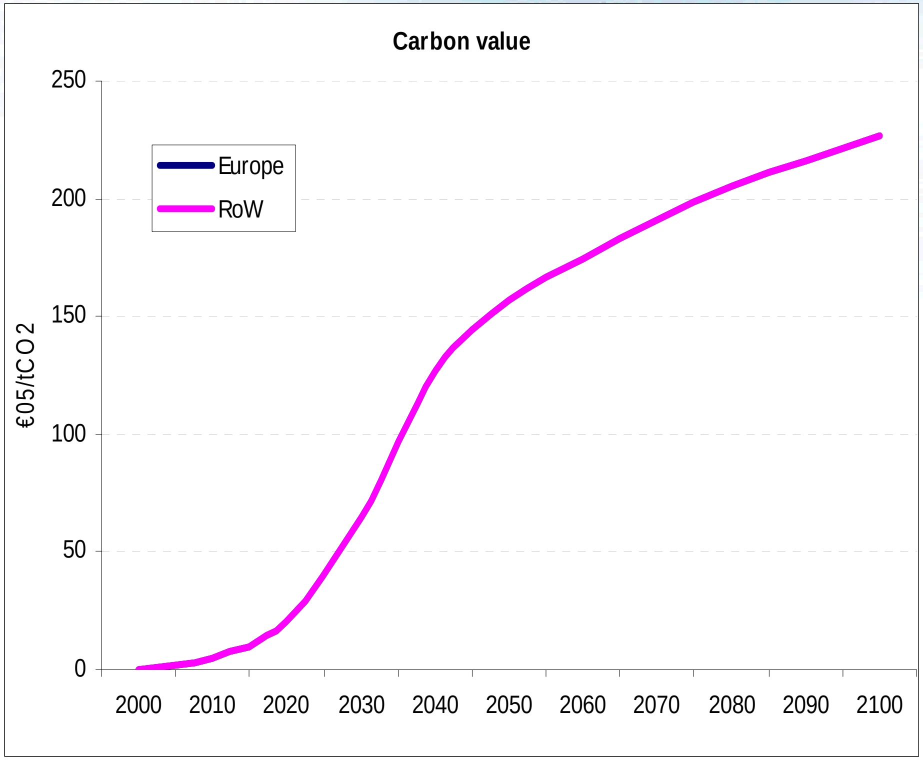
June 26, 2006

# A 550 ppmv CO2e scenario
# (US-CCSP level 2, or Stern type, or IPCC-AR 4 type 3)

- **The POLES carbon value is significantly higher than in the comparable CCSP case**

Figure 1 : Emission profile and corresponding carbon value in CCC



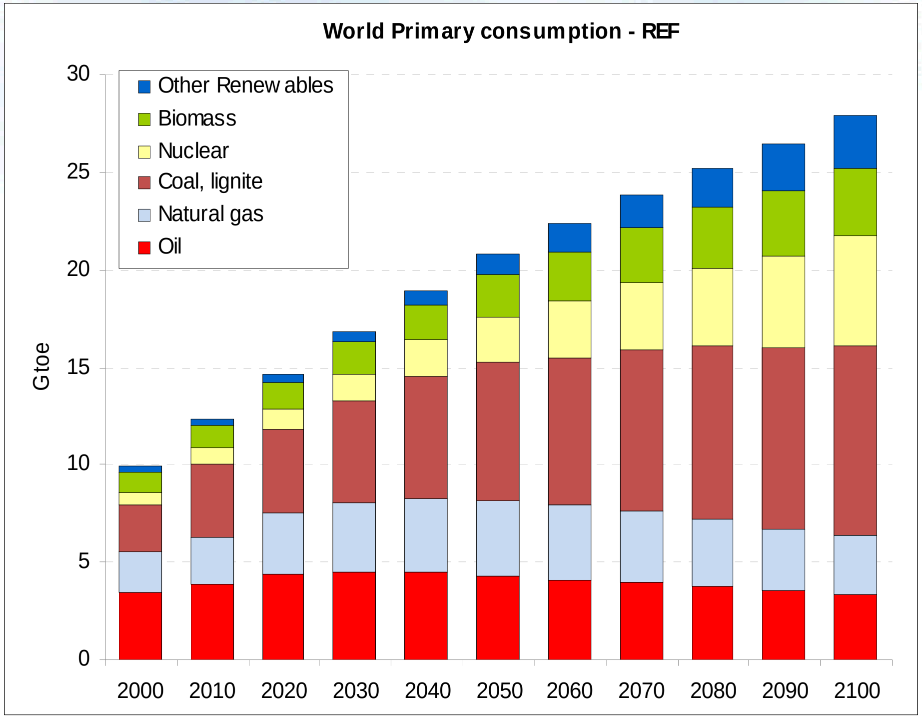



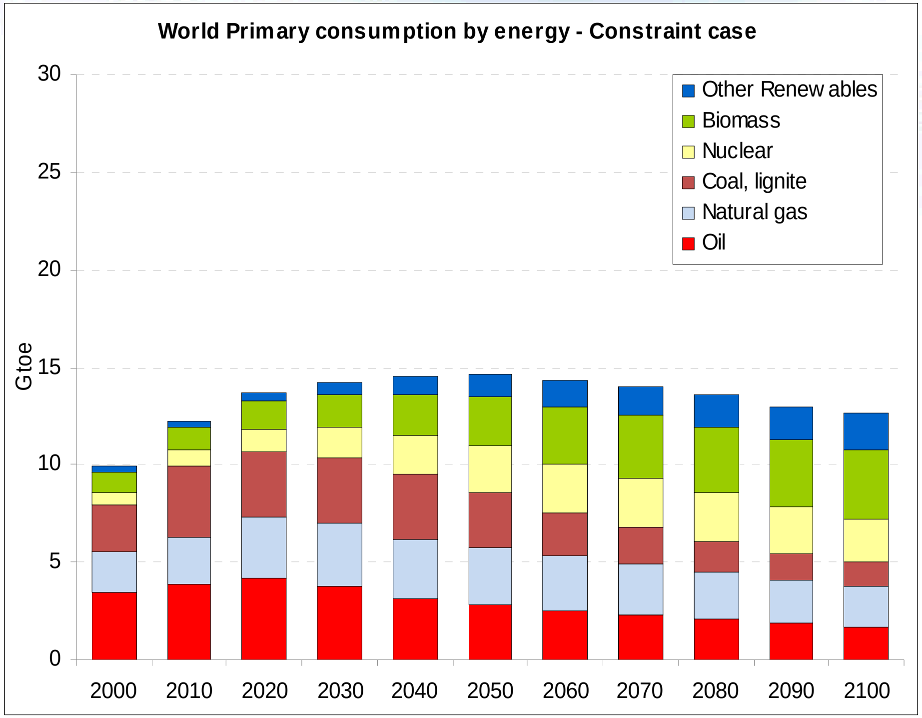

*SOURCE : POLES 550 PPMV MENGHTECH*

# World energy consumption in the 550 ppmv case

- **Total consumtion levels-off in 2050**
- **In spite of CCS the fossil consumption is divided by four in 2100**
- **Impacts on nuclear and particularly renewables are much more limited**

**Figure 1 : Emission World Primary energy consumption by energy**

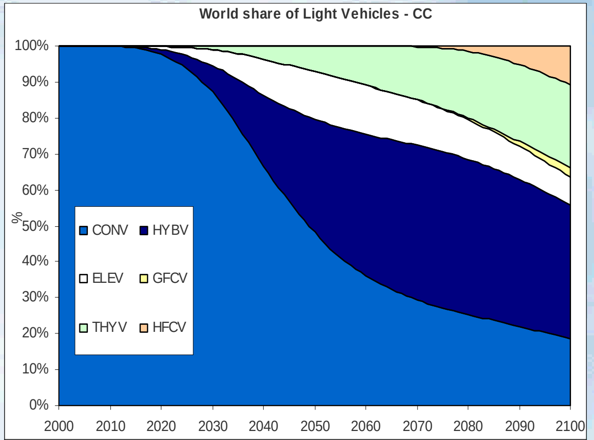


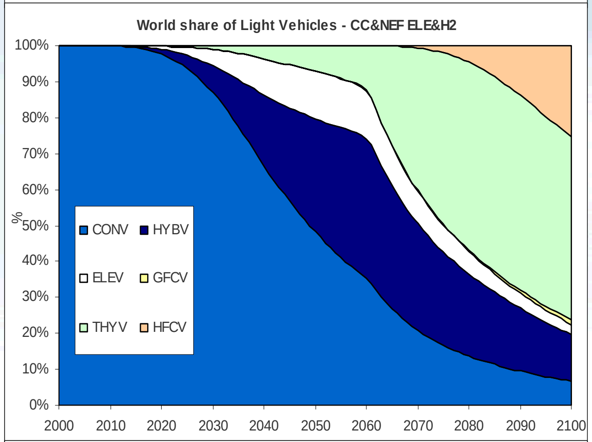



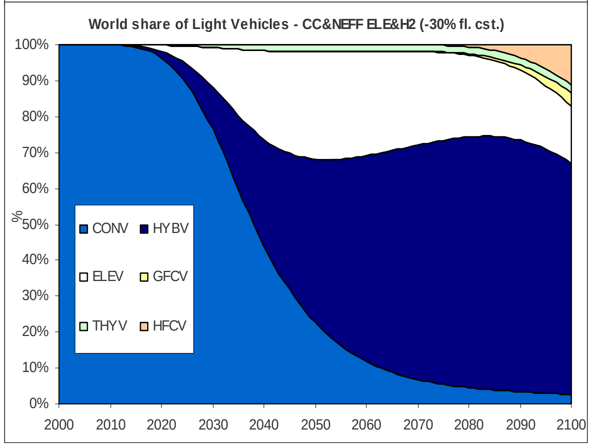

*Source : POLES-LEPII MENGTECH*

# Induced technical change with IRAs and breakthroughs

- Top simulation presents the POLES results for automotive technologies market in the standard case (mixed basket effect)
- Middle simulation corresponds to case with IRAs through network effects, with a first penetration of electrical vehicles and then a massive entry of hydrogen
- Bottom simulation also incorporates a breakthrough in both electrical and hydrogen vehicle, but results in a crowding-out effect of H2 vehicles



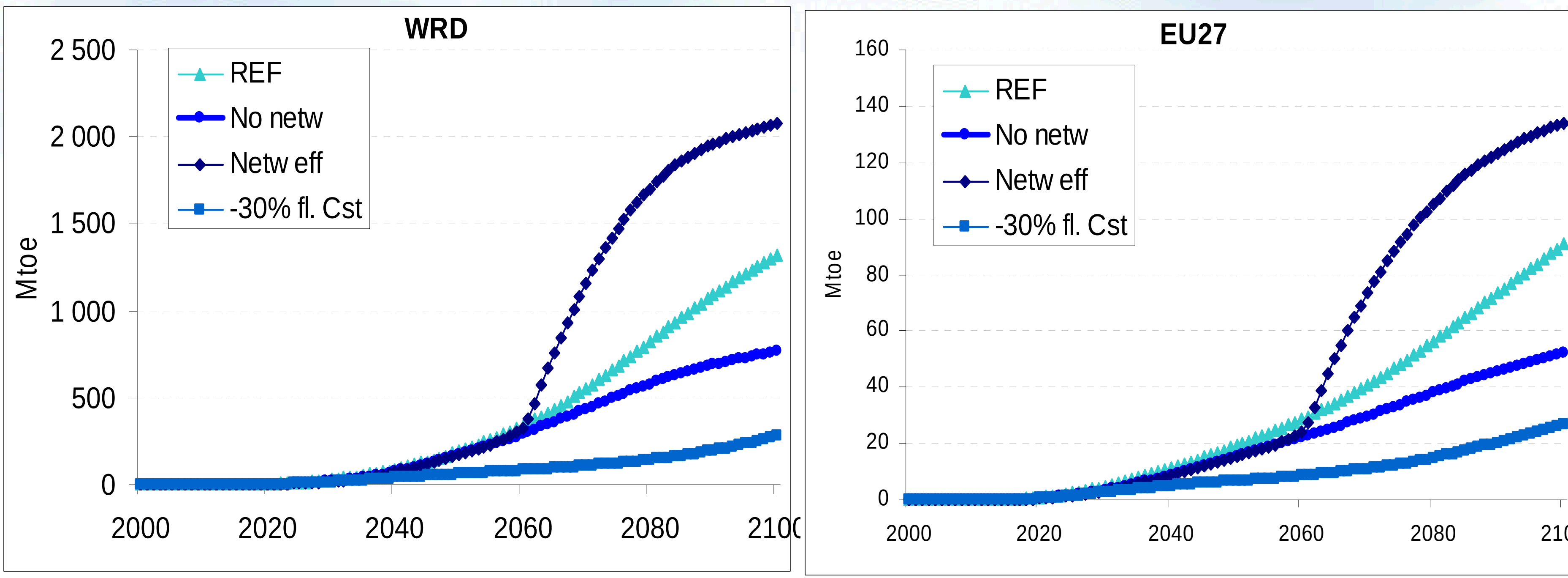



# World and EU H2 production in 4 cases

- The combination of IRAs and Breakthroughs introduces very contrasted model behaviours for H2

**Figure 1 : Total hydrogen production in the REF, CC, CC NEF ELE&H2, CC and NEF ELE&H2 and 30% reduction in floor costs scenarios**




*Source : POLES-LEPII MENGTECH*

# State of the Art for endogenous technology modelling in POLES

- The characteristics of the model now allow to simulate with simple hypotheses non linear technology trajectories with irreversibility and crowding-out effects
- There is still cumbersome work to be maintained on TECHPOL db (particularly for GERD and BERD)
- And a rich research agenda on: improvement of TFLCs, identification of technological breakthroughs, understanding and modelling of adoption behaviours
- The next frontier for the POLES modelling is the introduction of variables concerning urban patterns and the impacts of land use and transport systems on behaviours, technology adoption and energy consumption