  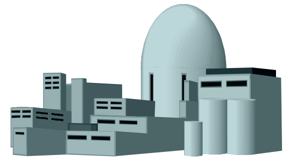  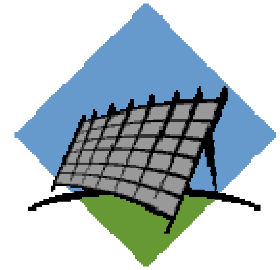

EUSUSTEL- WP 3
Electricity supply: technological and cost analysis

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Outline of presentation

- Short description of the scope and contents of the work in EUSUSTEL project on energy supply technologies (WP3)
- Main results and high-lights on findings on electricity generation technologies 2005-2030
- Elaboration on uncertainties in the findings

Aim and scope of work (WP3)

- analysis of electricity generation technologies and their integration into overall generation system, with emphasis on their future possibilities
- critical review and evaluation of existing studies
- technical, economic, environmental characterization of each technology

Contributing partners

Partic. Role*	Partic. No.	Participant name	Participant short name	Country
CO	1	Katholieke Universiteit Leuven	KULeuven	Belgium
CR	2	Universitaet Stuttgart	USTUTT	Germany
CR	3	Helsinki University of Technology	HUT	Finland
CR	4	National Technical University of Athens	ICCS/NTUA	Greece
CR	5	Uppsala University	UU	Sweden
CR	6	Associazione Italiana Economisti dell'Energia	AIEE	Italy
CR	7	Imperial College of Science, Technology and Medicine	Imperial	United Kingdom
CR	8	ECRIN	ECRIN	France
CR	9	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	CIEMAT	Spain
CR	10	Risø National Laboratory	Risoe	Denmark

Partners in WP3: 1,2,3,5,7,8,9,10

Energy technologies reviewed

Workpackage 3: **Electricity generation technologies and system integration**

3.1 Fossil-based electricity generation technologies:

a. Coal fired technologies
b. Oil & gas fired technologies
c. Combined heat and power
d. CO_2 capture and storage

3.2 Nuclear electricity generation

a. Nuclear fission
b. Nuclear fusion (limited scope)

3.3 Renewable flows & 'alternative' technologies & carriers

a. Wind power
b. Photo-Voltaic conversion
c. Biomass applications (including waste)
d. Hydro power
e. Geothermal conversion
f. Fuel cells
g. Hydrogen economy
h. Electricity storage
i. Less-conventional and speculative forms of renewables (ocean currents, space solar, other)

3.4 System integration

a. Integration of centralised and decentralised generation; influence on the grid
b. Greenhouse-gas emissions due to interaction centralised and decentralised generation (because of operation-time effects and investment consequences)

Characterization of energy technologies

- Each technology has been evaluated and characterized in three dimensions:
  - **technical, economic, environmental performance**

- Time points:
  - **2005, 2010, 2020, 2030**

- A uniform presentation of all technologies
  - **report on state-of-the-art and perceived progress**
  - **database of key parameters (to be used in the energy system modelling and optimizations)**

Review of technoeconomic parameters

Energy:

- Range of unit size and project size [MW]
- Nominal efficiency (which may depend on the size)
  - For electricity generation only [%]
  - For combined heat & power [%]
- Efficiency at partial load
- Flexibility towards fuel, fuel resource availability, plant siting and infrastructures (e.g. cooling water needs, high voltage, grid gas pipes, etc.)
- Flexibility towards exploitation:
  - Cold start [minutes from 0% to 90% of nominal power]
  - Warm/lukewarm start [minutes from 0% to 90% of nominal power]
  - Uncontrollable variation in load [% from nominal load]

Economy (without subsidies, price level for 2003):

- Investment cost [euro/MW]
- Availability [hours per year]
- Operational time [hours of nominal power/yr]
- Reliability [%]
- Technical life span [years; if this needs to be split by subsystems, then split investments correspondingly]
- Construction time[years]
- Fuel cost [euro/ MJ]
- Operation & Maintenance (O&M) cost (incl. replacement cost to keep the technology running over the projected life time) [euro/ $MWh_{electricity}$]
- Waste handling and dismantling [euro/ $MWh_{electricity}$]
- Total economic score

Industrial maturity

Potential for amelioration, development and innovations

Review of environmental parameters

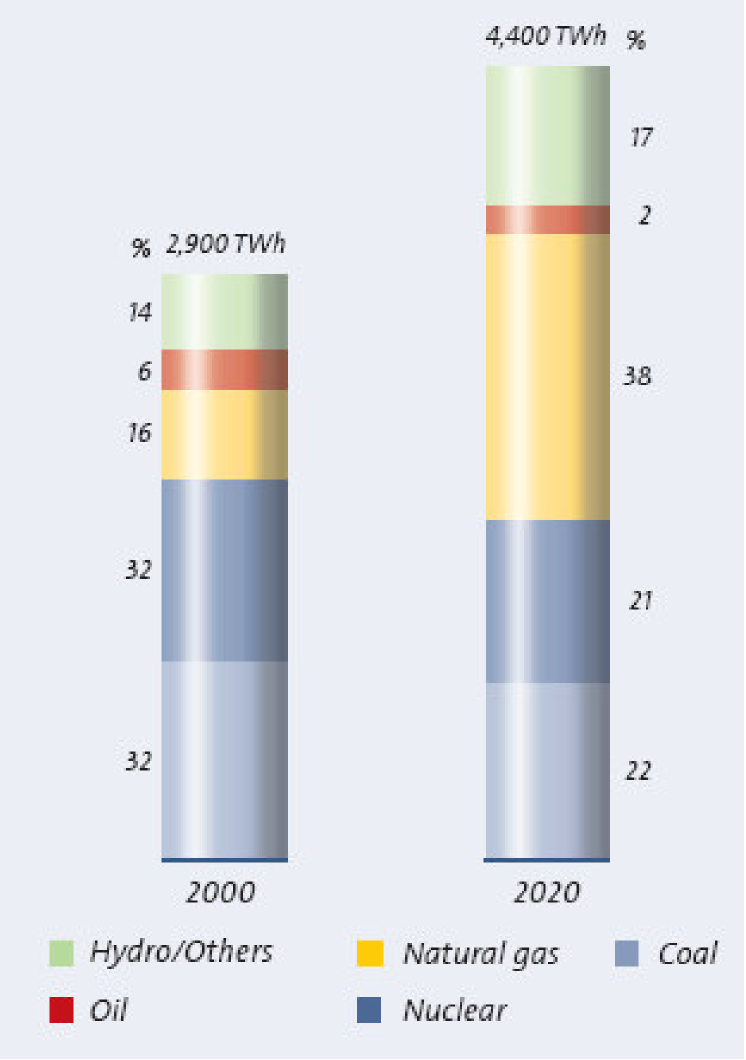
Ecology & resource use:

- Exhaust:
  - CO_2 [tonnes/GWh$_{electricity}$]
  - SO_2, NO_x [tonnes/MWh$_{electricity}$]
  - PM_{10} [particles with diameter smaller than 10 micrometers, tonnes/MWh$_{electricity}$]
  - MNVOC [tonnes/MWh$_{electricity}$]
  - Methan [tonnes/MWh$_{electricity}$]
  - N_2O [tonnes/MWh$_{electricity}$]
  - C_{14} [tonnes/MWh$_{electricity}$]
  - Heavy metals [most important ones, g/MWh$_{electricity}$]
- Thermal exhaust [TJ/GWh$_{electricity}$]
  - Into air
  - Into water source
- Liquid waste
  - Total liquid waste [tonnes/MWh$_{electricity}$]
  - Total Phosphor into water source [tonnes/MWh$_{electricity}$]
  - Total Chlorides into water source [tonnes/MWh$_{electricity}$]
  - Total Sulfates into water source [tonnes/MWh$_{electricity}$]
  - Others ($KMnO_4$, Iron, Organic materials, Solid materials)
- Solid waste [tonnes/MWh$_{electricity}$]
  - Flue dust
  - Slurry
  - Hazardous waste
  - Radioactive waste
  - Other solid waste
- Safety and health impacts
  - Population affected by worst perceived accident during operation [nr of persons]
  - Number of deaths over the fuel cycle [persons/ MWh$_{electricity}$]
  - Other effects
- Visual impact and noise

Footprint and use of resources

Starting point: electricity supply in EU

- **Electricity production increases more than 50% in 20 years**
- **EU's investment needs in electricity some 900 billion € over the next 20-25 years**
- **Coal, natural gas and uranium/plutonium are main fuels in 2000 and 2020 (BAU)**



Main results of the technology and cost analysis - 2005

- **Present supply technologies available in utility scale:**
  - Main: fossil fuels, nuclear, wind, biomass (limited), hydro (limited)
  - Marginal: geothermal, PV, fuel cells, marine, míni-hydro
  - Speculative: fusion, hydrogen
- **The electricity production cost depends not only on the technology and investments but**
  - Site dependence (geography, regulation, operator, market)
  - Financial engineering
  - Fuel, O&M, other variable costs
- **Rough range of costs**
  - Fossil fuels: 30-45 €/MWh
  - Nuclear: 25-35€/MWh
  - Biomass: 25..30 (CHP)- 50..60 (condensing/gasification) €/MWh
  - Wind: 30-60 €/MWh

	Range MWe	Nom. Eff. %	Investment €/kWe
3.1.1 COAL lignite ST	965	44.5	1300
Coal condensing	400	48	1136
3.1.2 OIL,GAS CCGT	400-500	55-60	515-580
3.1.3 CHP Small-scale			
Gas CCGT	58	46	1362
Gas Engine SCR	2x5.5	40	636
Gas Engine - SCR ind	0.527	40	1483
3.1.3 CHP Larg-scale			
Coal	400	48.5	1131
Gas CCGT	470	56	490
Gas CCGT, back pres.	200	45.5	535
3.2.1 FISSION	900-1450	34-36	1300-1600
3.3.1 WIND onshore	0.75-2	n.d.	800-900
Wind offshore	2	n.d.	1550-1750
3.3.2 PV System (Si)	0.0005	10-14	4500-6000
3.3.3 BIOMASS (GAS)	10-200	37.2	1747
3.3.4 HYDRO large	10-800	90	1400-1900
Hydro small	<10	90	900-4000
3.3.5 GEO conventional	3-120	n.d.	640-2400
Binary cycle	1-3	n.d.	800-2000
3.3.6 FUEL CELLS PEM	0.25	28-40	1000-70000
Fuel cell MCFC	0.3>	50-55	2800-5000

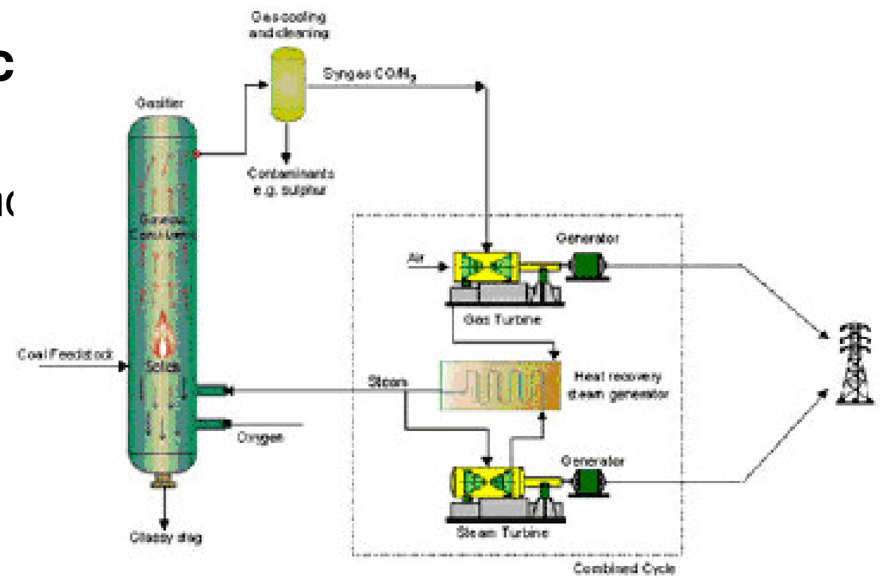
Electricity supply technologies in 2030

- Technology progress expected in most energy supply technology areas, e.g. fossil/bio fuel combustion and gasification
- Cost reductions in investments expected in several areas, including the main stream technologies but in particular with new technologies; some cost increases are expected with fossil fuels if CO_2 need to be eliminated
- Some supply technologies (wind power, CCS, distributed power generation ???) may enter the main stream bulk supply of electricity
- No major surprises to be expected, e.g. fusion or hydrogen breakthroughs improbable
- Next slides shows a few examples on technology and cost progress to be expected by 2030 (case: coal, gas, CCS, fission, wind)

Advanced coal power plants

- **Advanced pulverized coal combustion (APCC)**
  - Advanced materials; higher temperatures and pressures (super-critical, ultra s-c)
  - Plant and turbine optimization
  - 85-90% availability, good part-load efficiency
  - Investments 1500€/kW(2005)-1100€/kW (2030)

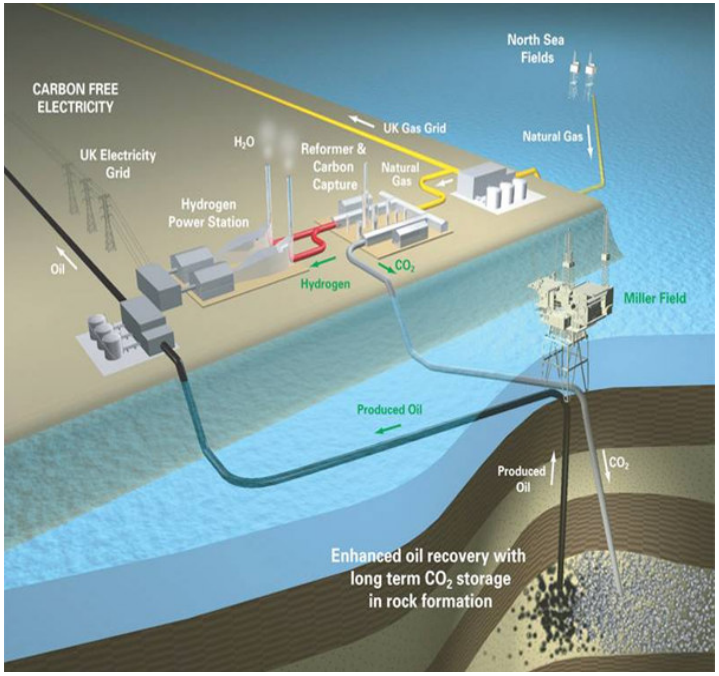
- **Integrated gasification combined cyc power plant (IGCC)**
  - Hard coal and lignite gasification, efficienc 50% (2005)- 62% (2005)
  - Flexible fuel feedstock and products
  - 160 IGCCs in use world-wide
  - Hybrid IGCC with fuel cells
  - Costs 1300€/kW (2030-)



Natural gas power plants

- **Combined Cycle with natural gas (CCGT)**
  - 800 MW up to 1000 MW (2010-); efficiency 57.5% (2005)-65% (2030); 0.35 tCO_2/MWh
  - Construction in 2 years, 80% availability, 25 yrs lifetime
  - Costs 550 €/kW (2005), some cost reductions excepted

CO_2 sequestration



- **CO_2 capture and storage**
  - geological storage, biological sinks, mineralization, oceans
- **Tested in Algeria and Norway (1Mt CO_2/a), commercial projects e.g. in UK and Norway**
- **CO_2 sequestration influences both cost and efficiency of fossil power generation**
  - 4-6% net efficiency loss, 280-560 €/kW for NGCC (+55%), 195-316€/kW for IGCC (+25%)

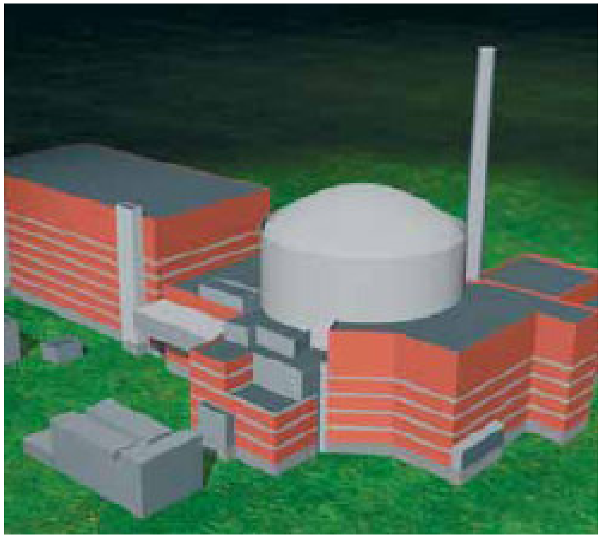
Sequestration option	Global capacity (Gt CO_2)	Part of cumulated emissions 2005 - 2030 (%)
Oil and gas reservoirs	100 - 1000	13 - 130
Deep saline aquifers	400 - 10000	51 - 1300
Coal seams	10 - 100	1 - 10

Steam → Split-up → Compression → Transport → Storage

Split-up	Compression	Transport	Storage
50-60€/t	8-10€/t	0.5 - 10€/t for 100km	2-8€/t

Nuclear power (2005): Generation III

- **EPR 1 600 MW reactor**
  - safety innovations to prevent core meltdown; better resistance to external hazards
  - flexible fuel management, MOX; 17% saving in U consumption, reduces 15% long life time actinides; burn up > 60 GWd/t.
  - life-span for non replaceable components 60 yea, availability 91%, refueling period 16 days, fuel cycle 2 yrs

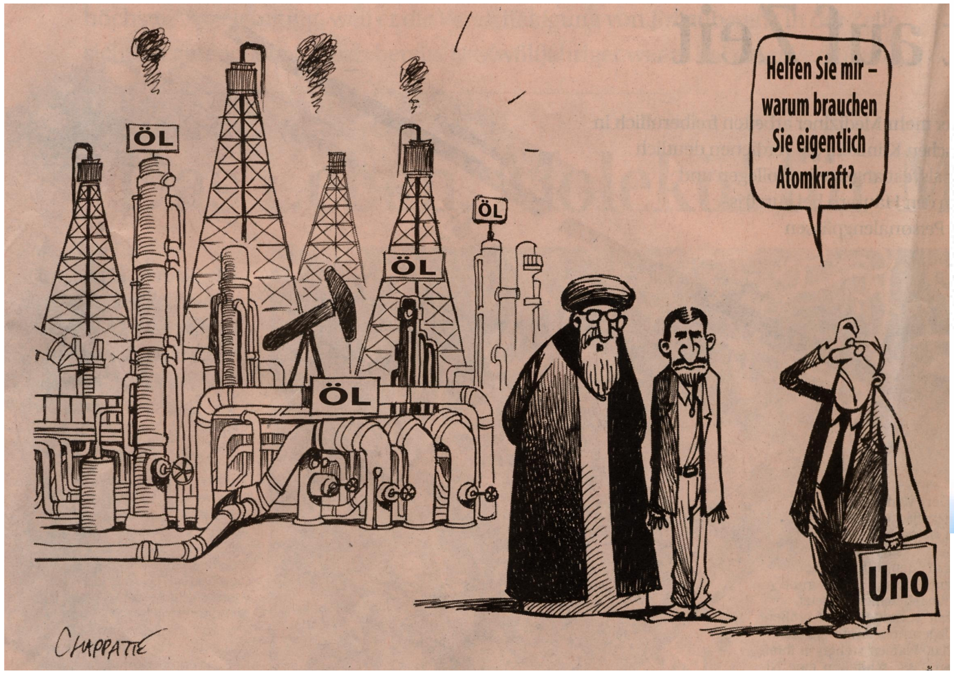


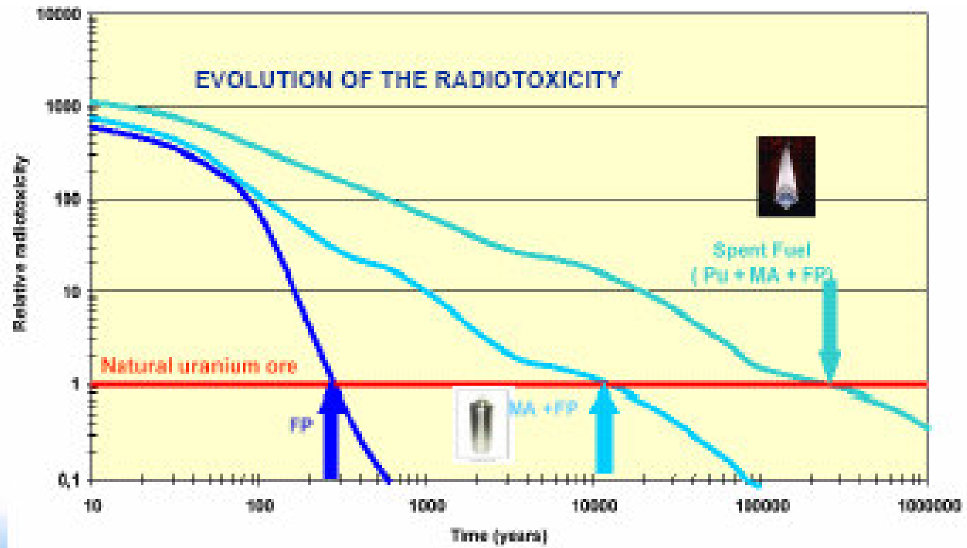
- **Finland Olkiluoto 3 NPP (1600 MW)**
  - Investment is 3 billion € =1875€/kW
  - Delays occurring in construction (2-3 years) causing Areva Ltd. a loss of 0.3-0.5 billion € =187-312€/kW

Fuel	15%	4,4€
Investment	58%	16,3€
Running	18%	5,1€
Taxes	7%	2€
R&D	2%	0,6€
Total	100%	28,4€

Cost split-down of EPR, 2003

Nuclear challenges: waste and weapons

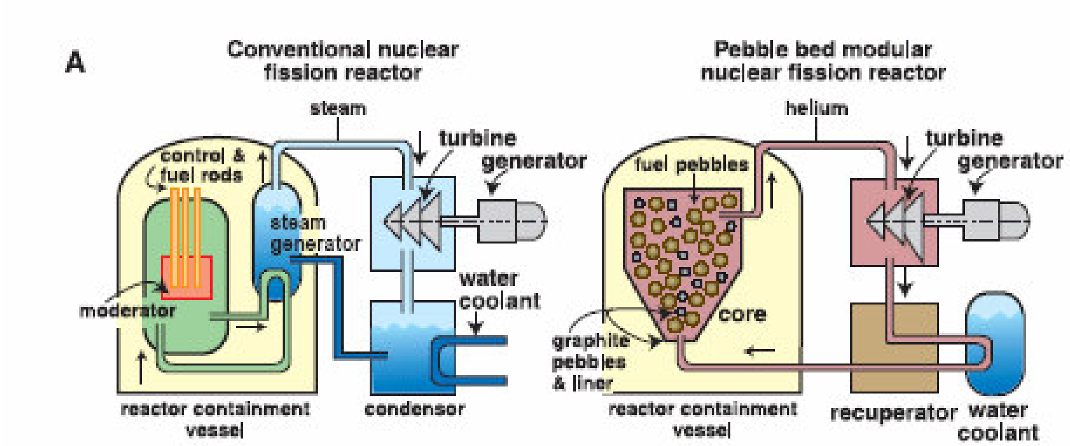




"the wide dissemination of the most proliferation-sensitive parts of the nuclear fuel cycle…could be the 'Achilles' heel' of the nuclear non-proliferation regime.

- **Nuclear waste: 93-94% U and 1% Pu which can be used as MOX fuel; 3-4% final waste and<0.1% actinide nuclei**
- **Transmutation of the long living nuclei into less dangerous elements may be possible**

Generation IV technologies to meet the challenges ahead

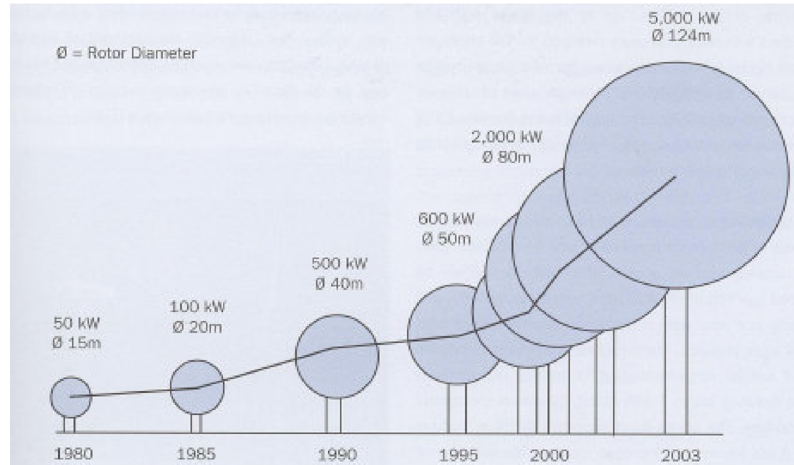


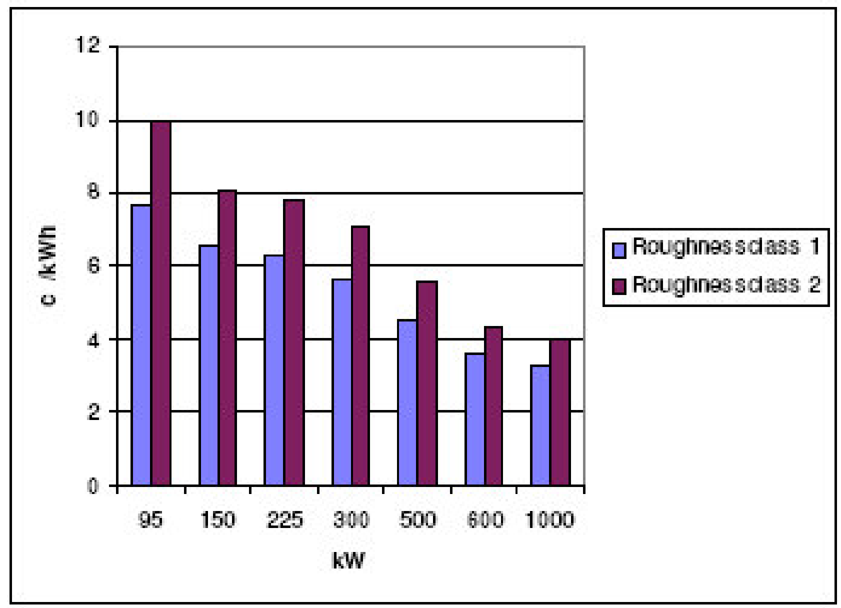
	Spectrum	Fuel cycle	Power(Mw_e)
1.Light water reactor Super Critical Water Cooled Reactor (SCWR)	Thermal/Fast	Open/Closed	1500
2.Very high temperature reactor with gas coolant Very High Temperature Reactor (VHTR)	Thermal	Open	600
3.Fast neutrons reactor Sodium Cooled Fast Reactor (SFR) Gas-Cooled Fast Reactor (GFR) Lead Alloy-Cooled Reactor (LFR)	 Fast Fast Fast	 Closed Closed Closed	 150-500 288 120-400
4.Molten salt reactor Molten Salt Reactor (MSR)	Thermal	Closed	1000

- **saving natural resources, higher profitability, reinforced safety, reduction of high-level waste**
- **use nuclear power for other applications than electricity**
- **available 2030-2040**

Wind energy technology (2005)

- Size of wind turbines has increased 100× in 25 yrs
- Typical unit size 1-5 MW
- Investments: 800-900€/kW on-shore, off-shore 1300-1700€/kW
- Siting of the wind power plants influences strongly the profitability
- Intermittency in integrated markets is compensated with 1-2€/MWh if 10-20% wind share (Nordpool experience)

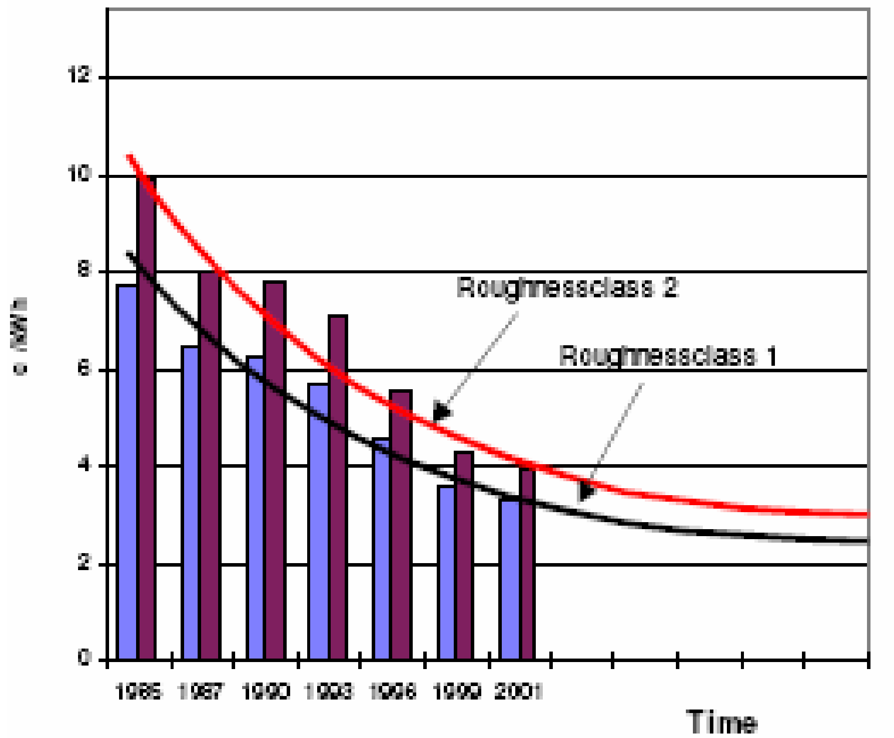




Total wind energy costs per unit of electricity produced, by turbine size. (2001 prices).

Wind power in 2030

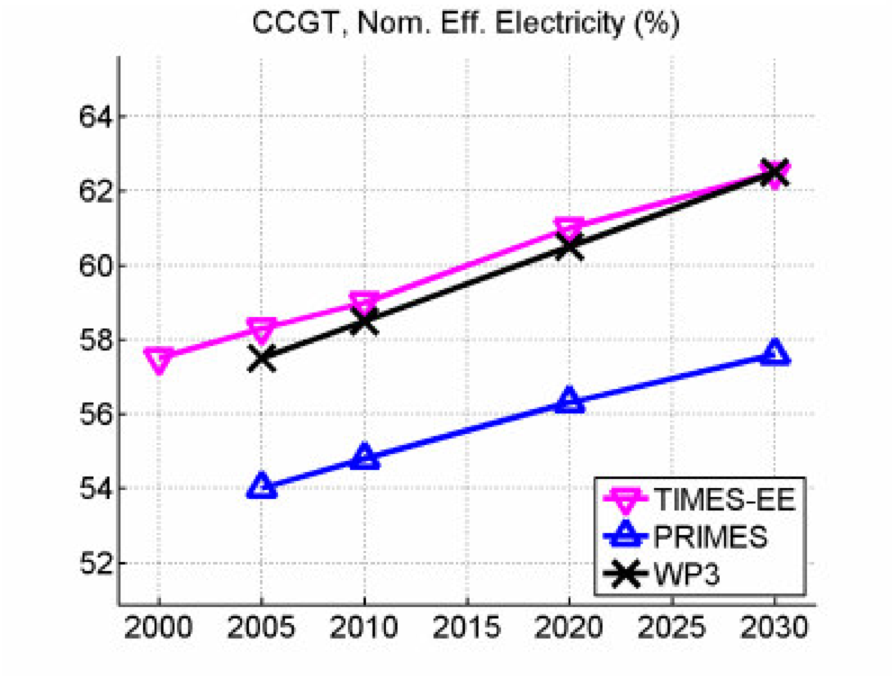
- Technological and economic progress will continue
- Size of wind turbines may increase
  - no major physical barriers < 20 MW
  - reducing weight may allow up to 30-40 MW units
  - 10MW= rotor Ø160 m, 20MW =220 m
  - barriers in transport infrastructure ?
- Investment cost may drop for on-shore down to 500-600€/kW, off-shore 800-1200€/kW

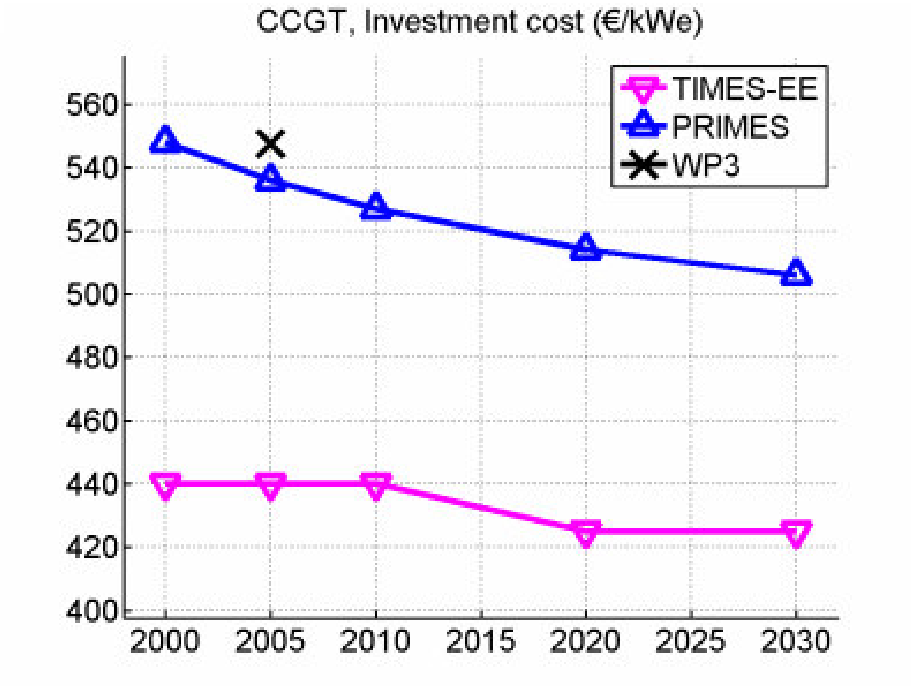


Reliability of the results ?

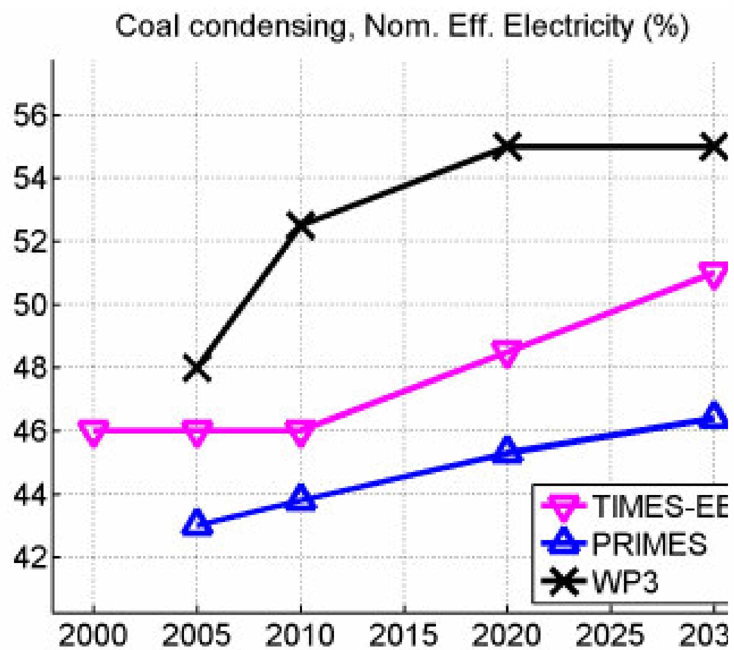
- **How do the results from the EUSUSTEL technology and cost analysis compare to other sources ?**
- **Comparison to data in PRIMES and TIMES-EE energy models**
  - the WP3 data set for 31 technologies /EUSUSTEL, 2006a/,
  - the TIMES data set for 61 technologies /TIMES, 2006a/,
  - the PRIMES data set for 61 technologies /PRIMES, 2006a/
- **Comprehensive analysis for four key technologies**
  - advanced CCGT, modern coal, 3rd generation nuclear and coal/lignite IGCC
  - electricity generation efficiency, investment cost, and technical lifespan
- **Differences found, also significant ones**
  - different unit sizes, differences in the compared technologies, different cost structures

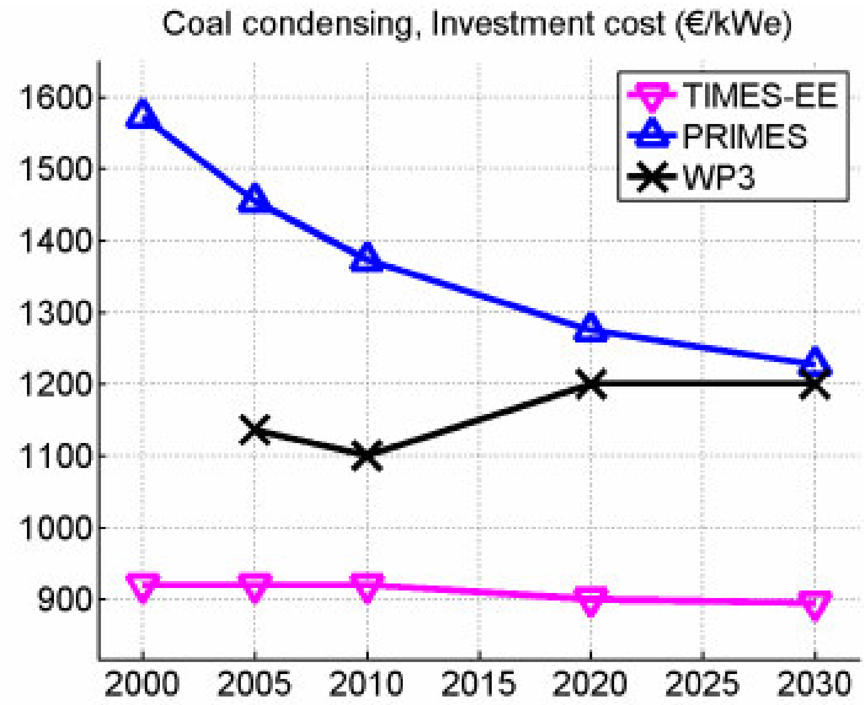
Comparison 1: CCGT





Comparison 2: coal condensing power





Summary and conclusions

- EUSUSTEL project has provided an in-depth technology, economic and environmental analysis of 31 energy technologies for 2005-2030 (www.eusustel.be)
- Comprehensive database on parameters + reports available on each technology
- No major surprises in the analysis 2005-2030, but clear progress in technology anticipated by 2030; we foresee cost reductions; CO_2 management adds to the costs
- Energy technology R&D needs to be clearly intensified to capture the promises that new technologies can provide in the future
- The values of technological and economic parameters of energy supply technologies vary by source and assumptions; using a range for the values is advisable (min-avg-max); other factors bring additional uncertainty to calculating the cost of electricity