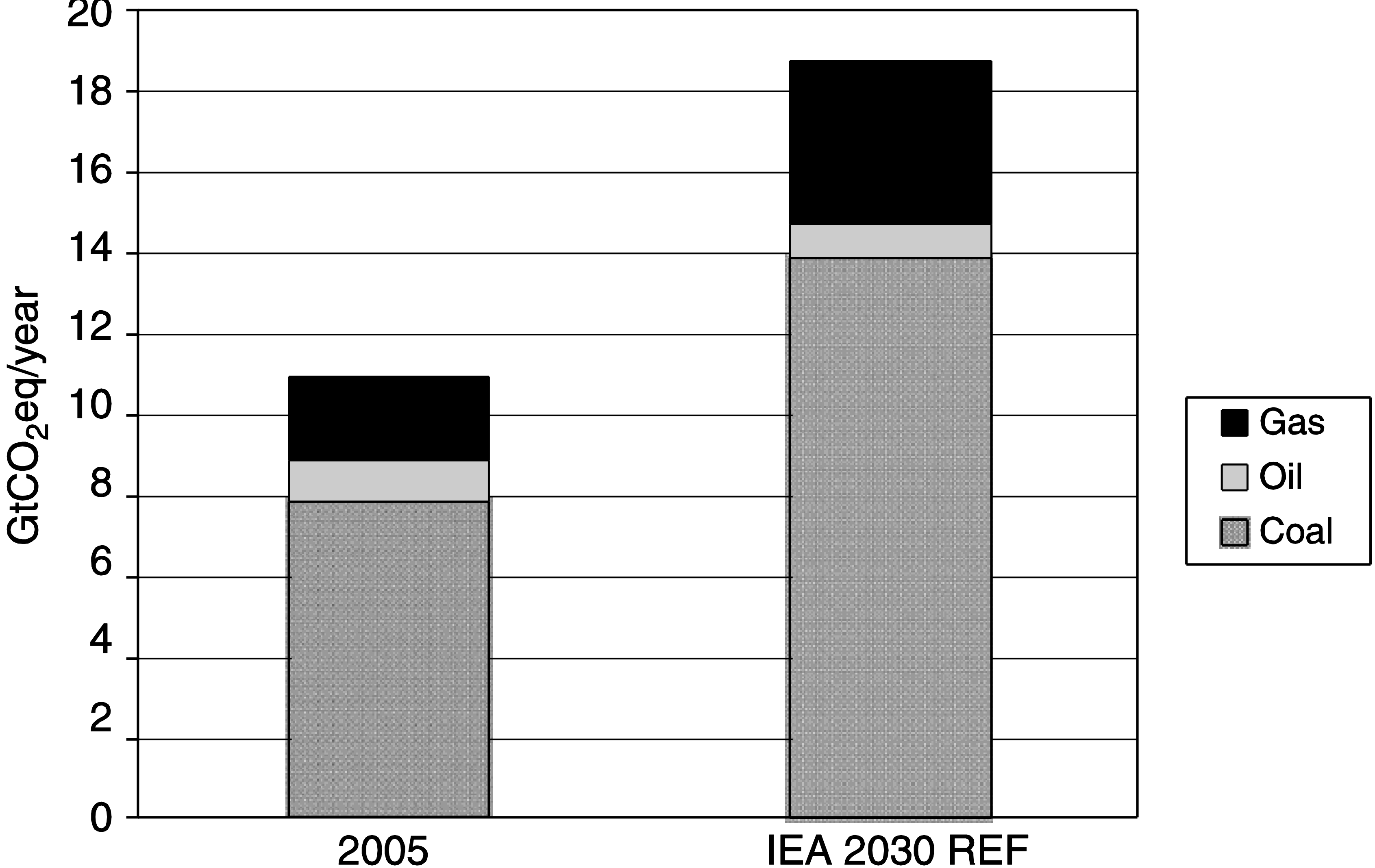
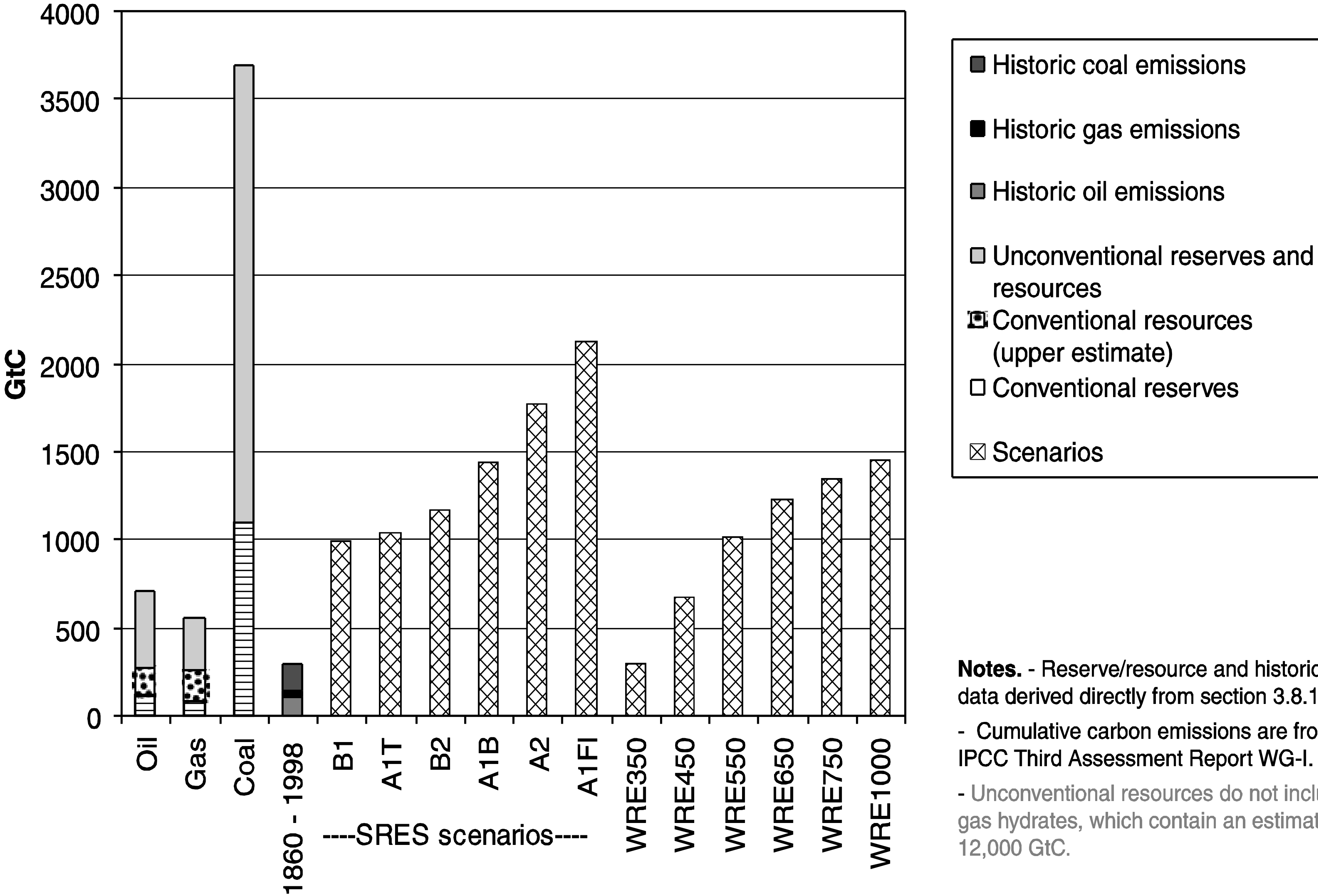
Energy supply

Emissions from electricity supply



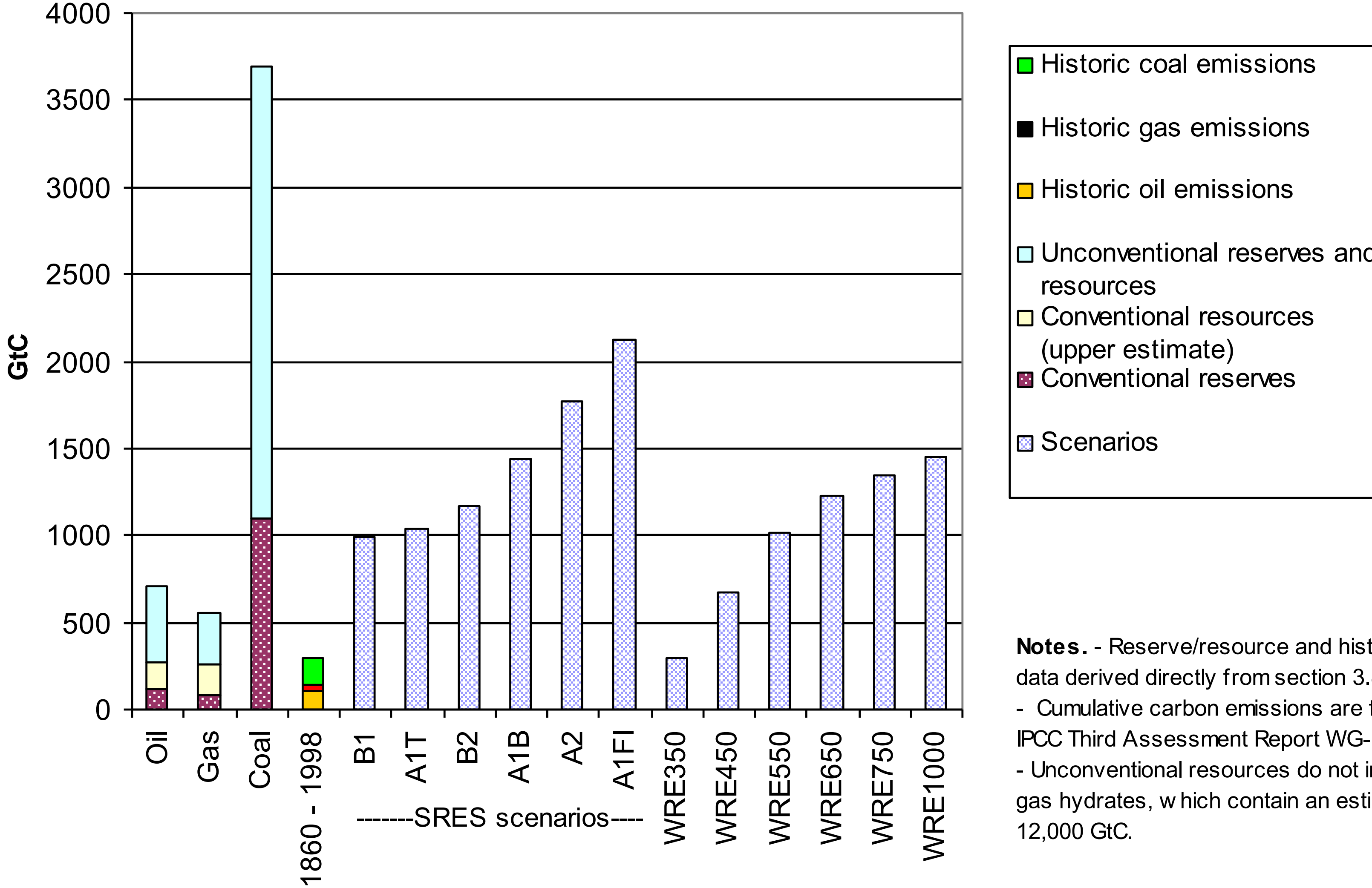


Notes. - Reserve/resource and historic use data derived directly from section 3.8.1.

- Cumulative carbon emissions are from the IPCC Third Assessment Report WG-I.

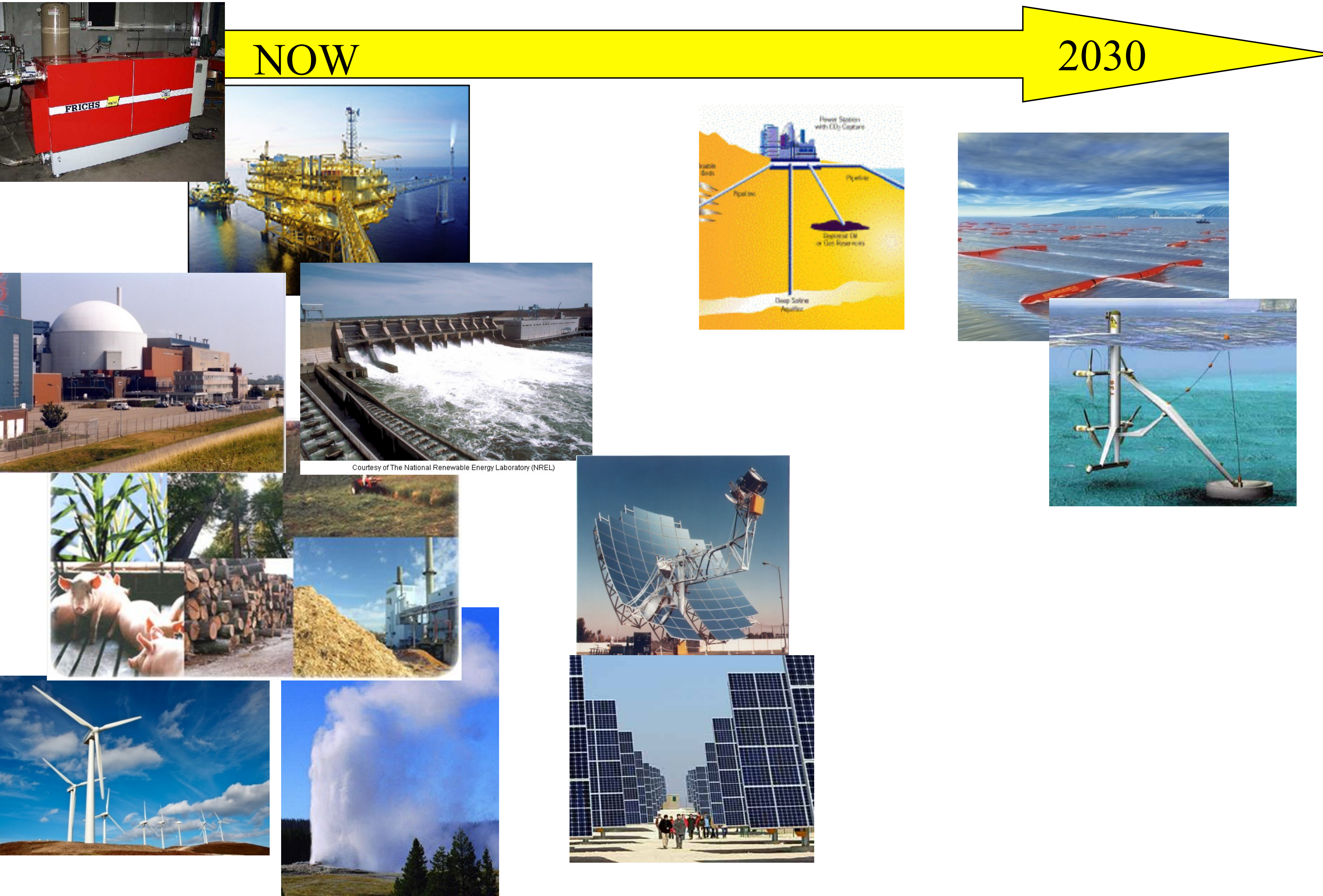
- Unconventional resources do not include gas hydrates, which contain an estimated 12,000 GtC.

Shortage of fossil fuel is not going to help us stabilise CO2 concentrations

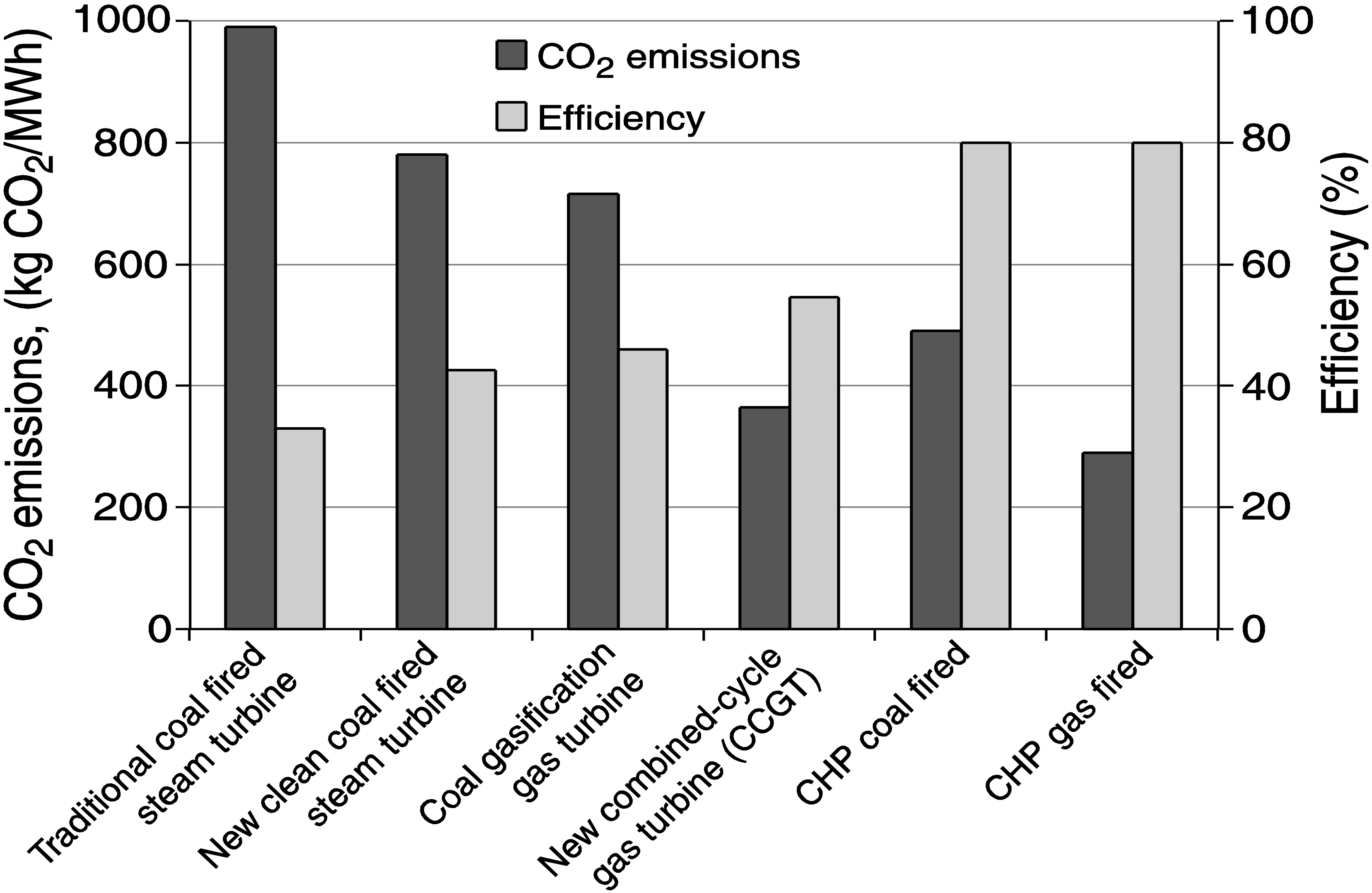


Notes. - Reserve/resource and historic use data derived directly from section 3.8.1.
- Cumulative carbon emissions are from the IPCC Third Assessment Report WG-I.
- Unconventional resources do not include gas hydrates, which contain an estimated 12,000 GtC.

Commercial energy supply mitigation technologies



Efficiency of power plants



)* pledged nuclear phase-out

Nucelar power around the world

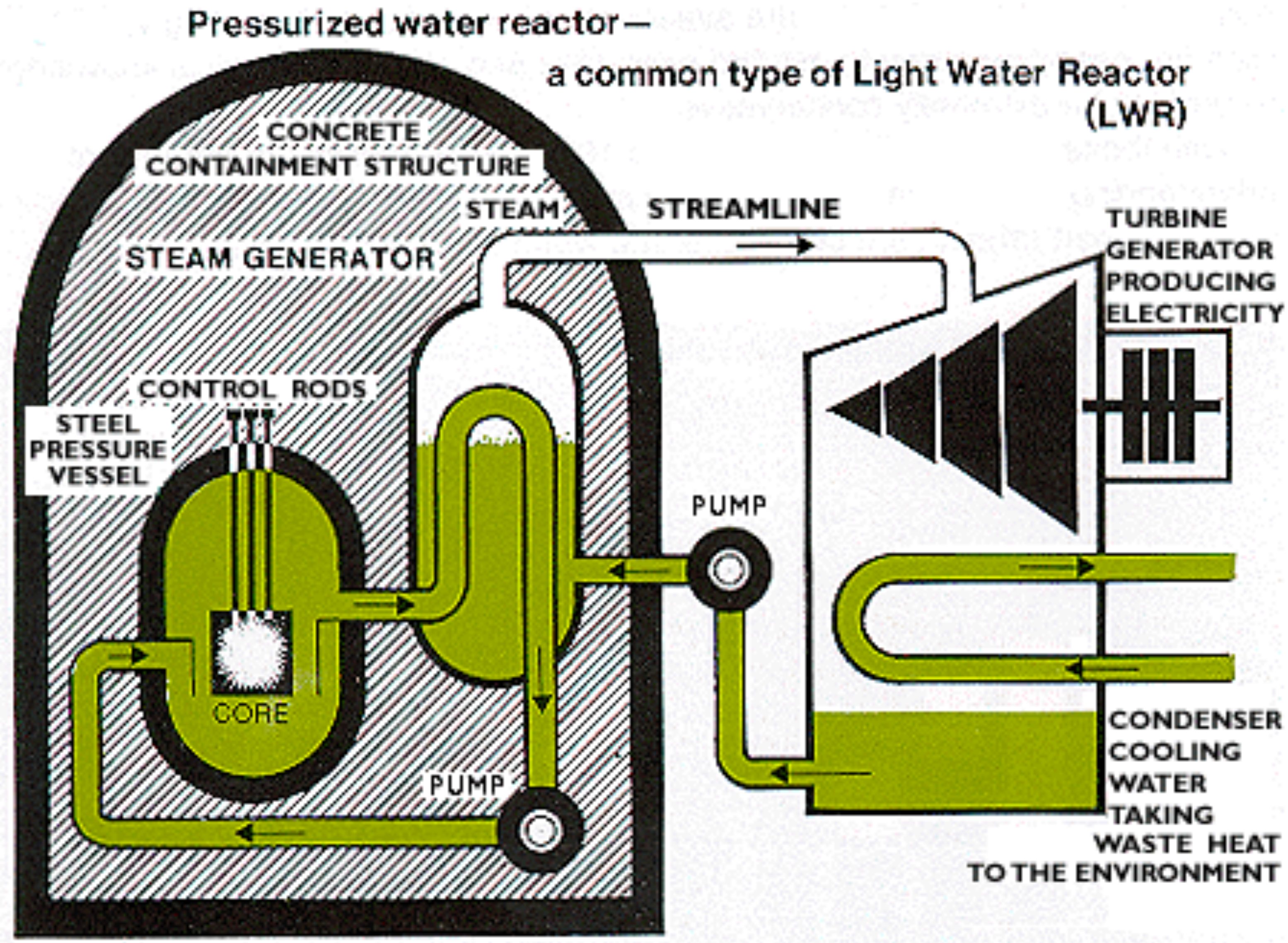
Country	Number of nuclear power stations in operation by end 2006	Number of nuclear plants under construction by end 2006	Number of nuclear reactors planned	% of electricity from nuclear power (2006)
USA	103	0		19
France	59	1		78
Japan	55	1	13	30
Russia	31	5	50% increase	16
Korea	20	1	60% increase	39
UK	19	0		18
Germany)*	17	0		31
India	16	7	16	3
Ukraine	15	2		48
China	10	4	28-40	2
Sweden)*	10	0		48

Nuclear power plants in commercial operation

GWe = capacity in thousands of megawatts (gross)

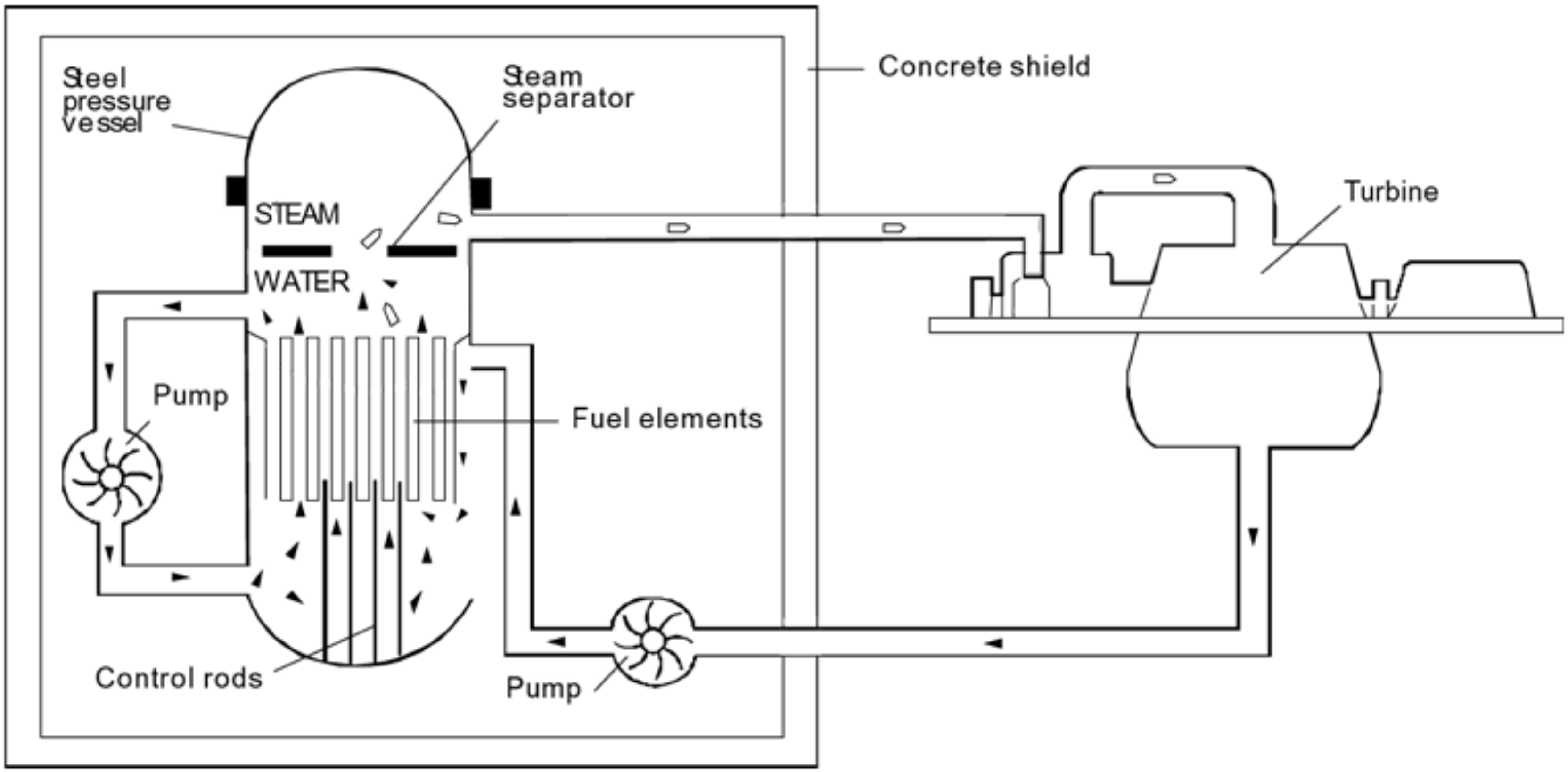
Source: Nuclear Engineering International Handbook 2008

Reactor type	*Main Countries*	*Number*	*GWe*	*Fuel*	*Coolant*	*Moderator*
Pressurised Water Reactor (PWR)	**US, France, Japan, Russia, China**	**265**	**251.6**	**enriched UO_2**	**water**	**water**
Boiling Water Reactor (BWR)	**US, Japan, Sweden**	**94**	**86.4**	**enriched UO_2**	**water**	**water**
Pressurised Heavy Water Reactor 'CANDU' (PHWR)	**Canada**	**44**	**24.3**	**natural UO_2**	**heavy water**	**heavy water**
Gas-cooled Reactor (AGR & Magnox)	**UK**	**18**	**10.8**	**natural U (metal), enriched UO_2**	**CO_2**	**graphite**
Light Water Graphite Reactor (RBMK)	**Russia**	**12**	**12.3**	**enriched UO_2**	**water**	**graphite**
Fast Neutron Reactor (FBR)	**Japan, France, Russia**	**4**	**1.0**	**PuO_2 and UO_2**	**liquid sodium**	**none**
Other	**Russia**	**4**	**0.05**	**enriched UO_2**	**water**	**graphite**
	TOTAL	**441**	**386.5**			



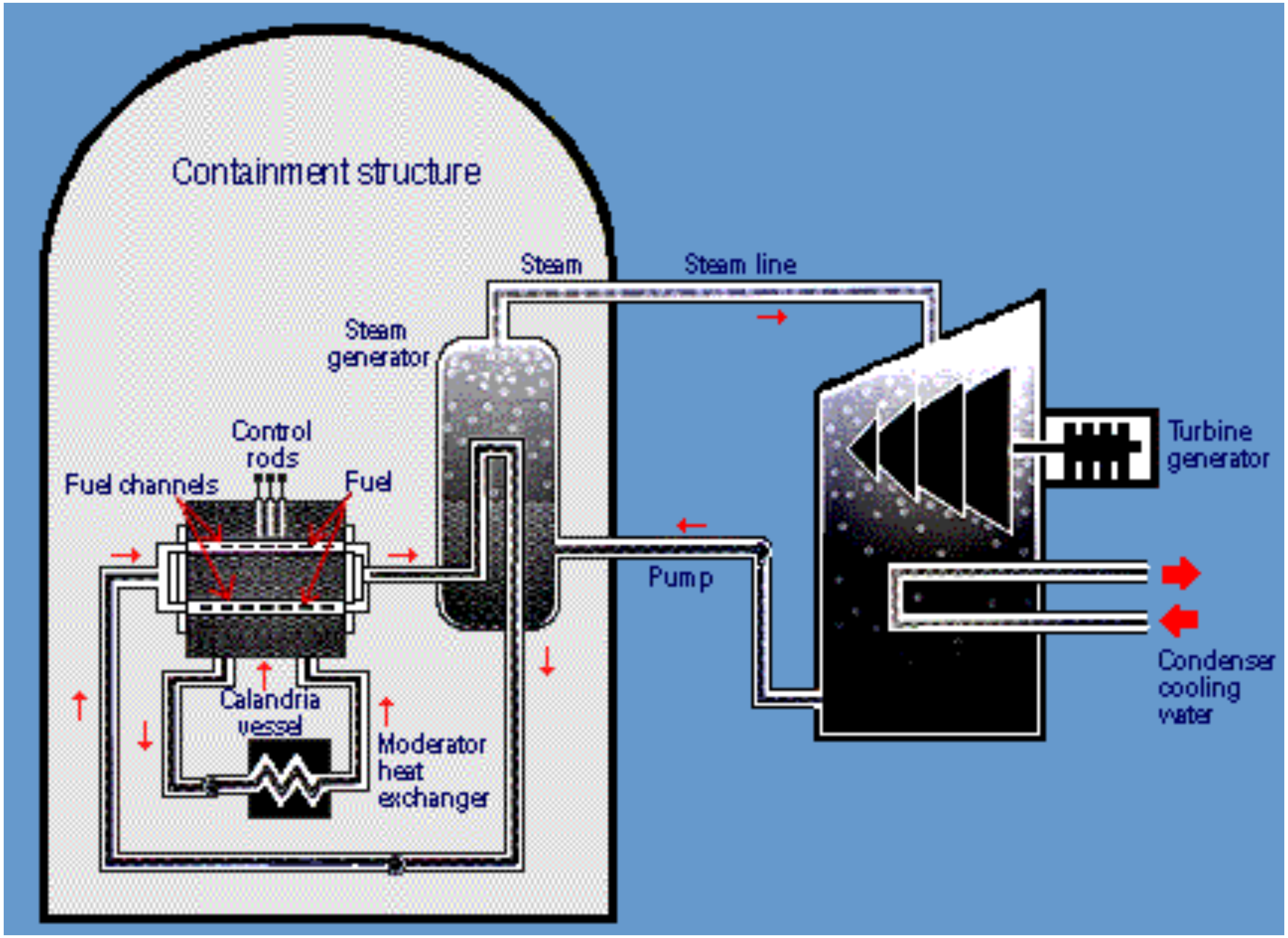
Source: www.world-nuclear.org

Boiling Water Reactor



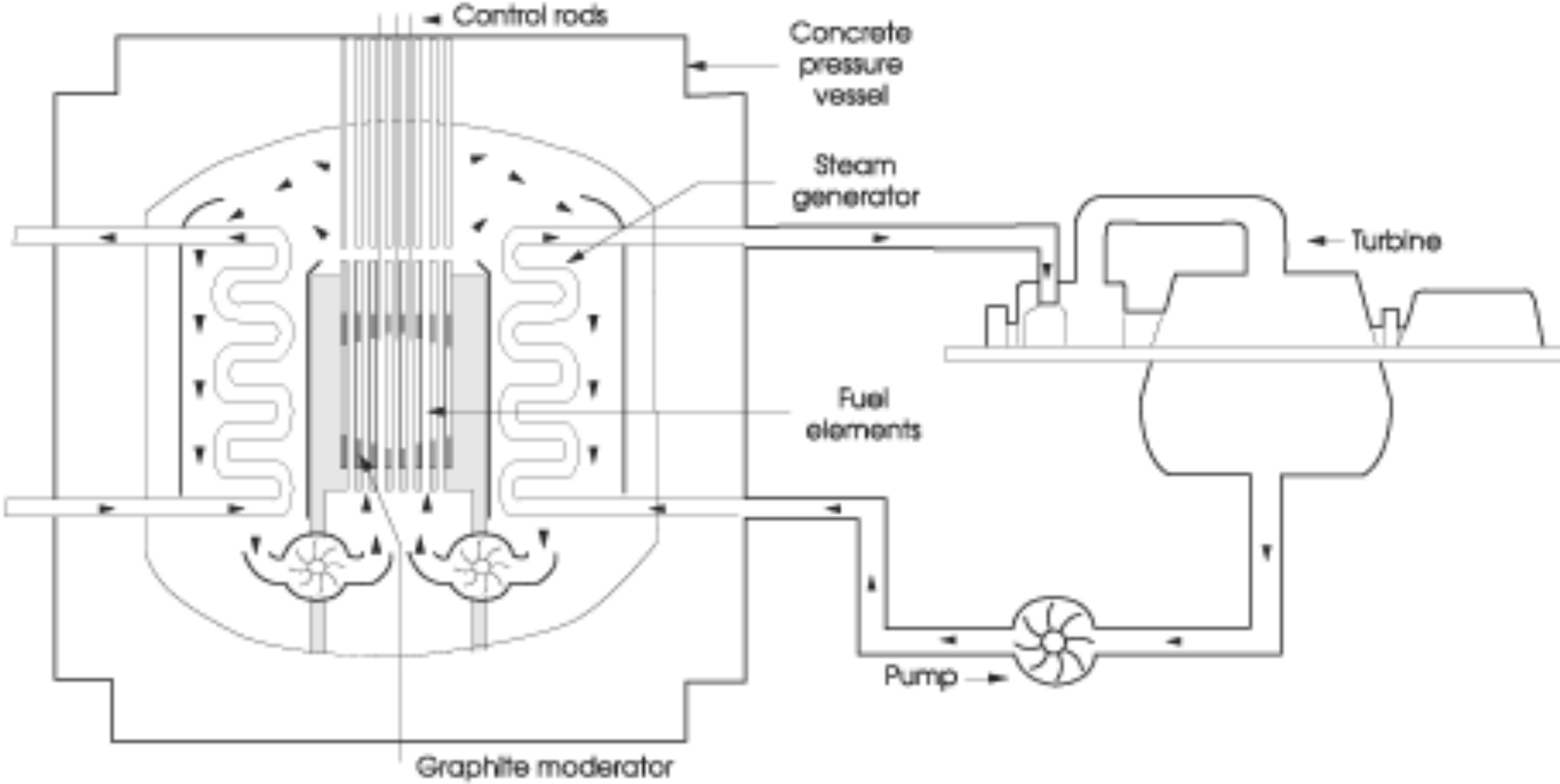
Source: www.world-nuclear.org

Pressurised heavy water reactor

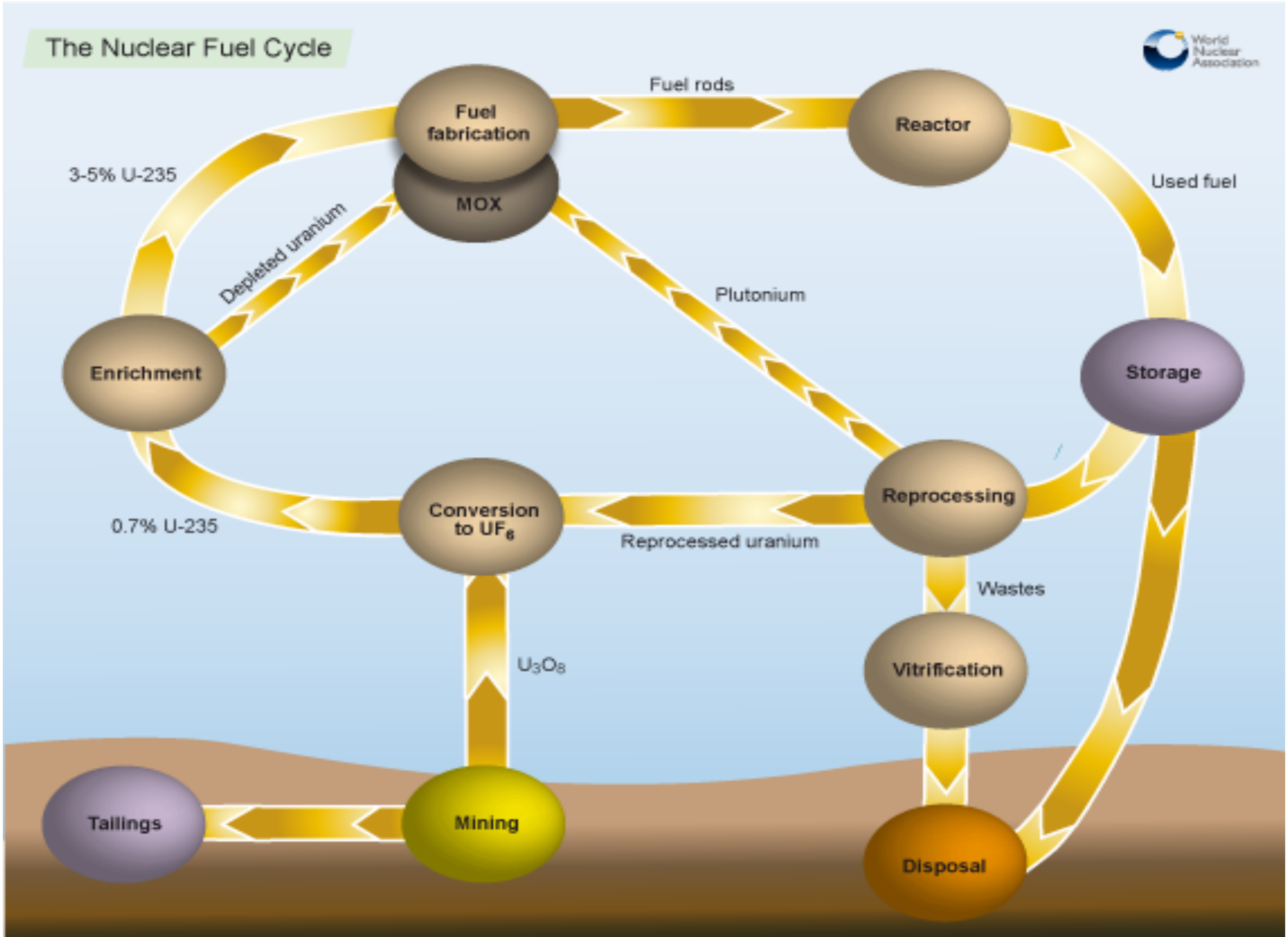


Source: www.world-nuclear.org

Advanced Gas Cooled Reactor



Source: www.world-nuclear.org



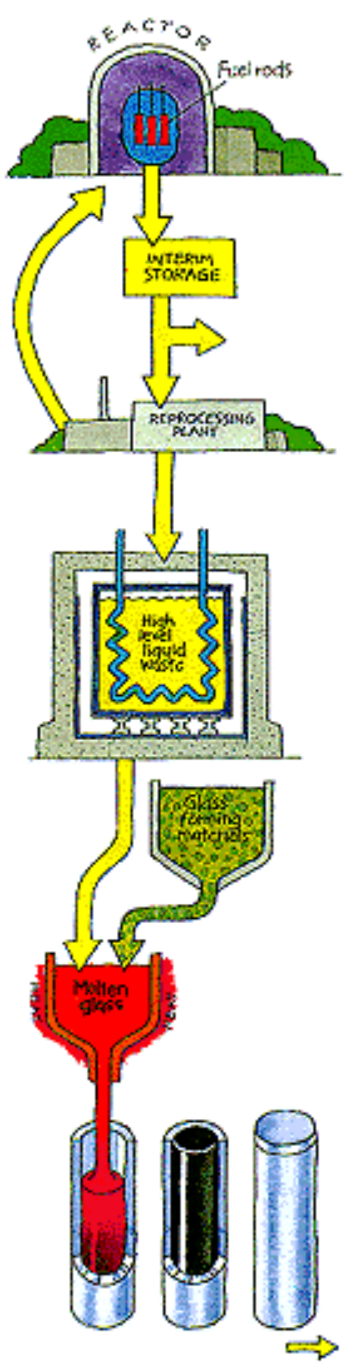
The Nuclear Fuel Cycle
World Nuclear Association
Fuel fabrication
MOX
Fuel rods
Reactor
Used fuel
3-5% U-235
Depleted uranium
Plutonium
Enrichment
Storage
Conversion to UF_6
Reprocessing
0.7% U-235
Reprocessed uranium
Wastes
U_3O_8
Vitrification
Tailings
Mining
Disposal

Nuclear waste management

1 GW plant

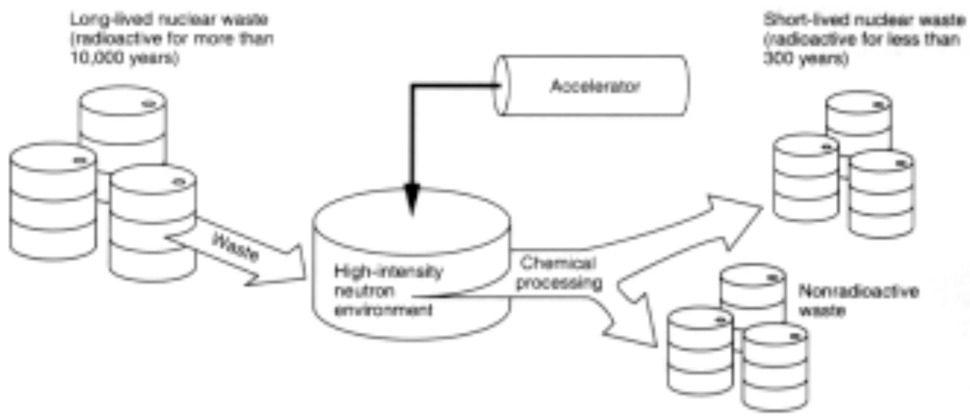
10 m3/yr high level waste

2.5 m3/yr processed high level waste

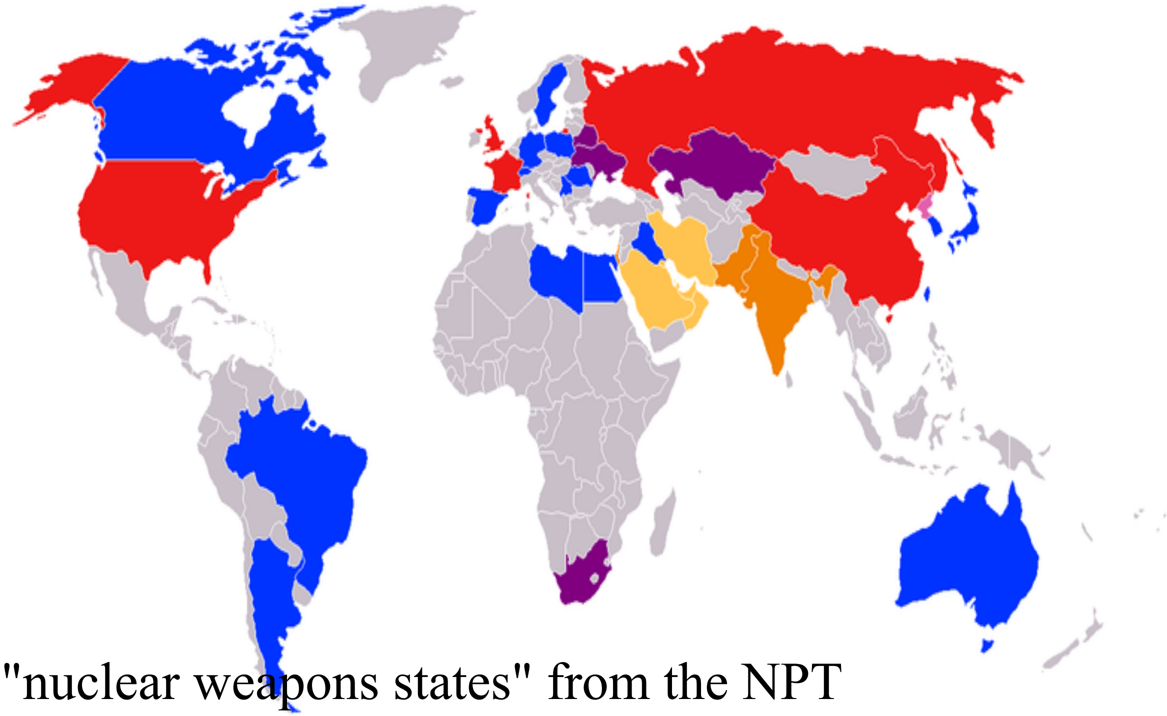


Deep geological waste disposal ??

Transmutation of nuclear waste



World map with nuclear weapons development status

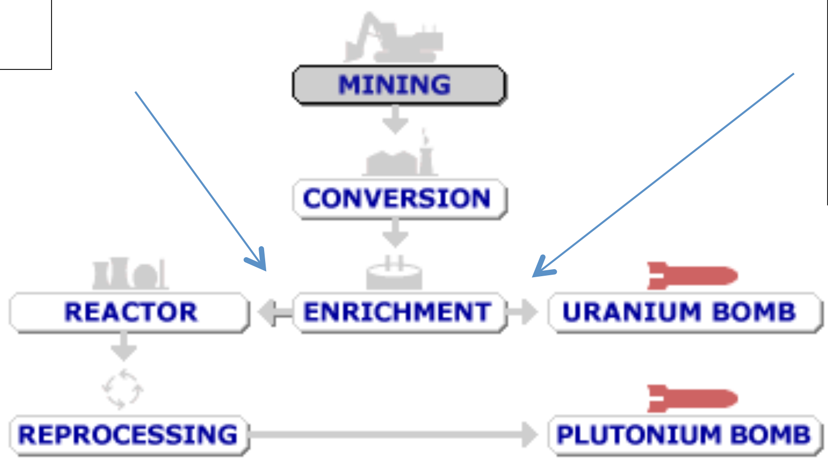


Five "nuclear weapons states" from the NPT
Other known nuclear powers
States formerly possessing nuclear weapons
States suspected of being in the process of developing nuclear weapons and/or nuclear programs
States which at one point had nuclear weapons and/or nuclear weapons research programs
States that possess nuclear weapons, but have not widely adopted them

Risk of nuclear weapons proliferation

3.5-5% enrichment for nuclear power

>20% enrichment for weapons

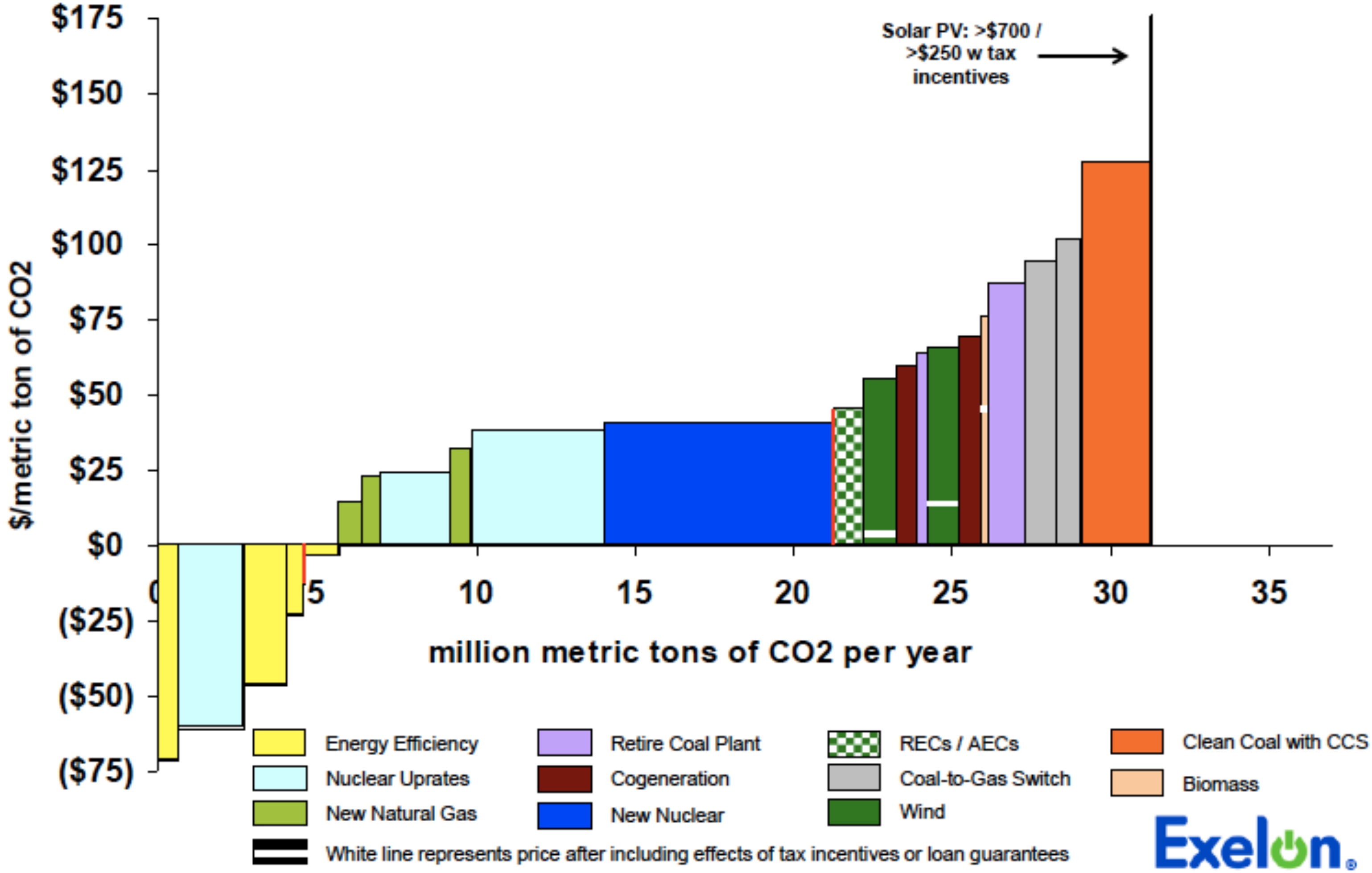


1 Gwe reactor> 200 kg Pu/ yr

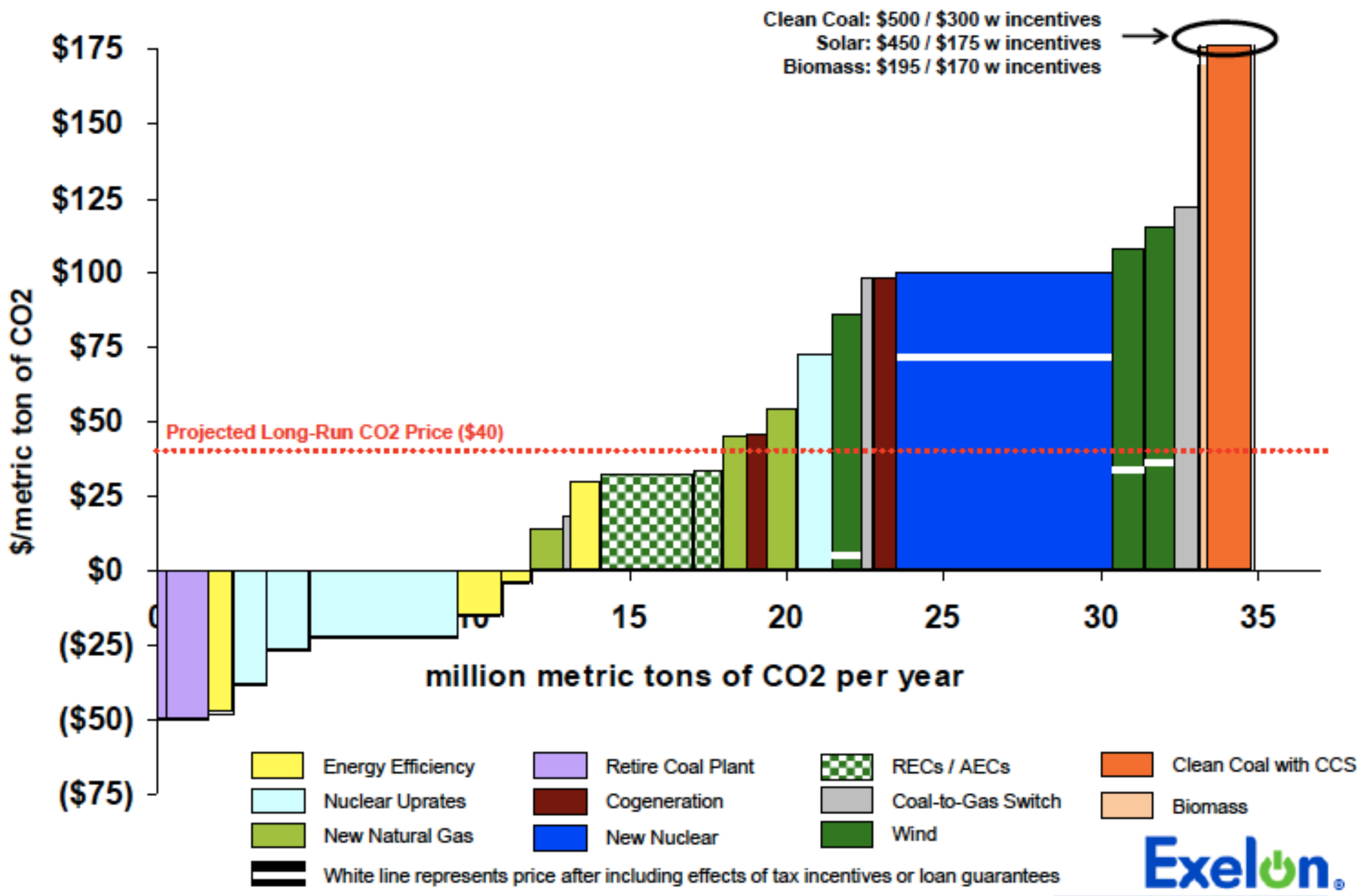
~ 10 kg needed for 1 Pu bomb

http://www.eurotrib.com/story/2005/8/5/75619/06294

2008 US prices

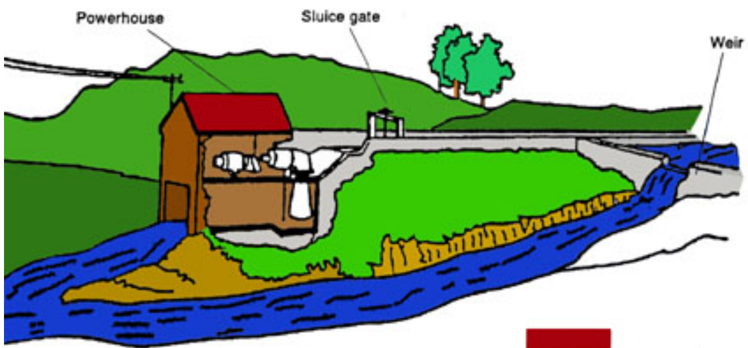


2010 US prices

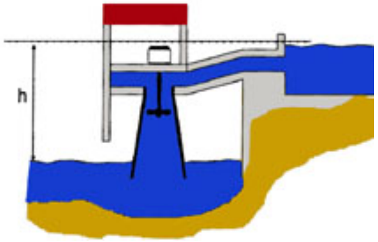


Hydropower

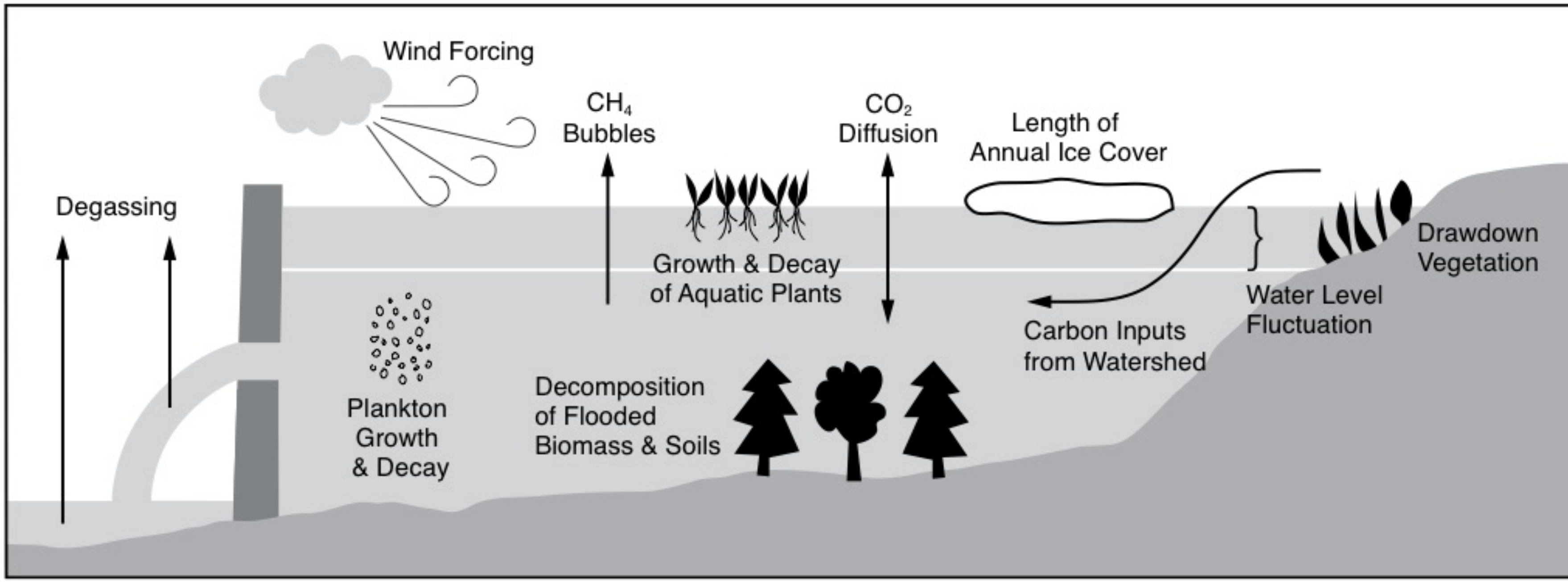
- Large hydro: 10 MW -22 GW
- Current capacity: 920 GW
- Estimated potential 2030: 2000 GW



- Potential small hydro: 400 GW

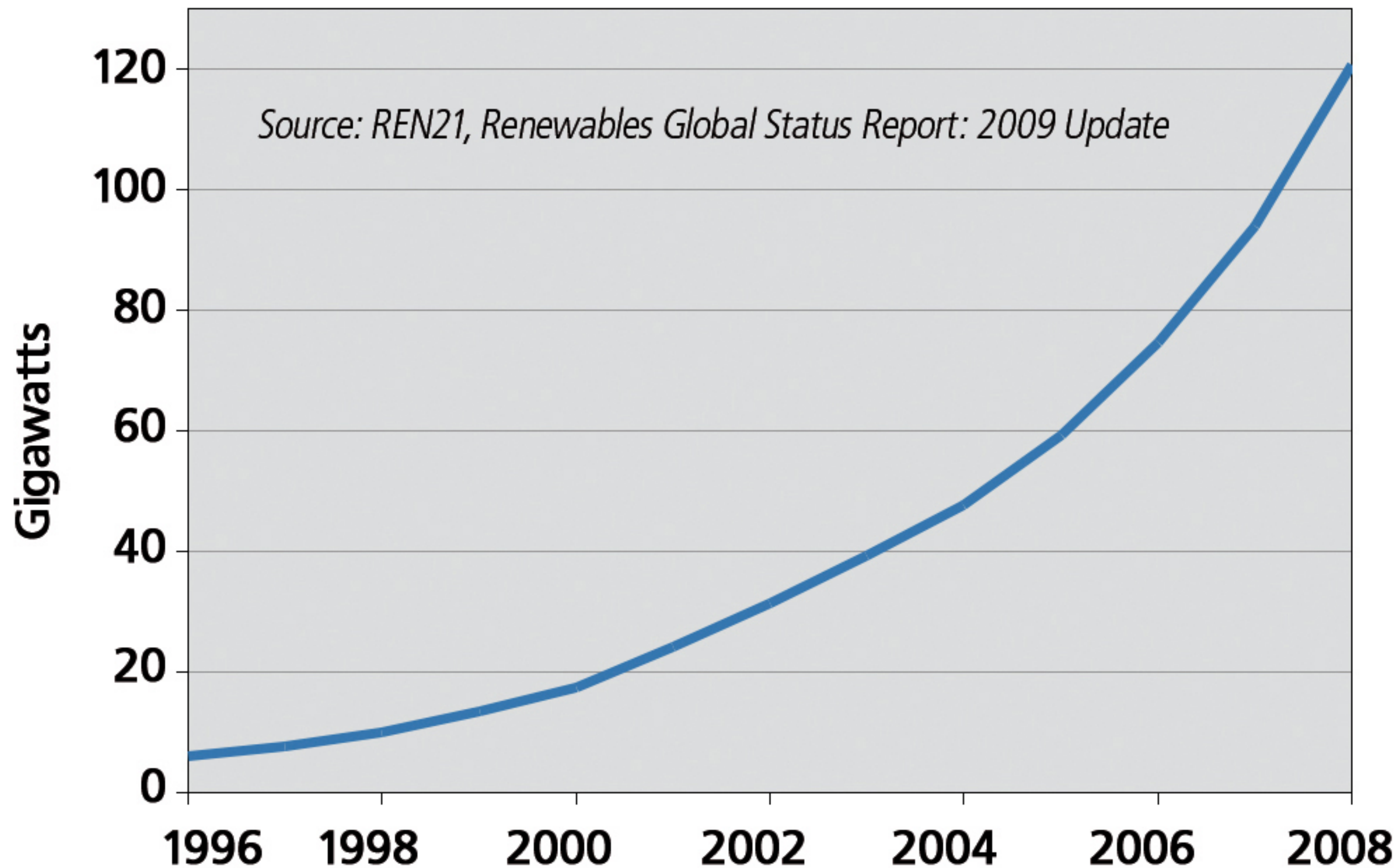


Methane from hydro reservoirs

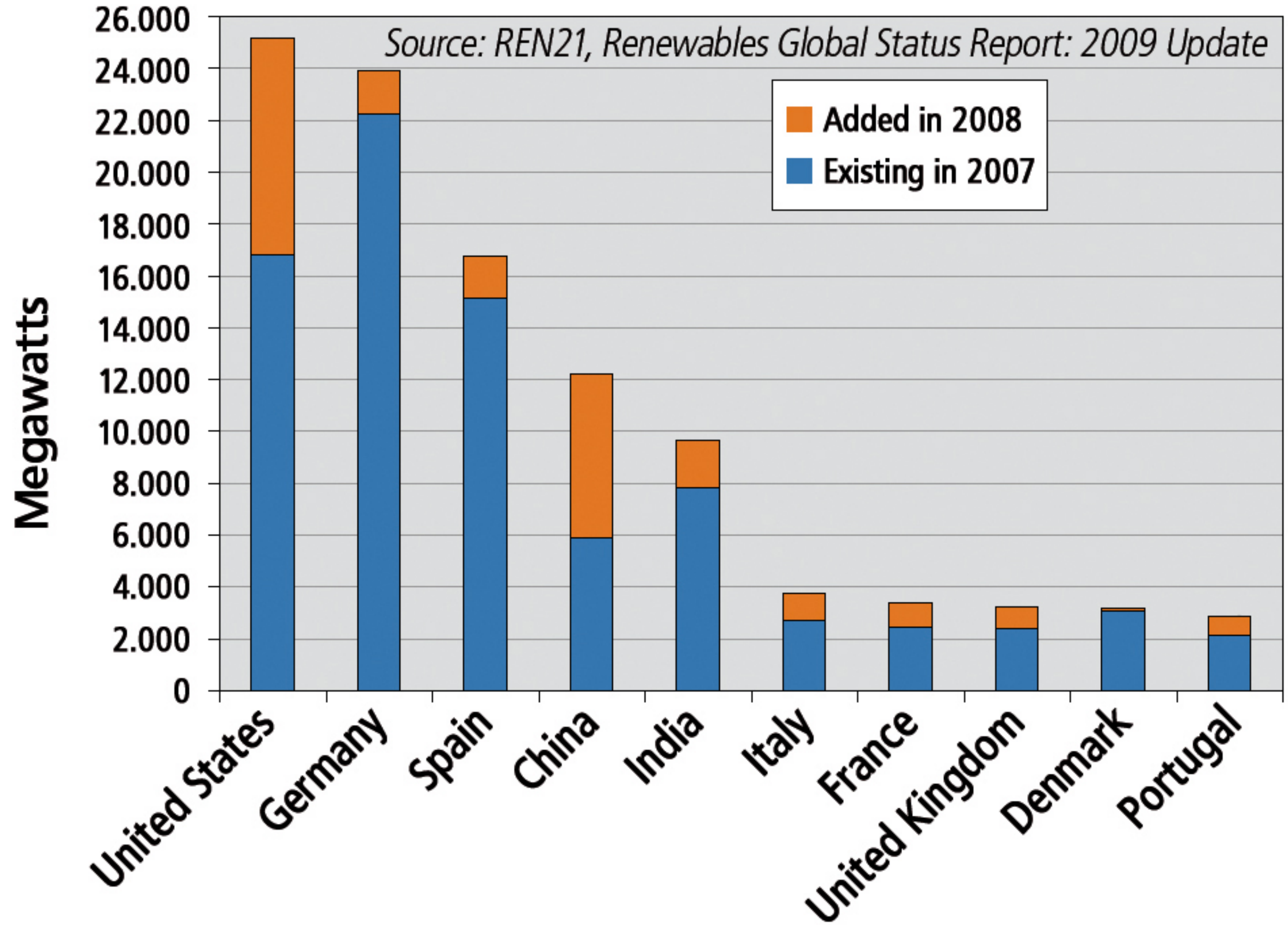


- Some reservoirs: 400 gCO2e/kWhe
- Average : 10-80 g CO2e/kWhe

Wind Power, Existing World Capacity, 1996–2008

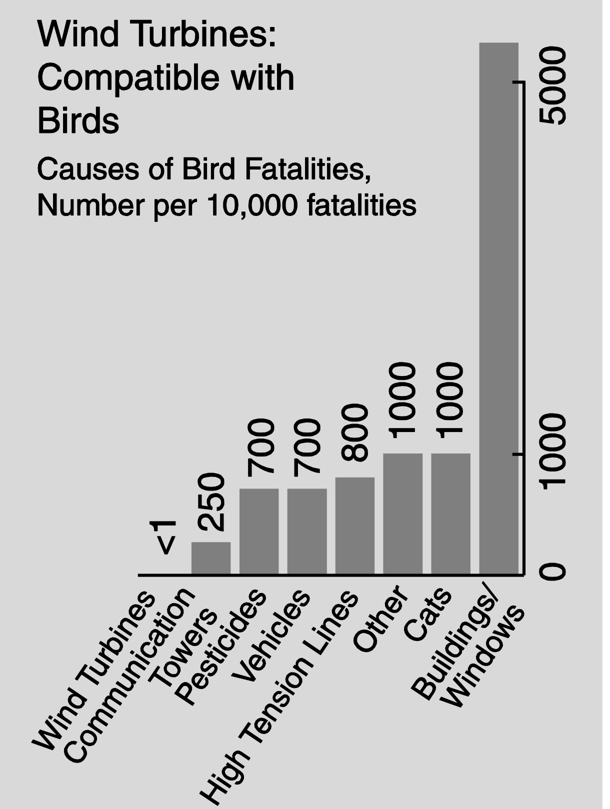


Wind Power Capacity, Top Ten Countries, 2008



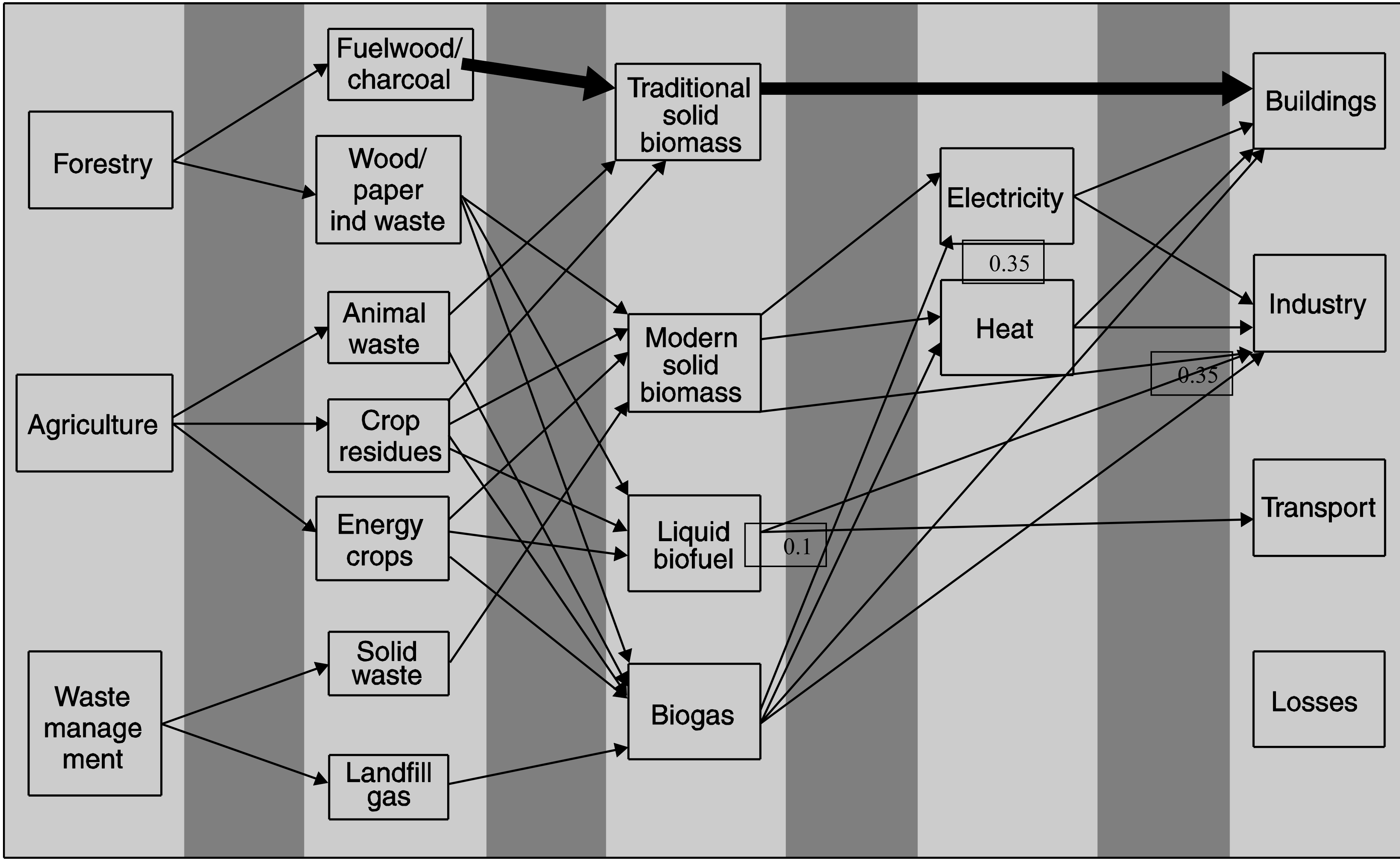
Issues with wind energy

- Size of wind turbines
- Load factor/ need for back up
- Costs
- Acceptability
- Migratory birds

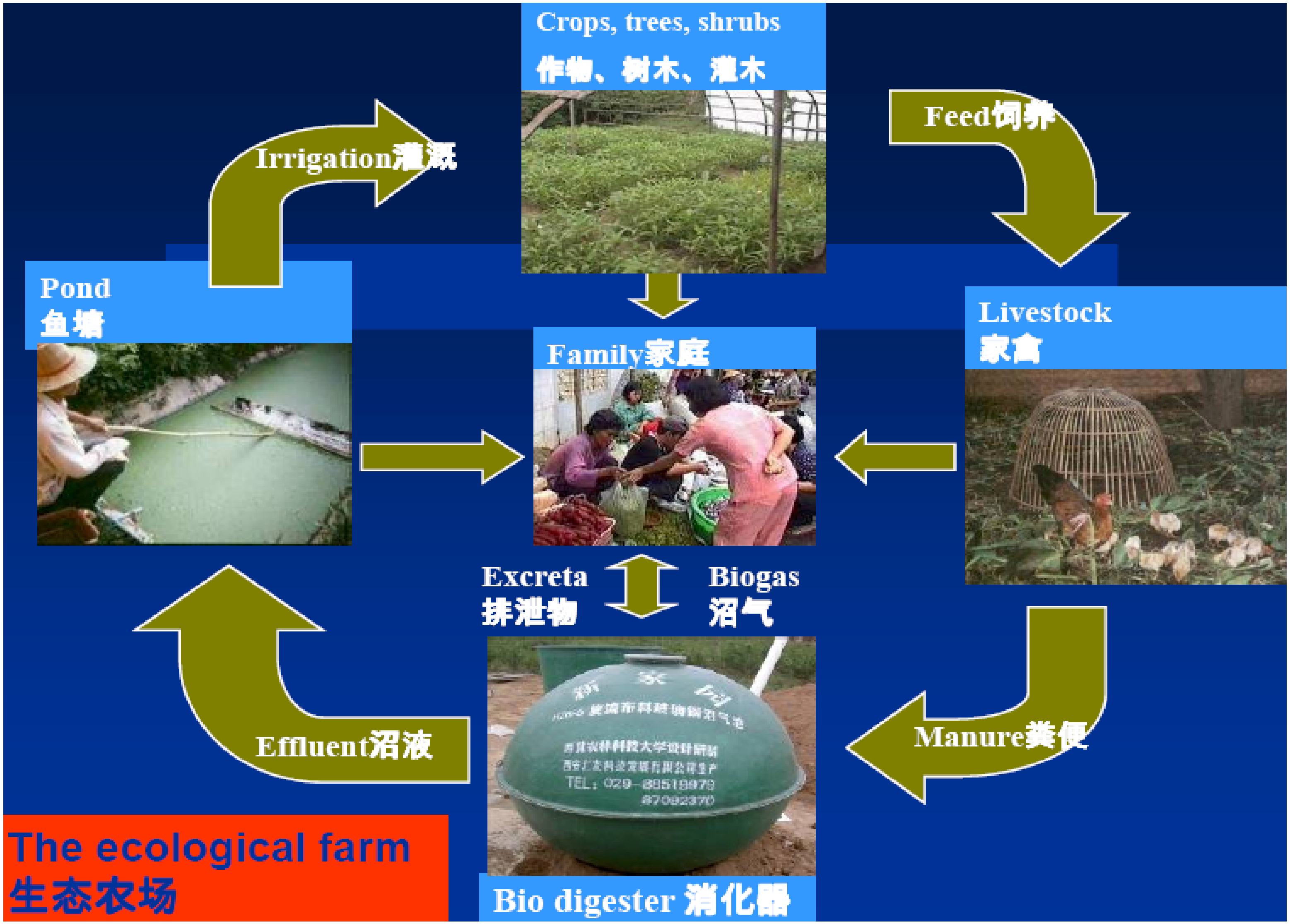


Data Sources: Erickson et al., 2002. Summary of Anthropogenic Causes of Bird Mortality.

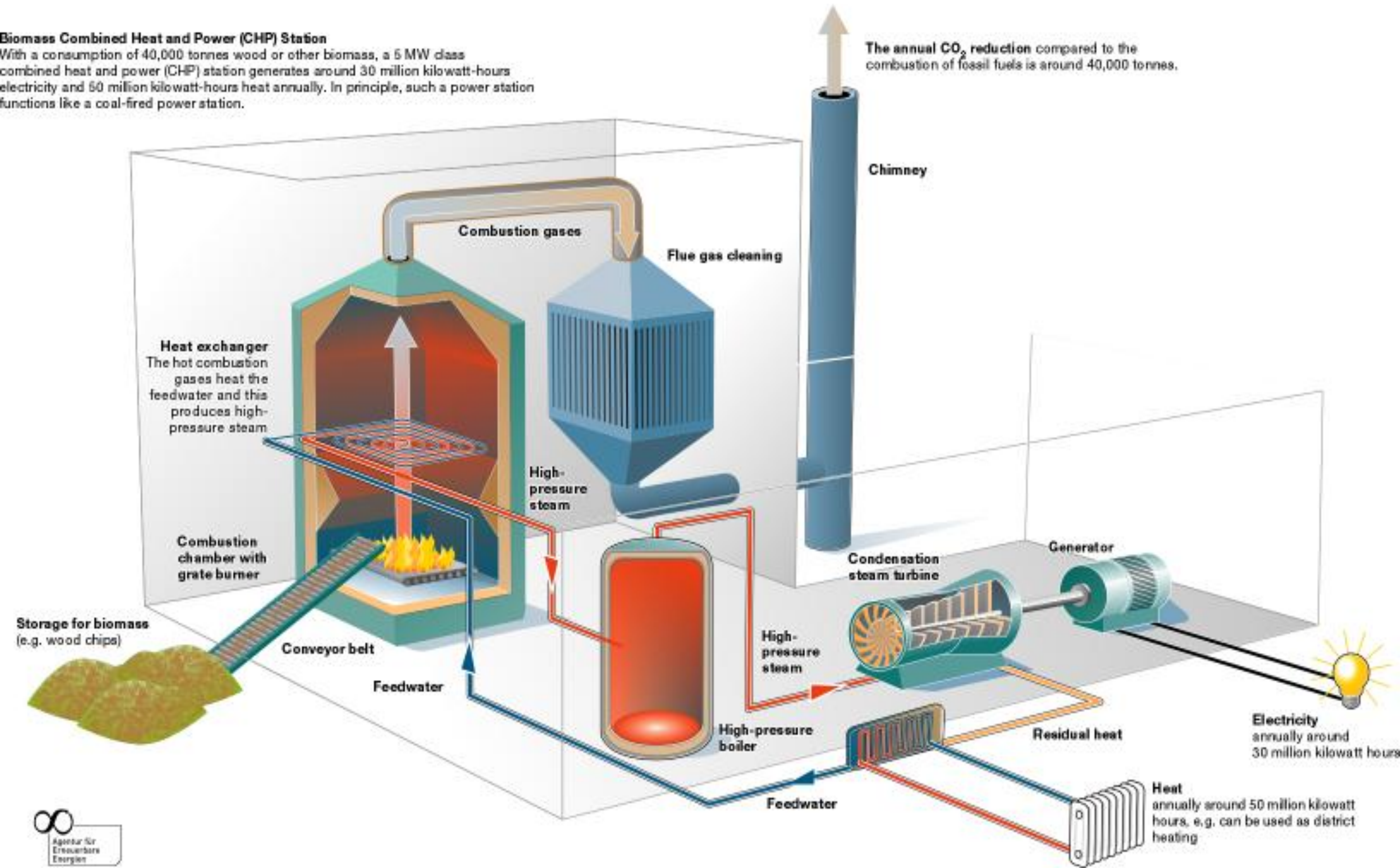
Bioenergy sources, carriers and end-use



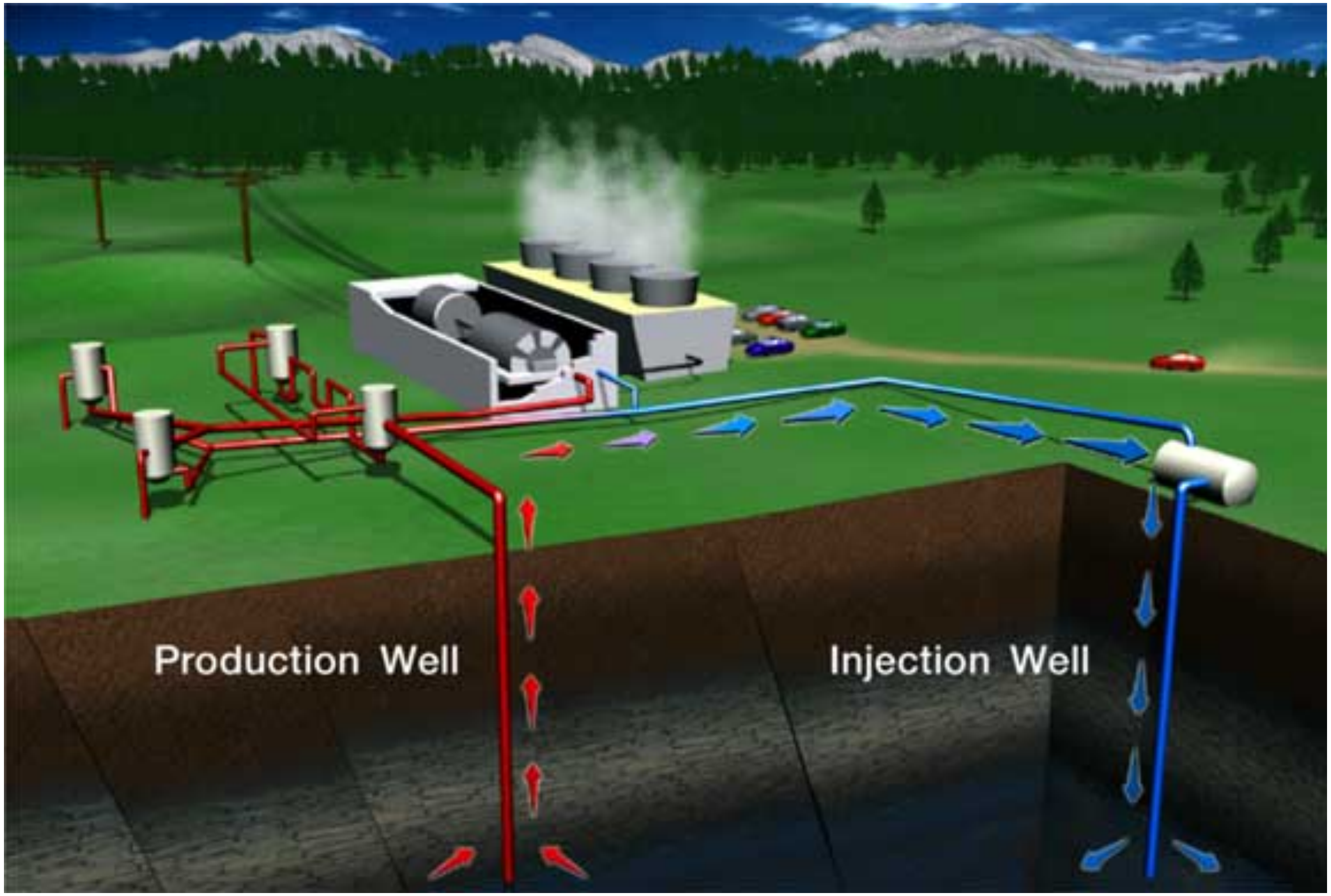
Rural biogas



Biomass fired CHP installation (source:http://www.unendlich-viel-energie.de/uploads/media/Biomass_CHP.jpg)



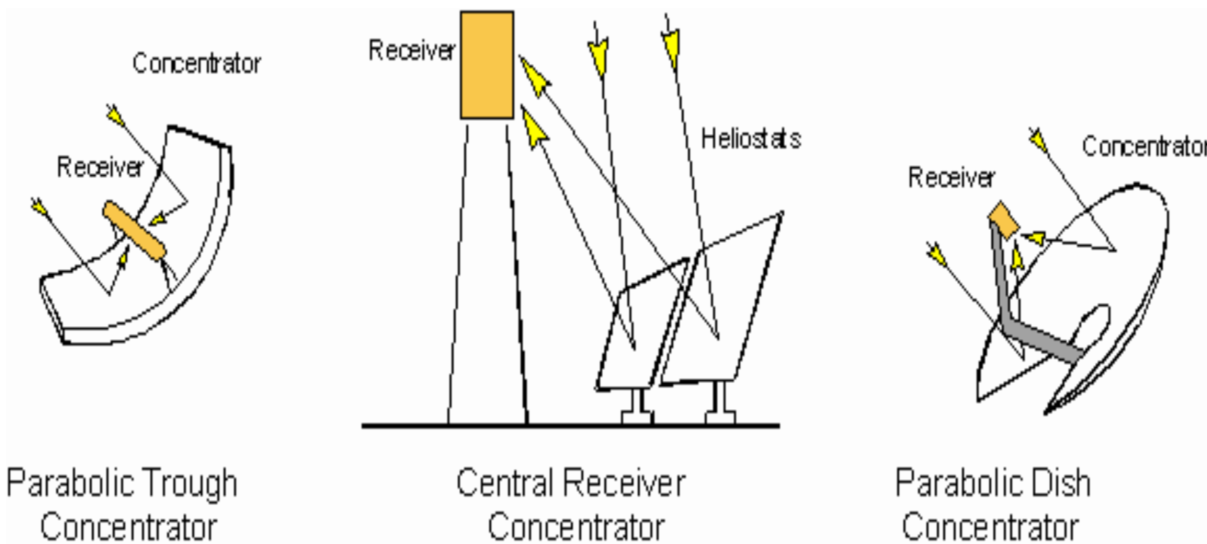
Geothermal energy



Top countries for geothermal electricity

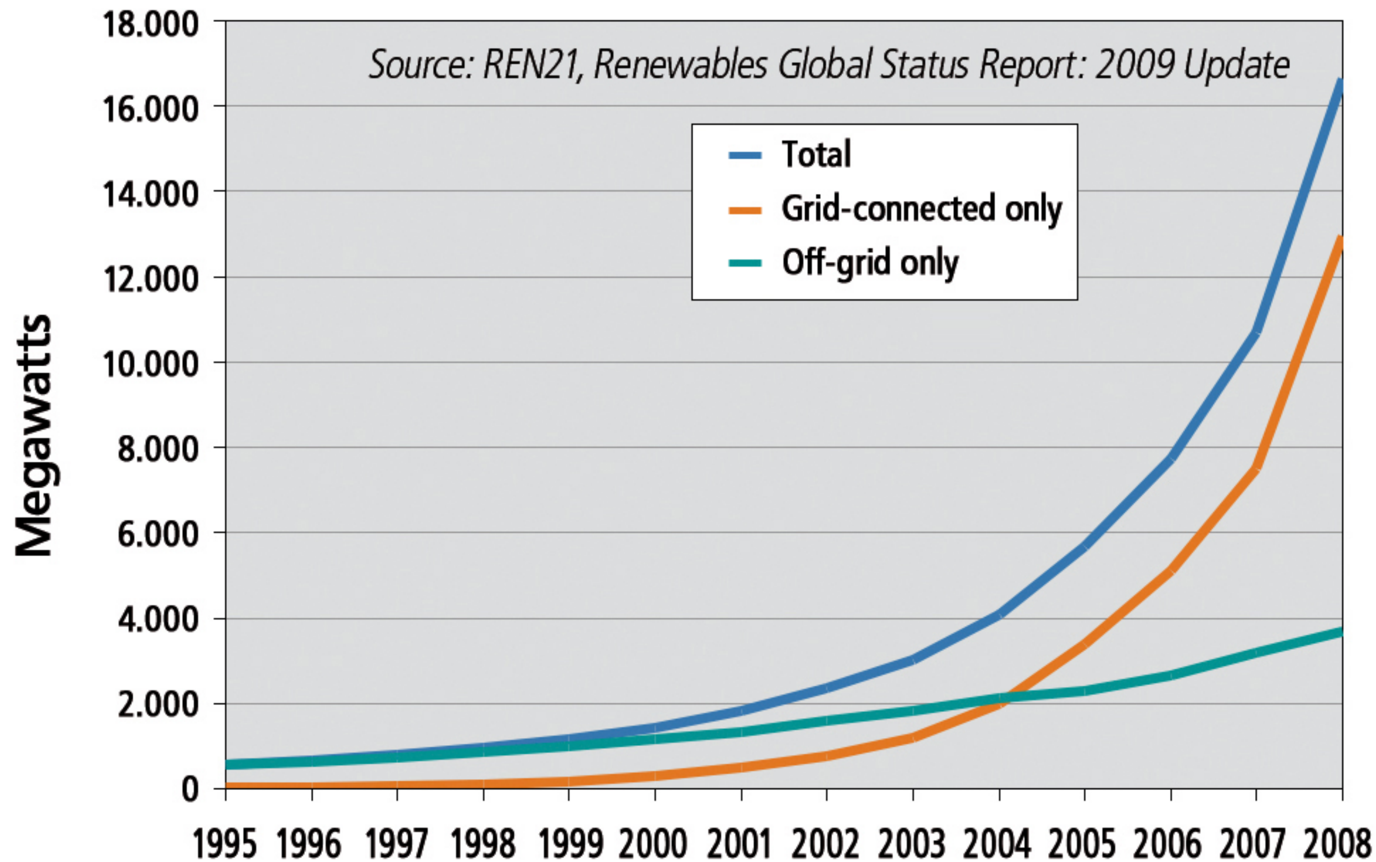
Country	*Geothermal electricity capacity (MW)*	*Percentage of electricity from geothermal*
USA	2540	
Philippines	1930	
Mexico	950	
Indonesia	800	
Italy	790	
Japan	535	
New Zealand	435	
Iceland	320	25
El Salvador	pm	20
Philippines	pm	18
Costa Rica	pm	14
Kenya	pm	14

Concentrating solar power- principles

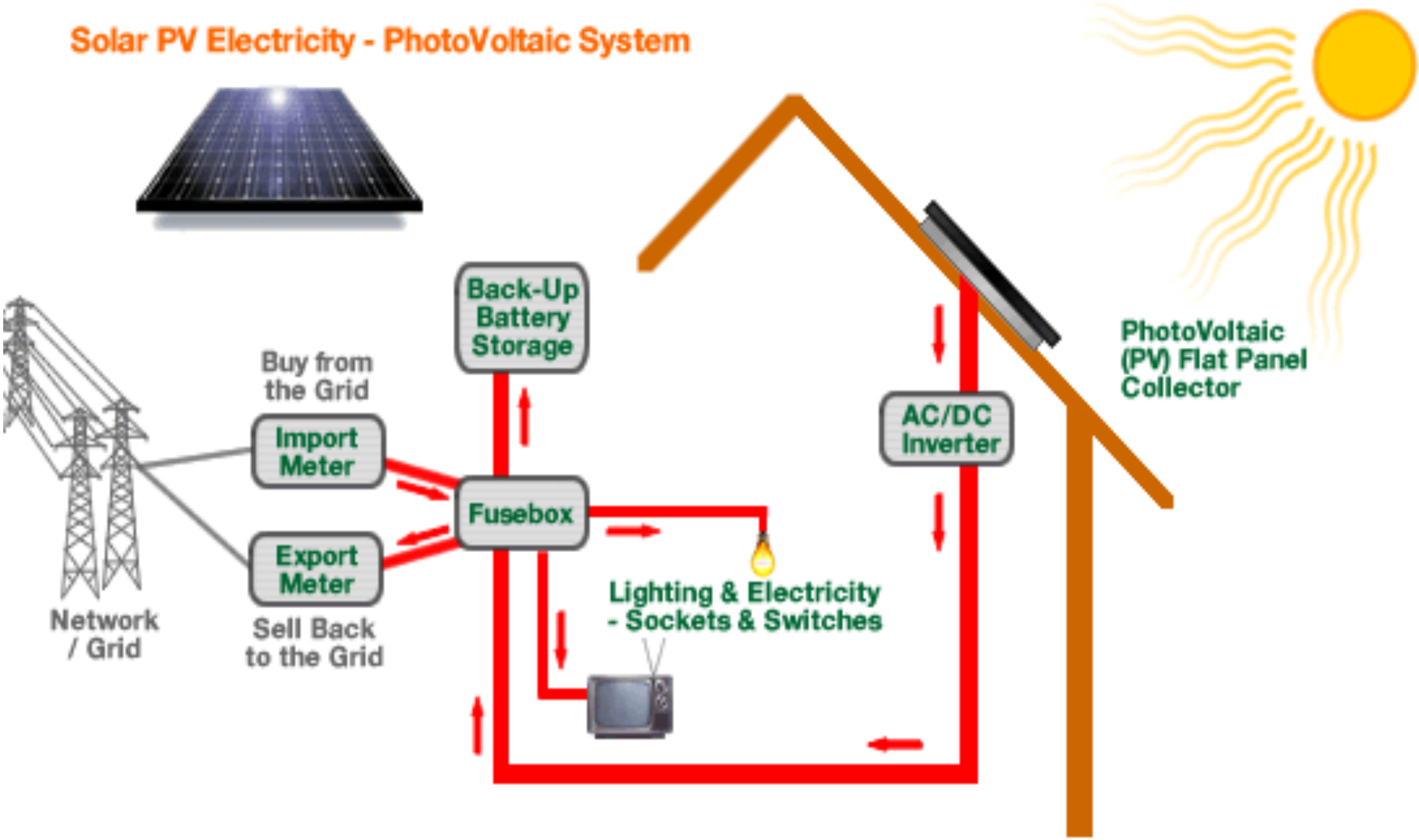


CSP systems in practice

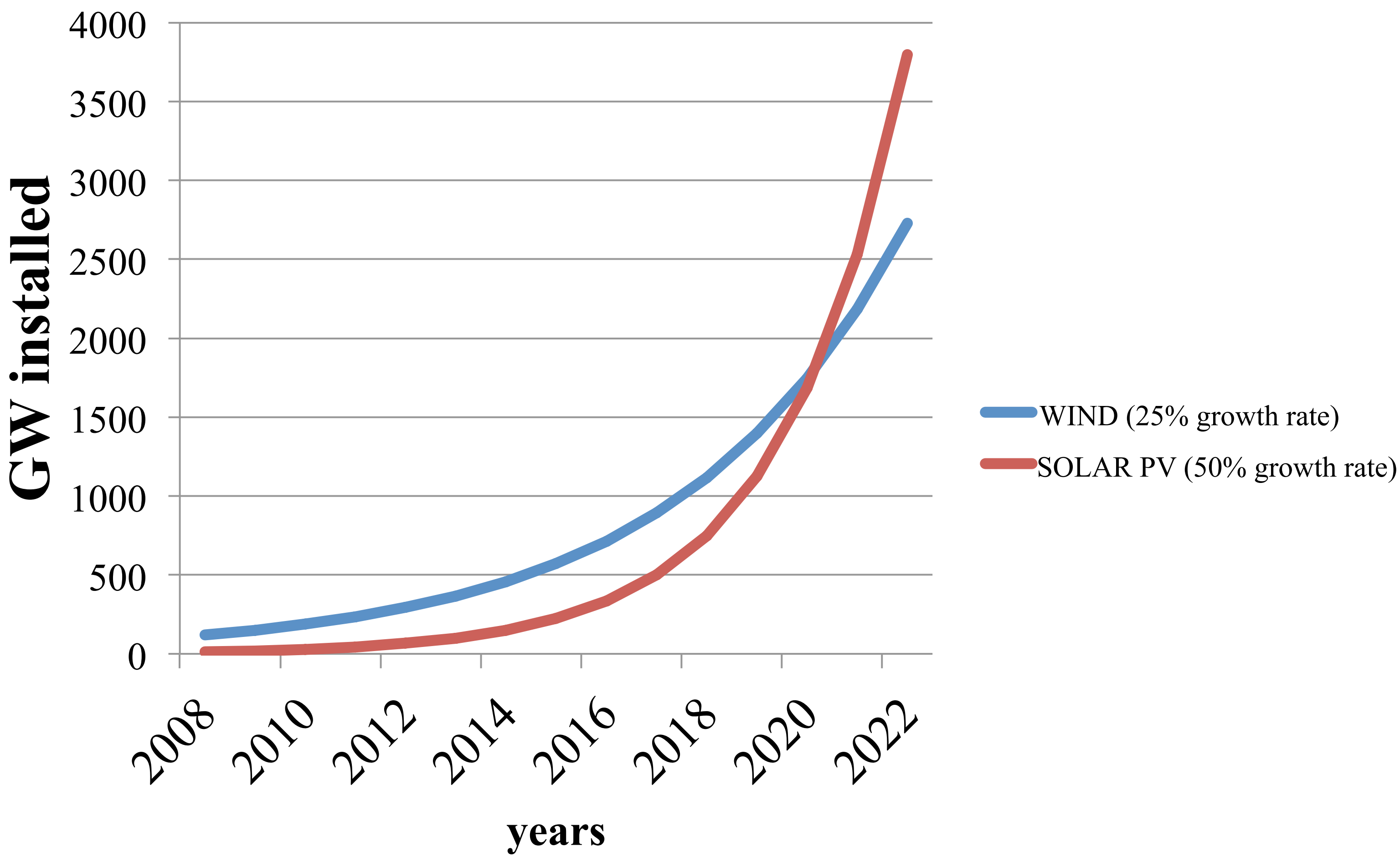
Solar PV, Existing World Capacity, 1995–2008

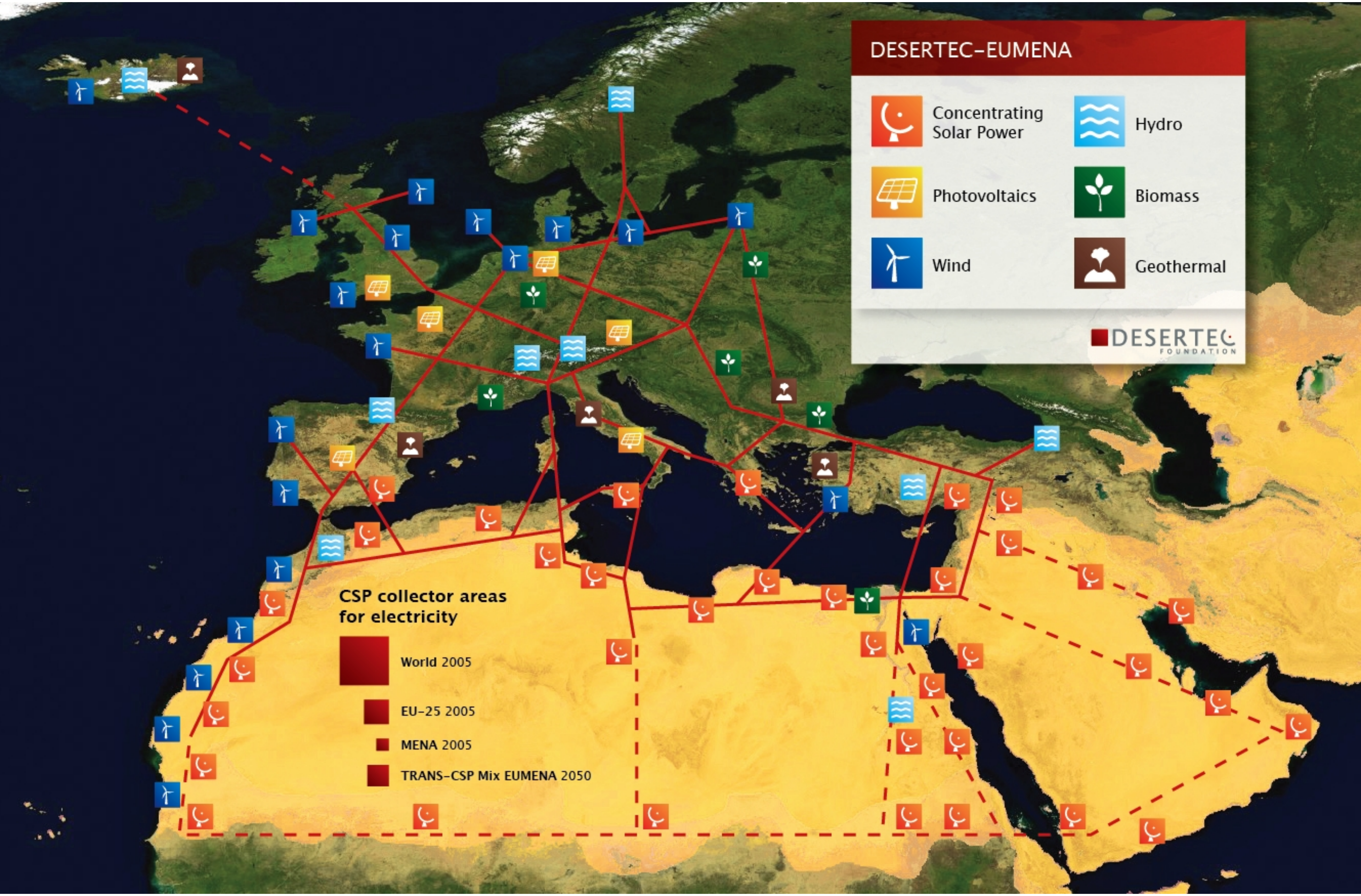


Solar PV Electricity - PhotoVoltaic System

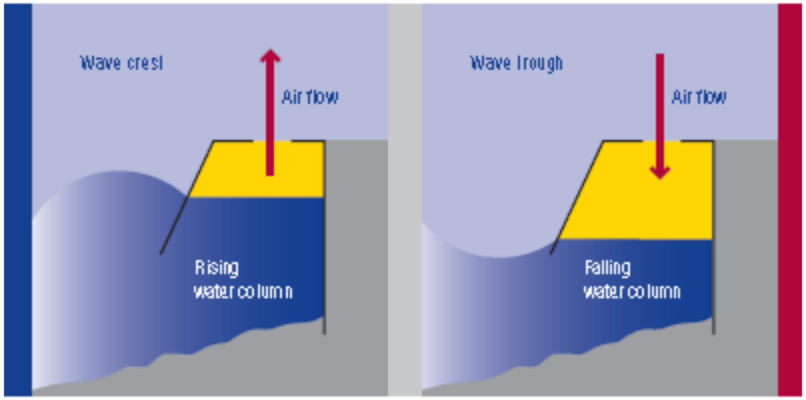


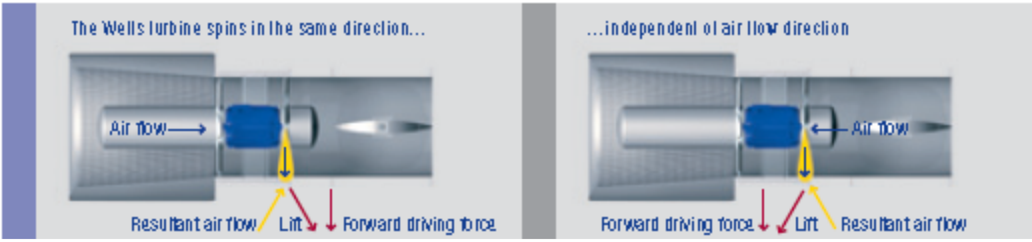
What exponential growth can do

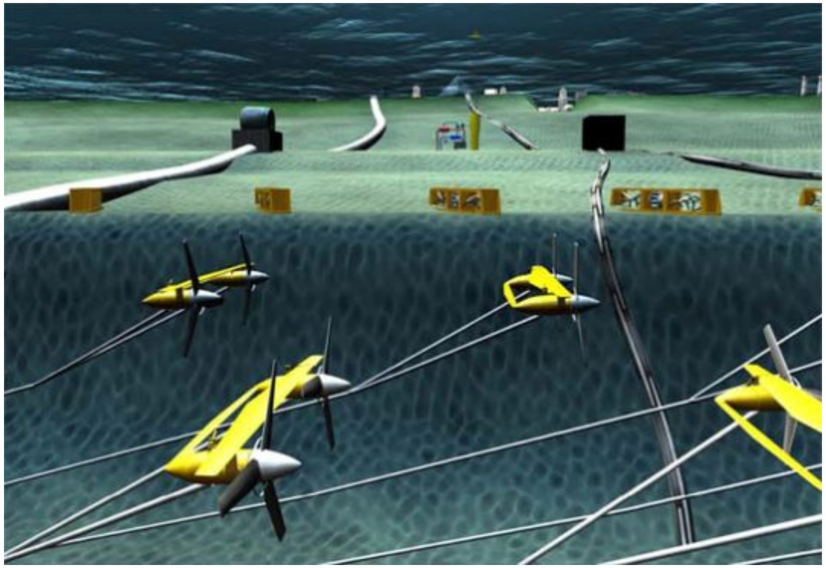



DESERTEC-EUMENA
Concentrating Solar Power
Hydro
Photovoltaics
Biomass
Wind
Geothermal
DESERTEC FOUNDATION
CSP collector areas for electricity
World 2005
EU-25 2005
MENA 2005
TRANS-CSP Mix EUMENA 2050

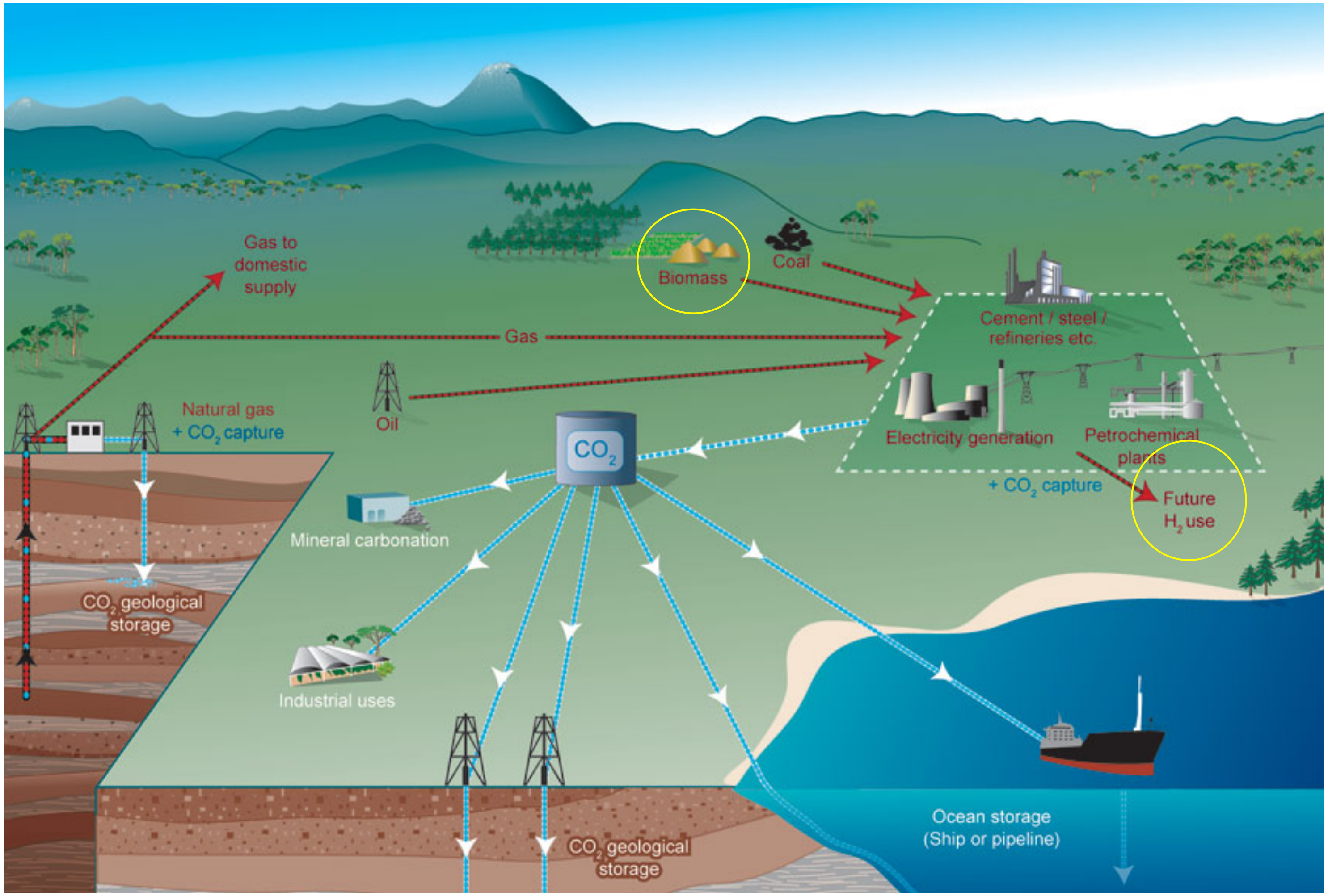
Ocean energy







CO_2 capture and storage system



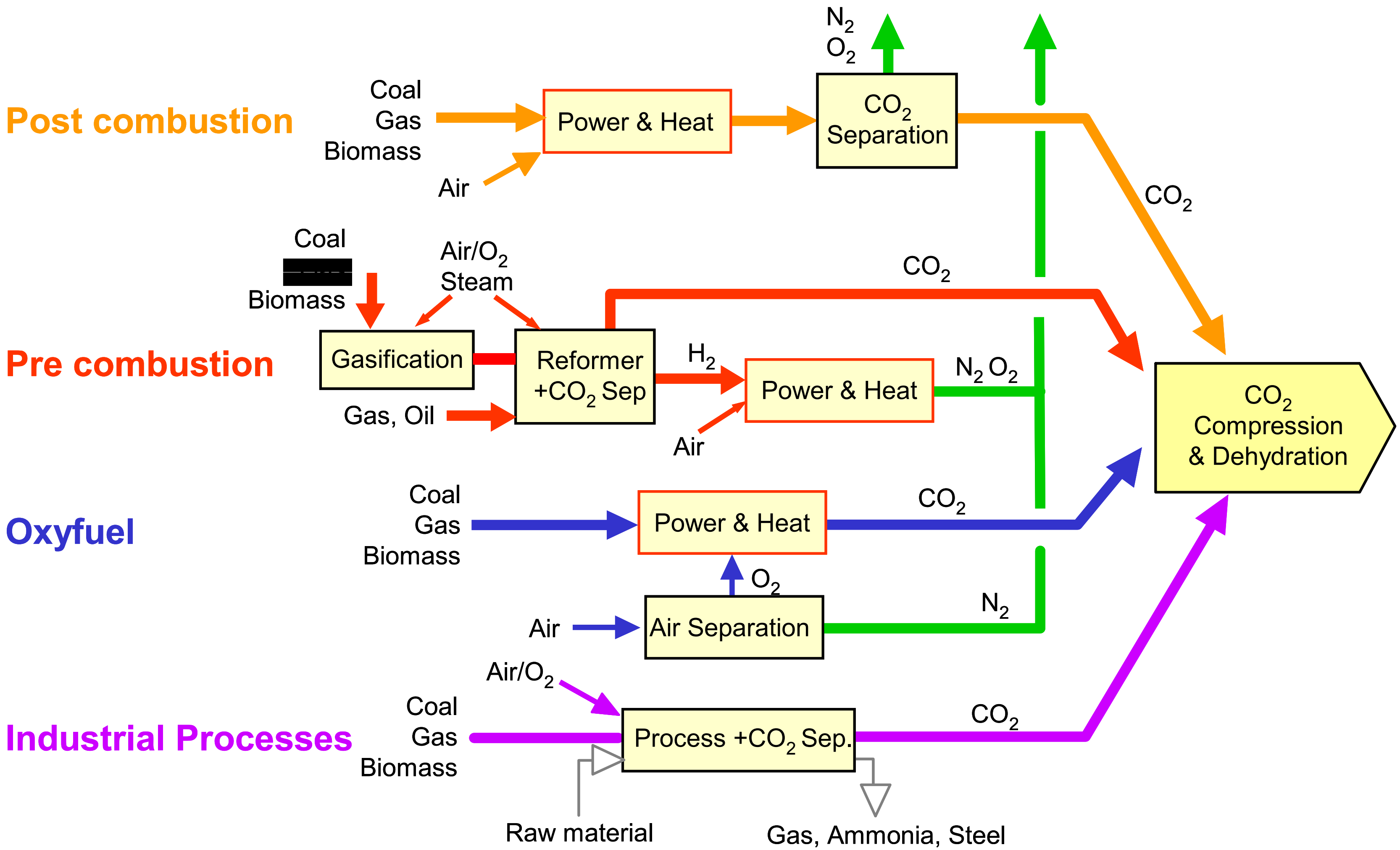
How could CCS play a role in mitigating climate change?

- Part of a portfolio of mitigation options
- Reduce overall mitigation costs
- Increase flexibility in achieving greenhouse gas emission reductions
- Application in developing countries important
- Energy requirements point of attention

Global large stationary CO_2 sources with emissions of more than 0.1 $MtCO_2$/year

Process	No. of sources	Emissions ($MtCO_2$/yr)
Fossil Fuels		
Power (coal, gas, oil and others)	4,942	10,539
Cement production	1,175	932
Refineries	638	798
Iron and steel industry	269	646
Petrochemical industry	470	379
Oil and gas processing	N/A	50
Other sources	90	33
Biomass		
Bioethanol and bioenergy	303	91
Total	**7,887**	**13,466**

CO2 Capture

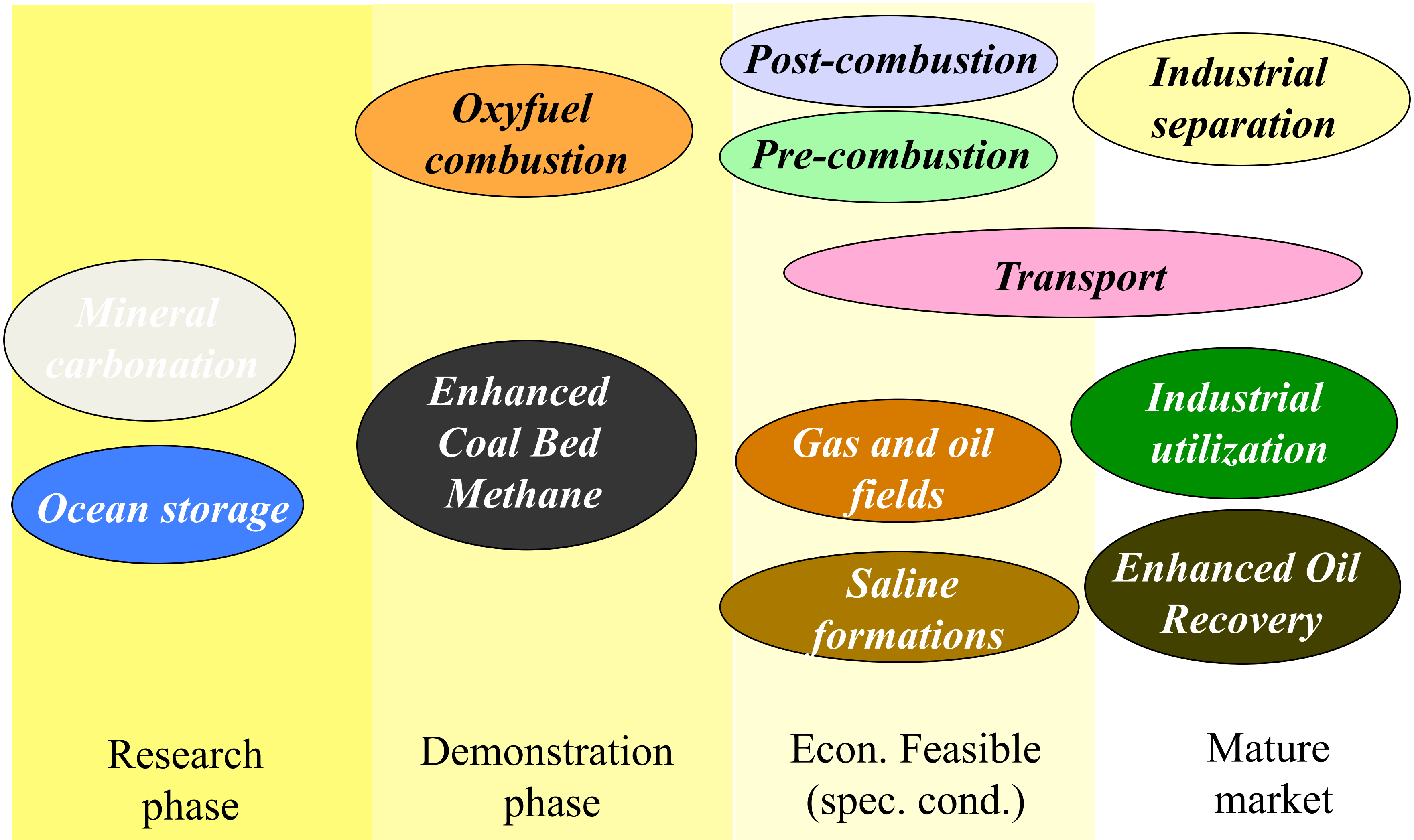


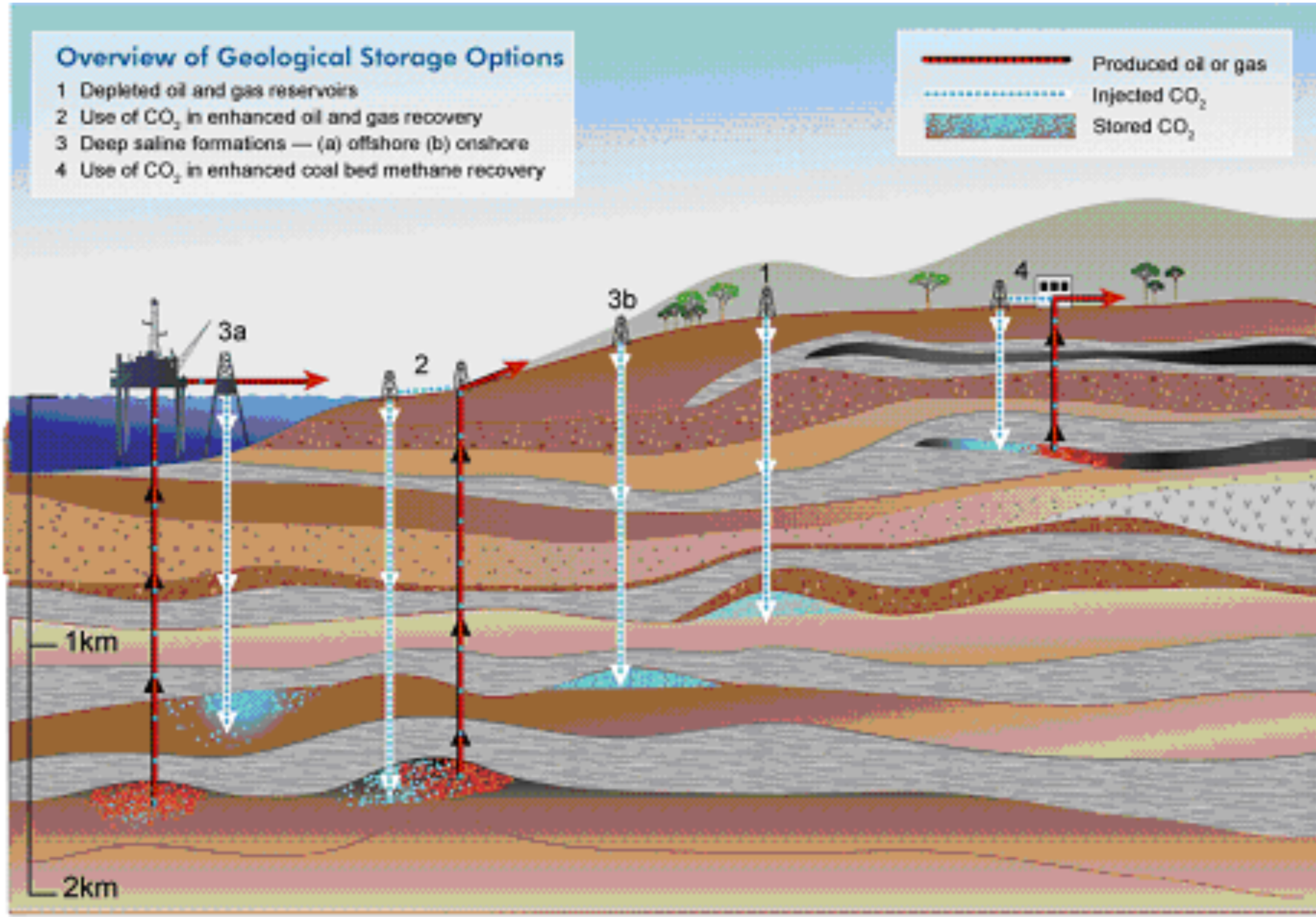
Post combustion
Coal
Gas
Biomass
Air
Power & Heat
N_2
O_2
CO_2 Separation
CO_2
Pre combustion
Coal
[redacted]
Biomass
Air/O_2
Steam
Gasification
Reformer +CO_2 Sep
Gas, Oil
CO_2
H_2
Power & Heat
Air
N_2 O_2
Oxyfuel
Coal
Gas
Biomass
Power & Heat
CO_2
O_2
Air
Air Separation
N_2
CO_2 Compression & Dehydration
Industrial Processes
Air/O_2
Coal
Gas
Biomass
Process +CO_2 Sep.
CO_2
Raw material
Gas, Ammonia, Steel

Capture energy requirements

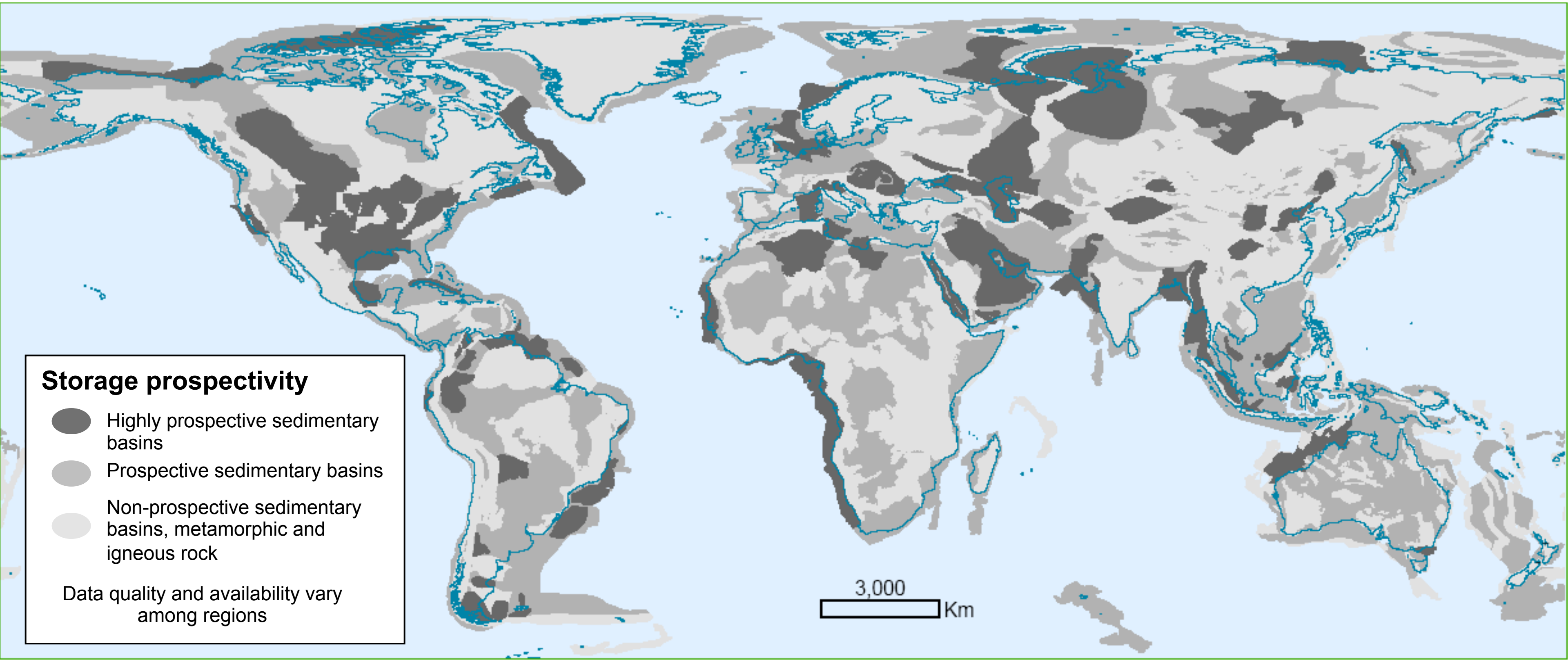
Power plant (new)	**Thermal efficiency w/o capture %**	**Thermal efficiency with capture %**	**Increased primary energy per unit of electricity output %**
Pulverized Coal	41- 45	30 - 35	24 - 40
NGCC	55 - 58	47 - 50	11 - 22
IGCC	38 - 47	31 - 40	14 - 25

"Complete CCS systems can be assembled from existing technologies that are mature or economically feasible under specific conditions, although the state of development of the overall system may be less than some of its separate components"




Overview of Geological Storage Options
1 Depleted oil and gas reservoirs
2 Use of CO_2 in enhanced oil and gas recovery
3 Deep saline formations — (a) offshore (b) onshore
4 Use of CO_2 in enhanced coal bed methane recovery
Produced oil or gas
Injected CO_2
Stored CO_2
3a
2
3b
1
4
1km
2km

“Large point sources of CO2 are concentrated in proximity to major industrial and urban areas. Many such sources are within 300 km of areas that potentially hold formations suitable for geological storage”



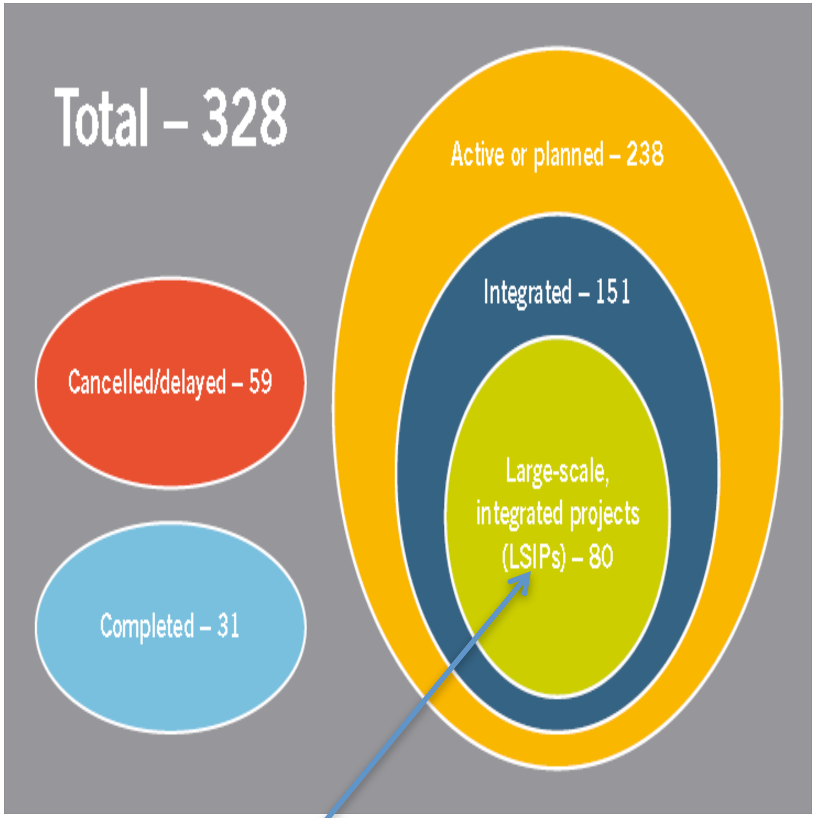
Prospective areas in sedimentary basins where suitable saline formations, oil or gas fields, or coal beds may be found. Locations for storage in coal beds are only partly included. Prospectivity is a qualitative assessment of the likelihood that a suitable storage location is present in a given area based on the available information. This figure should be taken as a guide only, because it is based on partial data, the quality of which may vary from region to region, and which may change over time and with new information (Courtesy of Geoscience Australia).

Progress in CCS activities

IPCC, 2005

GCI, April, 2010

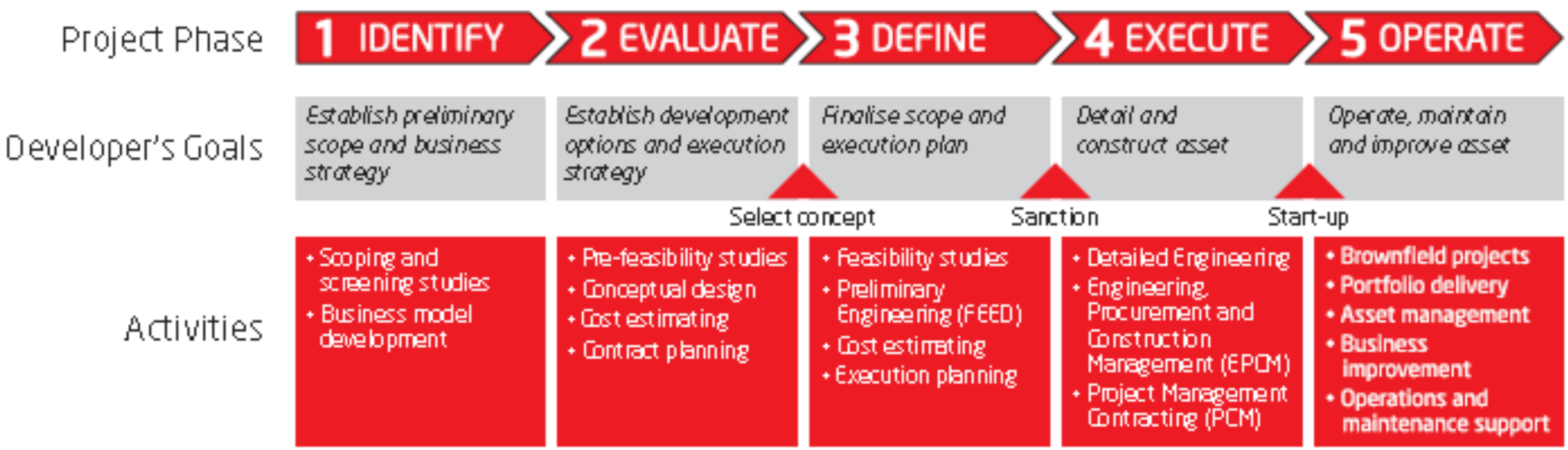
Active and planned geological storage projects (incl EOR): 18



CCS project life-cycle

Estimated success rate= …

Figure 1-1 The asset lifecycle model



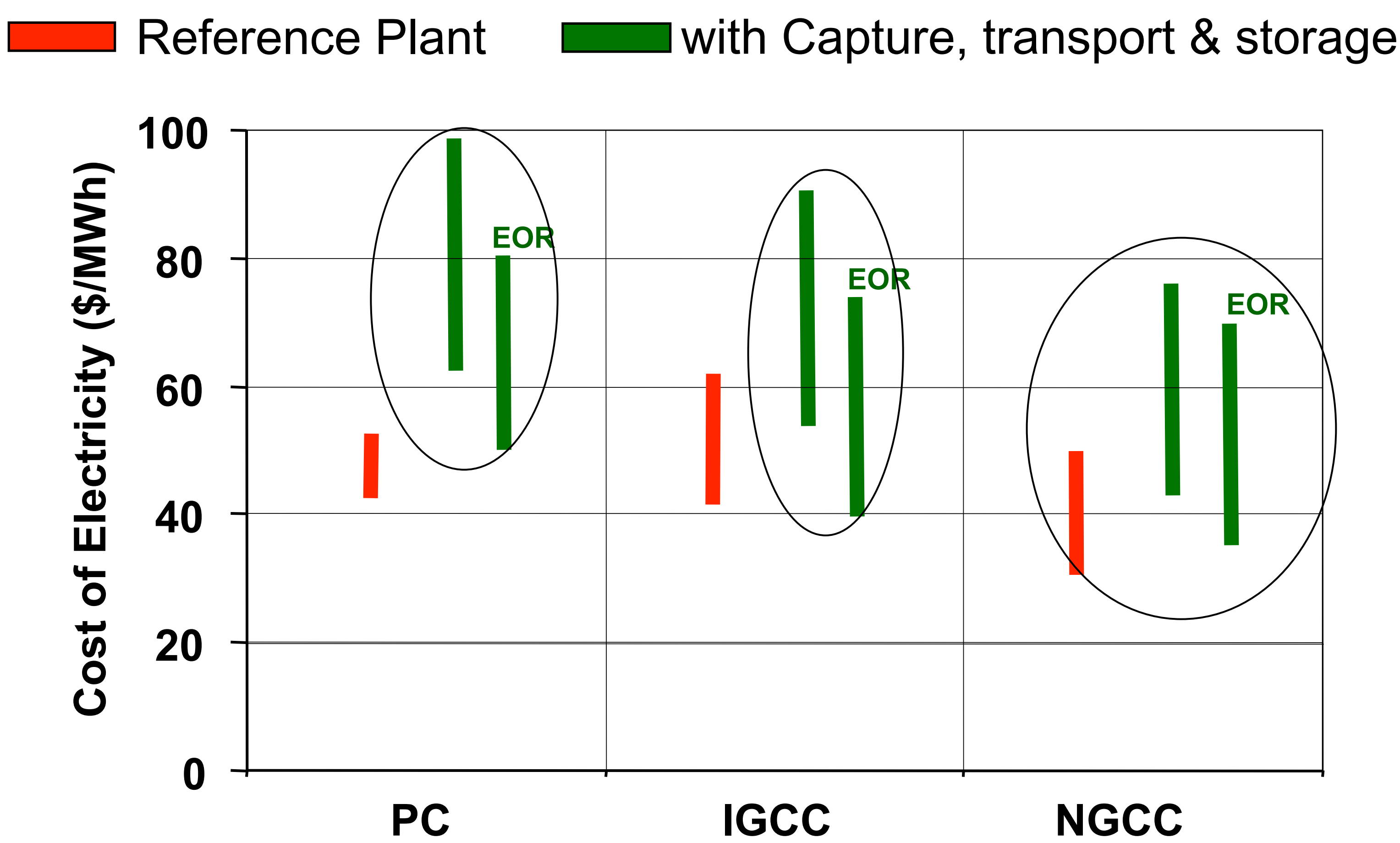
Source: WorleyParsons, 2009

Large scale integrated projects, 2010	24	24	21	2	9
Large scale integrated projects, 2009	19	20	16	2	7

Additional electricity costs
(for energy policy community)

- Coal/gas:
  - 0.01 - 0.05 US$/kWh
  - with EOR: 0.00 – 0.03 US$/kWh
- Biomass:
  - Substantially higher (small scale)
  - Co-firing better
  - Negative emissions

Power Generation Cost with CCS



CO_2 avoidance costs
(climate policy community)

- Coal/gas power plants
  - 20 - 270 US$/t$CO_2$ avoided
  - with EOR: 0 – 240 US$/t$CO_2$ avoided

low-end: capture-ready, low transport cost, revenues from storage: ~ 360 MtCO2/yr

- Hydrogen:
  - 3-75 US$/tCO2 avoided
  - With EOR: minus 15- 50 US$/ t$CO_2$ avoided

Cost of CO_2 Avoided
(US$/tCO2 avoided)

Type of Plant with CCS	NGCC Reference Plant	PC Reference Plant
Power plant with capture and geological storage		
NGCC	40 – 90	20 – 60
PC	70 – 270	30 – 70
IGCC	40 – 220	20 – 70
Power plant with capture and EOR		
NGCC	20 – 70	0 – 30
PC	50 – 240	10 – 40
IGCC	20 – 190	0 – 40

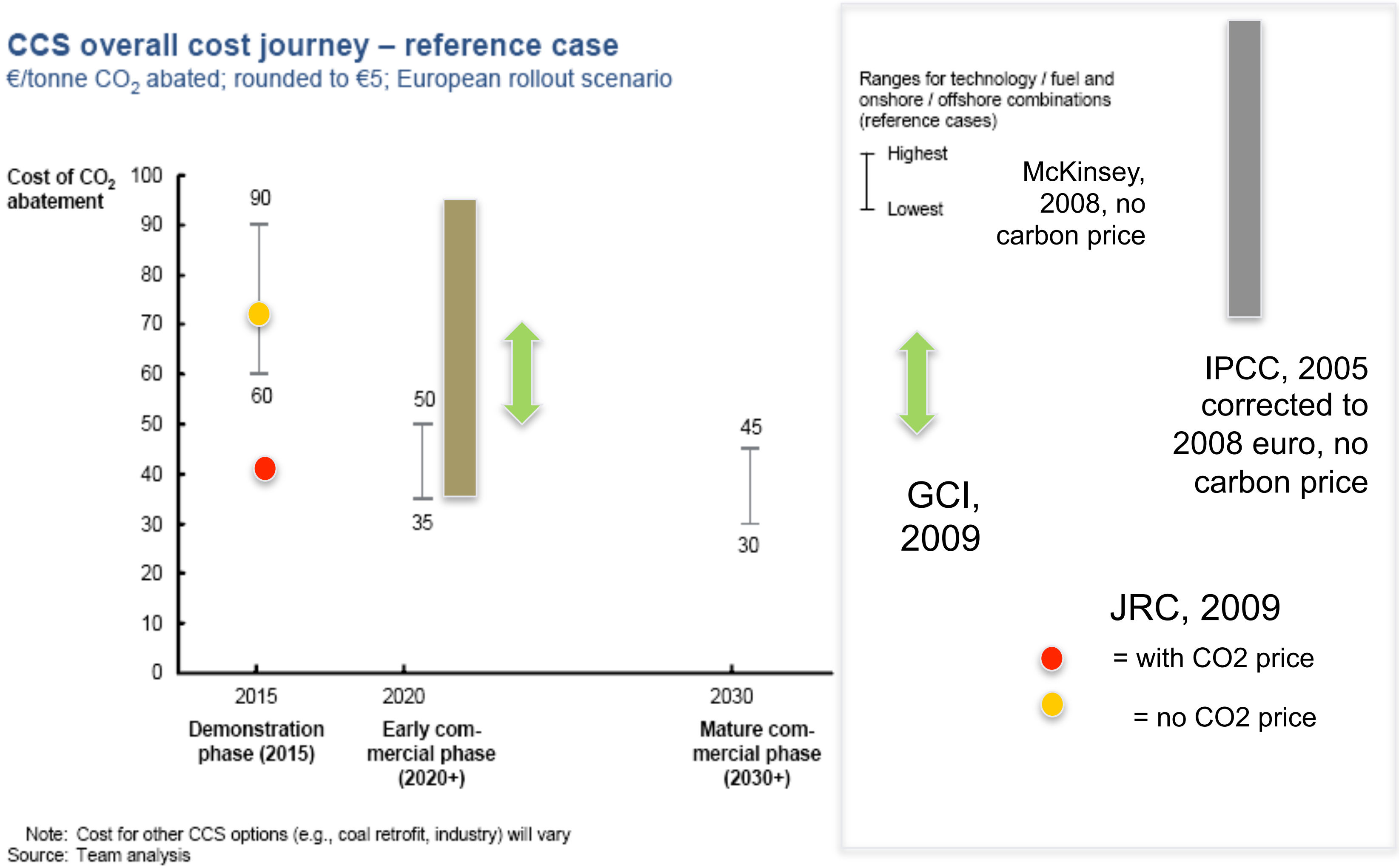
CCS component costs

CCS component	*Cost range*
Capture from a power plant	15 - 75 US$/t$CO_2$ net captured
Capture from gas processing or ammonia production	5 - 55 US$/t$CO_2$ net captured
Capture from other industrial sources	25 - 115 US$/t$CO_2$ net captured
Transportation	1 - 8 US$/t$CO_2$ transported per 250km
Geological storage	0.5 - 8 US$/t$CO_2$ injected
Ocean storage	5 - 30 US$/t$CO_2$ injected
Mineral carbonation	50 - 100 US$/t$CO_2$ net mineralized

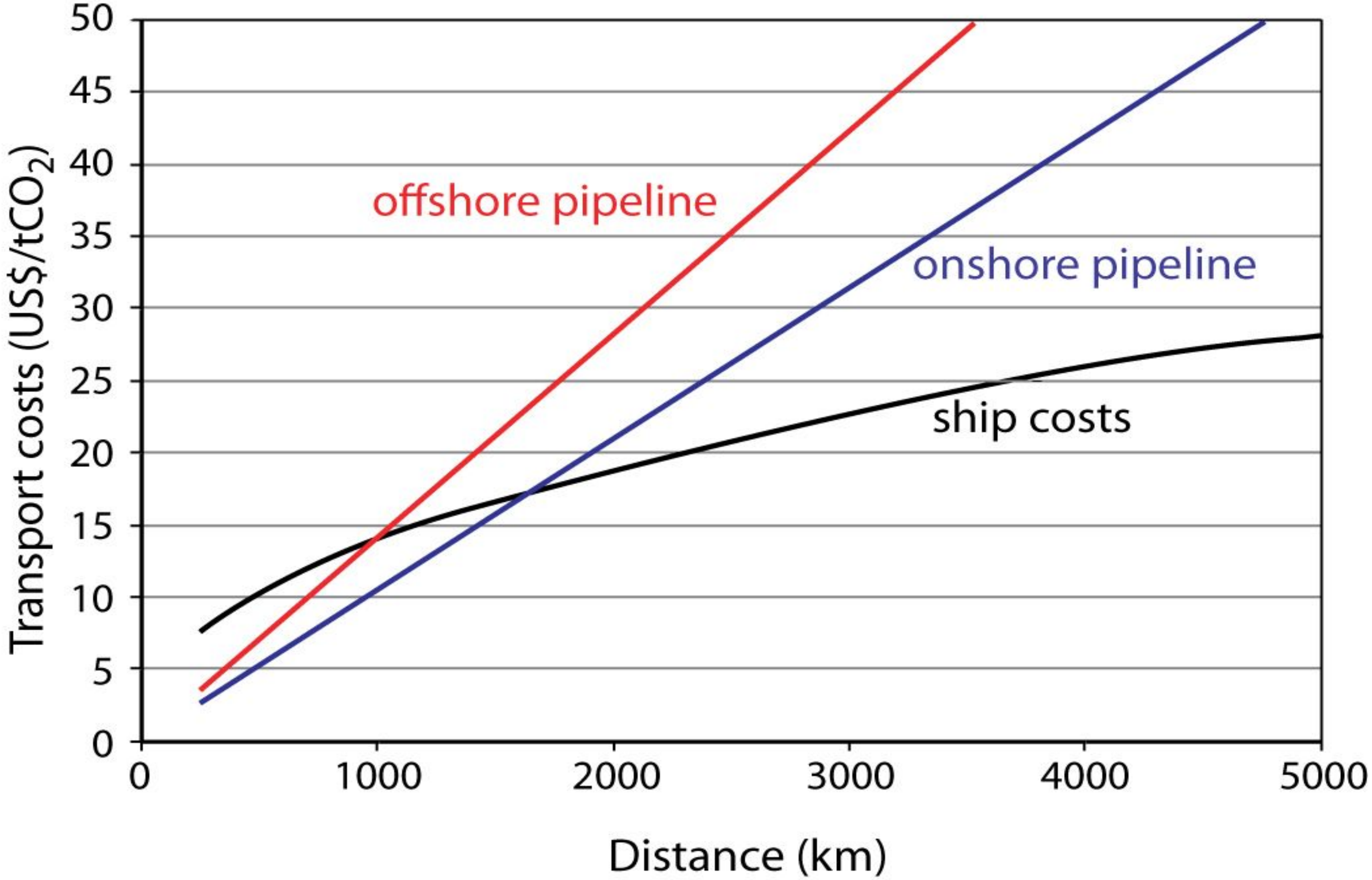
20-30% cost reduction over next 10 yrs

Monitoring/ verification: 0.1-0.3 US $/t CO2

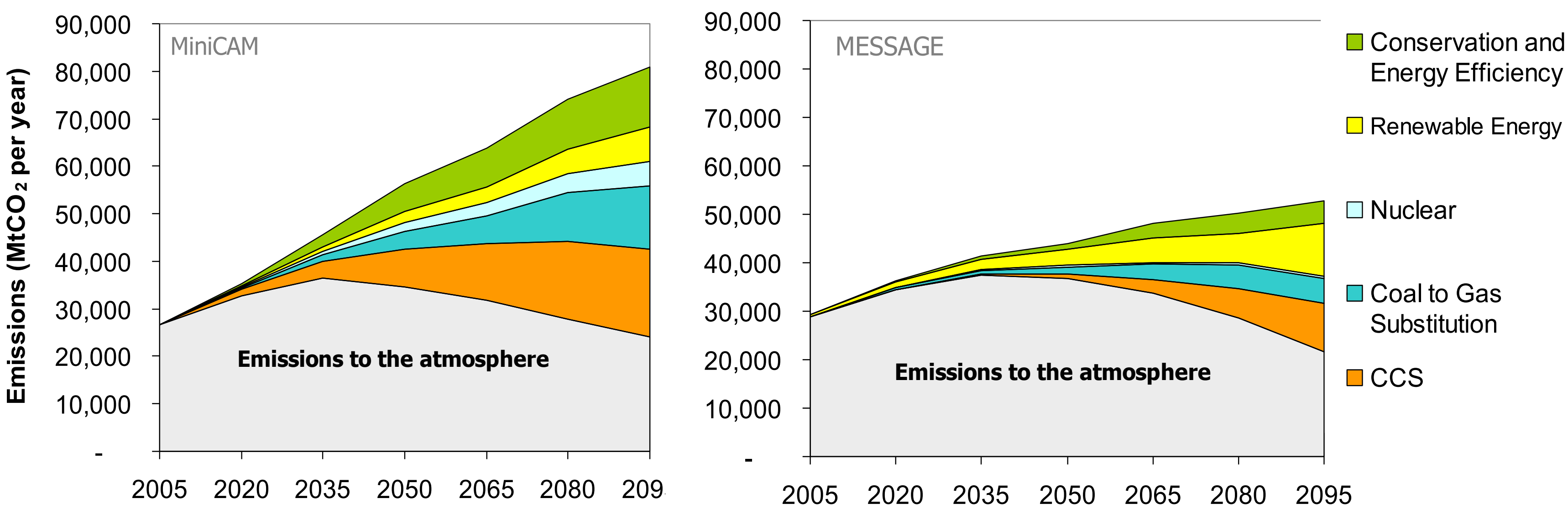
Cost estimates for Coal-CCS plants
(Euro/t CO2 avoided)



CO2 transport costs



Economic potential results from calculations for portfolio of mitigation options



Economic potential

- Cost reduction climate change mitigation: 30% or more
- Most scenario studies: role of CCS increases over the course of the century
- Substantial application above CO_2 price of 25-30 US$/t$CO_2$
- 15 to 55% of the cumulative mitigation effort worldwide until 2100
- 220 - 2,200 GtCO_2 cumulatively up to 2100, depending on the baseline scenario, stabilisation level (450 - 750 ppmv), cost assumptions

Storage potential

- Geological storage: likely at least about 2,000 $GtCO_2$ in geological formations

"Likely" is a probability between 66 and 90%.

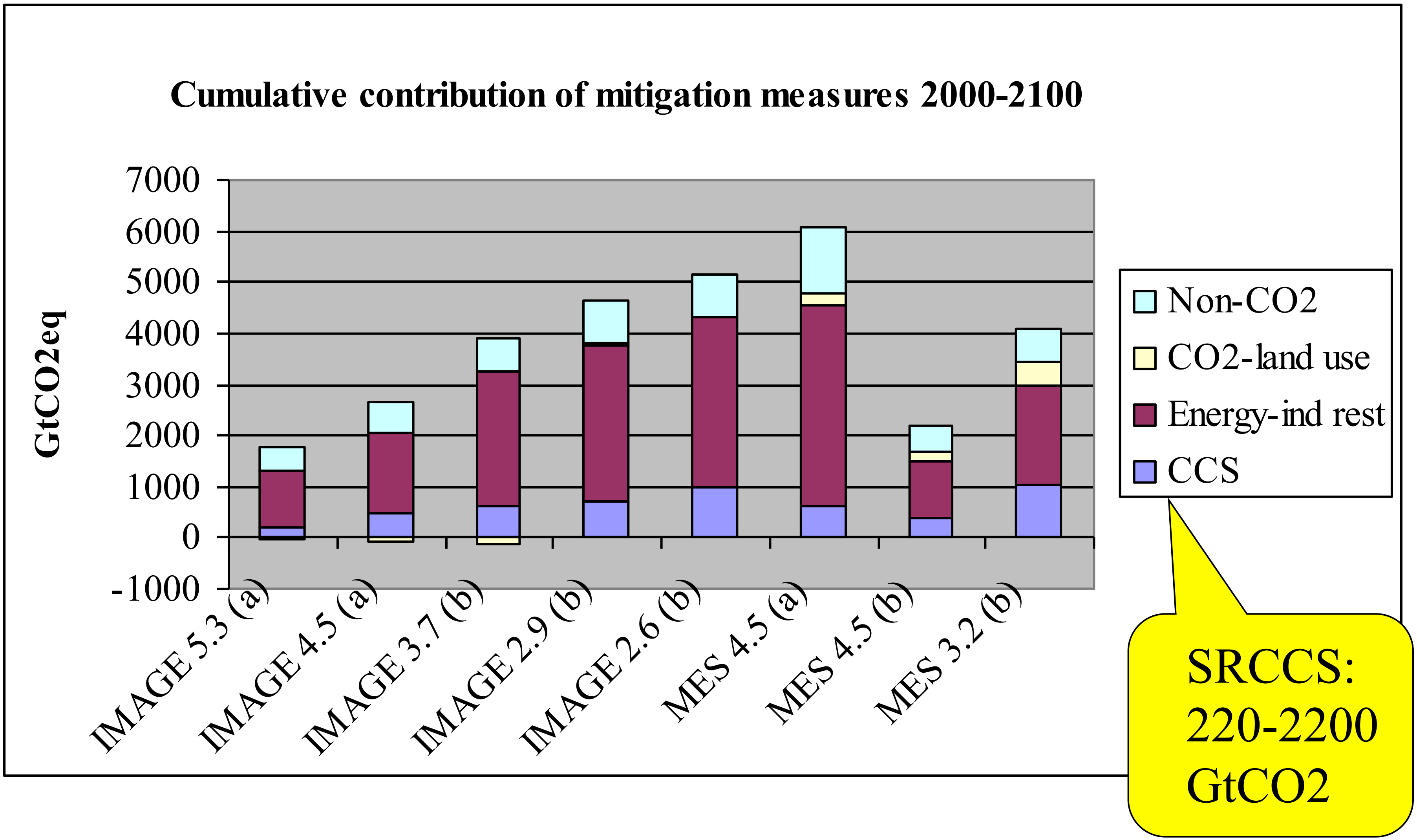
- Ocean storage: on the order of thousands of $GtCO_2$, depending on environmental constraints (theoretical)
- Mineral carbonation: can currently not be determined
- Industrial uses: Not much net reduction of CO_2 emissions

Technical and economic potential

- “It is likely that the technical potential for geological storage is sufficient to cover the high end of the economic potential range, but for specific regions, this may not be true.”

"Likely" is a probability between 66 and 90%.

The share of CCS



Health, safety, environment risks

- In general:
  - lack of real data, so comparison with current operations
- CO_2 pipelines:
  - similar to or lower than those posed by hydrocarbon pipelines
- Geological storage:
  - Various trapping mechanisms: the longer it stays the smaller the risk of release
  - IF appropriate site selection, a monitoring program to detect problems, a regulatory system, remediation methods to stop or control CO_2 releases if they arise, THEN
  - comparable to risks of current activities (natural gas storage, EOR, disposal of acid gas)

Health, safety, environment risks

- Ocean storage:
  - pH change
  - Mortality of ocean organisms
  - Ecosystem consequences
  - Chronic effects unknown
- Mineral carbonation:
  - Mining and disposal of resulting products (some of it may be re-used)

Will leakage compromise CCS as a climate change mitigation option?

Fraction retained assessed

- Geological storage (expert judgement):
  - very likely to exceed 99% over 100 years, and
  - is likely to exceed 99% over 1,000 years.

    "Likely" is a probability 66 - 90%, "very likely" of 90 to 99%
- Ocean storage (modeling):
  - 100yrs: 80-99%
  - 500yrs: 25-70%

Fraction retained"acceptable"

- Economic optimisation:
  - 90% over 100 yrs
  - 60% over 500yrs
- Securing low level stabilisation:
  - 99% over 100yrs
  - 95% over 500 yrs

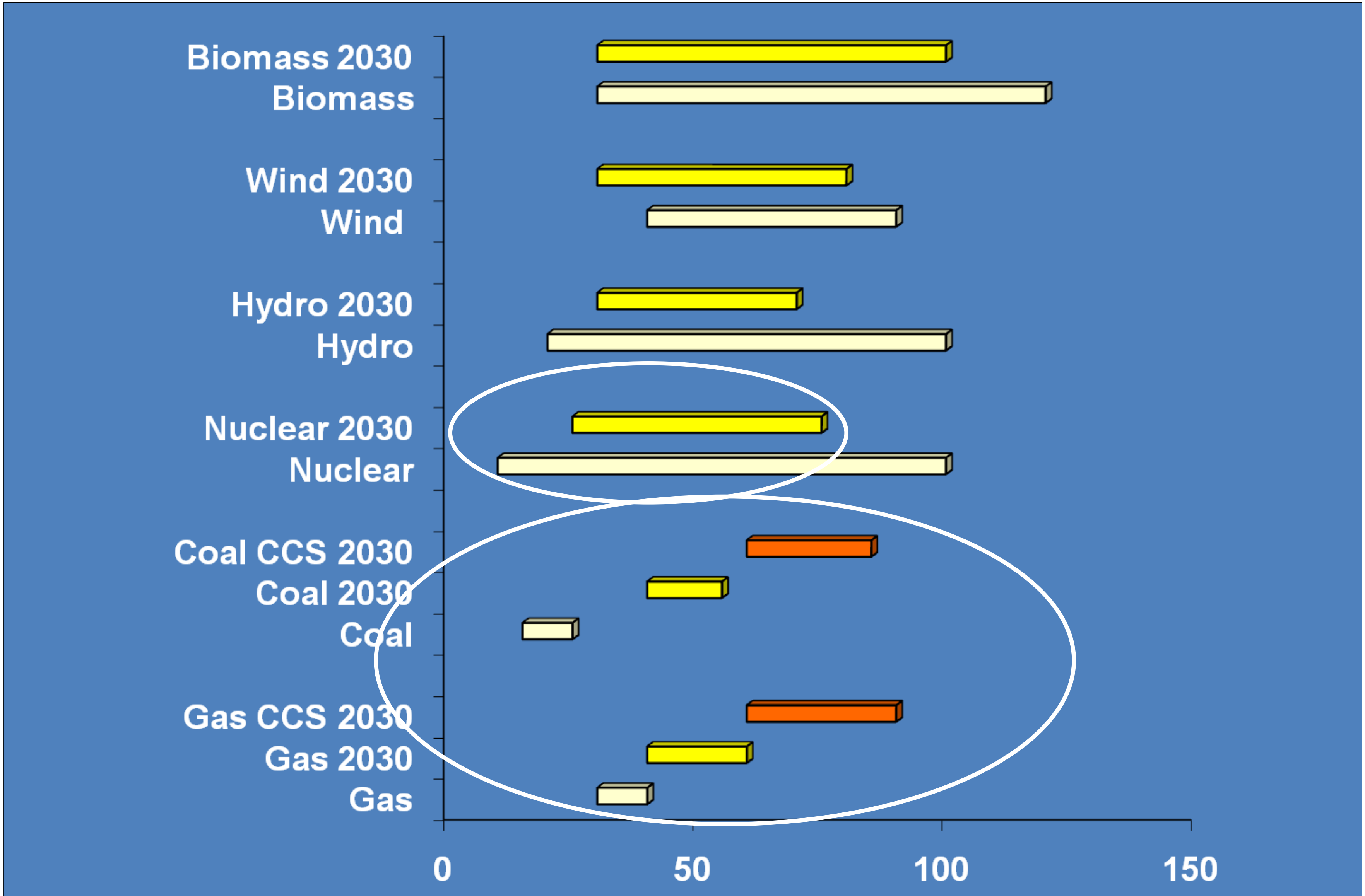
Other issues

- *Legal and regulatory barriers:*
  - National legislation for mining, drinking water, etc applicable
  - International legislation (oceans): adjustments being discussed
- *Public acceptance:*
  - Important issue, but very limited literature
  - Depends on perceived seriousness of climate change and need for deep emission reductions
- *Implications for emissions inventories and accounting:*
  - Issues for emission reporting, Kyoto Protocol compliance, emission trading and CDM

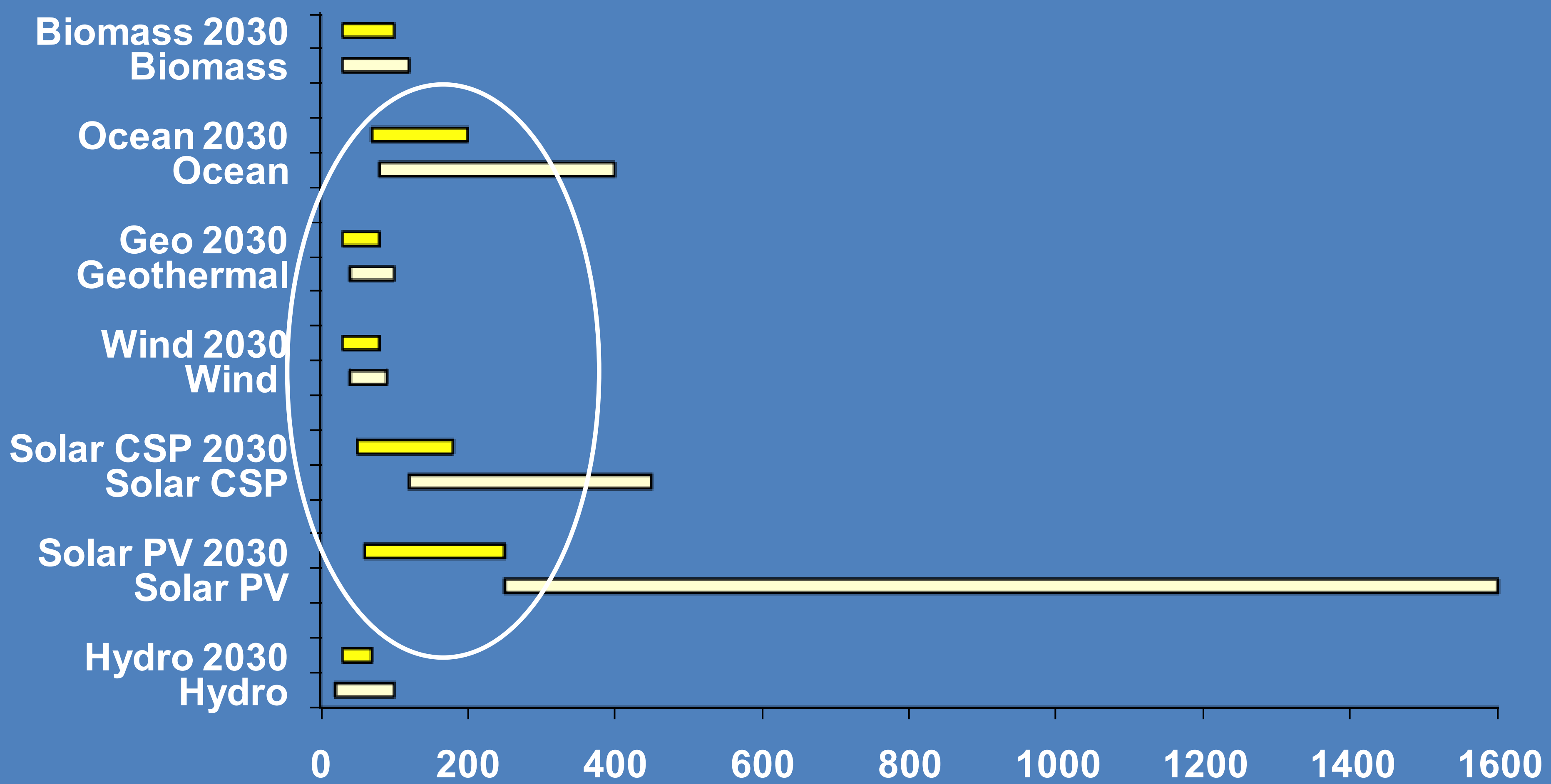
Comparing mitigation options

Option	**CO2 emissions (gCO2eq/kWh)**	**2006 electricity supply (TWh) (note 1)**	**2030 BAU electricity supply (TWh)**	**2030 ambitious climate policy (TWh) (note 2)**
Coal	680-1350	7760	14600	4230
Gas	350-520	3810	6720	4190
Coal CCS	65-150	0	0	1740
Gas CCS	40-70	0	0	670
Nuclear	40-120	2790	3460	5430
Hydro	10-80	3040	4810	6640
Modern Biomass	20-80	240	860	1730
Wind	0-30	130	1490	2750
Geothermal	n/a	60	180	220
Solar	10-100	4	350	720
Ocean	n/a	1	14	50

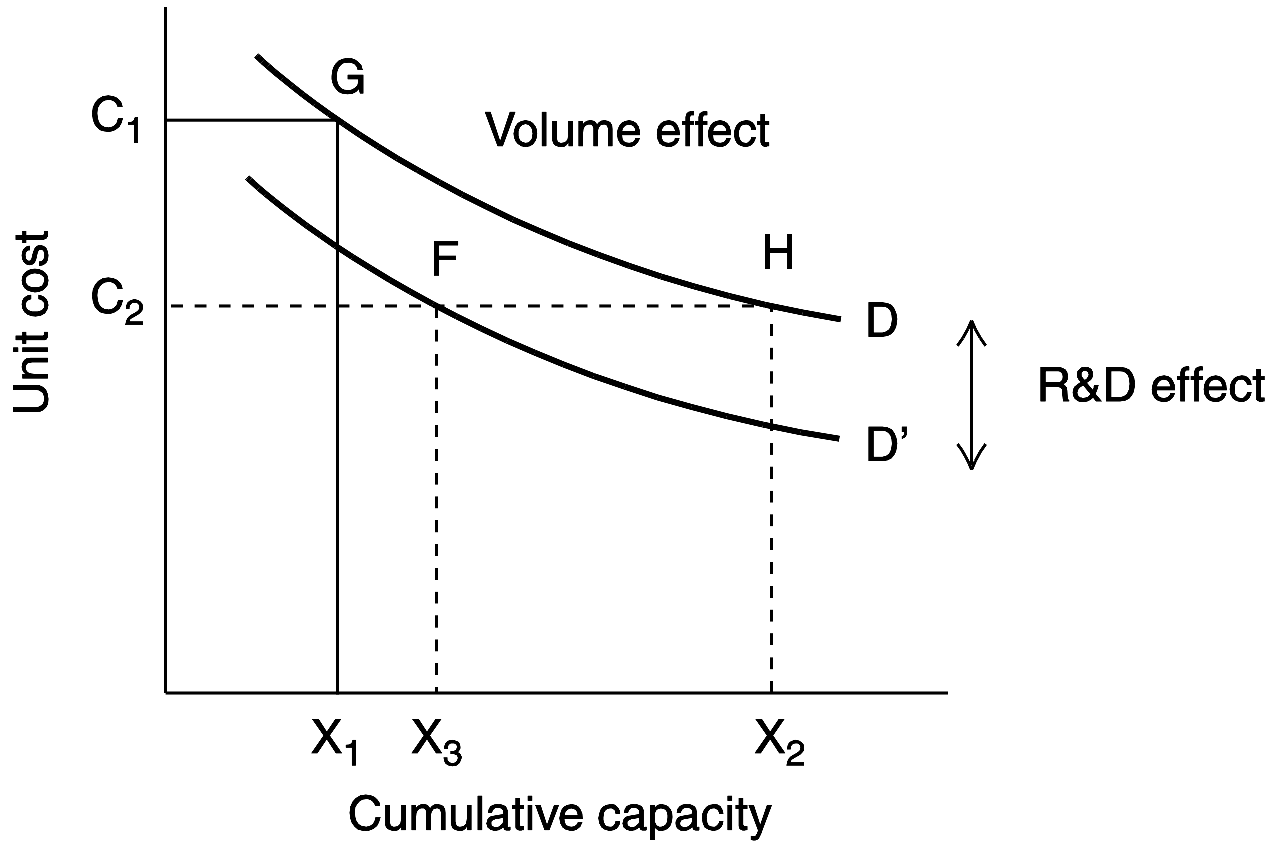
Global electricity costs 2000-2030 ($/MWh)



Global electricity costs 2000-2030 ($/MWh)

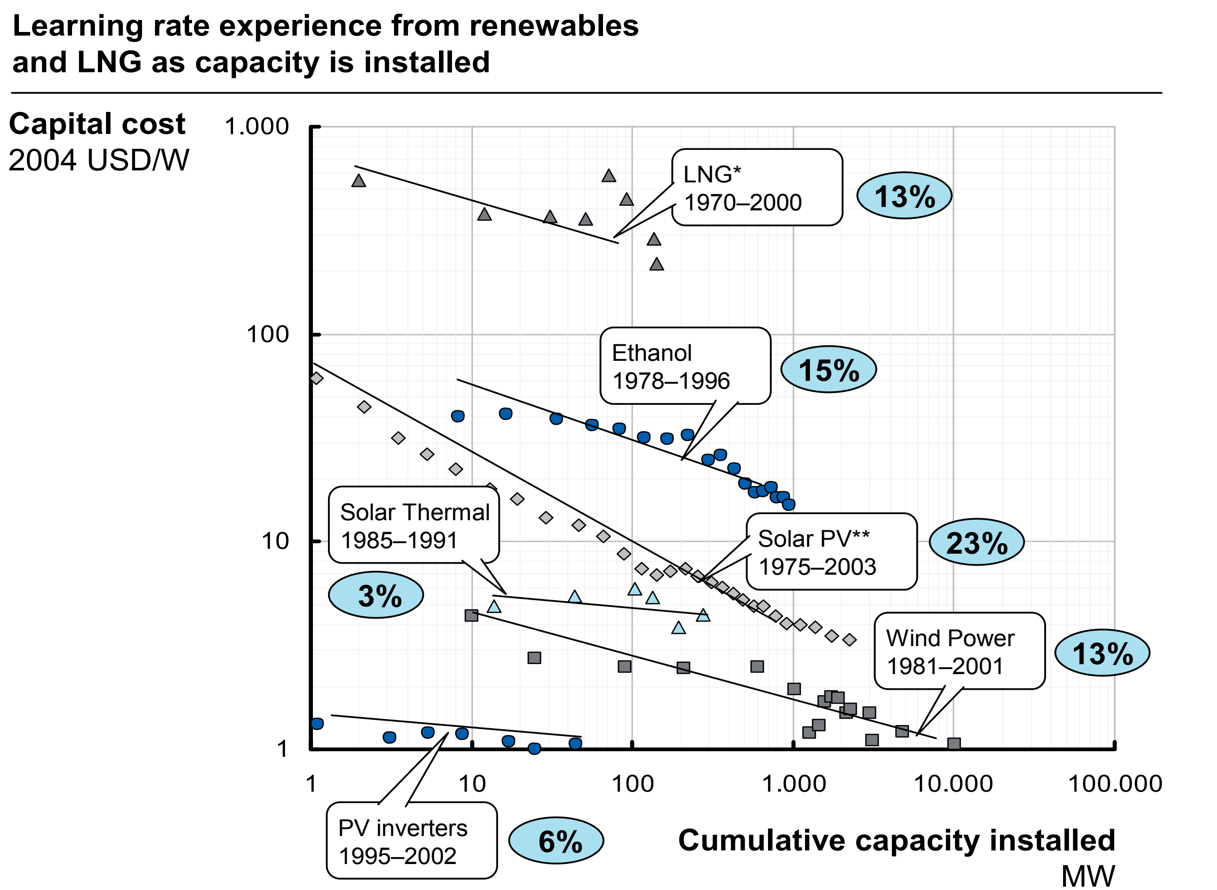


Learning



Unit cost
C1
C2
G
Volume effect
F
H
D
D'
R&D effect
X1
X3
X2
Cumulative capacity

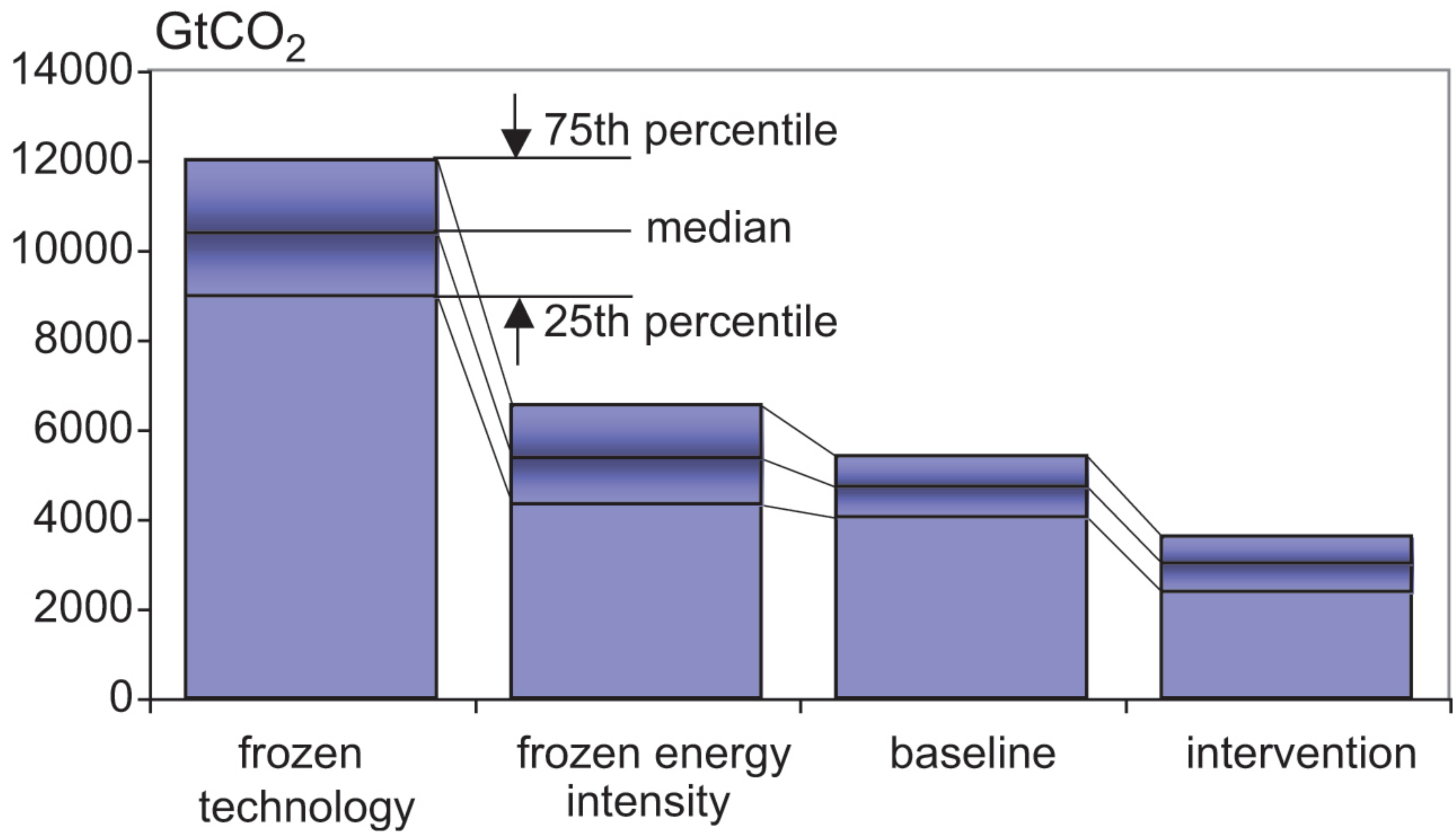
Technological learning



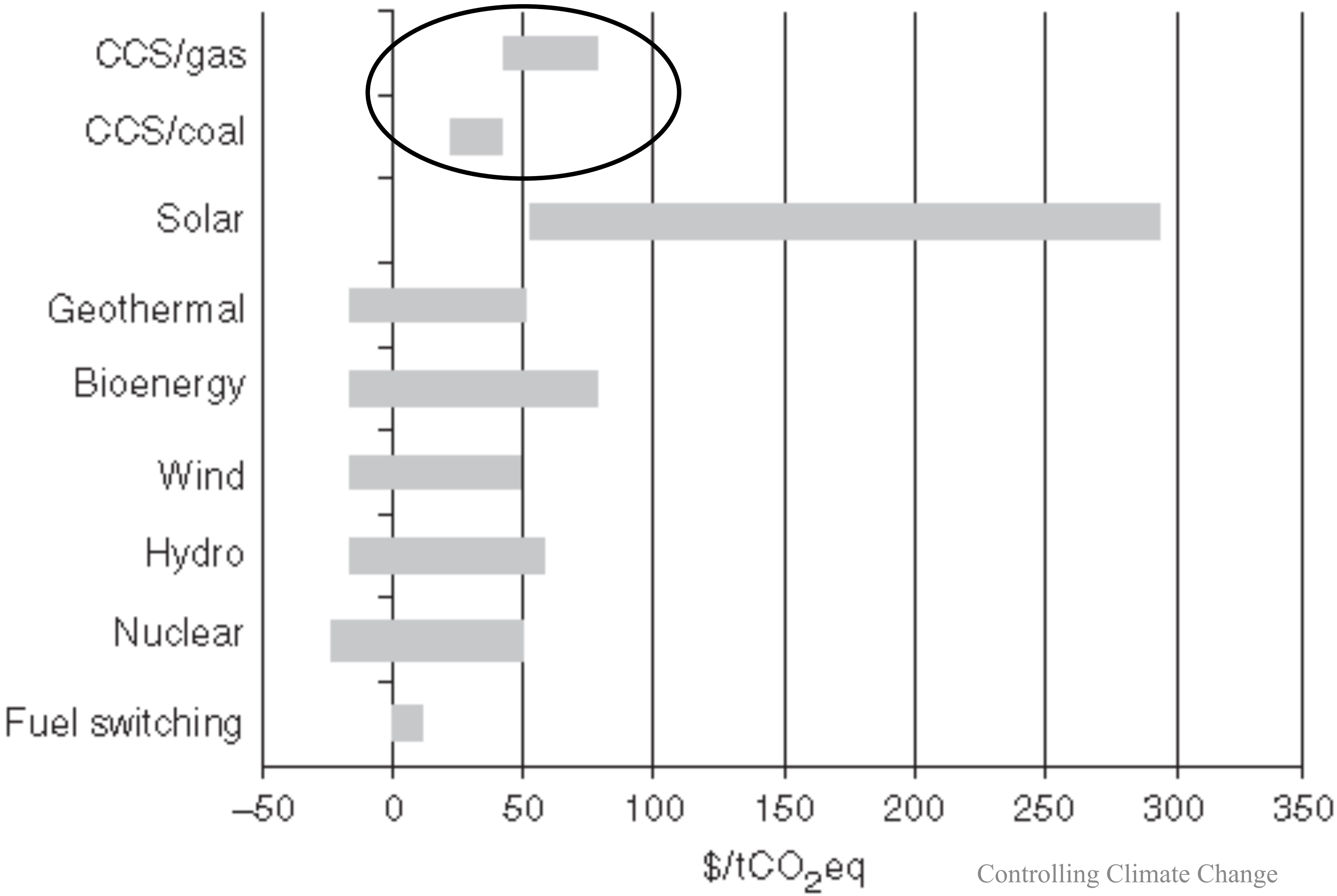
* LNG capital cost measured in USD/t and capacity measured in bcm
** Other sources indicate learning rates as low as 18% for solar PV
Source: Worldwatch Institute; IEA; BTM consult; ABS; NREL; IIIEE; ABI; Drewry 2007; UC Berkeley ERG
Team analysis

Soure: McKinsey

Effect of autonomous technological change



Cost per ton CO2 eq avoided, relative to coal fired power plant



What does US$ 50/ tCO_2eq mean?

- Crude oil: ~US$ 25/ barrel
- Gasoline: ~12 ct/ litre (50 ct/gallon)
- Electricity:
  - from coal fired plant: ~5 ct/kWh
  - from gas fired plant: ~1.5 ct/kWh

Cumulative technical potential reduction options

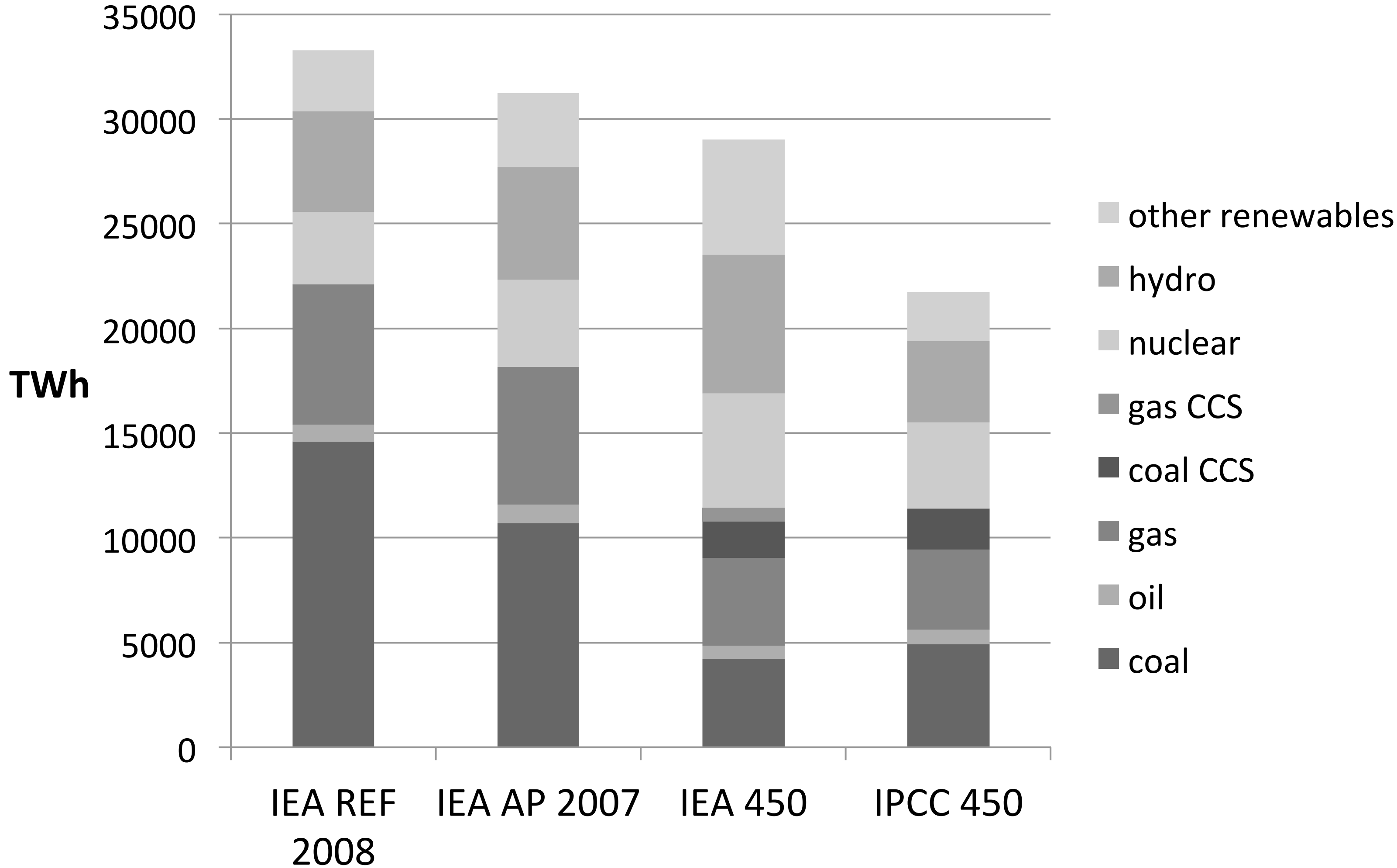
Energy efficiency:	> 1000 GtCO2
Wind/solar/ biomass:	> 3000 GtCO2
Nuclear:	> 300 GtCO2 eq
Non-CO2:	> 500 GtCO2-eq
Sinks:	> 350 GtCO2
CCS:	> 2000 GtCO2
Fuel switch:	0-200 GtCO2-eq

Cumulative reduction

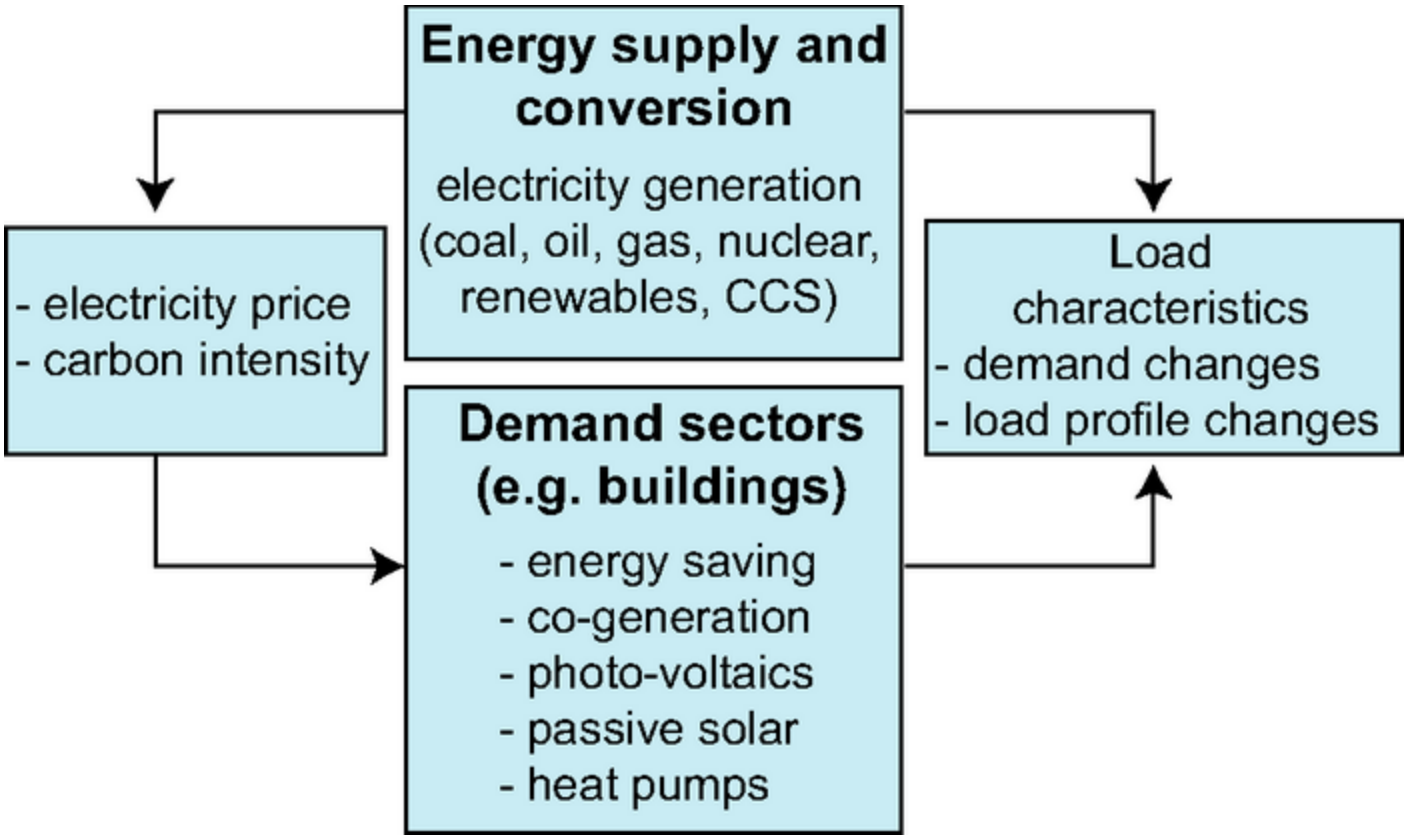
650: 260 GtCO2
550: 3600 GtCO2
450: 4300 GtCO2

- **Based on potential as reported in literature stabilisation at low levels should be possible.**

Relative share of low carbon options in 2030 (least cost approach)



Supply and demand side determine energy mix and reduction potential

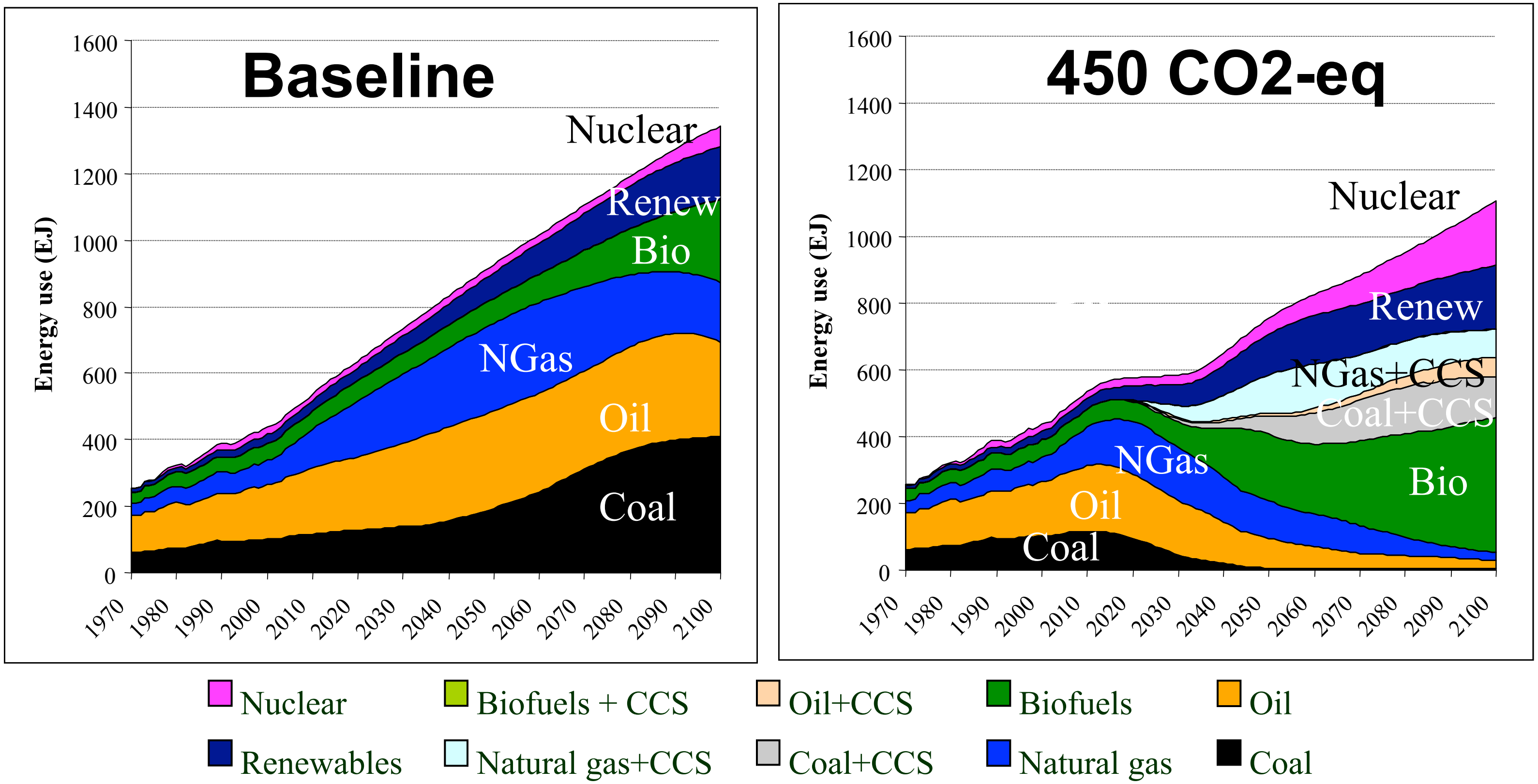


What a 450 ppm CO2eq scenario implies for the period till 2030

- >400 coal/ gas power plants with CCS
- 200-500 nuclear power plants
- Increasing hydro capacity with 50%
- Doubling/ tripling # of biomass CHP plants
- Increase # wind turbines from 50000 to > 500000
- 100 fold increase in solar PV and CSP capacity
- Additional investment of $9 bn (on top of $ 22 bn; energy savings $6 bn)

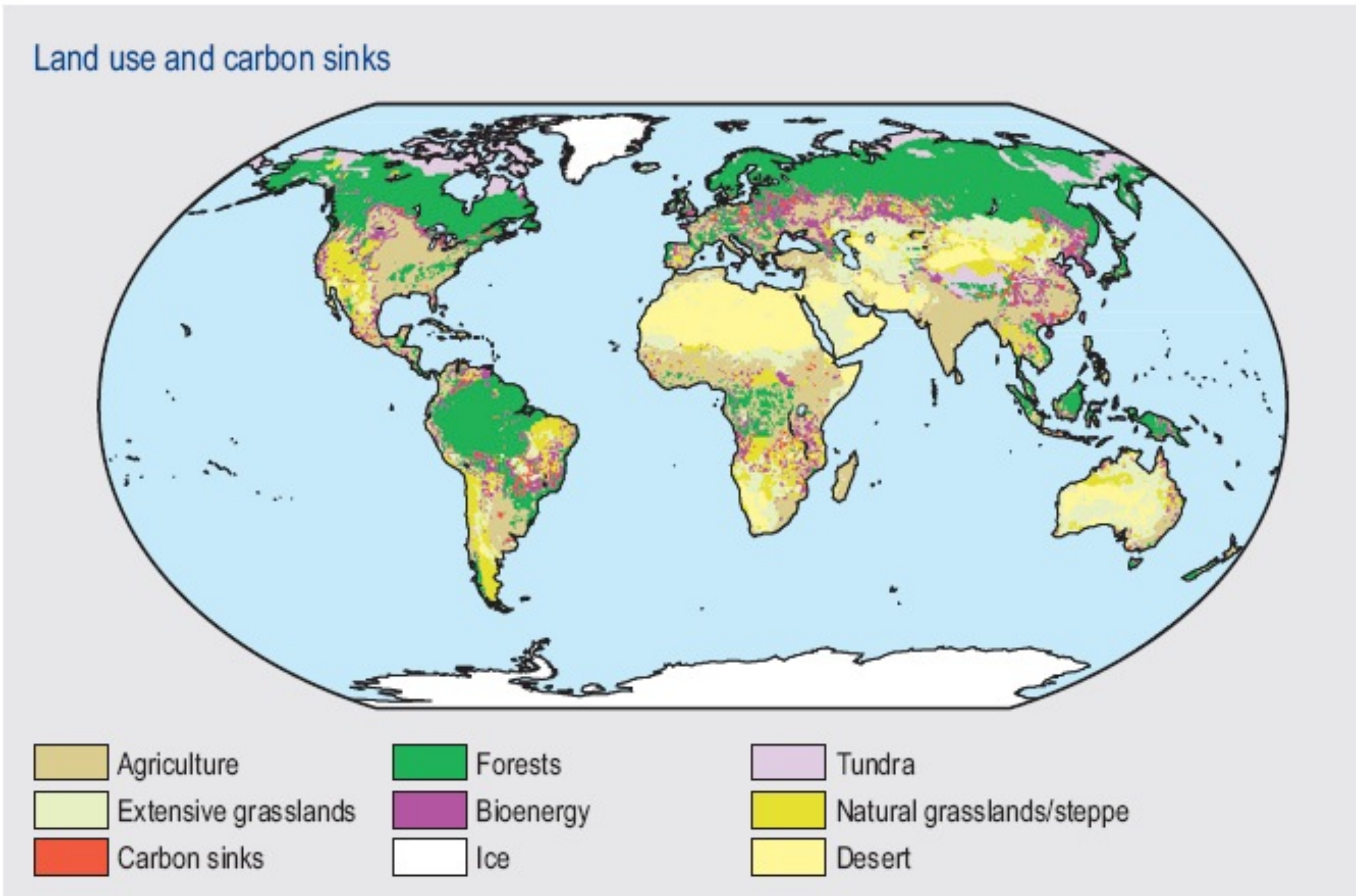
How to get to low emissions?

Indicative energy system changes



Source: Van Vuuren et al. Stabilising GHG emissions.

Bio energy plantations and carbon sinks in 2100 for 450ppm stabilisation



Source: IMAGE model