Global Mapping of Greenhouse Gas Abatement Opportunities up to 2030

Power sector deep-dive

January, 2007

Power sector – Key messages

Current emissions	• Emissions in the power sector come from **combustion of fossil fuels for electricity production** and contributes to **24% of the global GHG emissions in 2002**
BAU growth	• **BAU emissions growth will be 78% from 2002–2030** according to the IEA, **adding up to 38% of total GHG emissions in 2030**
Abatement opportunities beyond BAU	• The abatement potentials have been evaluated at a system cost, without any major political considerations; as such, the painted scenario should not be considered as a forecast • There are **five major abatement opportunities which together have the potential to decrease emissions with 20–25% through 2030 at a marginal cost of <40 EUR/tCO_2** compared to BAU, based mostly on known (but not all currently competitive) technologies – Installation of Carbon Capture and Storage (CSS) is assumed to ramp up to commercial scale over the period 2015-20 – Emerging renewables growing to 15–20% of total power production by 2030 – Nuclear grows ~100% to an installed base of ~740 GW; likely to be cost competitive with CCGT – Higher CO_2 prices incentivize growth in gas instead of growth in coal, and earlier replacement of old coal plants, leading to higher overall CO_2 efficiency – Demand reduction and increased energy efficiency is the most cost-effective measure to reduce emissions from power production, however, actions should target end-user sectors in order to realize this potential – aggressive action **could reduce electricity demand growth** 2002-2030 **from 2.5% p.a. in BAU to 1.3% p.a.** • **Additional technical potential clearly exists** (from, e.g., nuclear, renewables). However, this will come at significantly higher cost levels (e.g., EUR 55-65 for CCS repowering on gas plants); if new technologies do not come down in cost, CCS could potentially reach higher penetration to further decrease emissions
Implications	• **Feasibility in achieving power sector abatement is high** relative to other sectors (easy to track emissions, focus on industrialized countries, “rational” investors). The regulation required consists of measures to realize cost-effective energy efficiency improvements, a **financial incentive to invest in existing CO_2 efficient technology** (e.g. a CO_2 price), and **innovation support** to decrease CCS and renewables cost. However, **competitive distortion issues** arise if emissions regulations do not span all key geographies • Except for nuclear power and CCS with EOR, the majority of all abatement opportunities **require stable CO_2 prices above 15–20 EUR/tCO_2e** • Climate change will remain a major **regulatory uncertainty**, with **huge P&L impact**; but also **big chances to influence** • Big **shifts in technology-base vs. BAU** are highly likely if GHG regulation is rolled out globally – **Nuclear** likely to be strongly competitive with a stable CO_2 price – **CCS** could be “base-case” for fossil plants If cost go down as projected • This work reflects a perspective up until 2030; after this, the relative importance of CCS is likely to increase in order to secure energy supply

Content

Overview

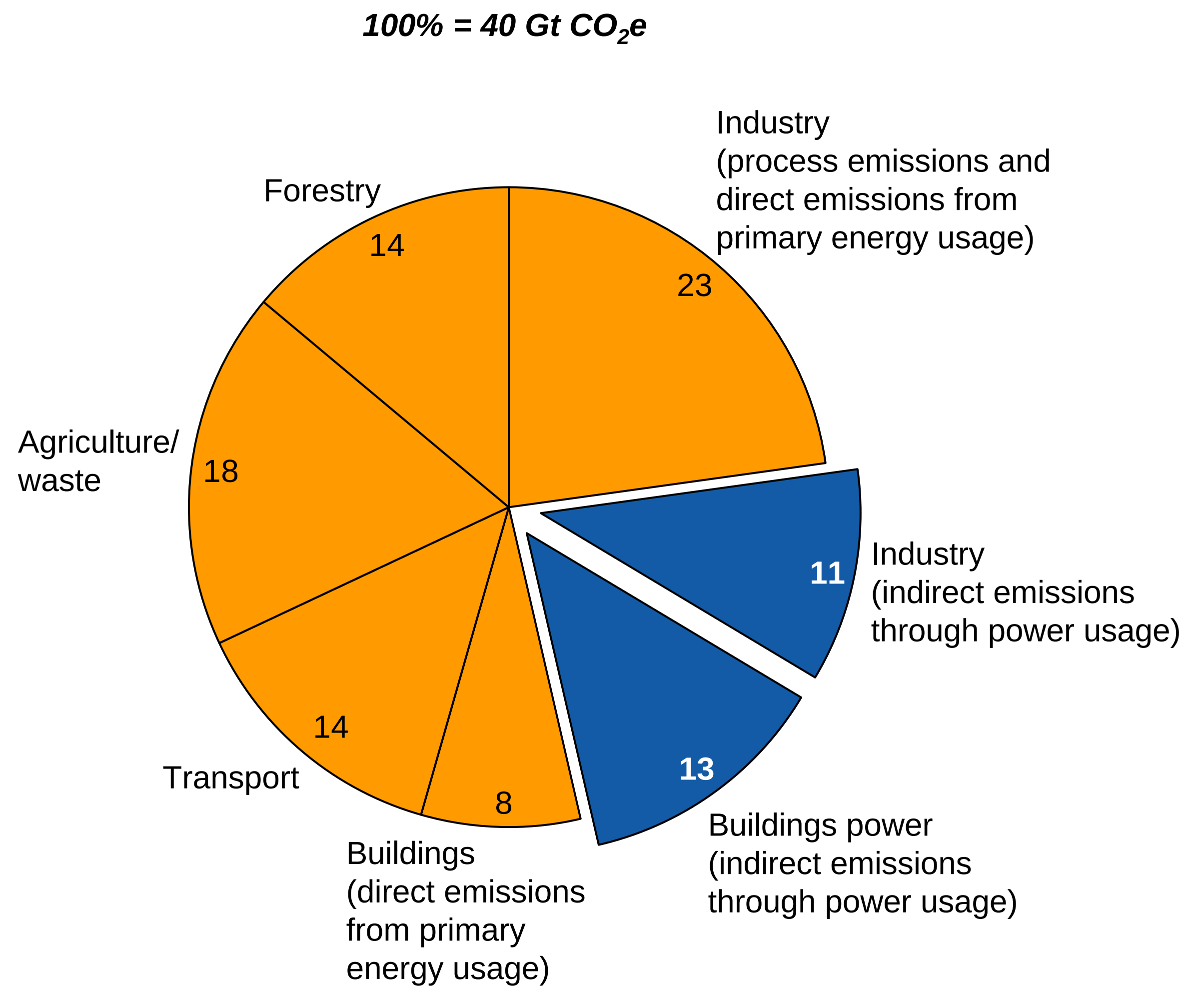
Details of abatement opportunities

- Carbon Capture and Storage
- Renewables
  - Summary
  - Wind
  - Solar
  - Biomass
- Nuclear
- CO2 efficient fossil sources

Appendix

Global greenhouse gas emissions, 2002

Percent



- The power sector contributed to 24% of the global GHG emissions 2002
- 54% of the electricity generated is used in residential and commercial buildings, the remaining 46% in industrial processes

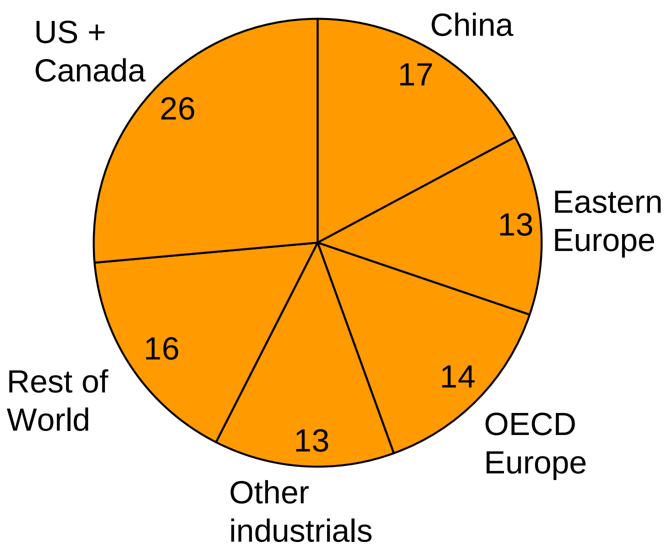
Source: IEA

Emissions by region and end-use 2002

Percent

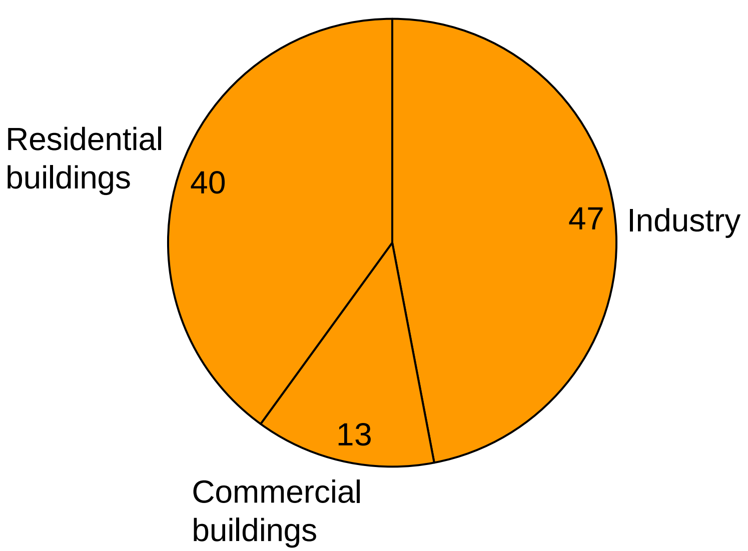
Geographic distribution

100% = 9.4 $GtCO_2e$



End-use distribution

100% = 9.4 $GtCO_2e$



- **Emissions from the power sector are spread across all regions**
- **The main electricity consuming sectors are the industrial sector and residential buildings**

Source: EPA

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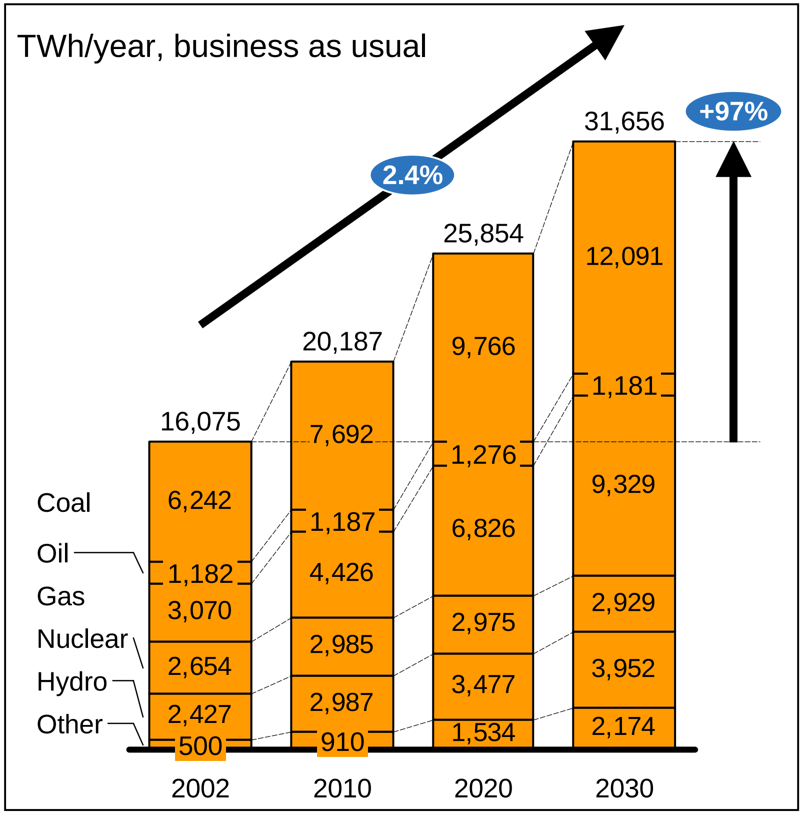
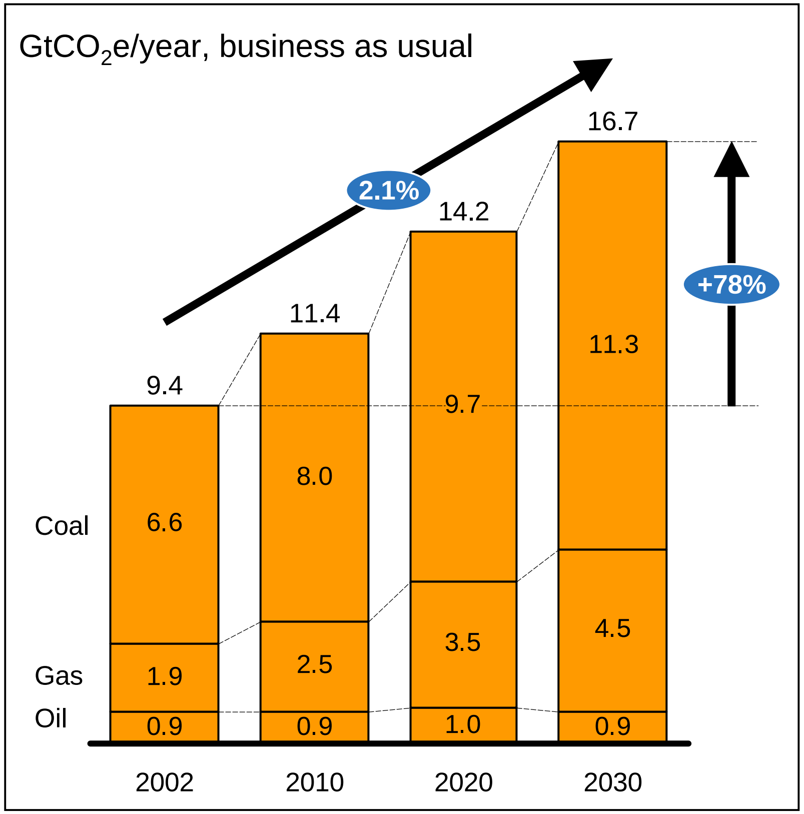
BAU development in the power sector

Power production



Emissions*



- **BAU power production will grow with 2.4% p.a. leading to a 78% increase of emissions by 2030**
- **China represents 47% of the coal plant growth through 2030**
- **Emissions grow slower than demand; implied decarbonization rate is 0.3%**

* Includes both power and heat production

Source: IEA

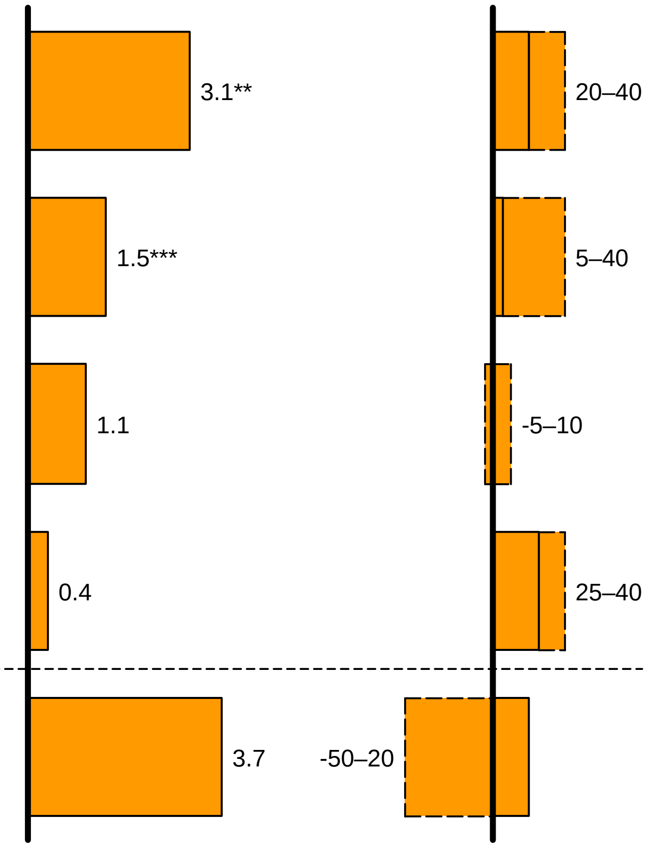
Assumptions for technology deployment in abatement scenario

Assumptions

- **Nuclear** power rolled out aggressively after 2020, doubling 2002's capacity by 2030 in absolute terms
- Emerging **renewable** technologies deployed at high pace, reaching 15–20% of power production by 2030
- **Fossil fuel-based power production** approximately constant in absolute terms at today's level, share of **coal vs. gas** ultimately determined by fuel price development and cost of CCS

Key power sector abatement potentials

	Description	Abatement potential* $GtCO_2e$, 2030	Abatement cost**** EUR/tCO_2e, 2030
Carbon capture and sequestration	• Assumed technologically proven by 2015–2020; volumes assumed to ramp up 2015–2020 reaching an implementation rate of ~85% of coal new-builds 2020–2030 • Abatement cost assumed to decrease to 20–30 EUR/tCO_2e for new-builds by 2030, more expensive for retrofit and gas/biomass applications	3.1**	20–40
Renewables	• Cost of wind power is assumed to decrease driven by learning curve effects, becoming cost competitive by 2015–2025 at 40 EUR/tCO_2e • Solar could be cost competitive at 40 EUR/ton by 2030 in some specifically attractive locations/applications, but is a minor share of the total renewables potential • Emerging renewables assumed to amount to 15–20% of power production by 2030 • Cost of biomass power production highly dependent on availability of cheap feedstock	1.5***	5–40
Nuclear	• Proven technology • Moderate cost improvement assumed driven by increased standardization • Volume development driven by political decisions; assumed in this scenario to approximately double in absolute volume through 2030	1.1	-5–10
CO_2 efficient fossil sources	• Incentivize gas power production instead of coal • Replace old plants with newer, more efficient • (Technological efficiency "creep" in coal and gas assumed to happen in BAU and is not seen as an additional potential)	0.4	25–40
Demand reduction	• Increased energy efficiency in buildings and industry • Impacts power sector emissions through reduced production, even though action is taken in other sectors • Abatement cost is generally low in the buildings sector and higher in industry	3.7	-50–20



* Below 40 EUR/tCO_2e
** Including CCS on biomass plants
*** Including co-firing of biomass in coal plants
**** Varies across regions

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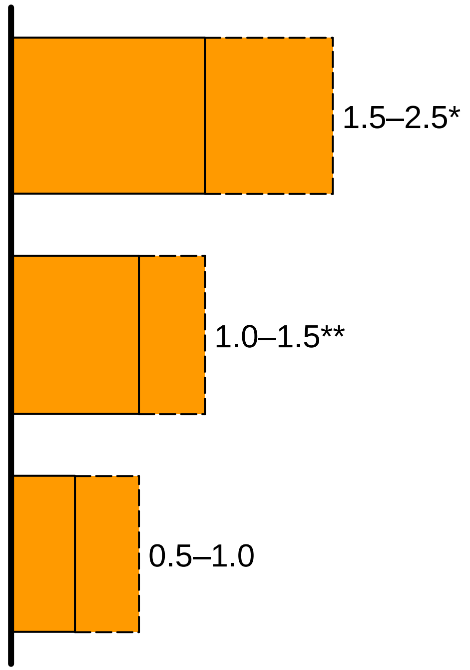
Additional abatement opportunities in the power sector at higher cost than 40 EUR/tCO2

Additional opportunities

Additional abatement potential between 40 and 60 EUR/t CO_2e
Gt CO_2e

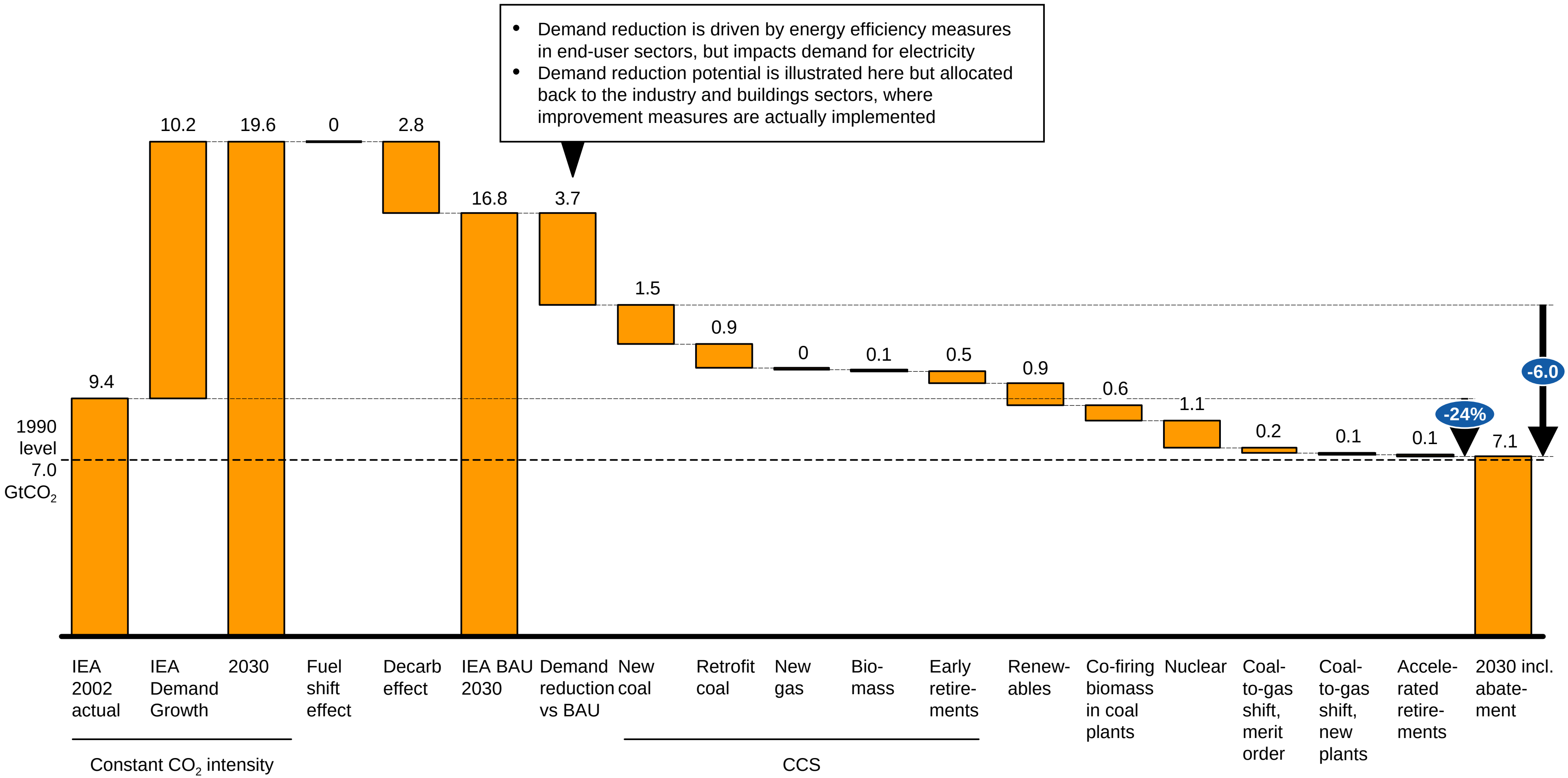
1. **Further carbon capture and storage**
   - Retrofitting of CCS on existing coal, gas and biomass plants
2. **Renewables**
   - Larger penetration of intermittent renewable energy sources possible if incentives become more attractive
   - Co-firing rate in coal plant could rise to 25% or more if CO_2 price make imported biomass from southern hemisphere profitable
3. **Further increased CO_2 efficiency**
   - Close-down or refurbishment of old plants increasingly profitable



* Assuming 100% penetration of CCS in industrialized countries and 50% in developing after 2020; retrofit also on small coal and gas plants
** 25-30% penetration of wind power in all regions, increased co-firing (also in plants with CCS)

Emissions from power sector and abatement opportunities

Gt CO_2e

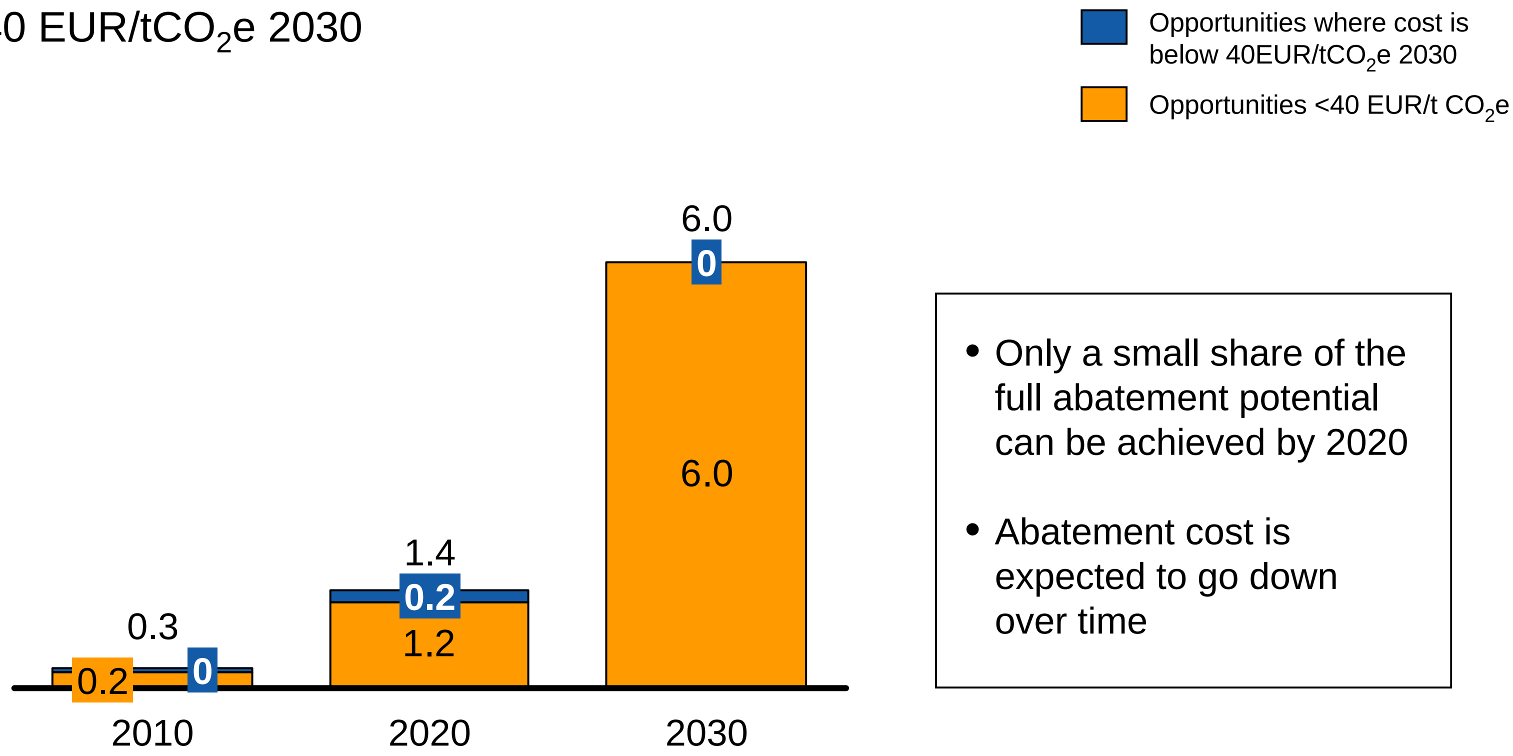


- **2030 emissions from the power sector could be reduced below current levels in an aggressive abatement scenario**
- **Total abatement potential is 6.0 $GTCO_2e$, from additional measures taken in the power sector itself**

Source: IEA

Development of power sector abatement opportunities over time

$GtCO_2e$, below 40 EUR/tCO_2e 2030



- Only a small share of the full abatement potential can be achieved by 2020
- Abatement cost is expected to go down over time

	2010	2020	2030
Average abatement cost EUR/t CO_2e	50	25	19

Detailed timeline of abatement opportunities in the power sector

$GtCO_2e$ per year

BACKUP

Abatement measure	2010	2020	2030	Accumulated 2030
Demand reduction	0.4	1.8	1.5	3.7
CCS on new coal plants	0.0	0.1	1.4	1.5
CCS coal retrofit	0.0	0.2	0.7	0.9
CCS on new gas plants	0.0	0.0	0.0	0.0
CCS on biomass	0.0	0.0	0.1	0.1
CCS on early retirements	0.0	0.0	0.5	0.5
Renewables	0.1	0.3	0.5	0.9
Co-firing biomass	0.0	0.0	0.6	0.6
Nuclear power	0.0	0.4	0.7	1.1
Coal-to-gas shift, merit order	0.2	0	0.0	0.2
Coal-to-gas shift, new plants	0.0	0.1	0.0	0.1
Accelerated retirements	0.0	0.0	0.1	0.1
Total @40 EUR/tCO2	0.3	1.1	4.5	6.0
Share of total impact realized	6%	32%	100%	-

- **Most abatement opportunities at below 40 EUR/tCO_2e are implemented when old assets are shifted out and replaced**
- **Long construction/planning time and long life time of assets contributes to lead time for abatement**
- **The majority of the abatement opportunities in the power sector are not realizable until after 2020**

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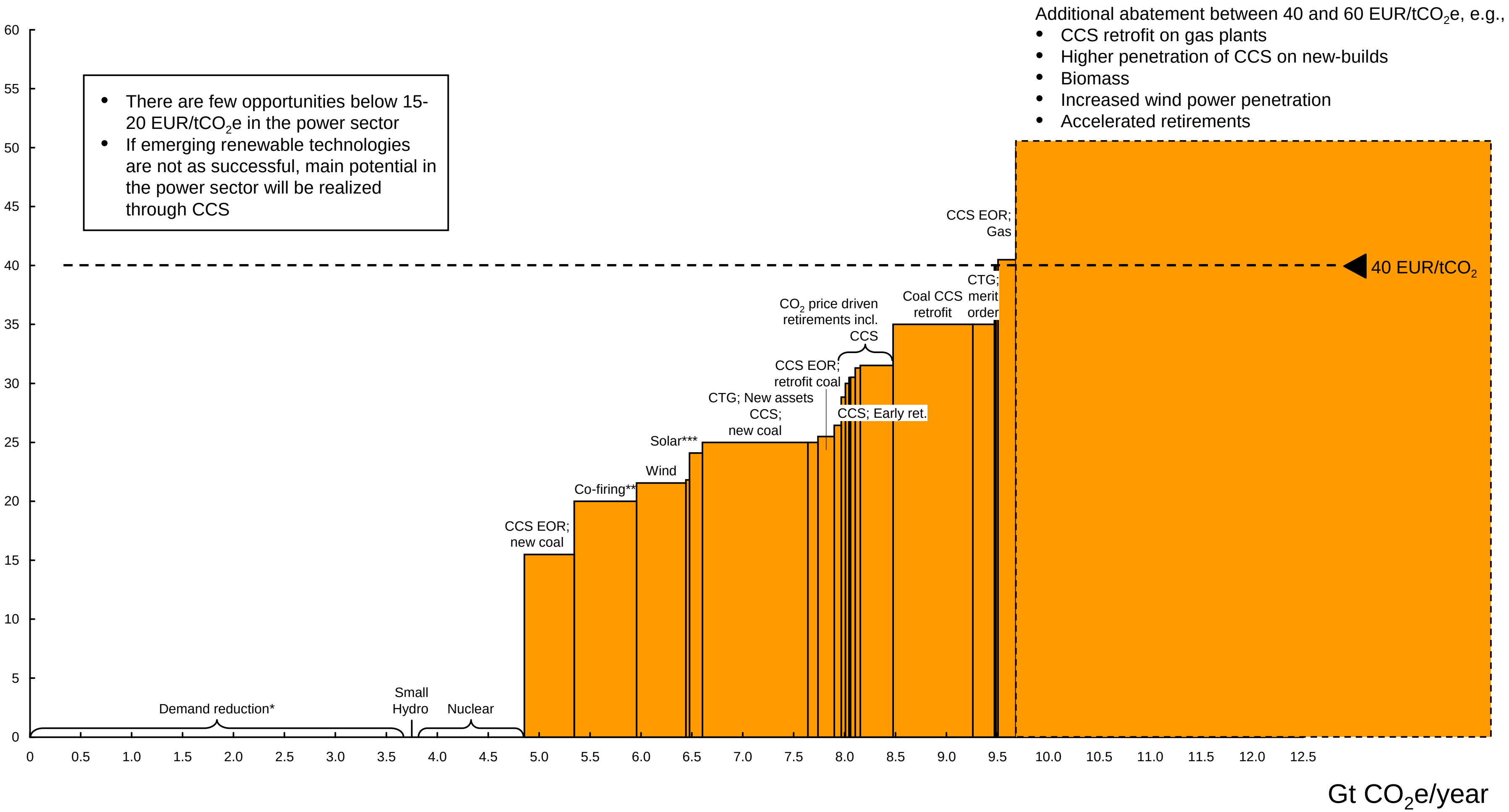
Marginal abatement cost curve for the power sector by 2030

EUR/t CO_2e, by 2030



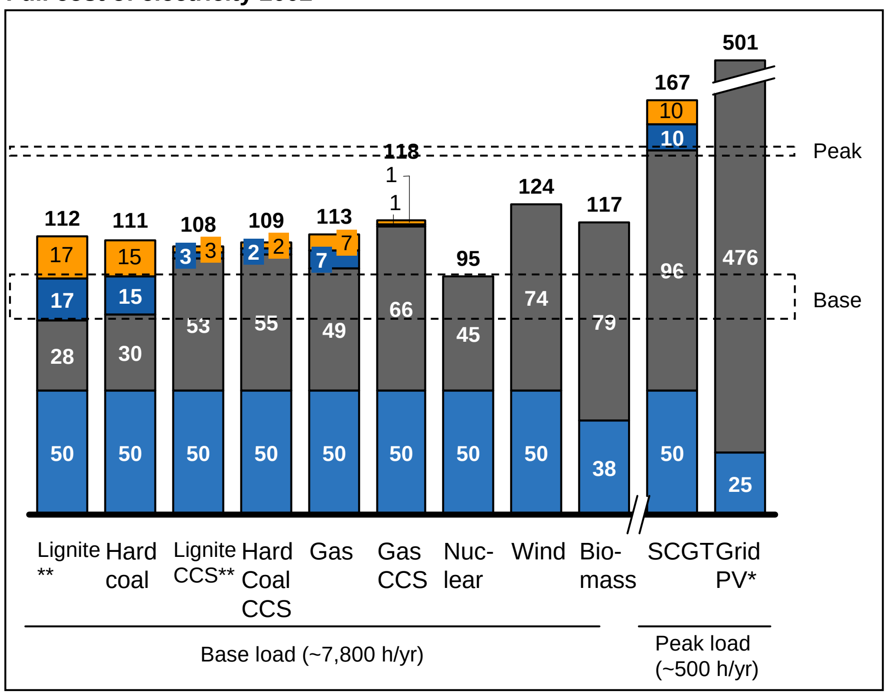
* Demand reduction is not zero cost but allocated rather to respective sector
** In coal plants both with and without CCS
*** Potential represents where electricity demand is heat-peak coincident; under different circumstances, solar power is significantly more expensive

Assumed cost development of key power generation technologies

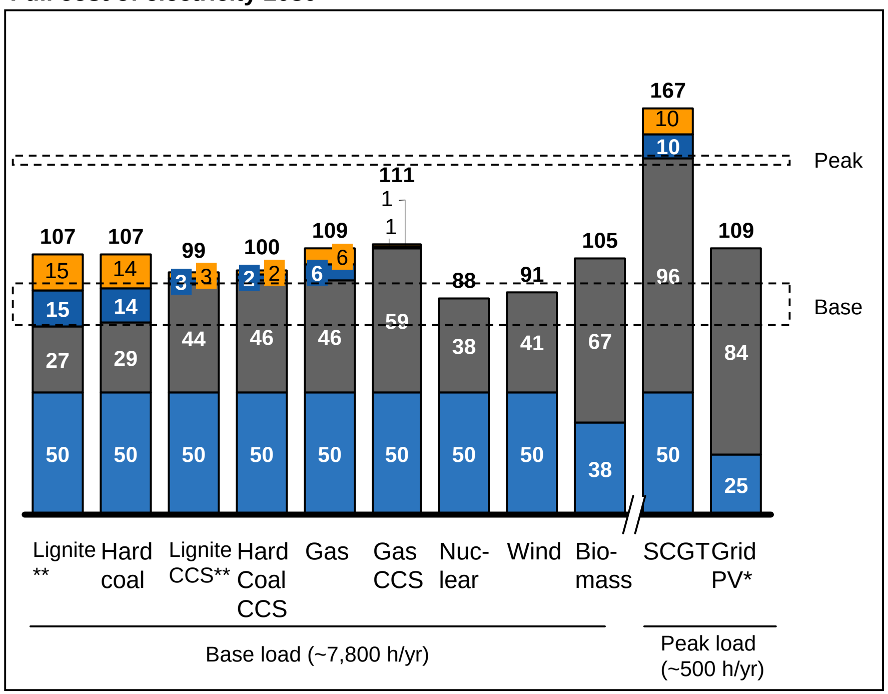
EUR/MWh including depreciation of capex

40 EUR/tCO_2
T&D
Full production cost
20 EUR/tCO_2
Reference cost @0 EUR/tCO_2

Full cost of electricity 2002



Full cost of electricity 2030

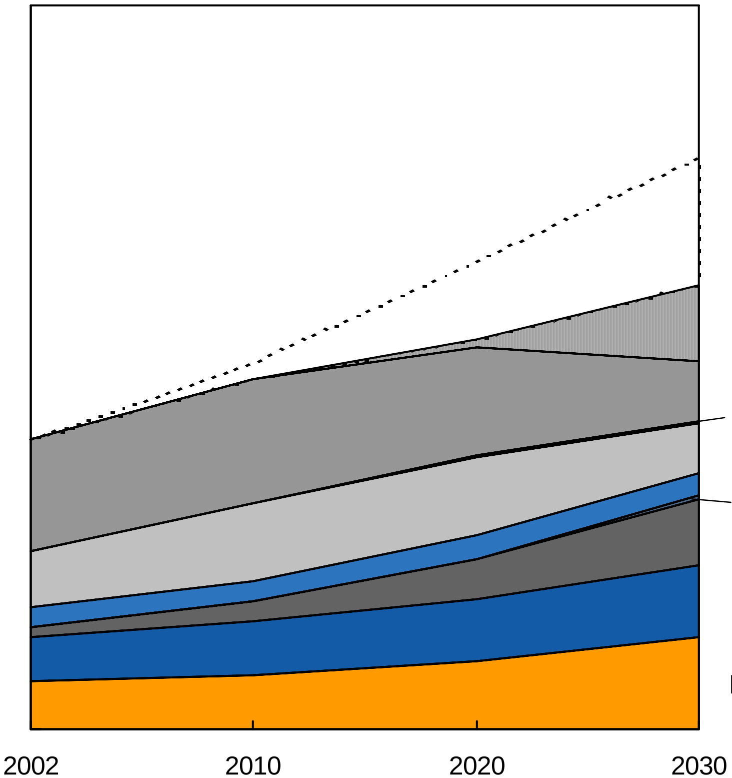


- **Nuclear assumed cost competitive vs. CCGT by 2030**
- **For renewables, only wind and biomass (in some regions) is close to competitiveness as baseload**
- **Cost development for CCS is a key uncertainty; shifts attractiveness of coal vs gas**

* Solar power is considered peak load technology in heat peaking regions
** Site specific, and hence not used as reference plant

Power production development over time in the abatement scenario

Power production by technology @ 40 EUR/ tCO_2
TWh



	Share of BAU power production 2002	2030
Demand reduction	0	n/a
Coal CCS	0	17
Coal	39	14
Gas CCS	0	~0
Gas	19	11
Oil	7	5
Biomass CCS	0	1
Renewables	3	15
Hydro	15	16
Nuclear	17	21

Key assumptions

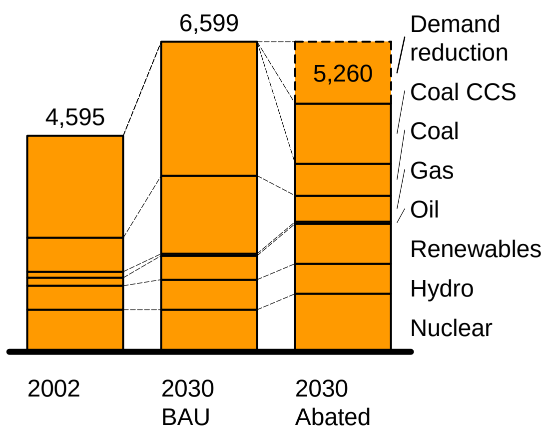
- **Demand reduction**
  - Electricity demand growth reduced from 2.5% p.a. to 1.3% p.a.
- **Coal vs. gas**
  - No strong coal to gas shift assumed due to security of supply concerns for petroleum of major coal-using nation (China, India, US)
- **CCS**: Deployment ramping 2015-20 to regional shares of new-builds after 2020:
  - 100% for US, EU, and other industrials
  - 75% for China and Eastern Europe
  - 25% for Developing countries
- **Oil**: Peak technology, assumed to be constant
- **Renewables (including small hydro)**: Subsidy-driven until learning rates makes wind competitive in 2015 (at 40 EUR/ton)
- **Large hydro:** No additional potential beyond BAU; limited by physical constraints
- **Nuclear:** Potentially growing to twice of current installed base until 2030, compared to a constant level in BAU

- **Demand reduction is an important source of emissions reduction**
- **Fast overall growth of nuclear and renewables**
- **Strong growth of CCS**

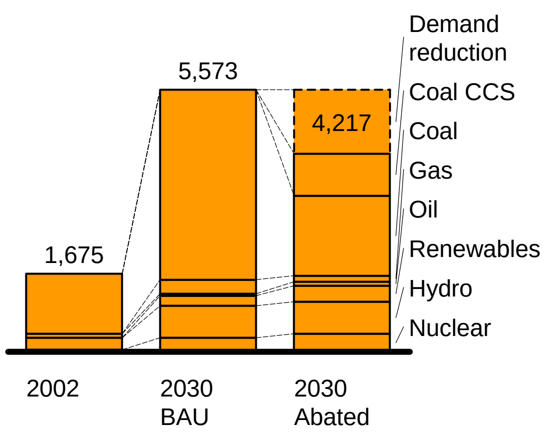
Regional power production break down in aggressive potential scenario

BACKUP

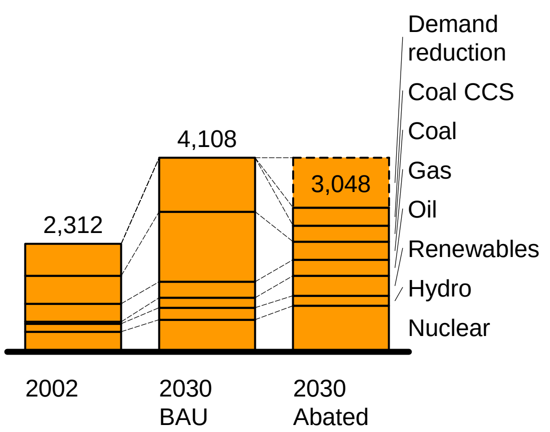
US + Canada



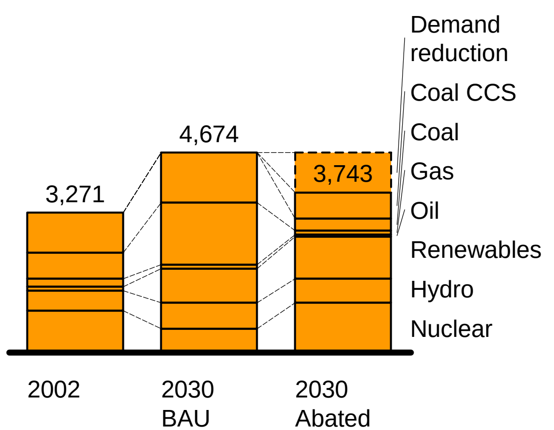
China



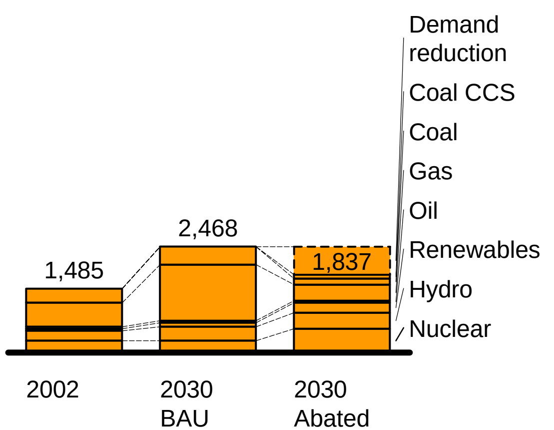
Other industrialized countries



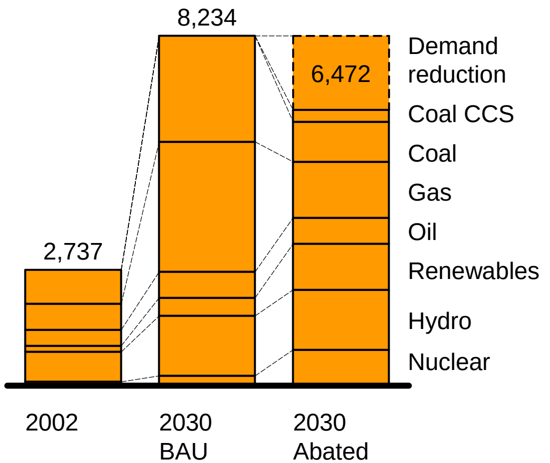
OECD Europe



Economies in transition



Rest of world



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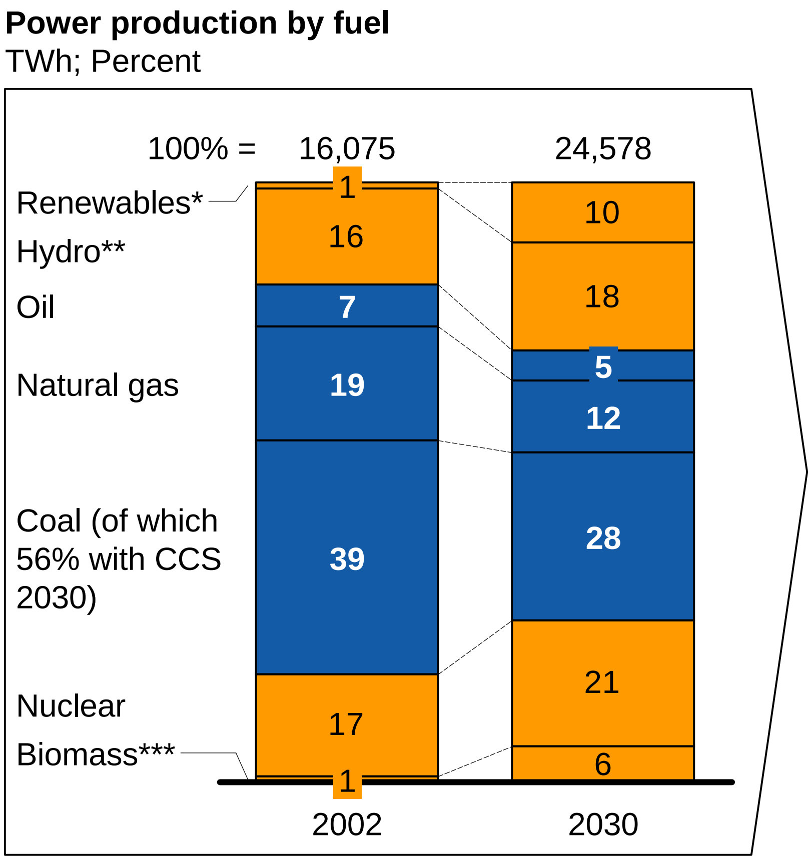
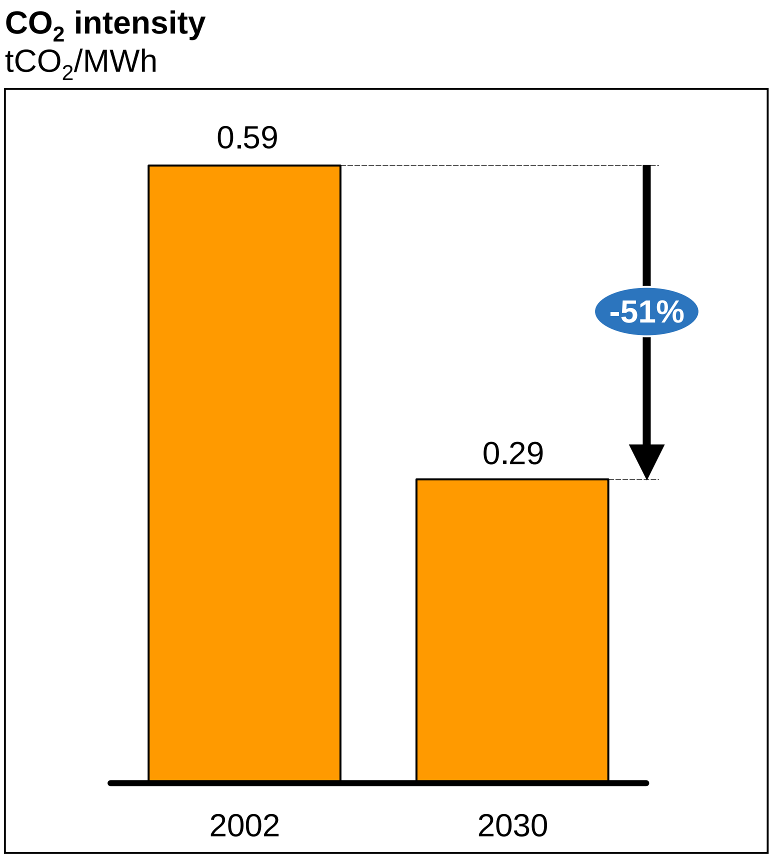
Power production mix development

Fossil



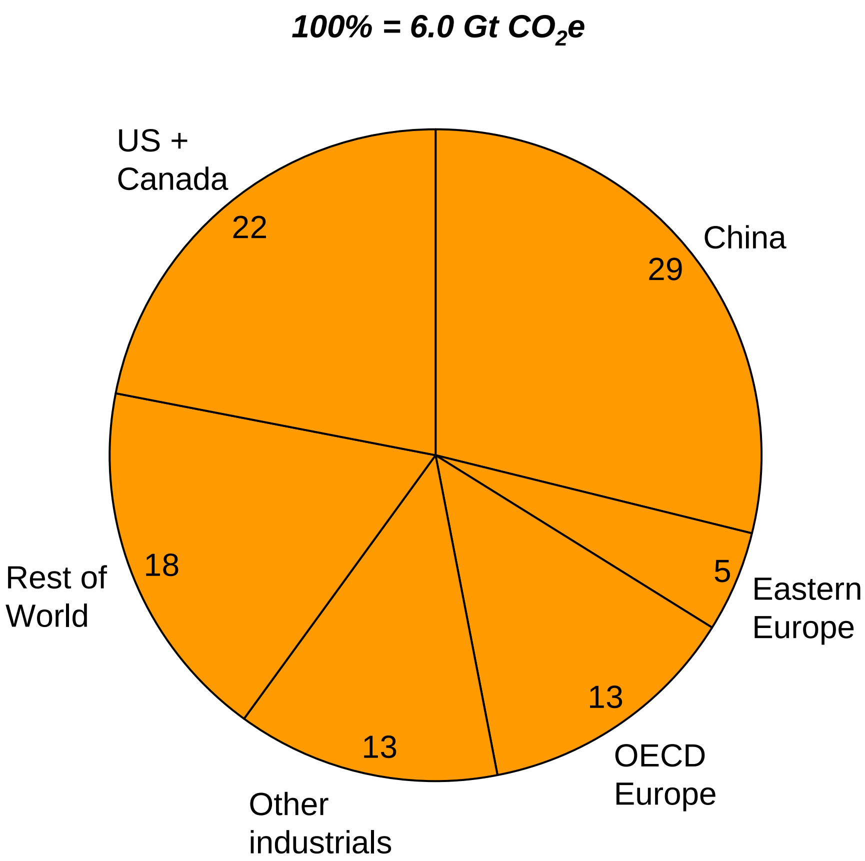


The CO_2 intensity within the power sector would in this scenario decrease with ~50% by 2030

* Does not include small hydro, biomass or cofired biomass
** Includes both big and small hydro
*** Includes also biomass cofired in coal plants

Regional split of power sector abatement opportunities

2030, Percent, below 40 EUR/tCO_2e



Most of the power abatement opportunities are in China and US, due to high projected growth of fossil fuel power production in baseline

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Content

Key messages – Carbon Capture and Storage

- The individual technologies in the CCS process are available but not proven at scale; several pilots have been initiated and the technique could potentially be broadly introduced at commercial scale around 2020
- Near-term cost of abatement with CCS on a new coal plant is estimated by several external sources to be 25–40* EUR/tCO_2e, and is in our model assumed to decrease to 20–30* EUR/tCO_2e by 2030 (CCS on gas plants and as retrofitting is more expensive); this future cost development is a key uncertainty for the future emissions and technology base of the power sector
- The main potential is in introducing CCS in new coal plants, but given the lead time of commercialization, this potential is limited to 1.5 GtCO_2e by 2030; an additional potential of 1.0 GtCO_{2e} per year is available through gas plant CCS and retrofitting of old plants but is not nearly as cost effective – it would likely cost 5–20 EUR/tCO_2e more than for a new-build
- In addition to traditional fossil power plants, CCS could as an option be applied to biomass power plants, creating a net sink of CO_2 emissions corresponding to an abatement of 0.1 GtCO_2e by 2030 – the specific cost of CSS is similar to that for a coal plant, hence lowering the total abatement cost for the integrated biomass plant
- The availability of storage seem to be sufficient to meet storage demand for the foreseeable future, but legal/regulatory issues remain to be solved
- In our model, ramp-up volumes of CCS are assumed 2015–20, and large-scale deployment from 2020
  – 100% in OECD countries
  – 75% in other industrialized + China
  – 25% in other developing countries
- Thus, CCS is a crucial abatement technology but requires initial innovation support to be rolled out quickly

* Cost of abatement is calculated comparing a new plant with CCS to a new plant of same technology without CCS

Components of Carbon Capture and Storage (CCS)

	Capture	Transportation	Storage
Description	• There are three emerging technologies for CCS capture but they are not fully mature and none have been implemented large scale – Post-combustion (can be added when plants are repowered) – Pre-combustion – Oxy-fuel	• Technologies for CO_2 transport are mature and commercially available – Pressure pipelines – (Shipping, e.g., LPG, above for long distances or off-shore storage)	• Two main storage alternatives – Storage in aquifers (on-shore and off-shore) – Enhanced oil and gas recovery • Long term leakage risk not fully understood and might lead to requirements to monitor storates
Assessment	• Cost improvement driven primarily by innovation; estimated to be ~13% per doubled capacity • Near-term capture only cost for new coal plants estimated at 15–30 EUR/tCO_2 and 20–45 EUR/tCO_2 for gas plants • Near-term cost of retrofitting of coal plants estimated at 25–50 EUR/tCO_2 • Future cost for coal plant estimated at ~10–20 EUR/tCO_2, and 15–20 EUR/ tCO_2 for gas plants	• No significant cost reduction is expected • Transportation cost is mainly volume driven	• Underground storage; 1–3 EUR/ tCO_2 • Globally, underground storage for up to 10,000 GtCO_2 available, corresponding to 200-2,000 years worth of storage • Storage is abundantly available, within 500–1,000 km, typically corresponding to 2.5–5 EUR/t CO_2, but remain to be validated • Regulatory framework for storing CO_2 under ground not formalized

- **Key individual CCS components are all largely mature but there is a need for full scale integrated pilot plants to prove the technology**
- **Regulations for storage yet unclear**
- **Cost development key uncertainty**

Source: IPCC; Ecofys; EU15; US Gas Technology Institute; IEA; Riahi Rubin, Shrattenholzer; Vattenfall

Main technologies for Carbon Capture and Storage (CCS)

Post combustion

- The CO_2 is separated from the flue gases
- Can be retrofitted to existing coal plants
- Technology can in principle be installed to all plants and industrial applications
- Three methods for separation of CO_2 from the flue gas
  – Absorption
  – Adsorption
  – Membranes (future)
- Coal consumption increased by around 30%*

Pre combustion (IGCC)

- CO_2 is separated from syngas
- Hydrogen is burned in a traditional gas turbine process
- Not suitable for retrofit
- This technology has been used for some time in chemical and petrochemical industry
- Original fuel can be any type of hydrocarbon
- Coal consumption increased by around 20 – 30%*

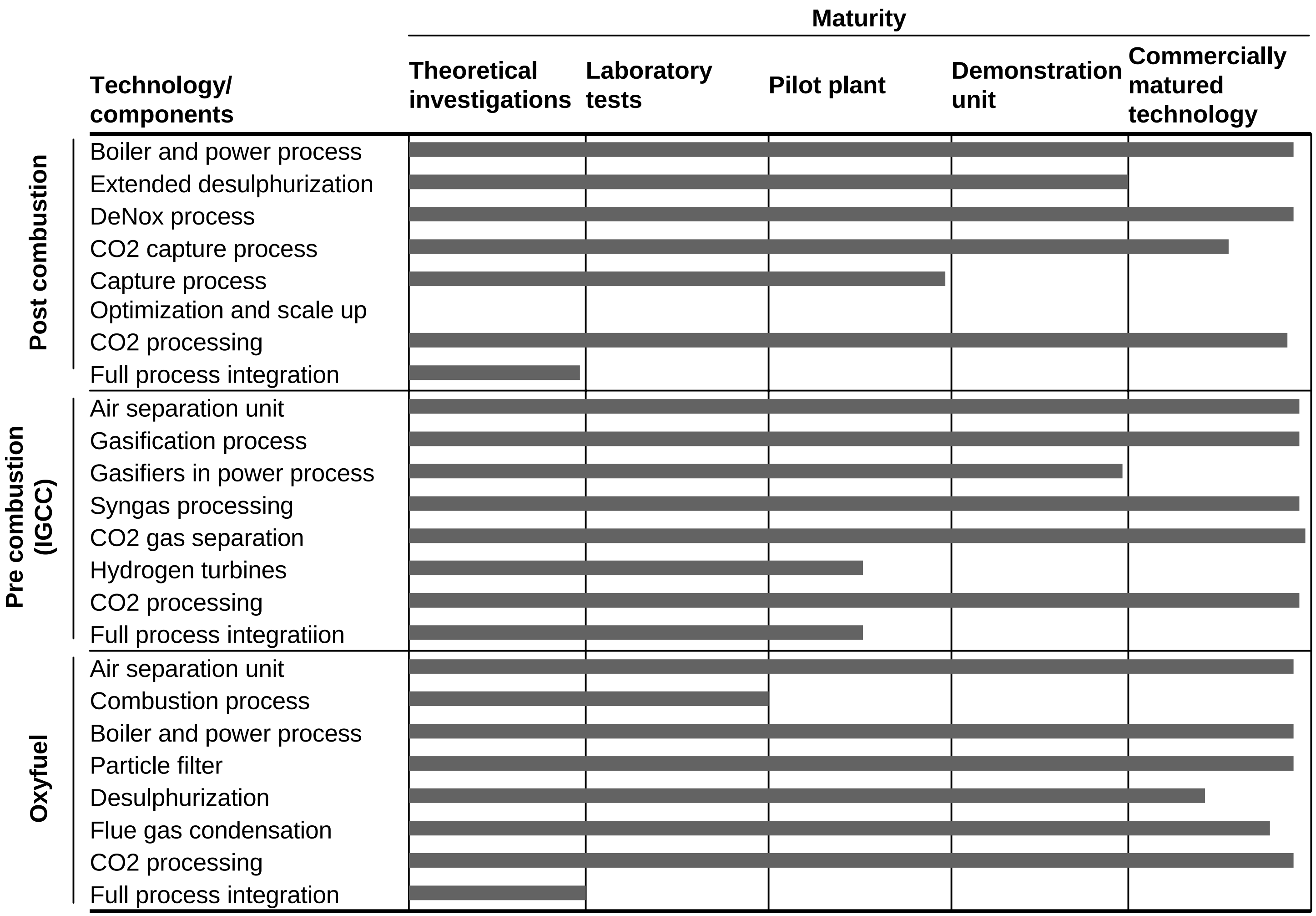
Oxyfuel

- Oxygen is separated from the combustion air
- The fuel is combusted with pure oxygen instead of air
- Flue gas consists of close to pure carbon dioxide and water vapor, from which the water can easily be condensed, and the CO_2 thus isolated
- Coal consumption increased by around 30%*

- **It is currently impossible to know which of the technologies will come out as the winner**
- **Post combustion is the only technology retrofittable on currently existing coal plants**

* Compared to same technology without CCS
Source: IPCC; Vattenfall

Overview of development status of the three CCS technologies



The Post Combustion capture process needs a reduction in energy use for regeneration and demonstration of full integration and optimization

The Pre Combustion Capture process, needs demonstration plants for process integration and optimization, and an optimized hydrogen turbine

The Oxyfuel Process needs a pilot plant to give design criteria for the combustion process and show if it is technically and economically feasible

CCS is in itself a mature technology but in need of large scale practical system integration

Source: Vattenfall

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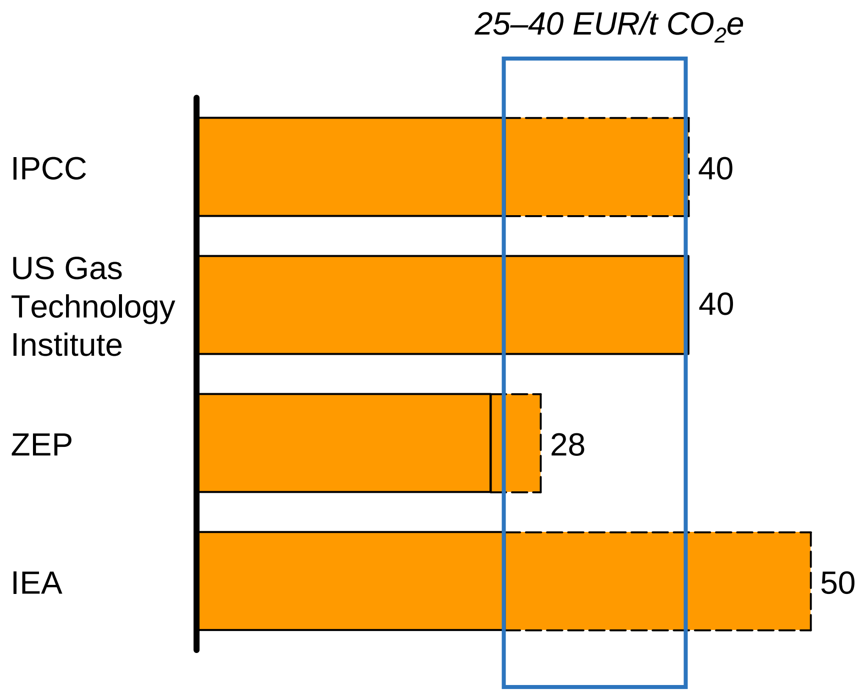
Cost estimates for near-term cost of CCS

Near-term abatement cost for CCS on new coal plants
EUR/t CO_2e



Conducted studies indicate that the near term full cost of CCS most likely will be EUR 25–40/tCO_2e

- It is not yet clear which of the separation techniques will be most cost effective, most sources project IGCC and/or oxyfuel to beat post-combustion, especially for newbuilds
- To repower post combustion CCS on a coal plant is 10–20 EUR/tCO_2e more expensive
- CCS on gas plants is 10–20 EUR/t CO_2e more expensive than on a coal plant

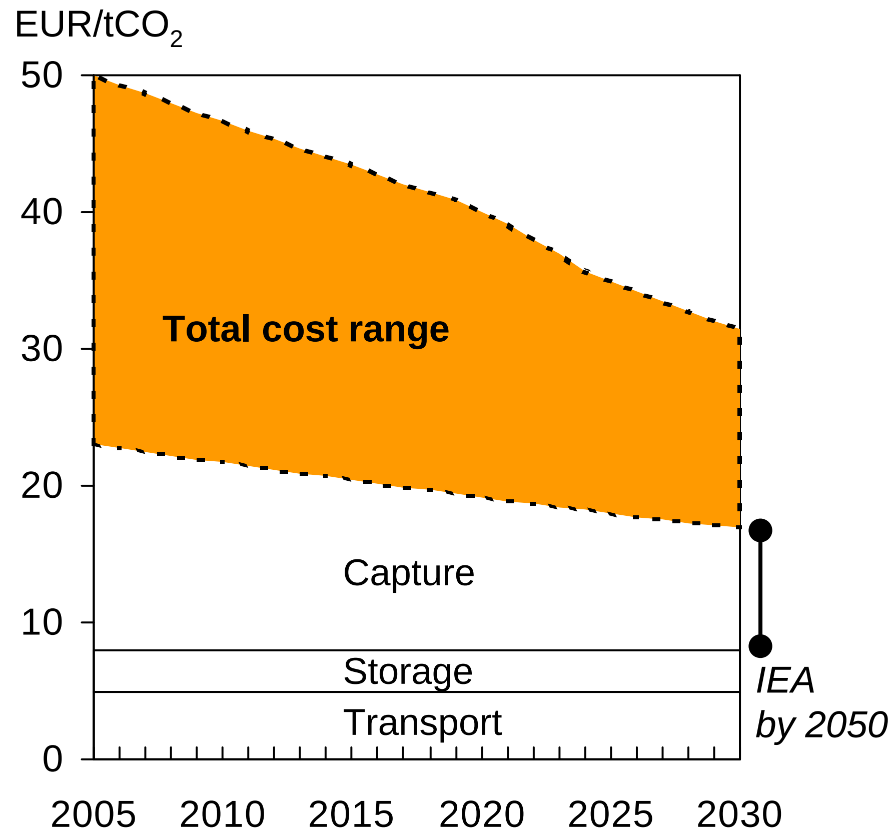
Source: IPCC; Zero Emissions for Power Plants (a collaboration among EU government, NGOs and industry):IEA "Energy Technology Perspectives 2006"

Future cost development of CCS – assumptions

Assumptions on cost development

- Storage and transportation techniques are mature and will not become significantly more effective
- Near-term cost of carbon capture ranges from 15–30 EUR/tCO_2
- Research suggests a learning rate of 13% for the capture process, based on experience from similar technologies (e.g., SO_4 scrubbing)
- Cumulative capture capacity to date adds up to an equivalent to 80–100 GW of coal capacity (including industrial applications), potentially growing to some 1,000 GW by 2030

Abatement cost development for CCS*



In an optimistic deployment scenario, the total cost of CCS could go down to 20–30 EUR/t CO_2 by 2030

* Assuming volume development according to evaluated scenarios

Source: IPCC; Ecofys; EU15; US Gas Technology Institute; IEA; Riahi; Rubin; Schrattenholzer (2003); European Commission

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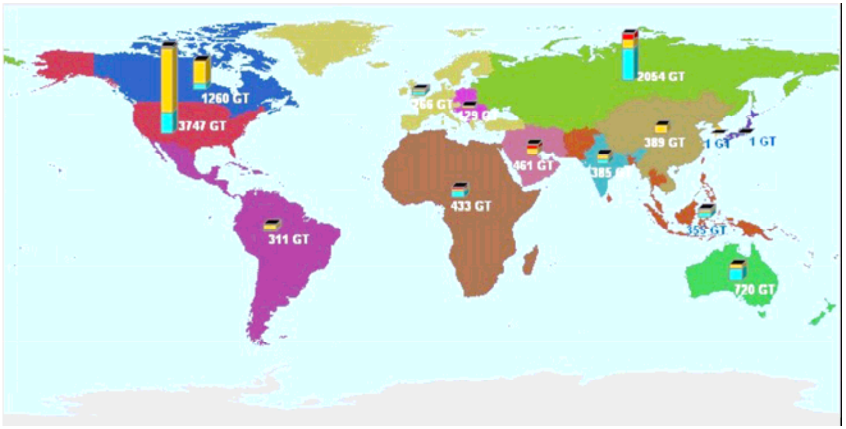
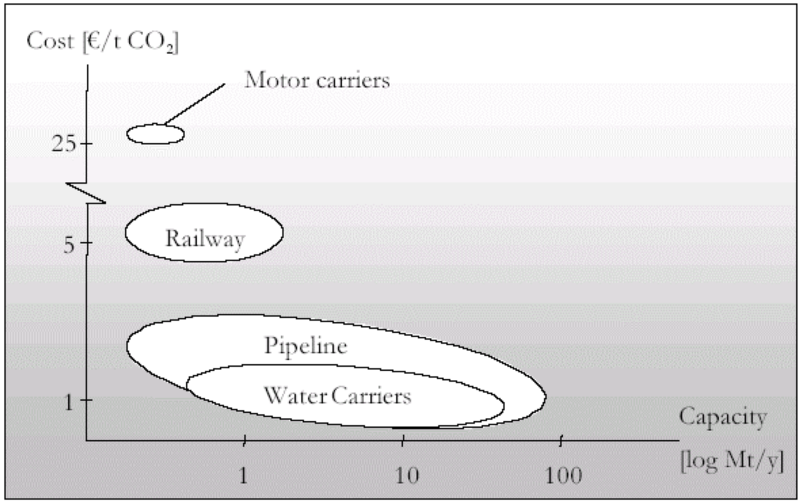
Storage and transport of CO_2

Available underground storage*
Gt CO_2



Source: Joint Global Change Research Institute

Transportation cost
Gt CO_2

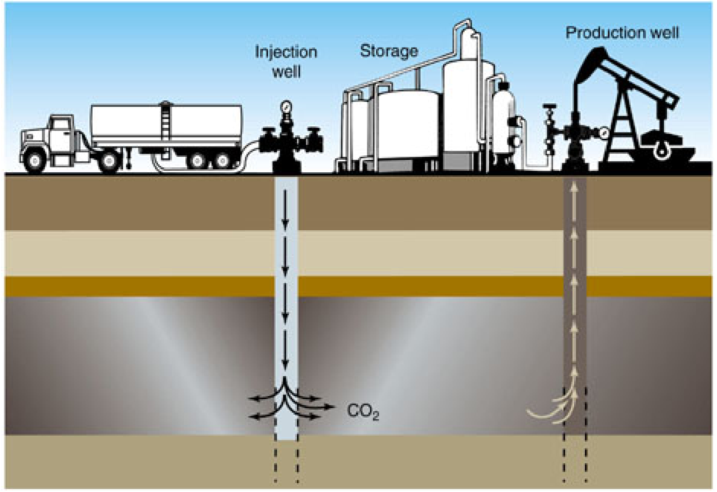


Source: Odenberger M, Svensson R, Analysis of Transportation Systems for CO2, Chalmers, 2003

- **Storage seem to be available in all regions of the world, possibly with the exception that China might be short on storage capacity given their large coal growth**
- **The annual storage demand for CO_2 will be 5–10 GtCO_2 by 2030 in an optimistic CCS scenario**
- **The assessed available storage, 2,000–10,000 GtCO_2, is sufficient to store CO_2 corresponding to 200 – 2,000 years' sequestration; this exceeds estimated reserves of fossil fuels**

* Only top-down estimates for some regions
Source: IPCC; Joint Global Change Research Institute; Odenberger M, Svensson R, Analysis of Transportation Systems for CO2, Chalmers, 2003

CO_2 can be used for Enhanced Oil Recovery technologies – basic facts

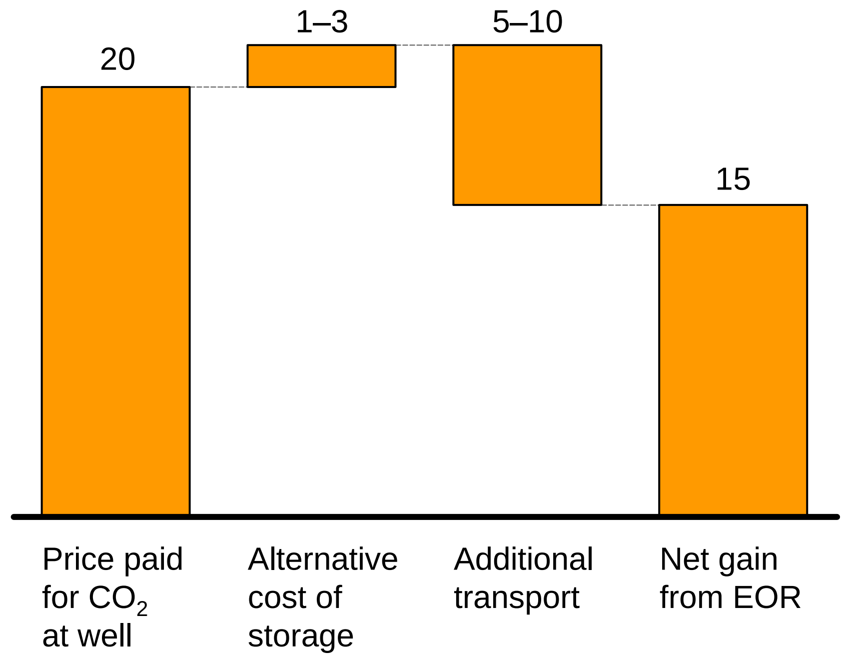


- CO_2-based EOR is a method for increasing total recovery from an average oil field by up to 50% by injecting CO_2 into the oil reservoir to increase pressure and push out additional oil
- CO_2 EOR is an established technology, that has been in use for three decades
  - The technology was developed for oil recovery rather than CO_2 abatement
  - Most CO_2 used comes from natural occurring geologic reservoirs, however new technologies are under development to generate CO_2 from industrial applications, such as natural gas processing, fertilizer, ethanol, and hydrogen plants in locations where naturally occurring reservoirs are not available
- There are currently approximately 100 CO_2 EOR projects operating globally, of which 85 are in the US
  - CO_2 EOR oil production amounts to 206 thousand barrels per day (<50MtCO_2/year), which equals 31% of the total US EOR, or 0.25% of the global oil production

Source: EIA; IEA

Gain and potential for using captured CO_2 for enhanced oil recovery

Economic gain of selling CO_2 for EOR
EUR/tCO_2e; representative ranges*



Assumption on applicability

- EOR could potentially consume 25% of all emissions from coal plants in 2030, according to IEA forecasts
- By 2030, CCS could potentially be installed in ~50% of all coal plants
- With current paid price for CO_2, long distance transport between regions is not economical
- EOR is assumed to be applicable for 50% of all CCS plants by 2030 in Europe, North America, and other industrialized countries, not in other regions
- If paid price for CO_2 at the well increases, however, shipping CO_2, e.g., from China to Middle East suddenly becomes viable

* Actual costs will be varying from one situation to another
Source: EIA; IEA

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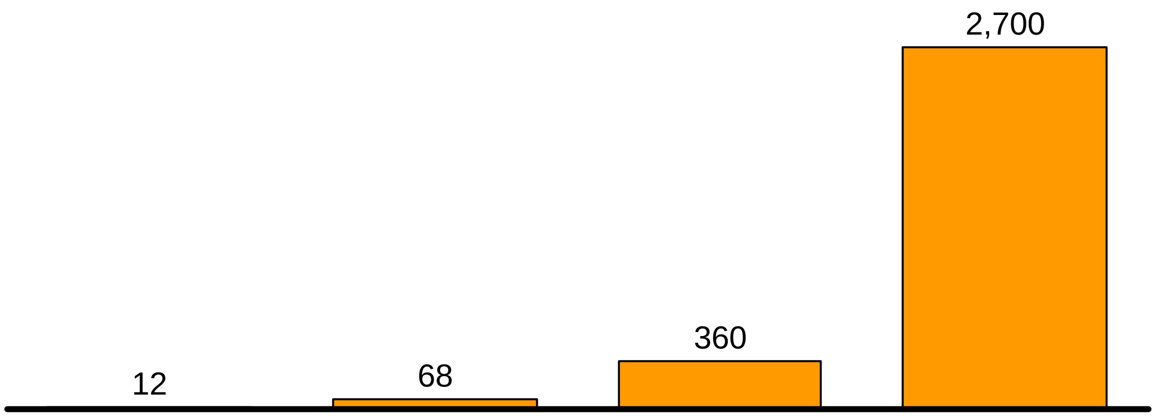
Technical potential for EOR

MtCO2/year of EOR



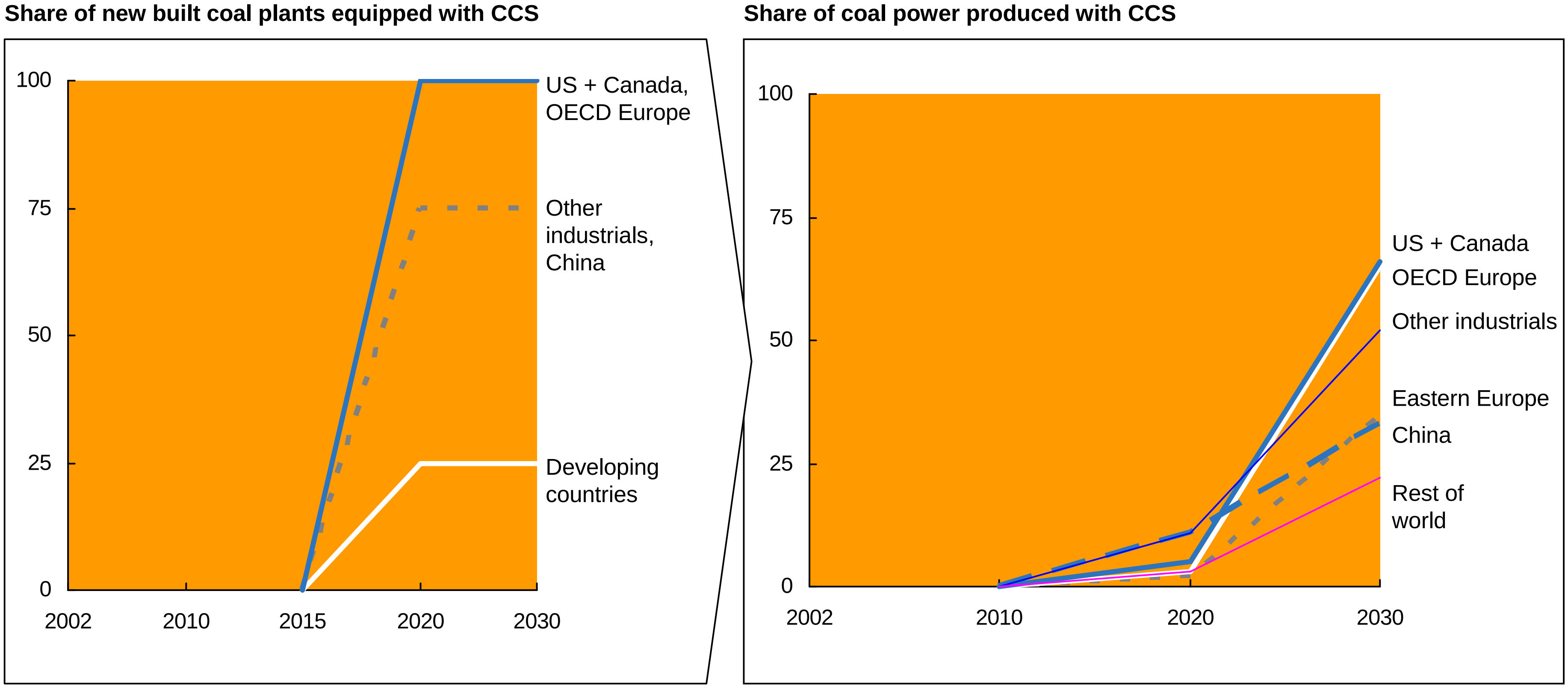
Source and region	Advanced Resources International (Gulf Coast)	Westcarb (California)	Williams (US)	IEA (Global)
Method	Total storage capacity split over 50 years	Total storage capacity split over 50 years	Annual potential over the next few decades	Major potential in Middle East would require high cost CO_2 shipments from major sources of CO_2
Equivalent coal IGCC with CCS capacity in GW	2	13	69	518

- Sufficient global potential to absorb CO_2 from over 500 GW of coal generation (25% of 2030 forecasted coal capacity)
- The technical potential will likely not be limiting for using captured CO_2 for EOR, rather the logistical cost

Source: Advanced Resources International, Westcarb, Robert Williams; IEA

Penetration of CCS in coal assets – assumptions in our model

Percent



A total of 55% of all coal power production could potentially be equipped with CCS by 2030

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Overview

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- Carbon Capture and Storage
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  - Summary
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  - Biomass
- Nuclear
- CO2 efficient fossil sources

Appendix

Key messages – Renewables

- Small hydro, wind, biomass and solar PV currently contribute to 3% of the global power production and could by 2030 potentially grow to 16%, twice the baseline projection from IEA; recent years' growth of, e.g., wind and solar power (25–40% p.a.) has shown high learning rates

- This development would correspond to a total abatement of 1.5 Gton vs. BAU by 2030
  – 1.0 from emerging renewable technologies (wind, solar PV, small hydro)
  – 0.5 from co-firing up to 15% biomass in coal plants

- The historical learning rates of emerging renewable technologies are 5–20% for each doubling of total capacity; in our forecast, we have assumed leaning rates at 80% of the historical rates

- A high share of weather dependent energy sources lead to increased system cost to secure sufficient production to meet demand at all times. These costs have been estimated as a part of the analysis and can be considerable at higher renewables penetration rates

- In addition to a price on carbon, the development of renewables will likely require continued innovation support, particularly for solar PV

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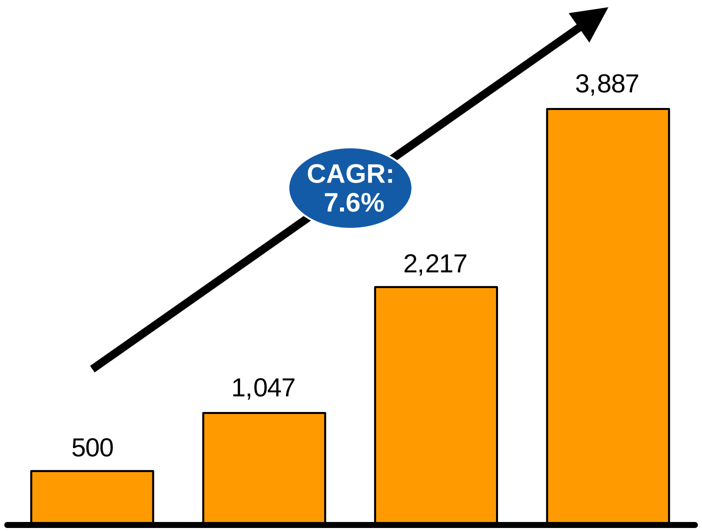
Renewables development in our abatement

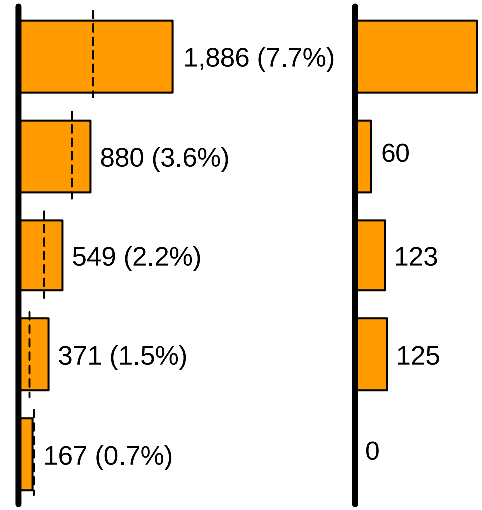
Total power production from renewables



	2002	2010	2020	2030
Total production	16,075	19,343	21,574	24,578
Share renewables	3.1%	5.4%	10.3%	15.8%

Power production per key technology 2030***

----- BAU penetration



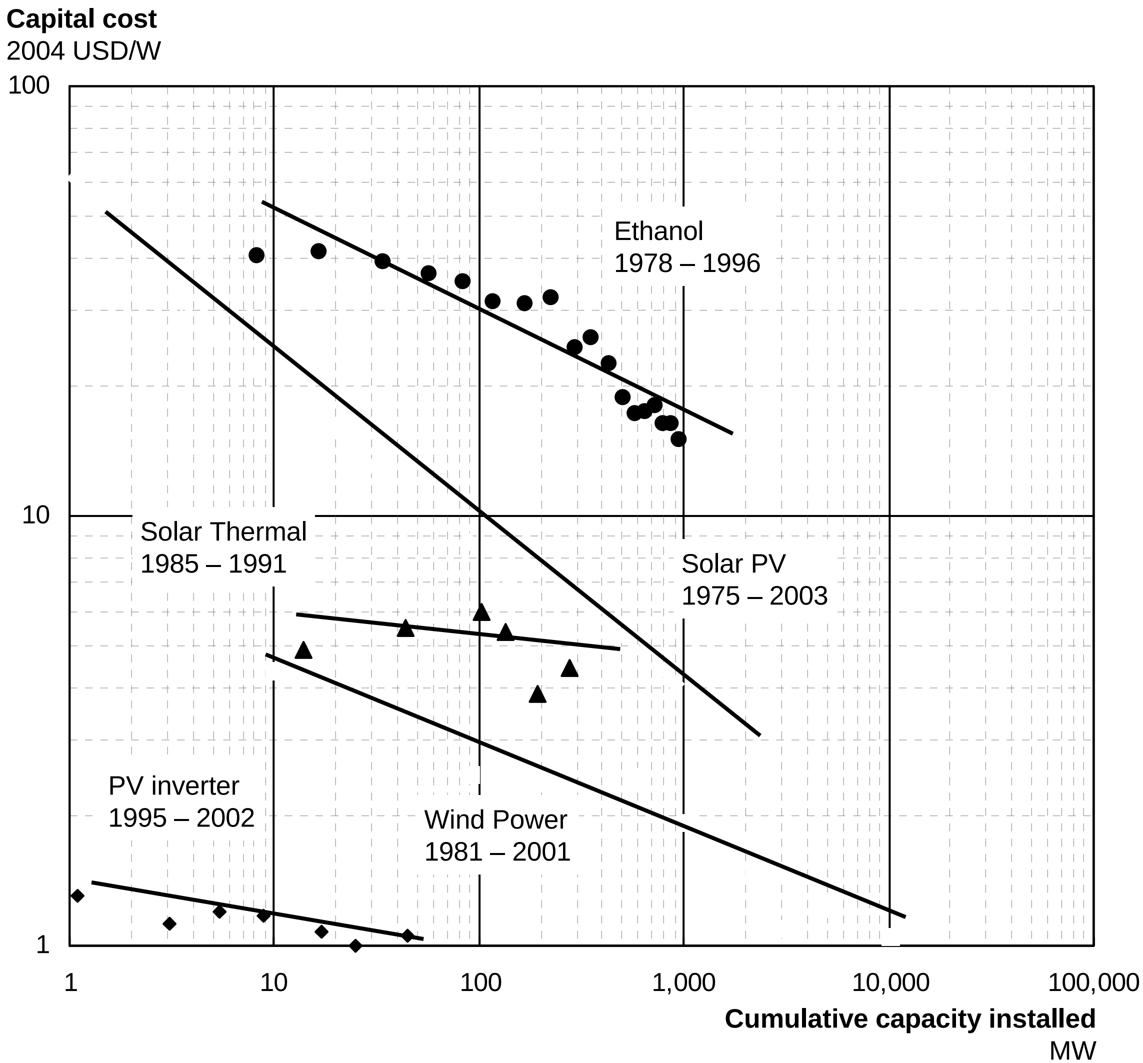
	Power produced TWh (share of total; percent)	**Abatement potential** Mt CO_2e	**Marginal cost** EUR/fCO_2e
Wind	1,886 (7.7%)	485	17****
Biomass	880 (3.6%)	60	~50
Small Hydro**	549 (2.2%)	123	~0
Solar PV	371 (1.5%)	125	24
Geothermal	167 (0.7%)	0	~0

3,887 TWh* = 16% of global production

- **Emerging renewables could contribute to 15–20% of power production by 2030 in an optimistic but realistic scenario**
- **Average abatement cost is ~21 EUR/tCO_2e**

* Includes 33 TWh from other renewable sources, e.g., wave/tidal
** Small Hydro is 7% of all hydro power production
*** In some region technical potential is higher, but limited due to intermittency and security of supply judgments
**** Not including additional intermittency cost due to high penetration
Source: Public reports; IEA, World Energy Outlook 2004

Historical cost development for renewables, and assumptions going forward



- **Historical learning rates (i.e., cost decreases) per doubled cumulative capacity of**
  - **23% for Solar PV***
  - **13% for Wind Power**
  - **15% for Ethanol**
  - **6% for PV inverters**
  - **3% for Solar Thermal**
- **80% of historical learning rates have been assumed through 2030 in our model**
  - **18% for solar PV modules**
  - **11% for wind**
  - **11% for geothermal**
  - **5% for small hydro**
  - **5% for biomass**

* Other sources indicate learning rates as low as 18% for solar PV

Source: UC Berkeley Energy Resource Group; Navigant consulting

Resulting development of full cost for renewable electricity

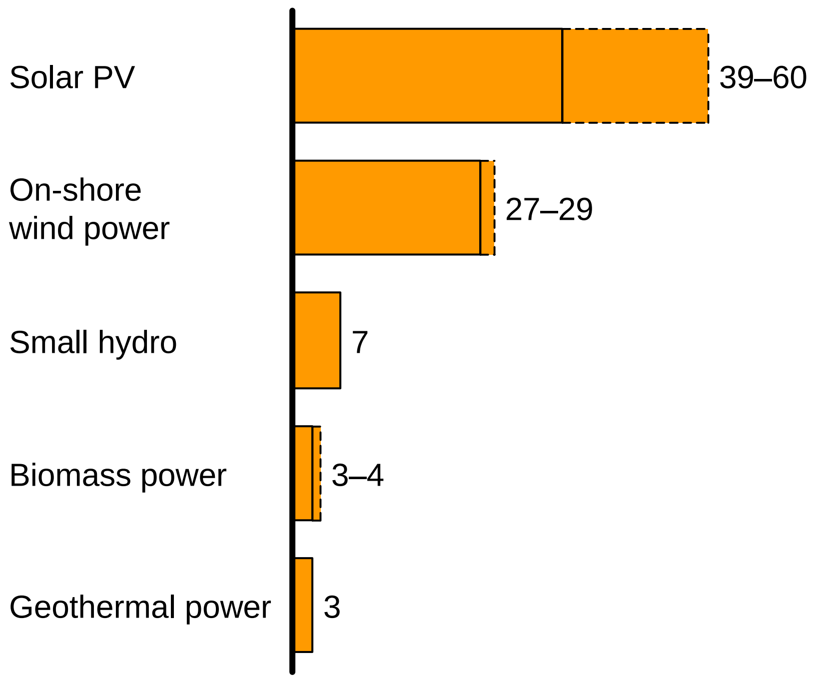
T&D

	Full cost* 2002 EUR/MWh			Full cost* 2030 EUR/MWh			Cost reduction**	Installed base 2002 GW	Installed base 2030 GW	Number of capacity doublings	Assumed learning rate***
	T&D			T&D							
Solar PV	27	469	496	28	82	110	82%	1	446	9.5	18%
Wind power	50	76	126	50	42	92	44%	22	1,089	5.6	11%
Geothermal	38	19	57	38	17	55	10%	8	16	1.0	11%
Small Hydro	38	47	85	38	37	75	21%	49	218	2.2	5%
Biomass	38	79	117	38	67	105	16%	29	136	2.2	5%

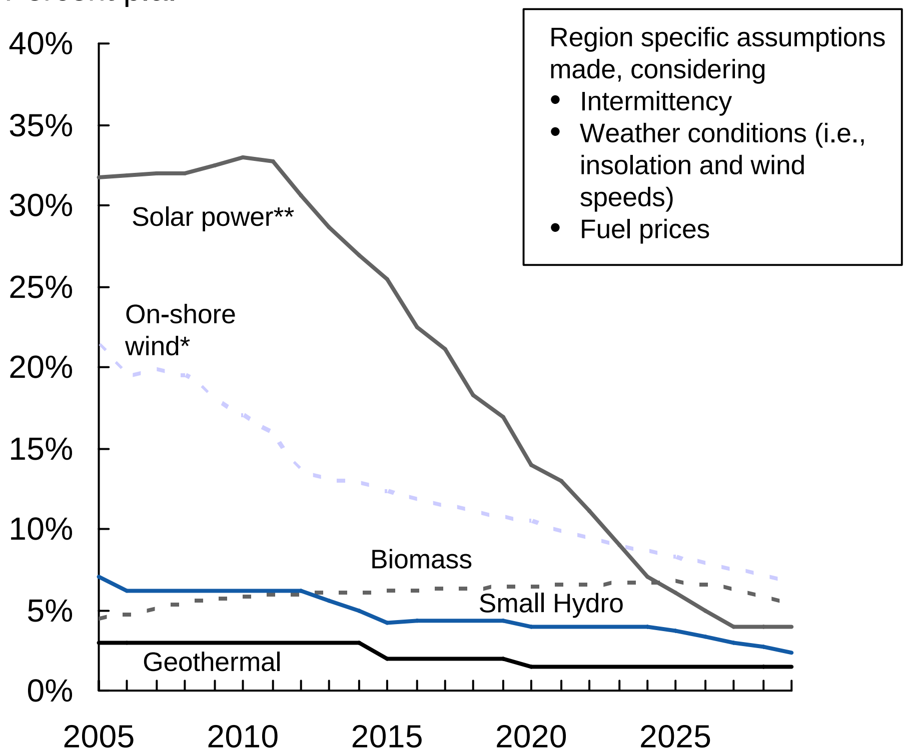
* Global average, not including intermittency cost
** Reduction of electricity generation cost, not including T&D
*** Reduction of full cost for each doubling of capacity

Growth rates of renewable technologies

Historical growth rates for renewables
Percent p.a. 2002–2005



Annual growth rates***
(global average, technical potential)
Percent p.a.

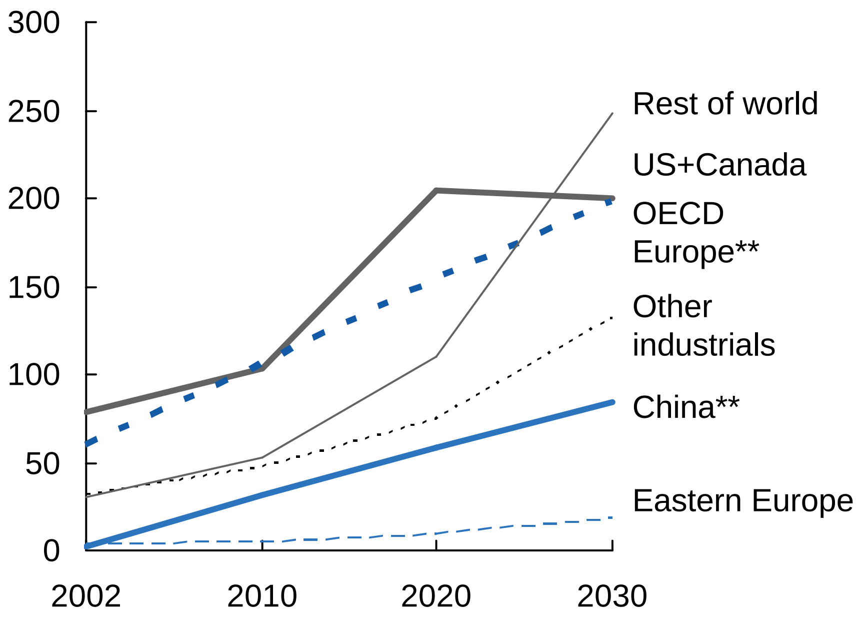


Emerging technologies are assumed to grow at historical or lower rates, except for biomass

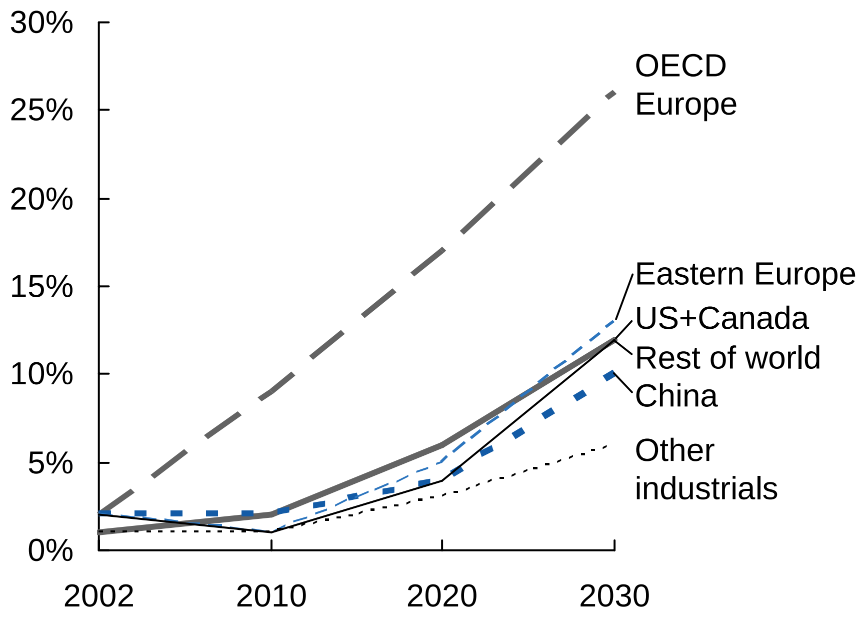
* Forecasted growth by BTM extended conservatively from 2020 to 2030; China's new optimistic wind power targets until 2010 and 2020 incorporated
** Technical industry growth potential as assessed by NREL
*** Region differentiated
Source: BTM; NREL; World Watch Institute (REN21); news clippings

Regional differentiation for renewable technologies – examples

Biomass power production
TWh



Wind power penetration*
Percent of installed capacity



- **Growth in Europe is expected to be constrained by feedstock availability**
- **Developing countries in the southern hemisphere have the opportunity to produce low-cost biomass**

- **Ambitious deployment plans of wind power (based on BTM forecasts) combined with overall demand reduction lead to a high penetration in Europe**
- **Technical potential limited in industrialized countries due to security of supply and intermittency considerations**

* Including effect of demand reduction
** No biomass potential included beyond BAU
Source: BTM Consult

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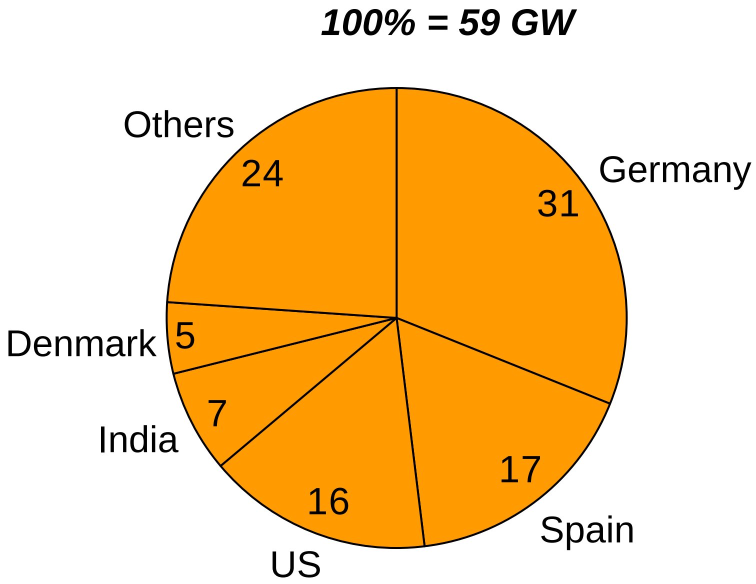
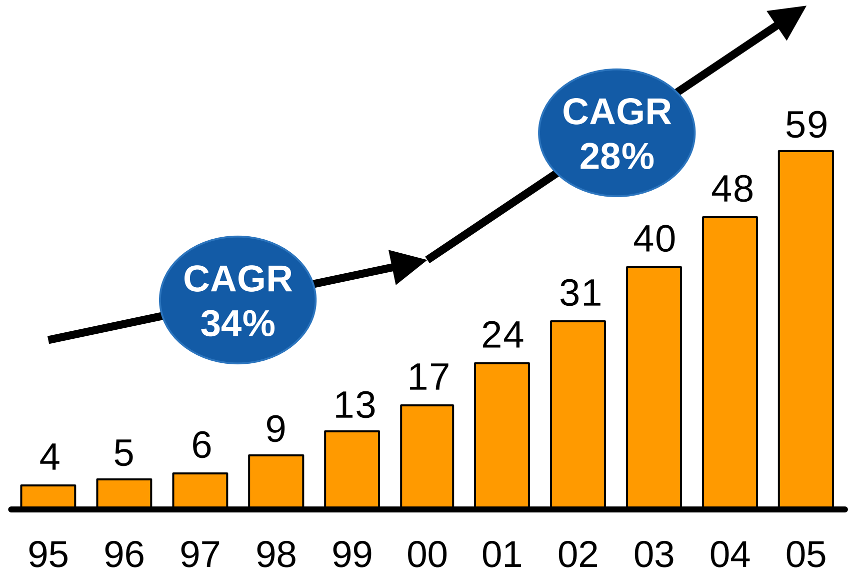
Historical deployment of wind power

Installed base 2005
Percent



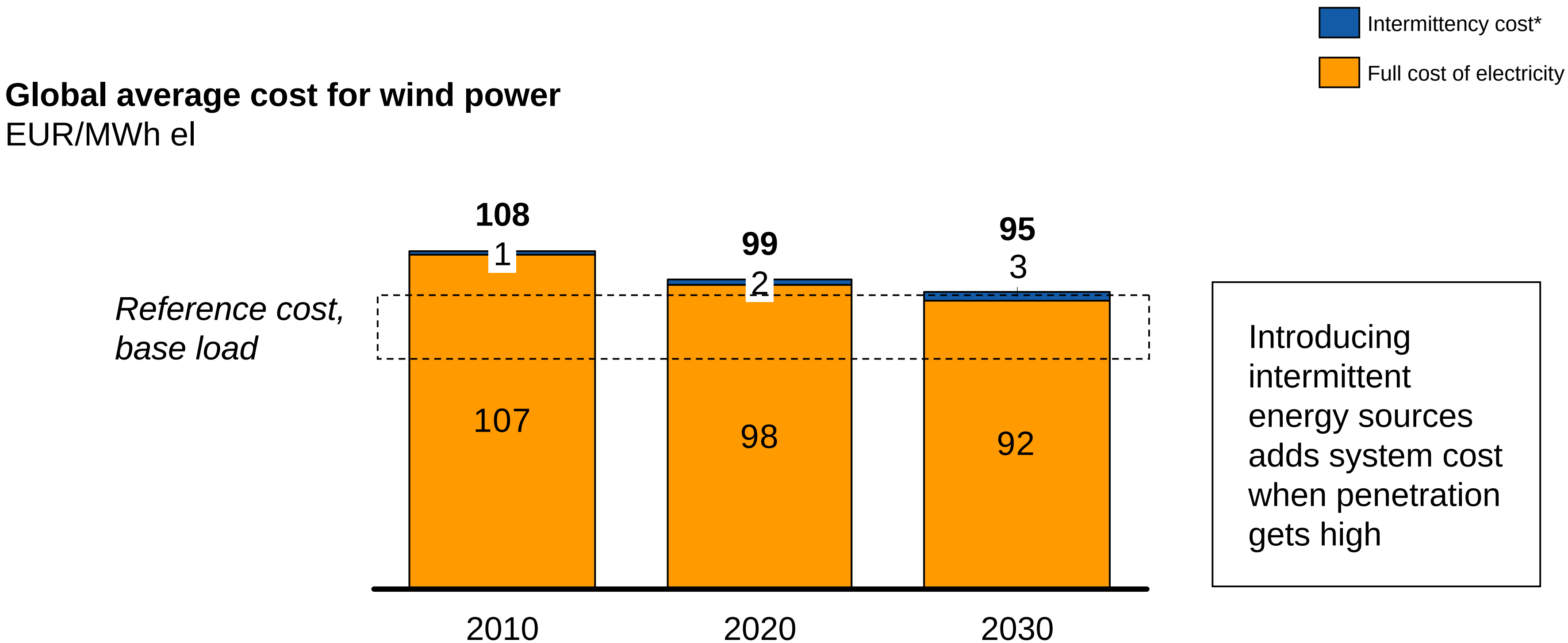
Historical installed base
GW



Wind power has grown rapidly over the last five years

Source: BTM Consult; PV news; Photon International; BP; IEA

Intermittency cost assumptions for wind in our abatement



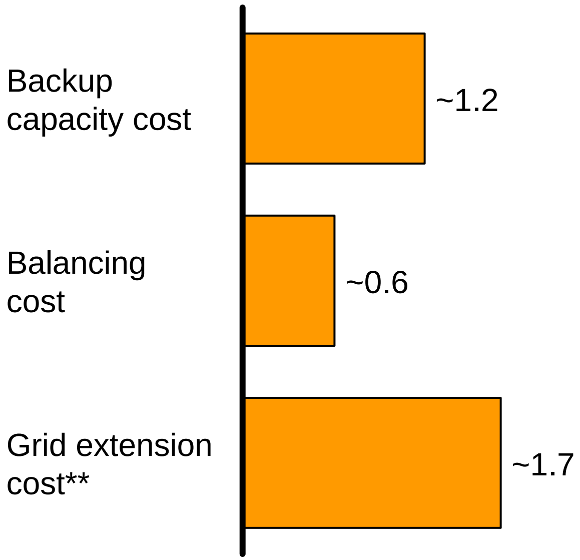
Introducing intermittent energy sources adds system cost when penetration gets high

	2010	2020	2030
Wind penetration**	3%	7%	13%
Total abatement cost EUR/tCO_2e	133	58	22

* Includes both backup capacity cost, balancing cost and grid extension cost; Varies by region with penetration
** Wind power capacity (GW) compared to total capacity (GW)
Source: ITP "Pushing a Least Cost Integration of Green Electricity into the European Grid – Work Package 3"; van Roy et al (2003); ILEX / UMIST (2002)

Components of intermittency cost for wind power

Additional cost
EUR/MWh el
at 20% penetration*



Total 3–4

Description

- Due to the unreliability of the intermittent power sources, 70–80% of the capacity must be backed up with controllable power sources
- Variability in the power output makes load following with backup plants less efficient
- Dimensioning after peak load requires higher infrastructure investment for intermittent power sources

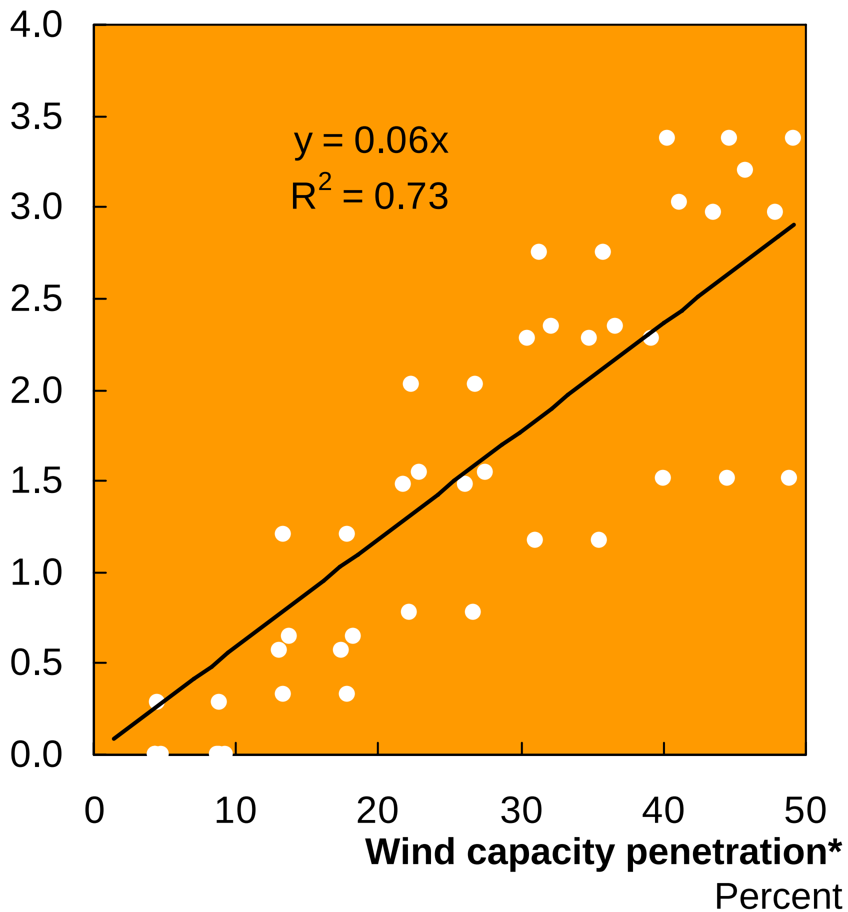
- **Full intermittency cost at 20% penetration is around 3.5 EUR/MWh**
- **There can be a potential of reducing this cost with energy storage or DSM, but has not been considered due to high uncertainties**
- **3.5 EUR/MWh corresponds to 5–10 EUR/tCO_2**
- **Intermittency cost is not considered to be prohibitive for the deployment of renewable energy sources**
- **More detailed studies are required to draw strong conclusions on exact costs**

* Wind power capacity (GW) compared to total capacity (GW)
** Correlates with share of power production; value is for 12% wind production (TWh) of total power production (TWh)
Source: GreenNet

Backup capacity cost

EUR/MWh

BACKUP



- **Backup capacity cost is difficult to measure but has been modelled considering total cost of a system**
- **Modelled results show a clear correlation between penetration rate and backup capacity cost**
- **The backup capacity cost correlates linearly with penetration**
- **At 20% penetration, the backup capacity cost is ~1.2 EUR/MWh**

* Wind power capacity (GW) compared to total capacity (GW)

Source: ITP "Pushing a Least Cost Integration of Green Electricity into the European Grid – Work Package 2"; van Roy et al (2003); ILEX/UMIST (2002)

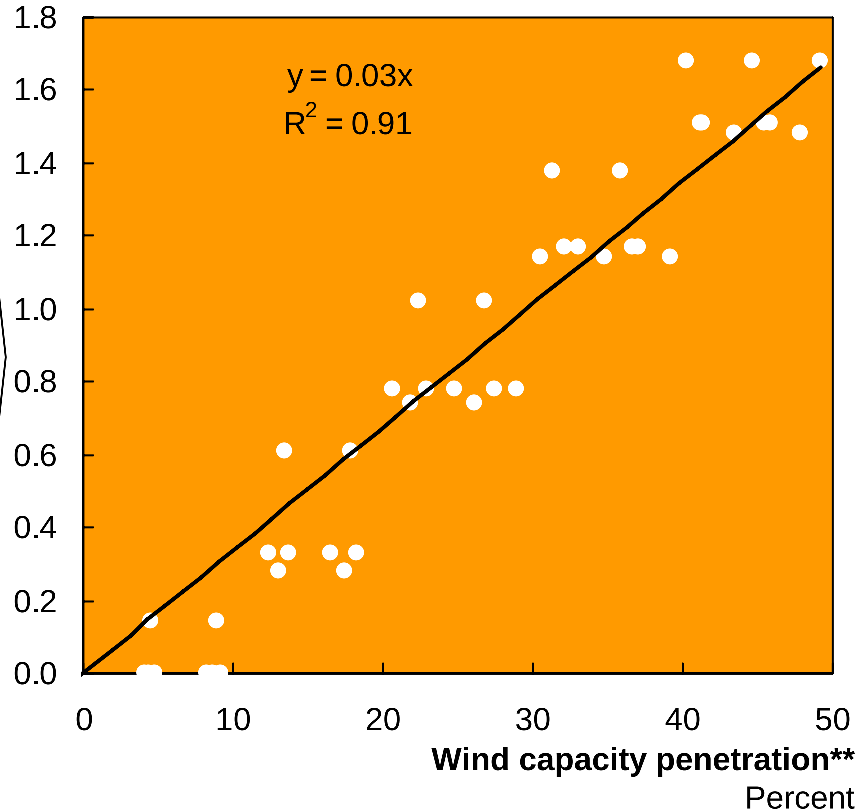
Wind balancing cost*

EUR/MWh

BACKUP

The variation in wind power production effects the grid on three different time scales

- Unit commitment
  - Starting slow thermal units taking up to 8–10 hours
  - To perform properly, day-ahead forecasts of demand are required
  - May have non-negligible impact on wind power cost for high penetration
- Load following
  - 10 minutes to few hours time scale
  - Units responding on this time-scale can be manually dispatched
  - Impact is primarily via energy market since there is no markets for load following
- Regulation
  - Second to minute time scale
  - Load regulated with automatic generation control (AGC) computers
  - Wind is generally uncorrelated with load on this time-scale



- **Grid integration cost correlates linearly with penetration**
- **At 20% penetration grid integration cost is ~0.6 EUR/MWh**

* Including both unit commitment, load following and regulation costs

** Wind power capacity (GW) compared to total capacity (GW)

Source: PacifiCorp; BPA/Hirst; PJM/Hirst; We Energies; Great River Energy; CA RPS Phase I; MN DOC/Xcel; CO/Xcel; UWIG/Xcel; DOE

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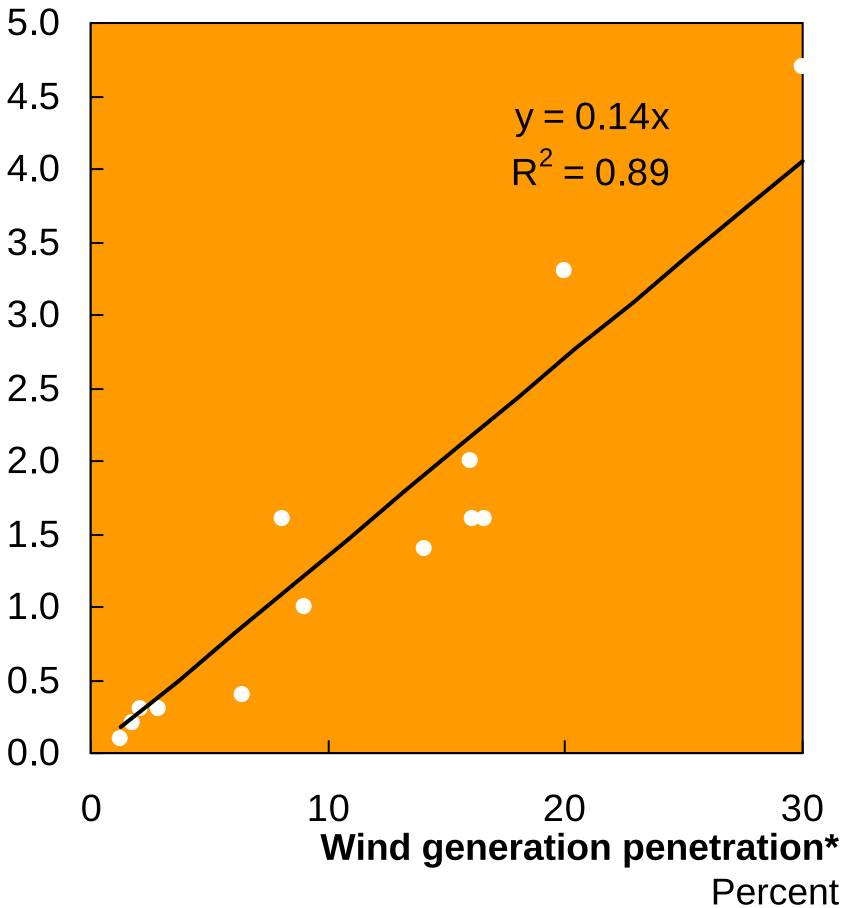
Grid extension cost

EUR/MWh

BACKUP



- **Dimensioning after peak load requires higher infrastructure investment for intermittent power sources**
- **Grid extension cost correlates linearly with share of power production**
- **At 20% of power production from wind power, grid extension cost is ~2.8 EUR/MWh**

* Wind generation (TWh) compared to total generation (TWh)

Source: ITP "Pushing a Least Cost Integration of Green Electricity into the European Grid – Work Package 2"; van Roy et al (2003); Consentec et al (2003); EEG (2003); Haidvogl (2001); Verseille (2003); Fuchs (2003); Janiczek et al (2003); Elässer (2003); t Hooft (2003); ILEX / UMIST (2002)

Uncertainties of intermittency cost and energy storage

- The estimates are based on GreenNet and can be seen as a first approximation that can be debated (the range of estimates vary significantly depending on assumptions and modeling approach)
- Clearly, the costs are highly dependent on the wind penetration and the system structure and market design, and are likely not linear as these results indicate
- Estimates depends on to what degree already existing capacity can be used for integration of wind energy – in the long run new supporting capacities will be needed, potentially to a considerably higher cost
- There can be a potential for energy storage and DSM as means for integration that possibly can lower the costs, but this is not included in this study due to the big uncertainty
- Adducing IEA: "A more in depth review of the studies is needed to draw conclusions on the range of integration cost for wind power“
- A transparent solution to figure out the intermittency costs in a system is critical to integrate wind energy at large scale in the competitive market

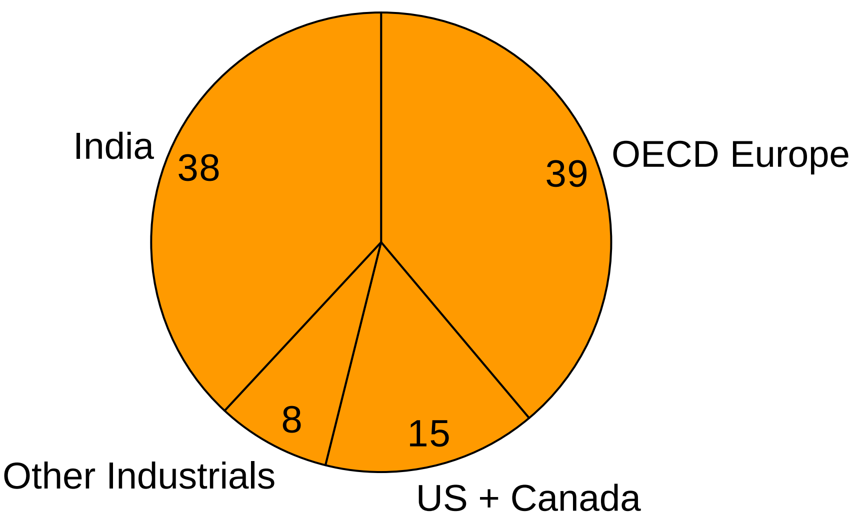
Source: IEA “Design and Operation of Power systems with Large Amounts of Wind Power, first results of IEA collaboration”

Content

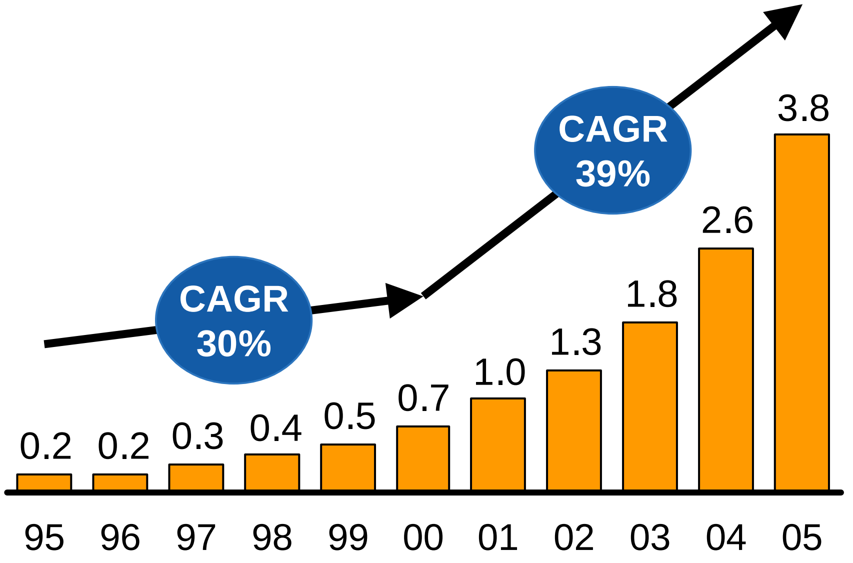
Historical deployment of solar PV

Installed PV capacity 2004
Percent

100% = 2,596 MW



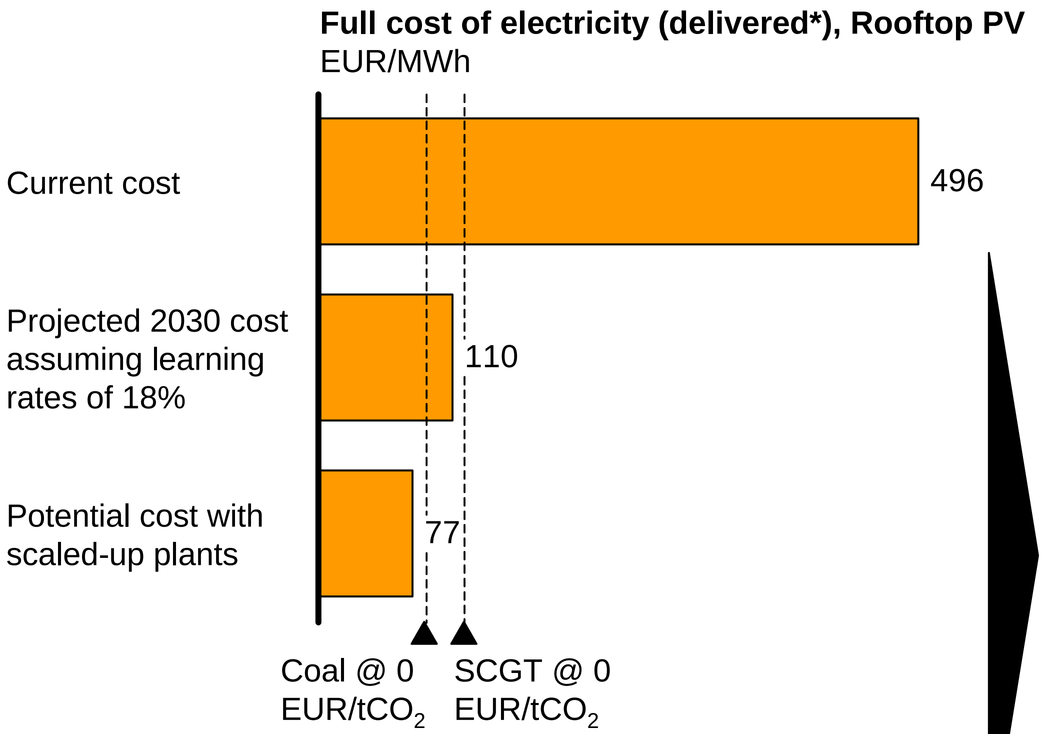
Historical installed base
GW



Solar PV has grown rapidly over the last five years

Source: BTM Consult; PV news; Photon International; BP; IEA

Comparison of projected cost with potential limit with scaled up plants



- **Assumed learning rates are aggressive, but supported by industry**
- **Projected cost of 110 EUR/MWh is cost competitive vs. peaking power source, i.e., solar PV is only cost competitive in regions where peak demand is heat coincident, even when assuming aggressive learning rates**

> "By the year 2010 we'll be able to half generation costs. By 2020 we expect a further reduction – half of 2010 – and by 2030 we expect half the 2020 level"

– Katsuhiko Machida
President, Sharp corp., Japan

* Including T&D cost of 5.5 EUR cent/kWh for coal/CCGT and 2.7 EUR cent/kWh for solar PV
** Rooftop PV installation displaces peak capacity, e.g., SCGT, in heat peaking countries – assumed to be everywhere except Europe and China
Source: NREL

Bottom-up analysis of theoretical cost compressibility of solar PV

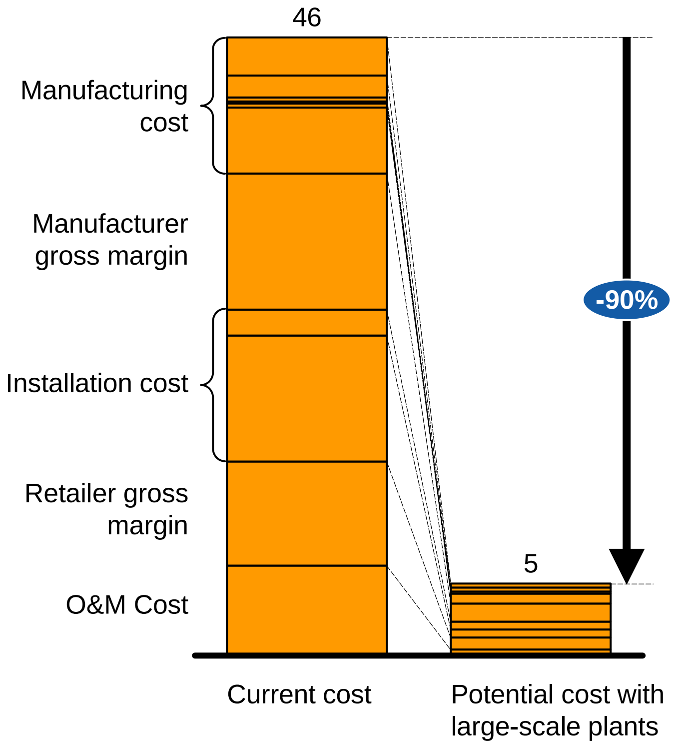
BACKUP

Assumptions on cost reduction potential for Solar PV

The assessment is based on bottom up analysis with a cost inflection point assumption analogous to the development of DRAM factories in mid 1990's

- Cost of glass sheets decreases from USD 24.6 per m^2 to USD 4.6 per m^2
  - Soda-lime float glass is for USD 10.5 per m^2 is replaced with Low-iron, soda-lime float glass for USD 3.2 per m^2
  - Packaging and transportation cost reduced from USD 1.5 to USD 0.1 per m^2
  - Glass finnishing improved from USD 5 to USD 0.5 per m^2
  - Breakage loss is decreased from USD 1 to USD 0.1 per m^2
  - Profit margins reduced from USD 5.62 to USD 0.75 per m^2
- Capital cost of deposition and patterning goes down from USD 20 million to USD 4 million; the cost is annualized over the lifetime of the plant (5 years) corresponding to USD 13.3 to USD 2.67 depreciation cost reduction per m^2
- Operator cost for deposition, patterning, vias and interconnect can be improved from USD 3 per m2 to USD 0.5 per m^2
- Power and gas cost remains at USD 0.5 per m^2 each
- Material utilization increase from 10% to 75% decreases cost of material from USD 2.33 per m^2 to USD 0.31 per m^2
- Through high volume materials and automated assembly, cost for packaging and final interconnect can be reduced from USD 41.7 to USD 10.5 per m^2
- Overall process yield improves from 60% to 93%
- Power converter (DC to AC) cost goes down from USD 0.4 to USD 0.12 per W
- Cost of installation decreases from USD 1.2–2.5 to USD ~0.1 per W due to lower complexity
- Manufacturer and retailer keep a gross margin of 50% and 20% respectively
- Lifetime of installations increases from 25 to 30 years
- O&M cost decreases from USD 0.08 per kWh to USD 0.005 per kWh

Full cost of electricity*
EUR/MWh



- **Full electricity cost of solar PV could decrease by up to 90%**
- **Result should be interpreted as a theoretical limit to validate modeled result as a boundary condition**

* Excluding T&D cost
Source: NREL

Content

Main technologies for power production from biomass

Condensation plants

- Biomass combustion plant dedicated for electricity production
- Burns raw biomass or refined in the form of, e.g., pellets

Key drivers

- Efficiency as function of scale
- Capex as function of scale
- Cost curve for biomass feedstock

Capital cost	27	EUR/MWh
Variable Cost	58	EUR/MWh
Typical plant size	30	MW
Fuel price*	14	EUR/MWh th
Efficiency	32	%
Capacity factor	80	%
Full cost**	123	EUR/MWh
Learning	medium: ~5	%

Gasification

- Partial combustion with restricted supply of air or oxygen, produce a combustible gas

Key drivers

- Efficiency
- Learning rate
- Timing of commercial scale deployment
- Cost curve for biomass feedstock

Capital cost	32	EUR/MWh
Variable Cost	45	EUR/MWh
Typical plant size	80	MW
Fuel price*	14	EUR/MWh th
Efficiency	40	%
Capacity factor	80	%
Full cost**	115	EUR/MWh
Learning	high: ~8	%

Co-firing

- Biomass is burnt together with coal in a coal-fired power plant, with up to 20% biomass

Key drivers

- Efficiency and marginal capex/opex as function of biomass ratio

Capital cost	23	EUR/MWh
Variable Cost	25	EUR/MWh
Typical plant size	600	MW
Fuel price*	9.5	EUR/MWh th
Efficiency	42	%
Capacity factor	90	%
Full cost**	85	EUR/MWh
Learning	low: ~0	%

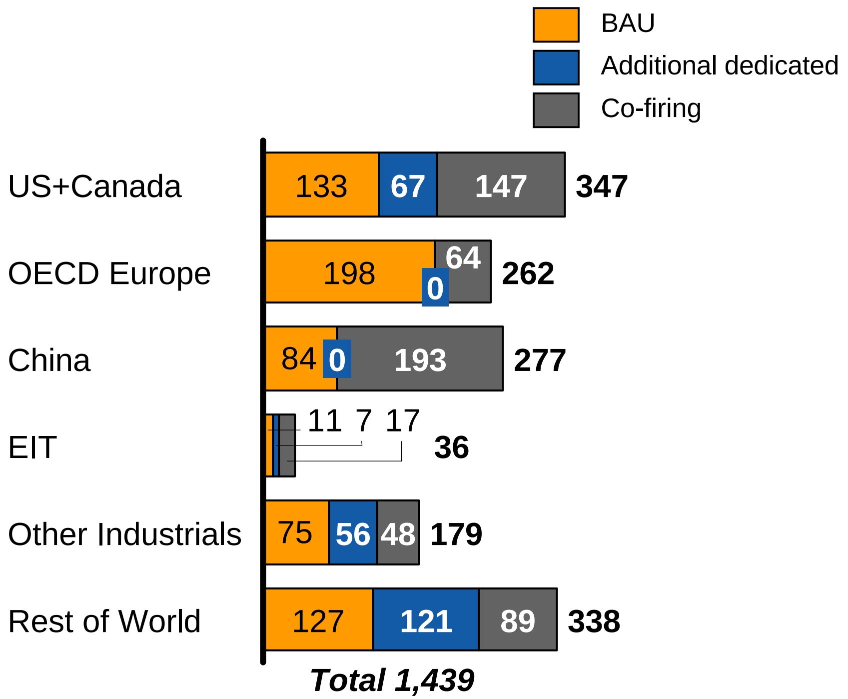
- **Co-firing is clearly the most cost efficient way of producing power from biomass**
- **The competitiveness between gasification and condensation plants will ultimately be driven by technical development and feedstock price, both which are highly uncertain**

* Reflects European biomass prices; up to 60% less expensive in tropical regions
** Includes T&D cost of 38 EUR/MWh for direct combustion and gasification but 50 EUR/MWh for co-firing

Source: NREL

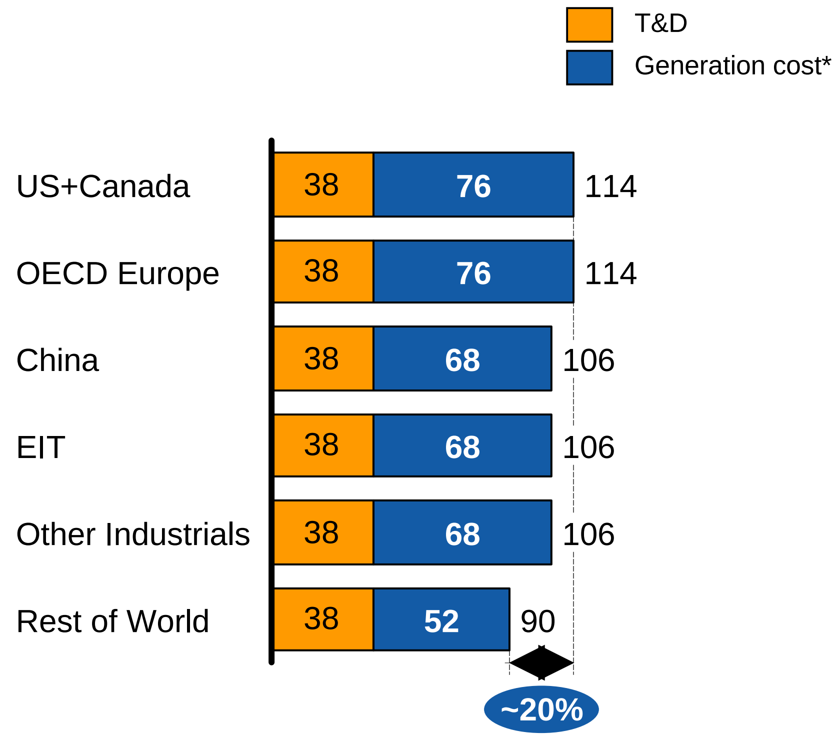
Regional differences in biomass potential and price

Power production from biomass
TWh



Key drivers
- Availability of cheap feedstock
- Subsidy programs
- CO_2 price

Full cost of dedicated biomass generation
EUR/MWh



Key drivers of differences
- Biomass feedstock price
- Biomass growth rate per area
- Land cost
- Transport distance

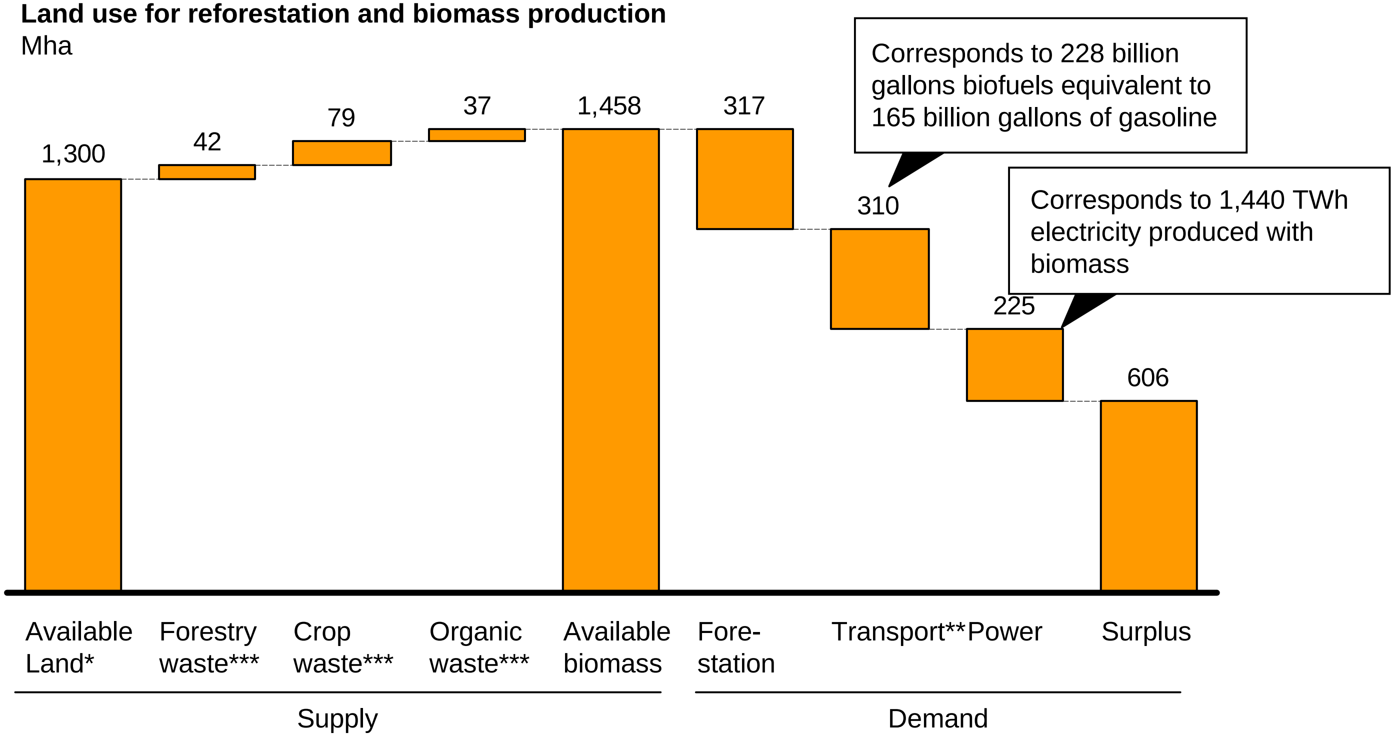
* Driven by variations in feedstock price; assumed to be 20% lower outside Europe and North America and 60% lower in developing countries, compared to EU

Will available land be a constraint, given land demands for reforestation, biofuels, and biomass for power generation? – Estimates

Assumptions

- Biomass is available from several sources e.g. cultivated crops and organic waste
- Land yield:
  - Pasture ~126GJ/ha (Biomass) and 58 GJ/ha (Cellulosic biofuel, assuming 25% crop/ethanol conversion increase)
  - Arable, Corn 76 GJ/ha, Cane 115 GJ/ha, Biodiesel 90 GJ/ha (sunflower/ Jatopha)
  - Forestry ~18 GJ/ha/yr

Land use for reforestation and biomass production
Mha



Land will not likely be a constraint to biomass power or biofuels production

* Deforestation is included in available land
** Conservative calculations for the transportation sector
*** Assuming 30% usage of organic waste and agricultural residuals from low estimates; equivalents in Mha through land yield conversion
Source: Minimum potential from total land use in 2030 by Hoogwijk; Faaij; Berndes; Interviews

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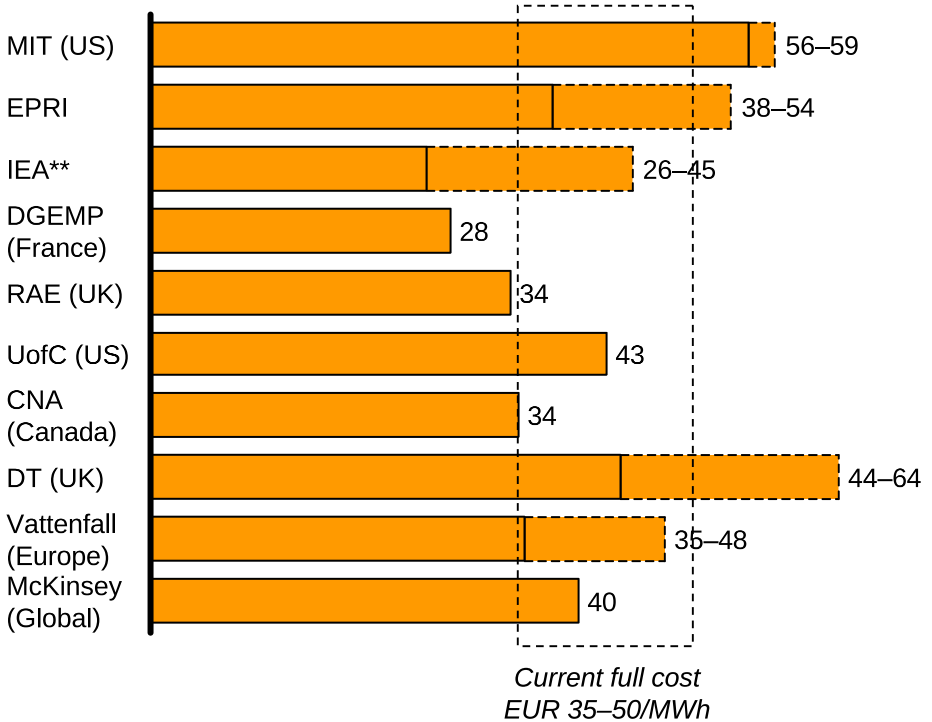
Key messages – Nuclear Power

- Nuclear power is an established, CO_2 free technology widely used for base load power production; main issues regard risk for radioactive leakages and waste handling
- Near term, most cost estimates indicate that nuclear power requires a CO_2 price of 5–20 EUR/tCO_2e to be cost competitive with coal or gas
- However, by increasing standardization and reducing investment risk, abatement cost may come down to 0–5 EUR/tCO_2e, indicating that nuclear power technically could be a zero cost abatement alternative
- Deployment rate will primarily be driven by political decisions and permits; political support is growing overall but is sensitive to security incidents
- Given a construction lead time of 7–10 years, only limited potential will be realizable until 2020
- However, a study by the World Nuclear Association indicates a potential large scale ramp up to an annual production capacity of 5,250 TWh by 2030, doubling today's installed base, corresponding to 1.1 GtCO_2e of abatement above and beyond BAU

Current nuclear production cost and political environment

Nuclear power production cost*
EUR/MWh



Overall, the political environment is improving due to
- **Increasing awareness of climate change**
- **New, safer nuclear technologies, e.g., pebble-bed**

US
A new system for early site permits has been introduced and several companies have applied for subsidies

UK
Government is acknowledging the importance of nuclear power to increase diversity of energy supplies and as a source of low-carbon generation, supported by the recent energy review

Rest of Europe
Varying attitude towards nuclear power, overall projected decline in installed base until 2030

China
Encourages development of nuclear as part of producing clean energy, but remains minor share of overall new capacity added

Australia
Government investigating increased uranium mining and whether nuclear can become cost efficient in the future

Near-term, nuclear is not likely to displace new coal/gas plants without subsidies

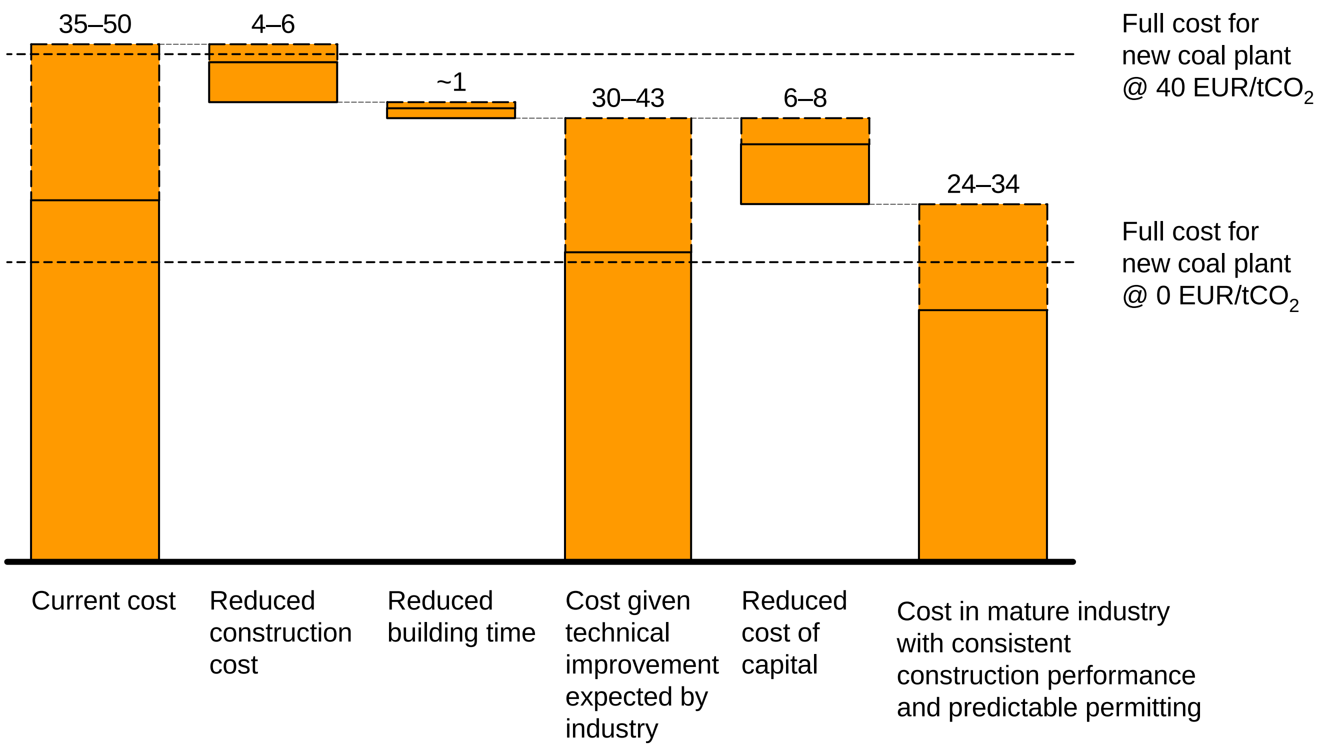
* Excluding T&D cost
** Low range corresponds to Czech Republic, high range Netherlands; North America is mid-range
Source: MIT “The Future of Nuclear Power”, 2003; EPRI “Generation Technologies in a Carbon-constrained World”, 2005; La Direction Générale de l'Énergie et des Matières Premières ”Reference cost for Power Generation”, 2003; IEA & NEA “Projected cost of Generating Electricity”, 2005; Royal Academy of Engineering “The Cost of Generating Electricity”, 2004; University of Chicago “The Economic Future of Nuclear Power”, 2004; Canadian Nuclear Association CNA, 2004; Vattenfall “Nuclear Generation in Sweden”, 2005; Financial Times; Department of Trade and Industry “Energy Review Report 2006”

Cost reduction potential for nuclear power

Assumptions

- With accelerated deployment construction cost might decrease by ~25% by modularizing and operational improvements
- Total building time might be decreased by up to one year through simplified processes and legislation
- Variation in construction time and cost is a major cost driver since it leads to a higher cost of capital
- This variation can be decreased by systemizing the legislative process and further modularizing production

Full cost of electricity in new Nuclear power plant
EUR/MWh



With improved cost structure, nuclear power might become cost competitive to coal even without introducing CO_2 pricing

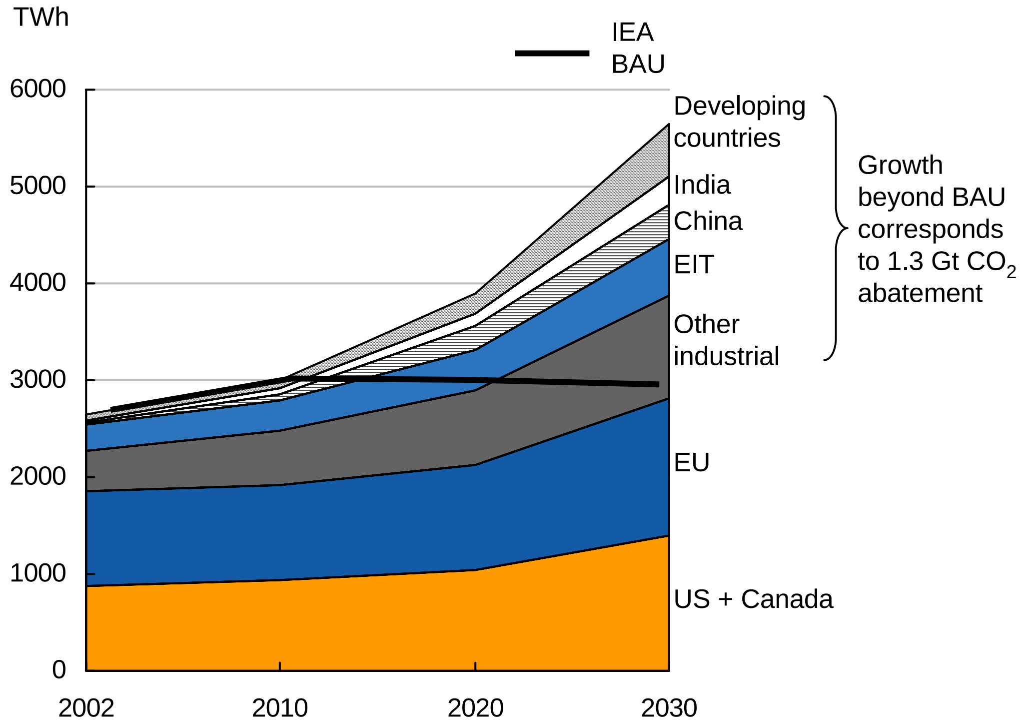
Source: MIT “The Future of Nuclear Power”; EPRI; IEA & NEA; WNA

Nuclear power growth potential

Assumptions for Nuclear Power deployment based on WNA aggressive scenario

- Assessments of volumes for 2010 and 2020 are based on plant-to-plant basis for all countries which currently have plans for Nuclear Power construction
- Post 2020, assessments are based on judgment on the political environment toward nuclear power for each region, e.g.,
  - *North America*
    The construction of new nuclear plants begun before 2020 is accelerated and lifetime of existing plants prolonged, compared to base case where lifetime is assumed to be shorter on existing assets
  - *China (West Asia)*
    China will have the fastest growing of the four nuclear programmes in the region after 2020; this scenario assumes a more ambitious nuclear programme after 2020
  - *Europe*
    A significant number of plants are expected to close down but the scenario assumes net growth compared to net constant capacity in base case

Nuclear Power production, technical potential



- **Nuclear power can grow to the double capacity compared to BAU by 2030**
- **Power plants are deployed across all regions**
- **Due to construction lead-times only small share of the capacity can be deployed by 2020**

Source: MIT; WNA; IEA

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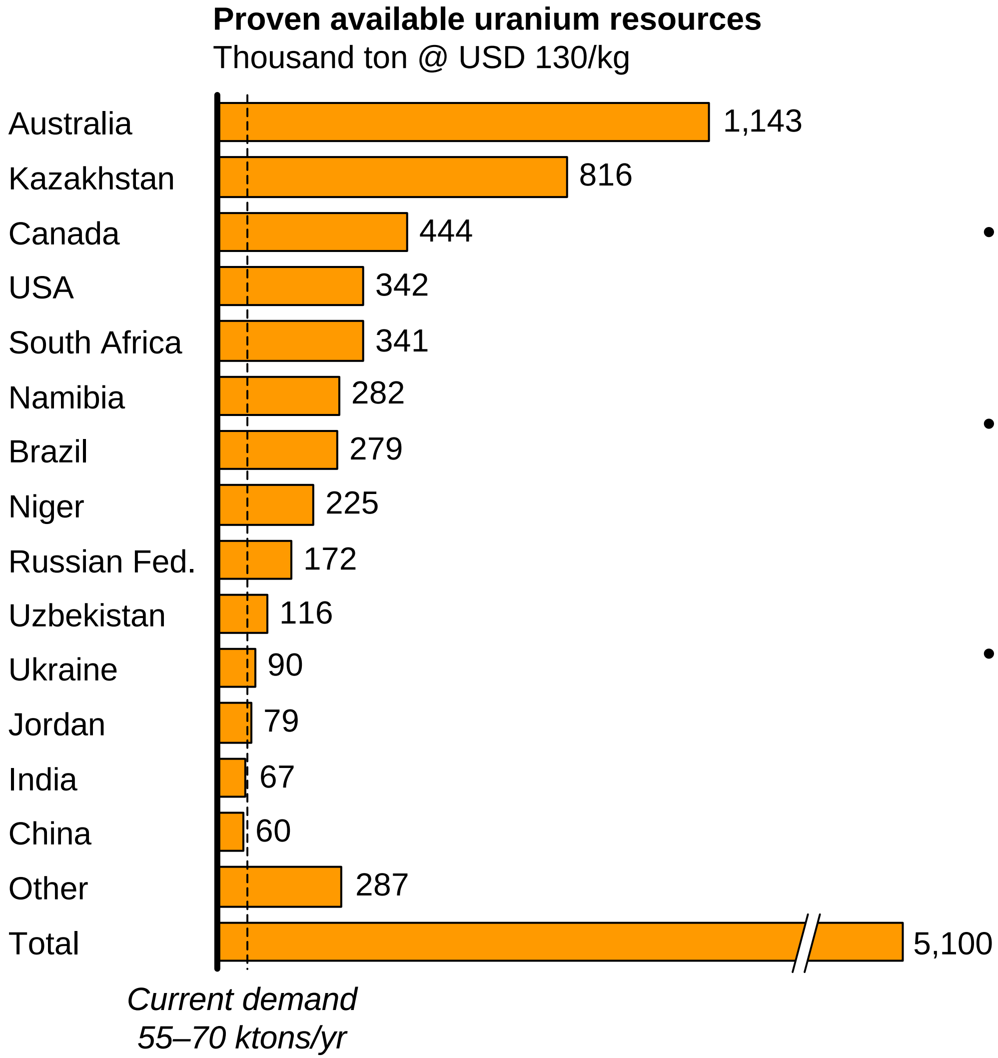
Uranium availability compared to global demand



- **Historically, spot prices have been steadily below 50 USD/kg but just recently risen to current level of 130 USD/kg**
- **Additional available resources at a cost of 130–260 USD/kg are estimated to some 5.1 million tons, and speculatively another 12.1 million tons can be sourced from ore**
- **The proven uranium resources of 5.1 million tons will last for at least 70–85 years at current consumption levels or 30–50 years with accelerated deployment**

Source: IAEA/OECD (NEA) Red book 2005; UNDP World Energy Assessment

Content

Overview

Details of abatement opportunities

- Carbon Capture and Storage
- Renewables
  - Summary
  - Wind
  - Solar
  - Biomass
- Nuclear
- **CO2 efficient fossil sources**

Appendix

Key messages – CO_2 efficient fossil sources

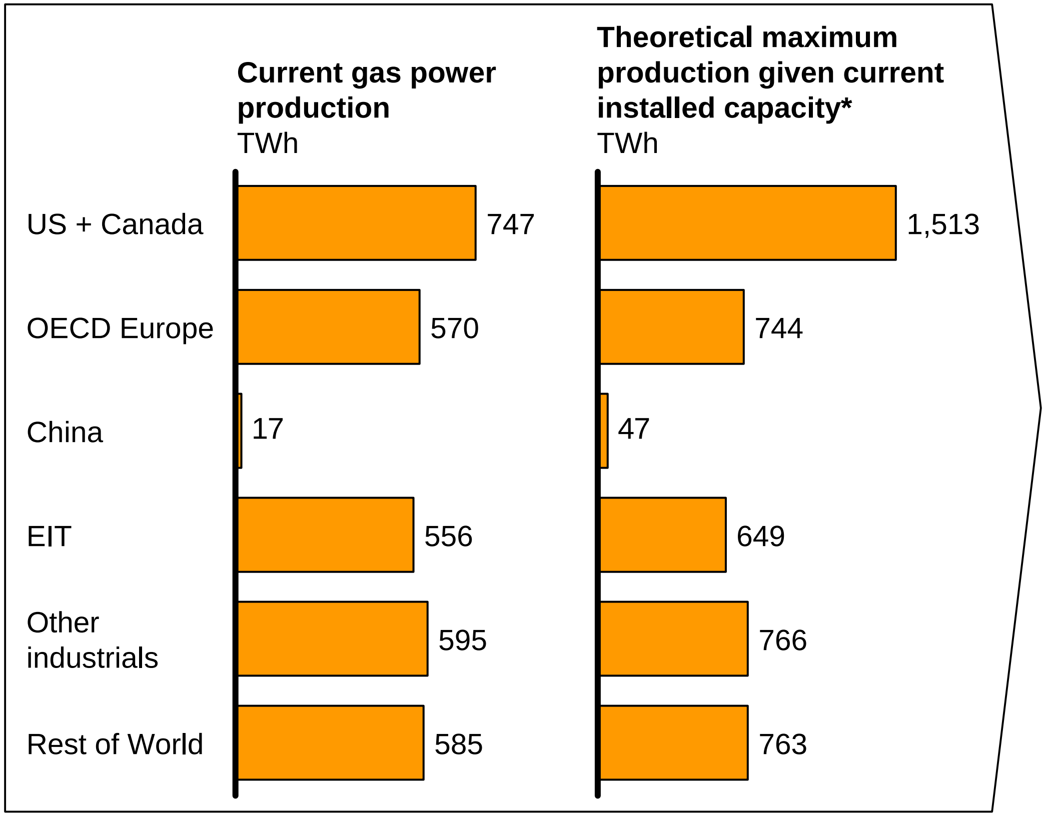
1. There is a short term opportunity of up to 0.2 $GtCO_2e$ p.a. in shifting merit order from coal to gas in existing assets

2. Longer term, investment decisions can be biased towards gas, driven by a sustained CO_2 price above 20–35 EUR/tCO_2e, yielding additional abatement of 0.1 $GtCO_2e$ is achieved from coal-to-gas shift; this effect is, however, limited by security of supply concerns, e.g., in China, USA and India

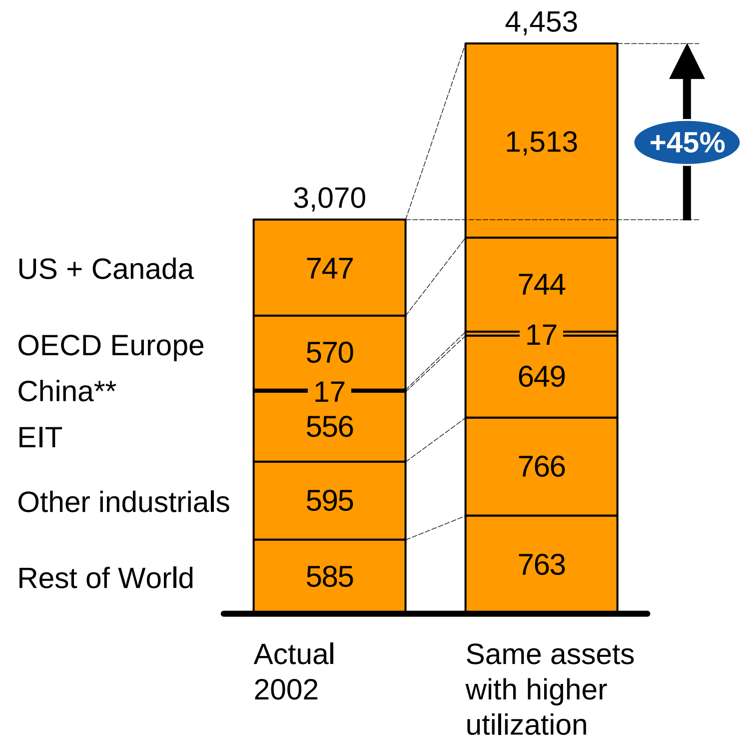
3. Increased CO_2 price will make it less profitable to extend lifetime of old coal assets, leading to an increased average CO_2 efficiency within technologies – at a CO_2 price of 40 EUR/tCO_2e, average coal plant retirement age decreases from 50 years to 25–30 years, contributing with 0.1 $GtCO_2e$ of abatement

4. New coal and gas plant are also expected to become better over time, mainly driven by increased efficiency; this effect is assumed to be included in the business-as-usual development

1. Potential for coal-to-gas shift in existing assets



Potential gas power production
TWh



Increasing utilization of existing gas plants corresponds to 0.2 $GtCO_2e$ abatement assuming that coal plants are displaced

* Assumes 80% utilization of CC and large ST plants (>300MW), 75% of small ST plants, 50% of IC plants and 20% of GT plants – note the actual utilization in some regions is higher than this in IEA BAU; in these regions, there is no potential

** No coal-to-gas shift potential assumed in China due to security of supply issues

Source: UDI; IEA

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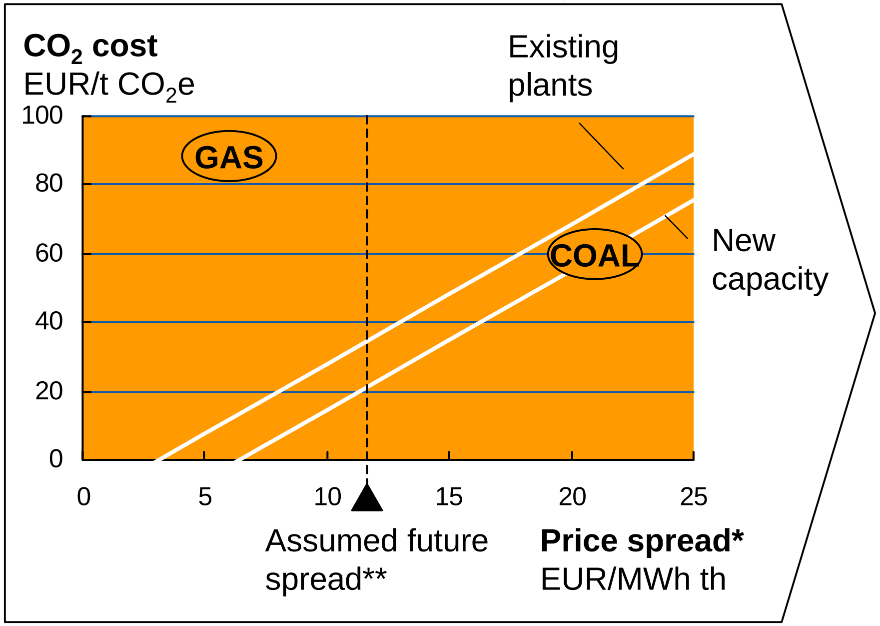
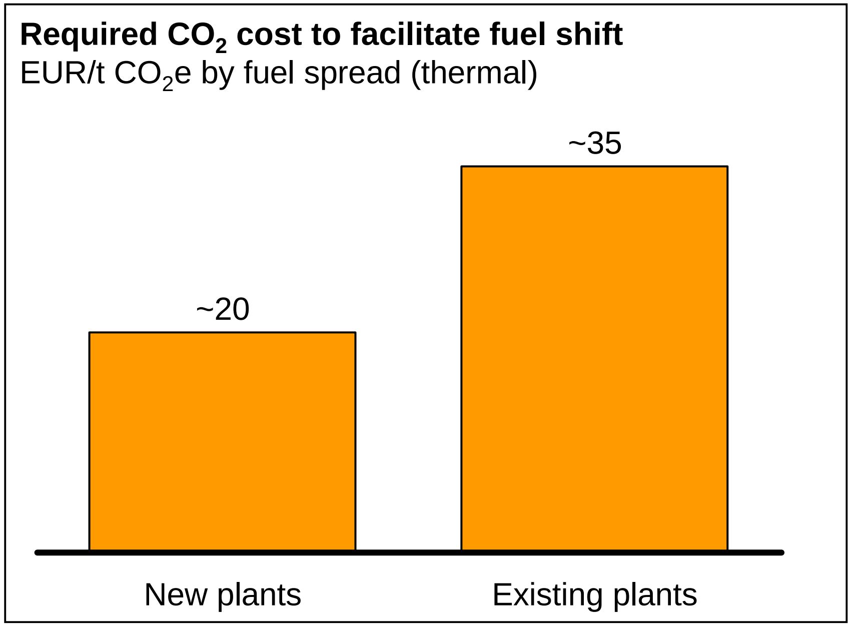
2. Break-points for coal-to-gas shift

BACKUP

Break points for fuel switch, coal to gas



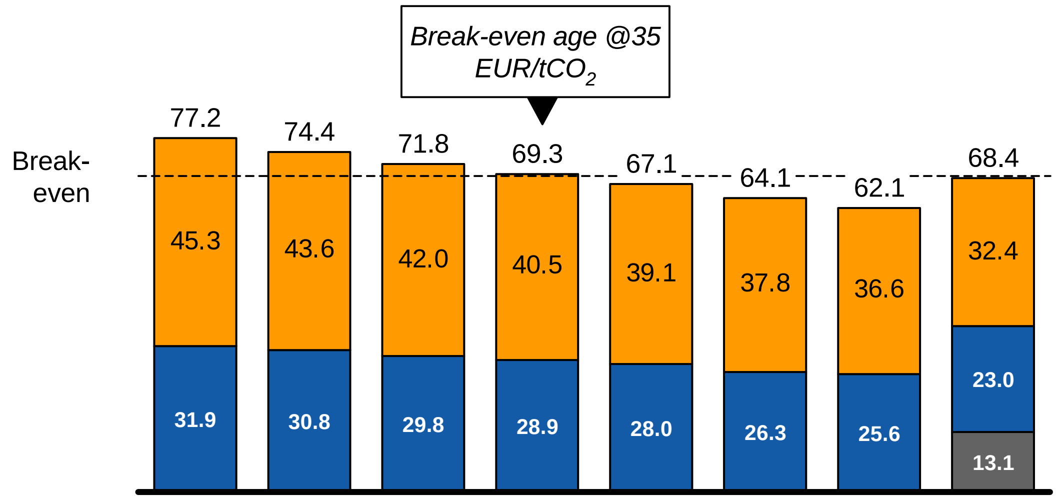


- **Cost of shifting from coal to gas in existing assets is ~35 EUR/tCO_2e**
- **Cost of shifting from coal to gas in new-builds is ~20 EUR/tCO_2e**

Note: Comparison is made with both coal and gas plant utilized to 90%, i.e., for base load
* Price of gas – price of coal
** Assuming future coal price of 8 EUR/MWh th and future gas price of 20 EUR/MWh th
Source: EPRI

3. Impact of higher CO_2 cost on coal plant close-down age

Electricity production cost @40 EUR/tCO_2
EUR/MWh el



Plant age	50	45	40	35	30	25	20	New plant
Assumed average efficiency	30%	32%	34%	35%	35%	35%	36%	42%

CO_2 price EUR/tCO_2e	**Break-even age** Years	**Improved CO_2 intensity** tCO2e/MWh el
20	50	0 *
30	40	0.24
40	35	0.20
50	30	0.17
60	30	0.13
70	30	0.13
80	25	0.13

- **At higher CO2 prices, old coal plants will be replaced with new ones at a younger age, leading to a lower CO2 intensity**
- **Efficiency increase achieved through replacement of old plants at 40 EUR/tCO_2 corresponds to 0.1 GtCO_2 of abatement**

* Assumption is that 50 year old coal plants are replaced already in BAU

Source: Team analysis

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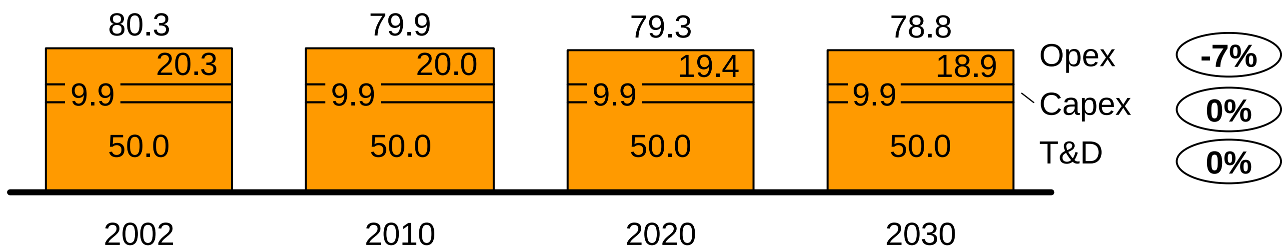
4. Assumed cost development of reference technologies in BAU

BACKUP

Conventional coal

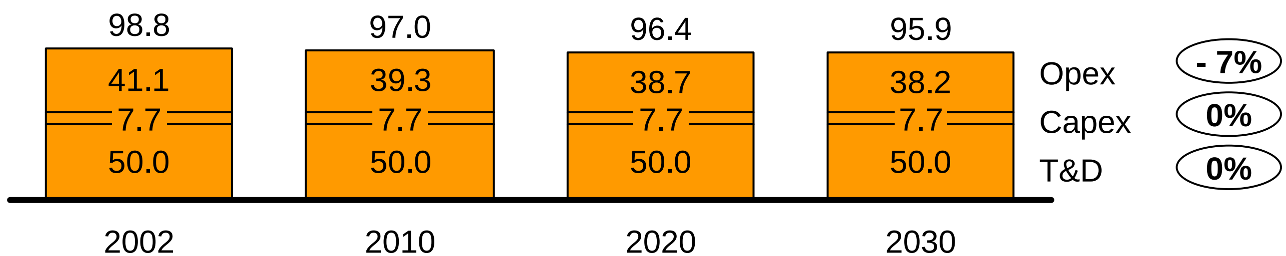
Full cost
EUR/MWh el



	2002	2010	2020	2030
Efficiency Percent	45	46	48	49
Emission intensity tCO_2/MWh	0.76	0.74	0.72	0.69

Combined cycle gas

Full cost
EUR/MWh el



	2002	2010	2020	2030
Efficiency Percent	54	57	58	59
Emission intensity tCO_2/MWh	0.35	0.33	0.33	0.32

Source: VDEW

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Appendix

Methodology overview

- IEA forecast from 2004 is used as baseline scenario until 2030
- Alternative technologies are compared to a reference technologies, represented by a mix of coal and gas proportional to their BAU new build rate; no existing assets are assumed to be closed down before the end of their economic lifetime
- Cost development assessment on emerging renewable energy sources is based on learning curves, i.e., assuming a specific cost reduction for each doubling of installed capacity
- Fuel prices and spreads have been assumed to be constant in real terms over time
- Advanced feedback loops are not included, e.g.,
  - Fuel price as function of demand
  - Electricity demand driven by price elasticity
  - Upstream secondary impact of abatement action, e.g., decreased fuel transport as a consequence of reduced coal demand
- Two scenarios have been evaluated to reflect the breadth of the solution space to reach lower emission levels
  - One scenario where coal and gas plants are effectively replaced by renewables and nuclear
  - One clean coal scenario where coal remains a major energy source due to, e.g., security of supply but where CCS is deployed aggressively

Definition of abatement cost

BACKUP

Definition

$$\text{Abatement cost} = \frac{[\text{Amortization* of initial capex}] - [\text{Annual savings}]}{[\text{Annual tons of } CO_2\text{e abated}]}$$

Power equivalent

$$\text{Abatement cost} = \frac{[\text{Full cost of } CO_2 \text{ efficient alternative}] - [\text{Full cost of reference technology}]}{[CO_2 \text{ intensity** of alternative}] - [CO_2 \text{ intensity** of reference technology}]}$$

Assumptions

- Abatement cost for new technologies are consistently compared to the specific cost and emission intensity of displaced alternatives
- For technologies displacing new-builds, the following reference technologies are assumed

– Demand reduction – Nuclear – Renewables	Avoided growth of base load capacity, i.e., mix of conventional coal and CCGT proportional to BAU new-builds (for solar PV, peak load ST gas plants are used in heat peaking regions)
– Coal CCS	New conventional coal plant
– Gas CCS	New CCGT plant
– Coal-to-gas shift	Full cost of CCGT compared to full cost of conventional coal plant

- Also for measures on existing assets, the replaced technology is used as reference

– Coal CCS	Old coal plant
– Gas CCS	Old CCGT plant
– Coal-to-gas shift	Opex of CCGT compared to Opex of conventional coal plant

- Subsidies or CO_2 costs are not included in the full cost of electricity

* Discount rate is set to 7% across all sectors; For Nuclear amortization, though, 10% is assumed for 2002, converging to 7% by 2030, reflecting a higher risk of investment

** tCO2 /MWh

Cost assumptions for reference technologies

BACKUP

Technology	CCGT	Coal	IGCC	SCGT	Nuclear	Coal with CCS
Installed capacity (kW) - typical plant	800,000	600,000	550,000	450,000	1,000,000	600,000
Efficiency (%) - new plant	0.54	0.42	0.53	39%	33%	33%
Capacity factor (%)	60%	90%	90%	10%	85%	90%
Equivalent hours	5,256	7,884	7,884	876	7,446	7,884
Production (kWh)	4,204,800,000	4,730,400,000	4,336,200,000	394,200,000	7,446,000,000	4,730,400,000
CO2 emissions [kgCO2/MWh]	352	810	642	513	0	155
Fuel cost (€/KWh el)						
- US + Canada	0.037	0.019	0.015	0.051	0.009	0.024
- OECD Europe	0.037	0.019	0.015	0.051	0.009	0.024
- China	0.037	0.019	0.015	0.051	0.009	0.024
- EIT	0.037	0.019	0.015	0.051	0.009	0.024
- Other Industrials	0.037	0.019	0.015	0.051	0.009	0.024
- Rest of World	0.037	0.019	0.015	0.051	0.009	0.024
[alt] O&M fixed cost (€/kW)	18.8	14.6	28.1	15.6	71.0	18.7
O&M variable cost (€/KWh el)	0.001	0.001	0.002	0.001	0.001	0.001
Total OpEx [€ / kWh el]						
- US + Canada	0.041	0.022	0.020	0.069	0.020	0.028
- OECD Europe	0.041	0.022	0.020	0.069	0.020	0.028
- China	0.041	0.022	0.020	0.069	0.020	0.028
- EIT	0.041	0.022	0.020	0.069	0.020	0.028
- Other Industrials	0.041	0.022	0.020	0.069	0.020	0.028
- Rest of World	0.041	0.022	0.020	0.069	0.020	0.028
Investment (€/KW el)	472	971	1,500	292	1,859	1,699
Useful life (years)	25	30	20	30	40	30
Capital cost (€)	32,402,051	46,949,639	77,874,164	10,589,053	190,100,251	82,161,868
WACC (%)	7%	7%	7%	7%	10%	7%
Capex [€ / kWh el]						
- US + Canada	0.008	0.010	0.018	0.027	0.026	0.017
- OECD Europe	0.008	0.010	0.018	0.027	0.026	0.017
- China	0.008	0.005	0.018	0.027	0.026	0.017
- EIT	0.008	0.010	0.018	0.027	0.026	0.017
- Other Industrials	0.008	0.010	0.018	0.027	0.026	0.017
- Rest of World	0.008	0.010	0.018	0.027	0.026	0.017
T&D cost (€/kWh)	0.05	0.05	0.05	0.05	0.05	0.05
CO2 cost (€/kWh)	0	0	0	0	0	0
Total cost of electricity [€ / kWh el]						
- US + Canada	0.099	0.082	0.088	0.146	0.095	0.095
- OECD Europe	0.099	0.082	0.088	0.146	0.095	0.095
- China	0.099	0.077	0.088	0.146	0.095	0.095
- EIT	0.099	0.082	0.088	0.146	0.095	0.095
- Other Industrials	0.099	0.082	0.088	0.146	0.095	0.095
- Rest of World	0.099	0.082	0.088	0.146	0.095	0.095

Source: Idae, Unesa, Plan de fomento de energías renovables, Instituto de Estudios Económicos, University of Lappeenranta, Finland

Assumptions for current cost of emerging renewable technologies

BACKUP

Technology	On-shore wind	Off-shore wind	Rooftop PV	CSP	Biomass	Small Hydro	Geothermal
Installed capacity (kW) - typical plant	2,000	15,000	5,000	200,000	30,000	5,000	50,000
Efficiency (%)					32%		
Capacity factor (%)							
- US + Canada	26%	35%	18%	28%	80%	35%	80%
- OECD Europe	28%	37%	11%	21%	80%	35%	80%
- China	21%	30%	13%	23%	80%	35%	80%
- EIT	26%	35%	13%	23%	80%	35%	80%
- Other Industrials	26%	35%	13%	23%	80%	35%	80%
- Rest of World	26%	35%	13%	23%	80%	35%	80%
Equivalent hours							
- US + Canada	2,300	3,088	1,569	2,445	7,008	3,066	7,008
- OECD Europe	2,453	3,241	991	1,867	7,008	3,066	7,008
- China	1,840	2,628	1,156	2,032	7,008	3,066	7,008
- EIT	2,300	3,088	1,156	2,032	7,008	3,066	7,008
- Other Industrials	2,300	3,088	1,156	2,032	7,008	3,066	7,008
- Rest of World	2,300	3,088	1,156	2,032	7,008	3,066	7,008
Production (kWh)							
- US + Canada	4,599,000	46,318,500	7,843,485	488,939,400	210,240,000	15,330,000	350,400,000
- OECD Europe	4,905,600	48,618,000	4,953,780	373,351,200	210,240,000	15,330,000	350,400,000
- China	3,679,200	39,420,000	5,779,410	406,376,400	210,240,000	15,330,000	350,400,000
- EIT	4,599,000	46,318,500	5,779,410	406,376,400	210,240,000	15,330,000	350,400,000
- Other Industrials	4,599,000	46,318,500	5,779,410	406,376,400	210,240,000	15,330,000	350,400,000
- Rest of World	4,599,000	46,318,500	5,779,410	406,376,400	210,240,000	15,330,000	350,400,000
CO2 emissions [tCO2/kWh]	0	0	0	0	0	0	0
Fuel cost (€/KWh el)							
- US + Canada	0	0	0	0	0.044	0	0
- OECD Europe	0	0	0	0	0.044	0	0
- China	0	0	0	0	0.036	0	0
- EIT	0	0	0	0	0.036	0	0
- Other Industrials	0	0	0	0	0.036	0	0
- Rest of World	0	0	0	0	0.018	0	0
O&M fixed cost (€/kW)	24.0	255.0	79.5	233.3	50.0	10.0	50.0
O&M variable cost (€/KWh el)	0.008	0.017	0.000	0.000	0.006	0.007	0.000
Total OpEx [€ / kWh el]							
- US + Canada	0.019	0.099	0.051	0.095	0.058	0.010	0.007
- OECD Europe	0.018	0.095	0.080	0.125	0.058	0.010	0.007
- China	0.021	0.114	0.069	0.115	0.049	0.010	0.007
- EIT	0.019	0.099	0.069	0.115	0.049	0.010	0.007
- Other Industrials	0.019	0.099	0.069	0.115	0.049	0.010	0.007
- Rest of World	0.019	0.099	0.069	0.115	0.031	0.010	0.007
Investment (€/KW el)	1,200	1,700	3,973	2,333	2,000	1,250	1,000
Useful life (years)	20	15	25	15	20	25	30
Capital cost (€)	226,543	2,799,763	1,704,626	51,237,492	5,663,576	536,316	4,029,320
WACC (%)	7%	7%	7%	7%	7%	7%	7%
Capex [€ / kWh el]							
- US + Canada	0.049	0.060	0.217	0.105	0.027	0.035	0.011
- OECD Europe	0.046	0.058	0.344	0.137	0.027	0.035	0.011
- China	0.062	0.071	0.295	0.126	0.027	0.035	0.011
- EIT	0.049	0.060	0.295	0.126	0.027	0.035	0.011
- Other Industrials	0.049	0.060	0.295	0.126	0.027	0.035	0.011
- Rest of World	0.049	0.060	0.295	0.126	0.027	0.035	0.011
T&D costs (€/kWh)	0.0500	0.0500	0.025	0.050	0.038	0.038117002	0.038
CO2 costs (€/kWh)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total cost of electricity [€ / kWh el]							
- US + Canada	0.118	0.210	0.293	0.250	0.123	0.083	0.057
- OECD Europe	0.114	0.203	0.449	0.312	0.123	0.083	0.057
- China	0.133	0.235	0.388	0.291	0.114	0.083	0.057
- EIT	0.118	0.210	0.388	0.291	0.114	0.083	0.057
- Other Industrials	0.118	0.210	0.388	0.291	0.114	0.083	0.057
- Rest of World	0.118	0.210	0.388	0.291	0.096	0.083	0.057
Reference technology							
- US + Canada	Base	Base	Peak	Base	Base	Base	Base
- OECD Europe	Base	Base	Base	Base	Base	Base	Base
- China	Base	Base	Base	Base	Base	Base	Base
- EIT	Base	Base	Peak	Base	Base	Base	Base
- Other Industrials	Base	Base	Peak	Base	Base	Base	Base
- Rest of World	Base	Base	Peak	Base	Base	Base	Base

Note: Base load reference is mix of CCGT and coal (based on replacement in region) and peak load plant is Single Turbine Gas

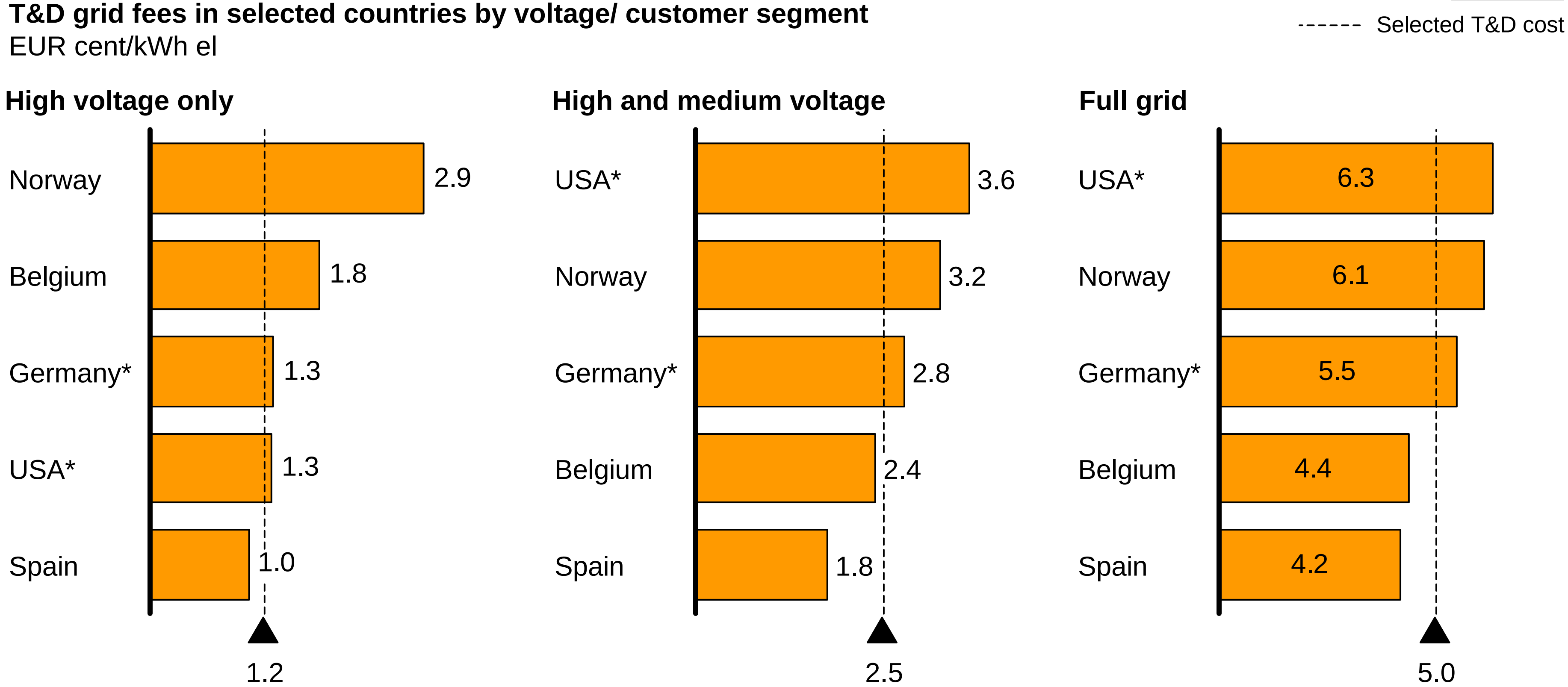
Source: REN 21 Global Market Review

Transmission and distribution cost (T&D)

PRELIMINARY

BACKUP

T&D grid fees in selected countries by voltage/ customer segment
EUR cent/kWh el



- **Grid cost for sources only using the low-voltage grid (e.g., solar PV) is ~2.5 EUR cent/kWh**
- **Grid cost for sources using mid- and low-voltage grid only (e.g., local small biomass plants) is 3.8 EUR cent/kWh**

* Current cost ~15% lower due to deregulation of market
Source: VDEW; EIA; NVA; CNE

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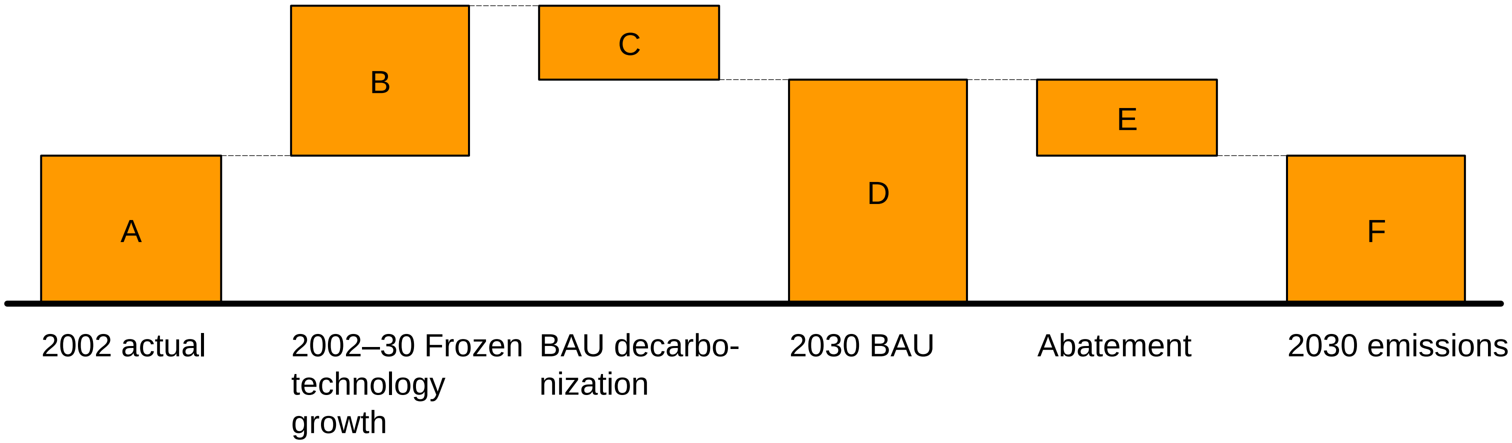
Sources and assumptions



Item	Calculation	Source/assumptions
A. 2002 emission	• N/A	• IEA
B. Fixed carbon intensity	• Scaled by power production forecast	• IEA
C. BAU Decarbonization	• Residual broken down into fuel shift and decarbonization within technologies	• IEA
D. 2030 BAU emissions	• N/A	• IEA
E. Abatement	• Bottom-up analysis by technology, integrated with buildings and industry model	• E.g., IEA, IPCC, EU Commission, NREL
F. Potential emissions in 2030	• Residual	• N/A

Assumptions of fuel prices in calculations

2002; USD; assumed constant real price through period

BACKUP

Fuel	Main scenario		High cost scenario*		Comment
Crude oil	40 19.6	USD / bbl EUR / MWh th	60 29.4	USD / bbl EUR / MWh th	• Assumption
Heavy fuel oil	250 17.6	USD / ton EUR / MWh th	350 24.7	USD / ton EUR / MWh th	• Typical 2005 price (low) and current 2006 (high) LSFO FOB Cgo Rotterdam
Natural gas	7 19.9	USD / mbtu EUR / MWh th	9 25.6	USD / mbtu EUR / MWh th	• Price delivered to plant • Linked to crude price
Average coal	2.8 8.0	USD / mbtu EUR / MWh th	2.8 8.0	USD / mbtu EUR / MWh th	• Price delivered to plant • Kept constant in scenarios since price is considered stable and since price spread to coal is key sensitivity
Biomass**	5 14.2	USD / mbtu EUR / MWh th	7.5 21.3	USD / mbtu EUR / MWh th	• Low price is IEA BAU assumption • Imported biomass price setting
Uranium	80 3.1	USD / kg EUR / MWh th	130 5.1	USD / kg EUR / MWh th	• Main scenario price is historical average • High price is current spot price (2006)

* Used in sensitivity analyses
** Reflects EU market prices; assumed to be 20% lower in Eastern Europe, China, and other industrials, 60% lower in developing countries
Note: 1 bbl crude = 5.8 mbtu; 1 ton HFO = 40.4 mbtu; 1 kg 235U = 77 TJ; 1 EUR = 1.2 USD
Source: UXC

VATTENFALL

CO_2 intensity for existing and new plants

tCO_2/MWh

BACKUP

CO_2 intensity for new plants in BAU

Power source	Region	2010	2020	2030
Coal	US + Canada	0.74	0.72	0.69
	OECD Europe	0.74	0.72	0.69
	China	0.76	0.73	0.70
	EIT	0.76	0.73	0.70
	Other Industrials	0.74	0.72	0.69
	Rest of World	0.77	0.74	0.72
Gas	US + Canada	0.33	0.33	0.32
	OECD Europe	0.33	0.33	0.32
	China	0.35	0.33	0.33
	EIT	0.35	0.33	0.33
	Other Industrials	0.33	0.33	0.32
	Rest of World	0.36	0.33	0.33

CO_2 intensity for remaining plants in BAU

Power source	Region	2010	2020	2030
Coal	US + Canada	0.96	0.98	0.93
	OECD Europe	1.06	1.08	1.07
	China	1.45	1.27	1.17
	EIT	1.63	1.72	1.83
	Other Industrials	1.01	1.04	0.98
	Rest of World	1.17	1.19	1.08
Gas	US + Canada	0.62	0.53	0.57
	OECD Europe	0.55	0.61	0.51
	China	0.91	0.67	0.56
	EIT	1.26	1.24	1.02
	Other Industrials	0.57	0.57	0.55
	Rest of World	0.64	0.61	0.55

Source: IEA; VDEW

Key uncertainties

- Abatement costs are dependent on future fuel price spreads
- The projected cost development of emerging technologies is unclear; the currently assumed 80% of historical trends might still be aggressive but might also prove too low
- The cost of intermittency has not been sufficiently explored; the upper range of estimates is higher than what is included in this analysis, however, there is a clear need of further, comprehensive studies
- Ultimately, the full cost of electricity generation is site specific and the assumptions used as basis for the abatement costs can not be expected to be generally true for all occasions