Energy, Environment and Public Health

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A) Air pollution

Health risks of fine particles, NO_2 (?) and ozone proven by epidemiological studies

- **Highest health risks due to ‚chronic mortality' caused by PM2.5**
- **1. study: Dockery, Pope et al.: an Association between Air Pollution and Mortality in Six U.S. Cities, Dec. 1993**
- **Newest studies and meta-studies: EC 7th FP project ESCAPE; WHO/REVIHAAP (Review of evidence on health aspects of air pollution) and WHO/HRAPIE (Health risks of air pollution in Europe),**

Pollutant	Relative Risk (95% C.I.) All cause natural mortality >30 years
PM2.5 (per 10 µg/m3)	1.062 (1.04-1.083)
NO2 (per 10 µg/m3) above 20 µg/m3	1,055 (1,03-1,080) up to 33% overlap

WHO: all PM2.5 content (except sea salt?) equally toxic

Combustion of Fossile Fuels

Products of combustion

Complete combustion

CO_2, H_2O

Incomplete combustion

CO, soot, VOC

Byproducts from ingredients

of air

NO_x

of fuel

SO_2, SO_3, H_2S, NOx, heavy metals, fine particles, HCl, Furane

Conversion in the flue gas:

aerosols, dioxines/ furanes, NO_2

Avoidance or reduction due to

Substitution of fuel

Energy saving

Renewable and nuclear energies

Change of combustion process

More oxygen
Higher temperature
Higher residence time

less oxygen
lower temperature
lower residence time

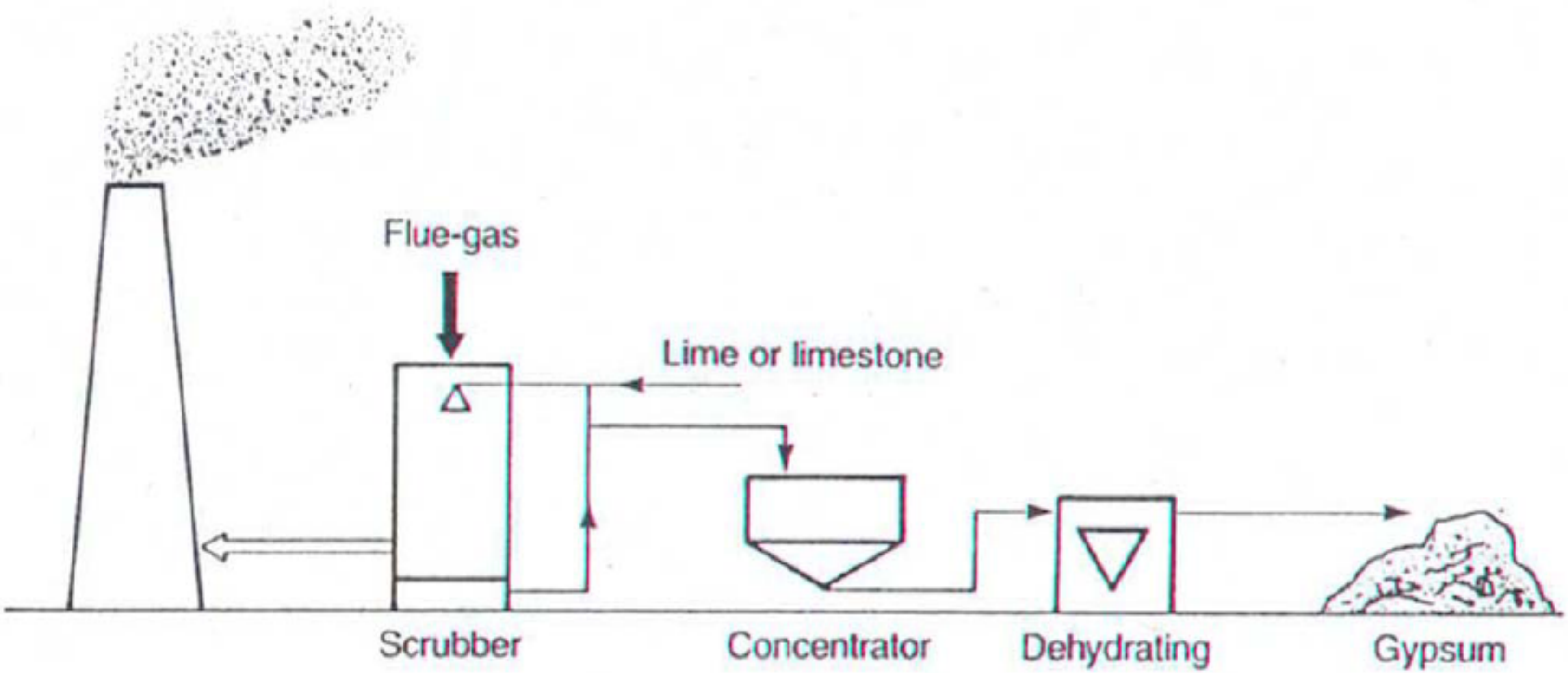
Choice of fuel
Additive
Fuel treatment

Flue gas cleaning

fuel	EU limits of sulfur content in weight-%
heavy fuel oil residual oil – ships (IMO) EU passenger ship	< 1,0 since 2003 < 4,5%, effectively 2,7%; since 2012: <3,5%; since 2020/2025: < 0,5 %; SECAs = North and Baltic sea< 1%; as of 2015 0,1% from 2010 in harbours < 0,1%
light fuel oil	< *0,2 (since 2003)* < 0,1 (since 2008) < 0,005 in Ger, voluntary agreement since 2009
gasoline	< *0,015 (since 2000*) < *0,005 (since 2005)*,< 0,001 from 2009
diesel • road vehicles	< *0,035 since 2000, 98/ 70 EG)* < *0,005 since 2005, 98/ 70 EG*), < 0.001 since 2009
•inland water ships, rail	< 0,1 (since 2008)
kerosene (air planes)	< 0,3; real value 0,03
wood	Not detectable
tree bark	< 0,15
natural gas	0,0005 – 0,02
lignite	1
hard coal	0,9 -1.1

Flue gas desulphurisation

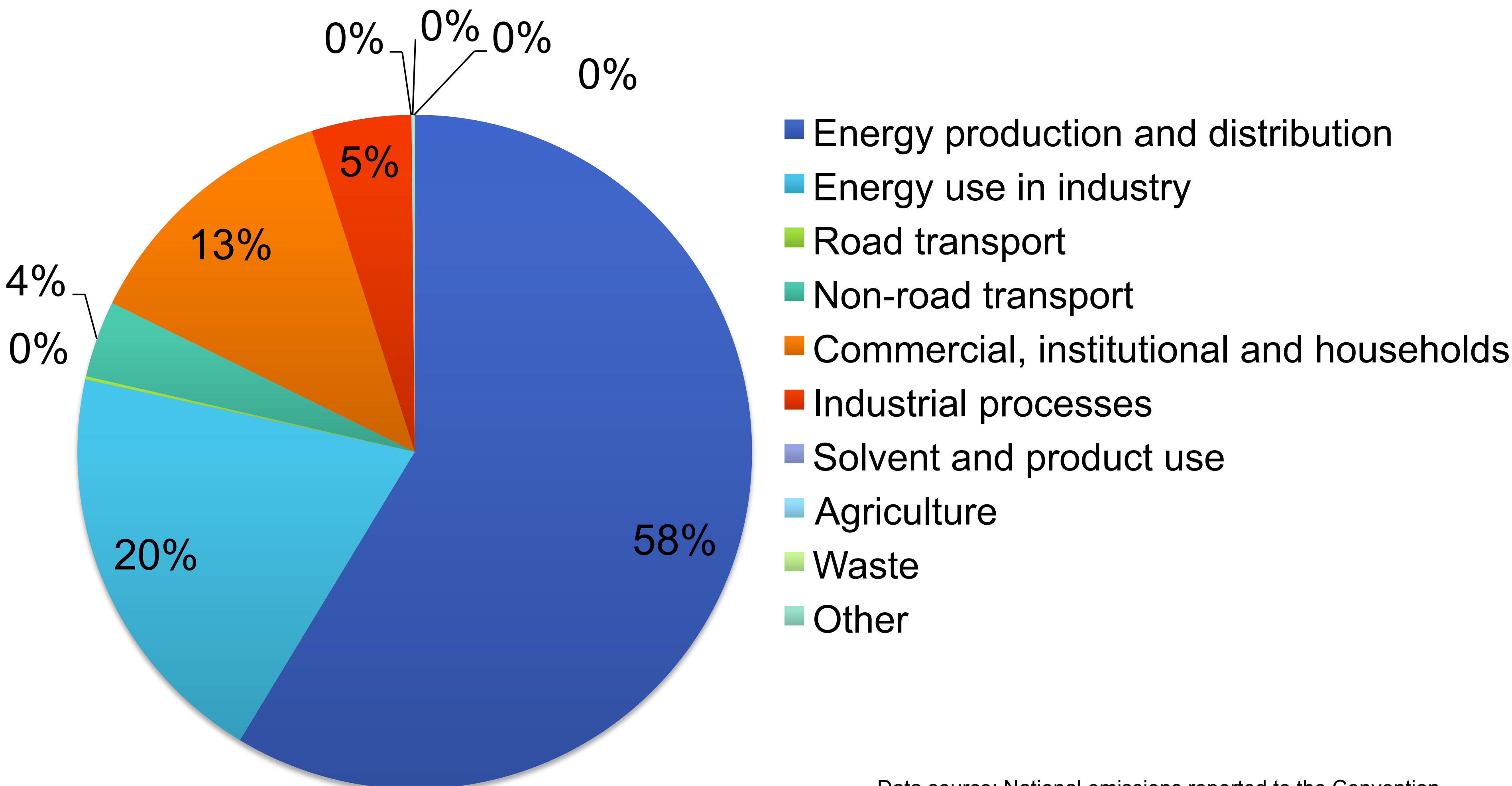
Lime scrubbing



$$Ca(OH)_2 + SO_2 + H_2O + 1/2\ O_2 \rightarrow CaSO_4 \cdot 2H_2O$$

Source: Baumbach 1996

Share of total emissions (EU27) of SOx in 2010



Data source: National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention)

Total amount of SOx for EU27: **4574** Gg (kt)

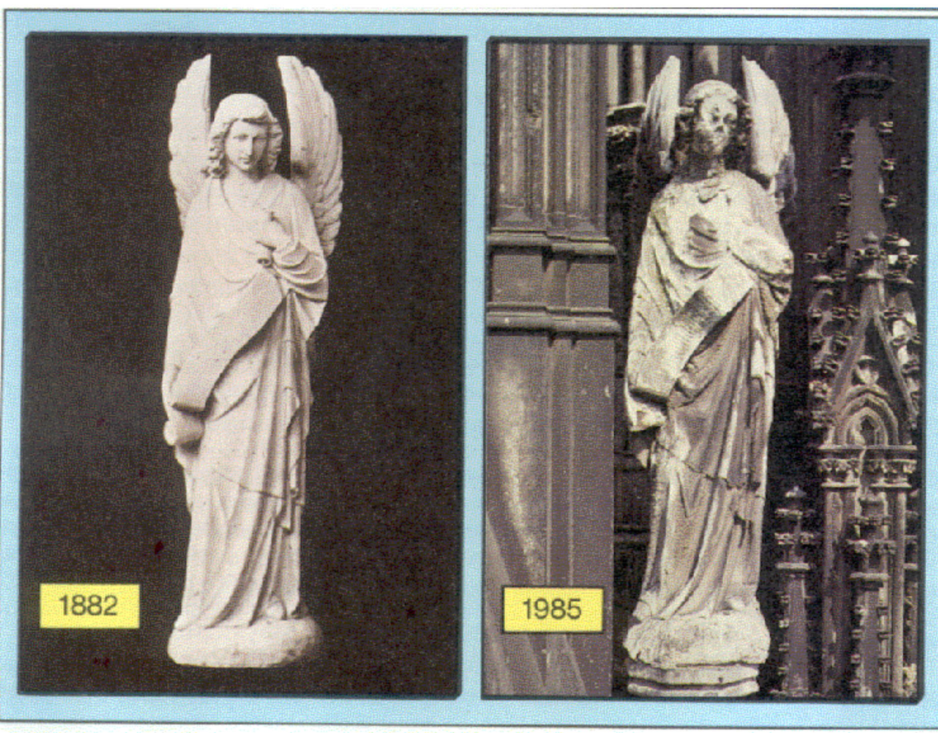
Material damage: Corrosion of metals;

With suluric acid:

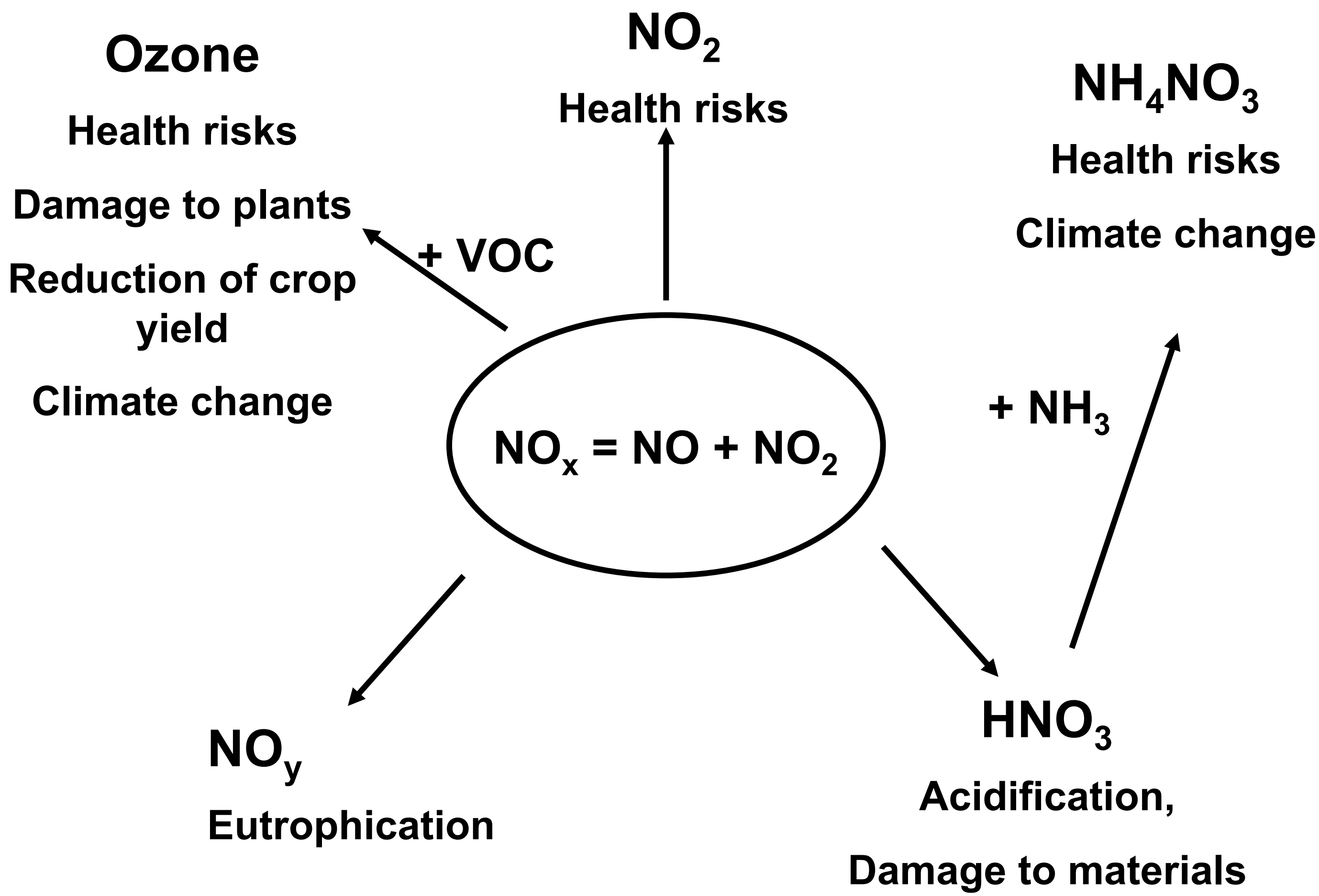
$Fe + H_2SO_4 + H_2O \text{ ->} FeSO_4 \cdot H_2O + H_2$

Decomposition of lime stone

$$CaCO_3 + SO_4^{2-} + 2\,H^+ + H_2O \rightarrow CaSO_4 \cdot 2H_2O + CO_2$$



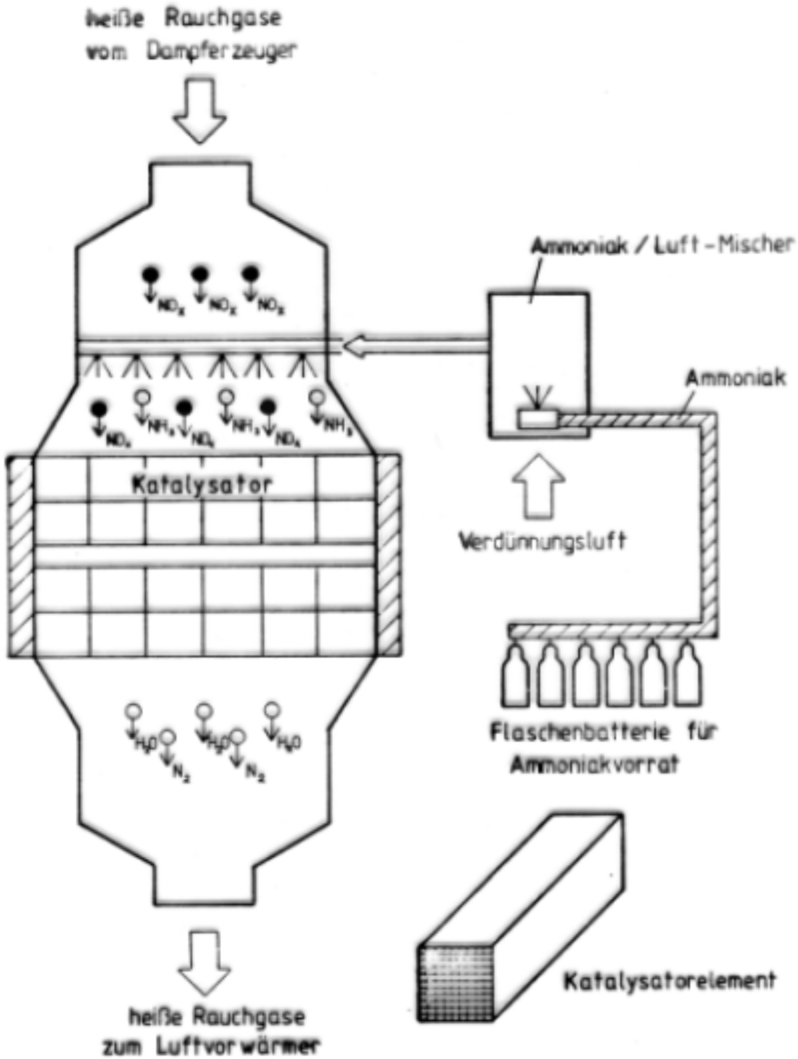
NO_x – the most important impact pathways



Three processes for generating NOx during combustion

Thermal NO_x	Fuel – NO_x	Prompt NO_x
N_2 from air used for combustion $\rightarrow$ $N_2 + O \rightarrow NO + N$ $N + O_2 \rightarrow NO + O$ High emissions, if: • high temperature in the flame > 1300 C° • excess oxygen • residence time in the high temperature zone high	N bound organically in the fuel > 750 C° Nitrogen content von coal: 0,5 – 2 mass % fuel oil: 0,1 – 0,6 mass % Transformation rate: coal: 20 – 40 % fuel oil: 80 – 90 %	N from combustion air, mechanism not fully understood $CH + N_2 \rightarrow HCN + N$ $C_2 + N_2 \rightarrow 2\,CN$ Oxidation to NO

Secondary technical measure SCR:



SCR ("selective catalytic reduction process„):

$$6NO_2 + 8NH_3 \rightarrow 12H_2O + 7N_2$$

$$4NO + 4NH_3 + O_2 \rightarrow 6H_2O + 4N_2$$

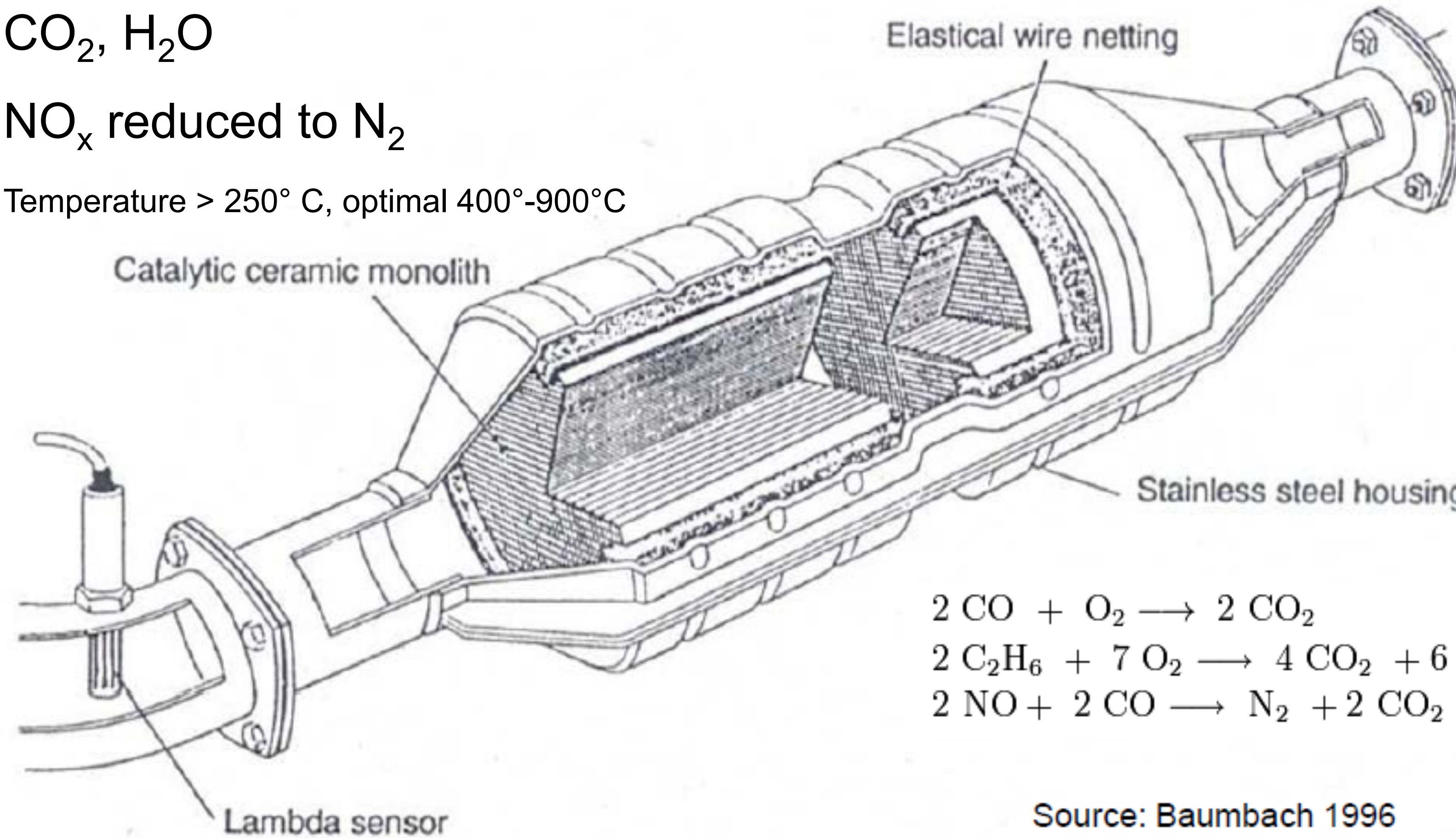
- Works only between 340 °C to 380 °C

Secondary Measure for gasoline cars: three way - catalytic converter

CO and VOC are oxidised to CO_2, H_2O

NO_x reduced to N_2

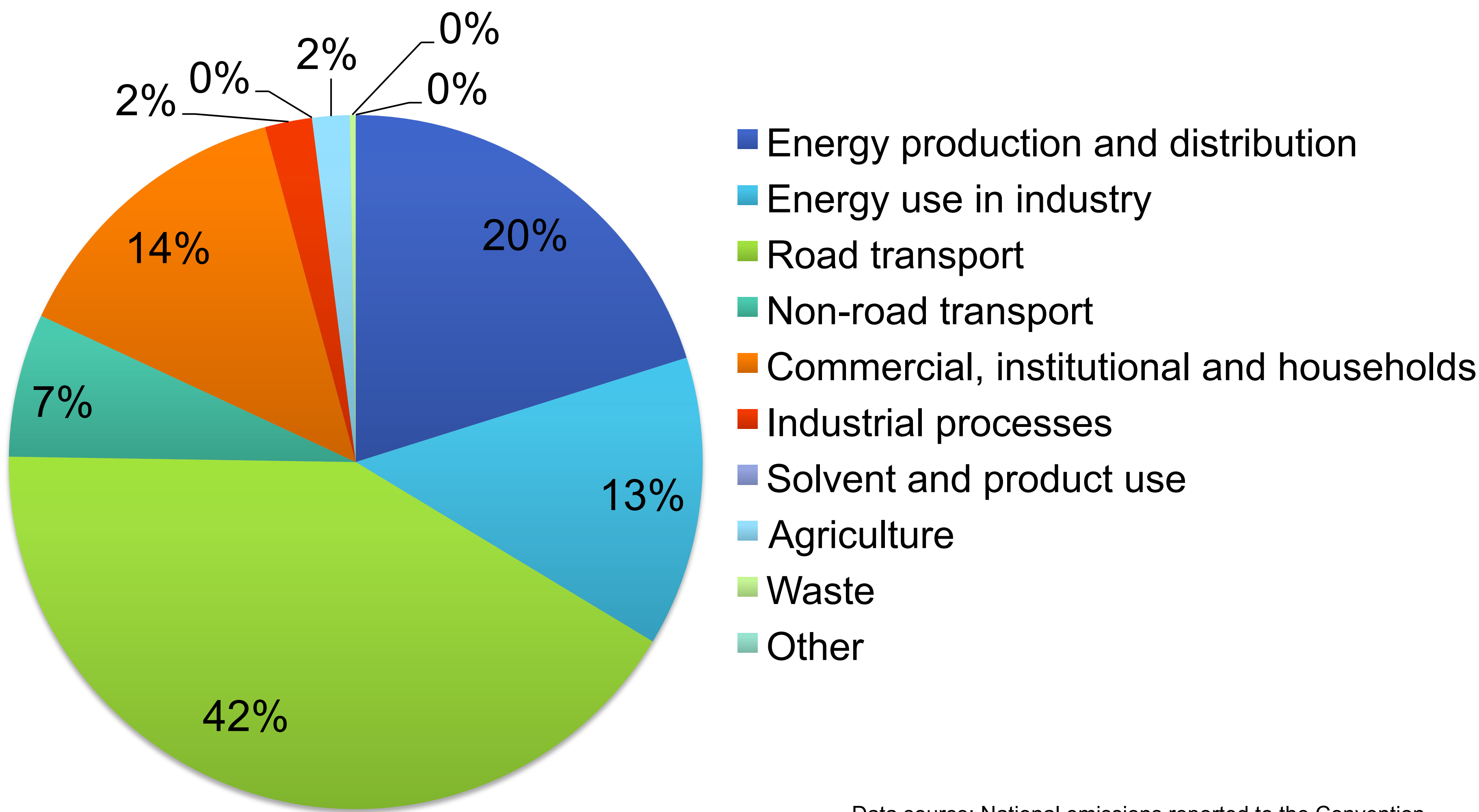
Temperature > 250° C, optimal 400°-900°C



$$2\,CO + O_2 \longrightarrow 2\,CO_2$$
$$2\,C_2H_6 + 7\,O_2 \longrightarrow 4\,CO_2 + 6\,H_2O$$
$$2\,NO + 2\,CO \longrightarrow N_2 + 2\,CO_2$$

Source: Baumbach 1996

Share of total emissions (EU27) of NOx in 2010



Data source: National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention)

Total amount of NOx for EU27: **9162** Gg (kt)

Photochemical reaction generating ozone

$$NO_2 + h\nu\ (\lambda \leq 420\ nm) \rightarrow NO + O$$

$$O + O_2 + M \rightarrow O_3 + M$$

(M = energy absorbing molecule such as N_2, O_2)

$$NO + O_3 \rightarrow NO_2 + O_2$$

Equilibrium -> no increased ozone concentration

Generation of the OH Radical

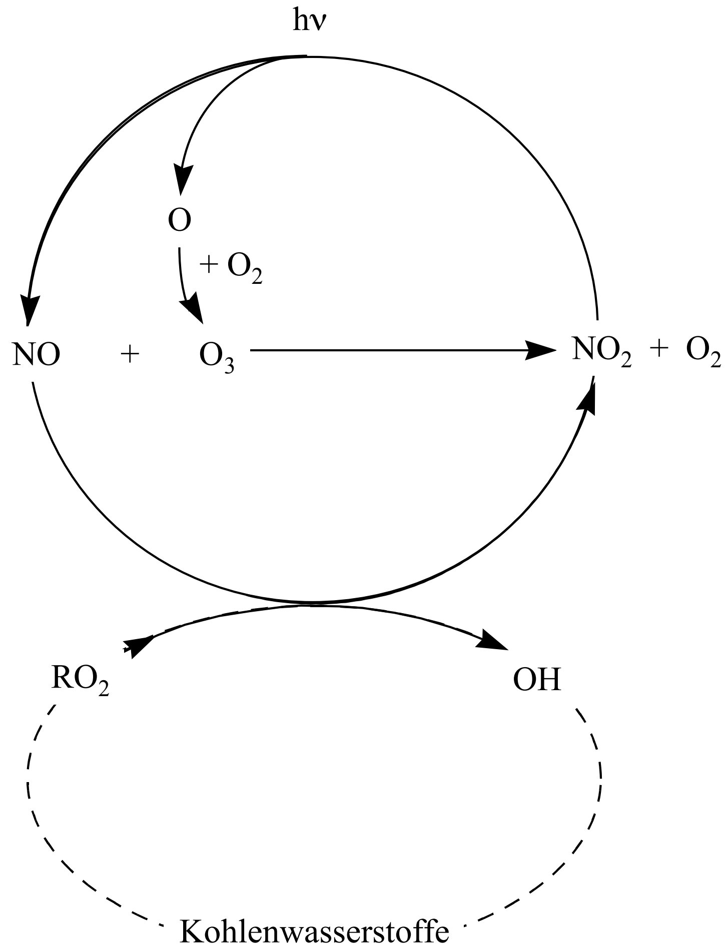
$O_3 + h\nu\ (\lambda < 320\ \text{nm}) \rightarrow O(^1D) + O_2$

$O(^1D) + H_2O \rightarrow 2\ OH$

$R\text{-}H + OH \rightarrow R + H_2O$

$c(OH) = 10^6$ molecules per cm^3

Contribution of VOCs to the generation of ozone: Oxidation of NO to NO_2



OH-radicals break up VOCs and CO:

$$OH\bullet + RH \longrightarrow H_2O + R$$
$$OH\bullet + CO \longrightarrow CO_2 + H$$

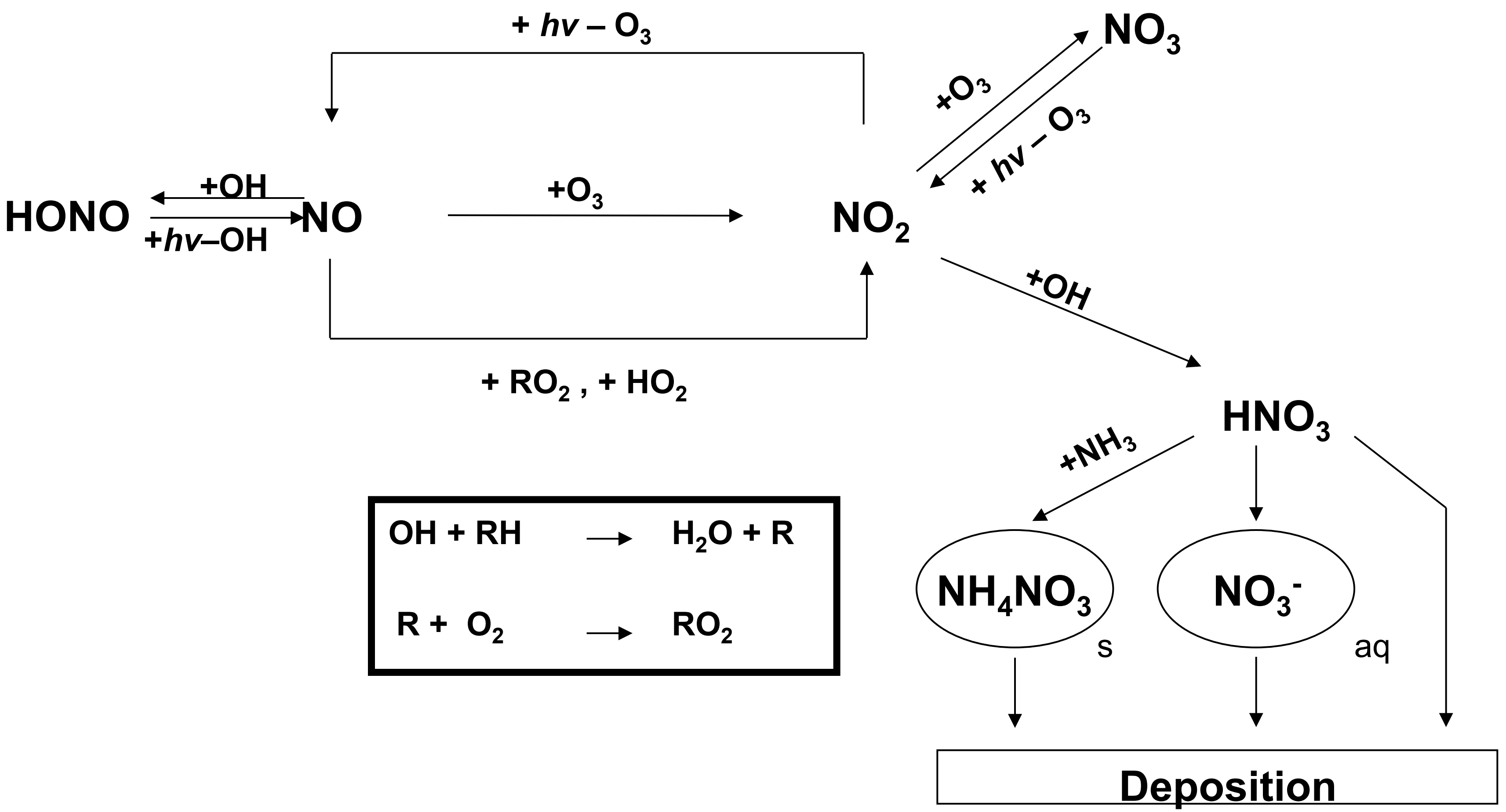
Organic remainder R forms peroxiradical with oxygen (HO_2 or RO_2):

$$R + O_2 \longrightarrow RO_2\bullet$$
$$H + O_2 \longrightarrow HO_2\bullet$$

peroxiradicals oxidise NO to NO_2:

$$RO_2\bullet + NO \longrightarrow NO_2 + RO\bullet$$
$$HO_2\bullet + NO \longrightarrow NO_2 + OH\bullet$$

N-atmospheric chemistry – during the day



OH + RH	$\rightarrow$	H_2O + R
R + O_2	$\rightarrow$	RO_2

Most significant emission sources in Germany year 2000

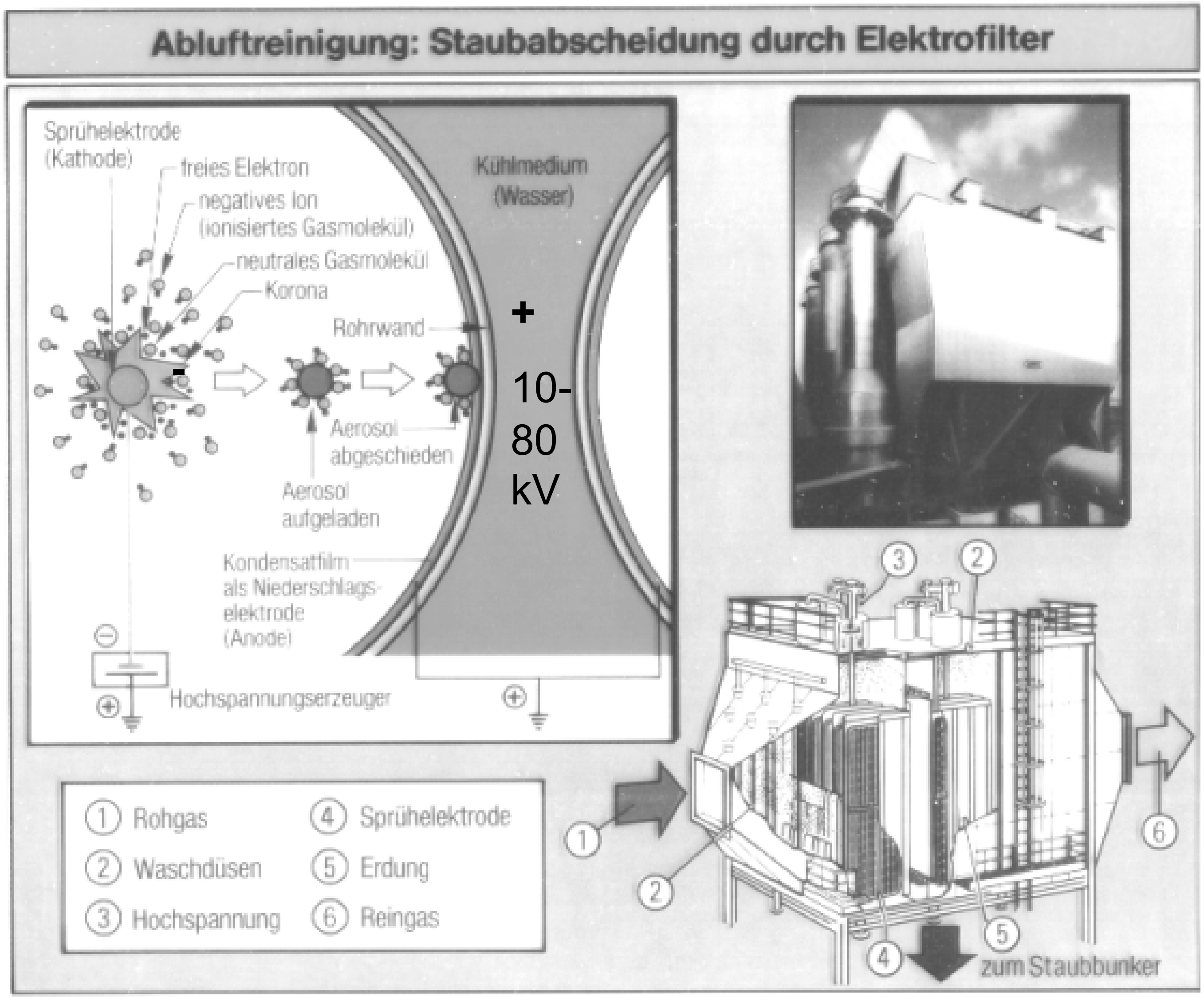
20 processes emitting 74 % of anthropogenic PM2.5

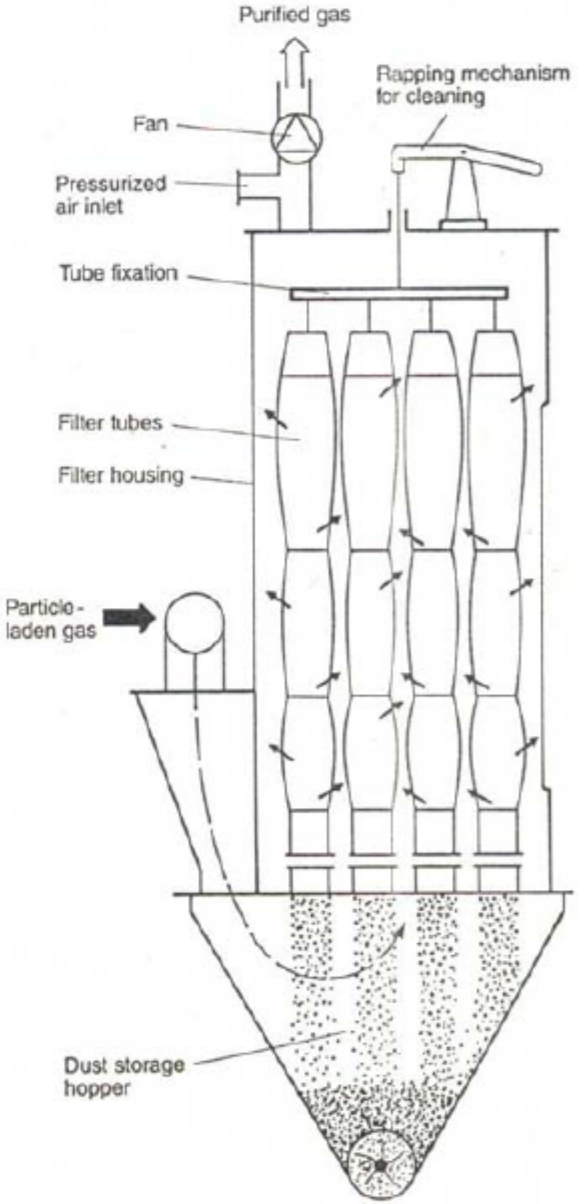
	PM10 [t]	PM2,5 [t]
Small combustion households - wood	18427	17111
Other mobile sources agriculture - diesel engines	15580	14760
Road traffic passenger cars - diesel engines	7913	7571
Other mobile sources construction - diesel engines	7600	7200
Road dust suspension	25423	6411
Commercial and residential barbecues	6164	6164
Cement production	7215	4466
Public power plants - lignite	5024	4217
Sinter production	8728	4192
Road traffic light duty vehicles - diesel engines	4221	4039
Marine ships - heavy fuel oils, diesel	4293	3993
Road traffic lorries w/o trailer - diesel engines	4147	3968
Oxygen steel production	4373	3887
Public power plants - hard coals	4286	3709
Pig iron production	13399	3594
Road traffic lorries with trailer - diesel engines	3731	3570
Road articulated lorry - diesel engines	3651	3493
Small combustion commercial - wood	2803	2438
Small combustion households - coal	2437	2285
Fireworks	2589	1726

Smoking:

1 300 t PM2.5

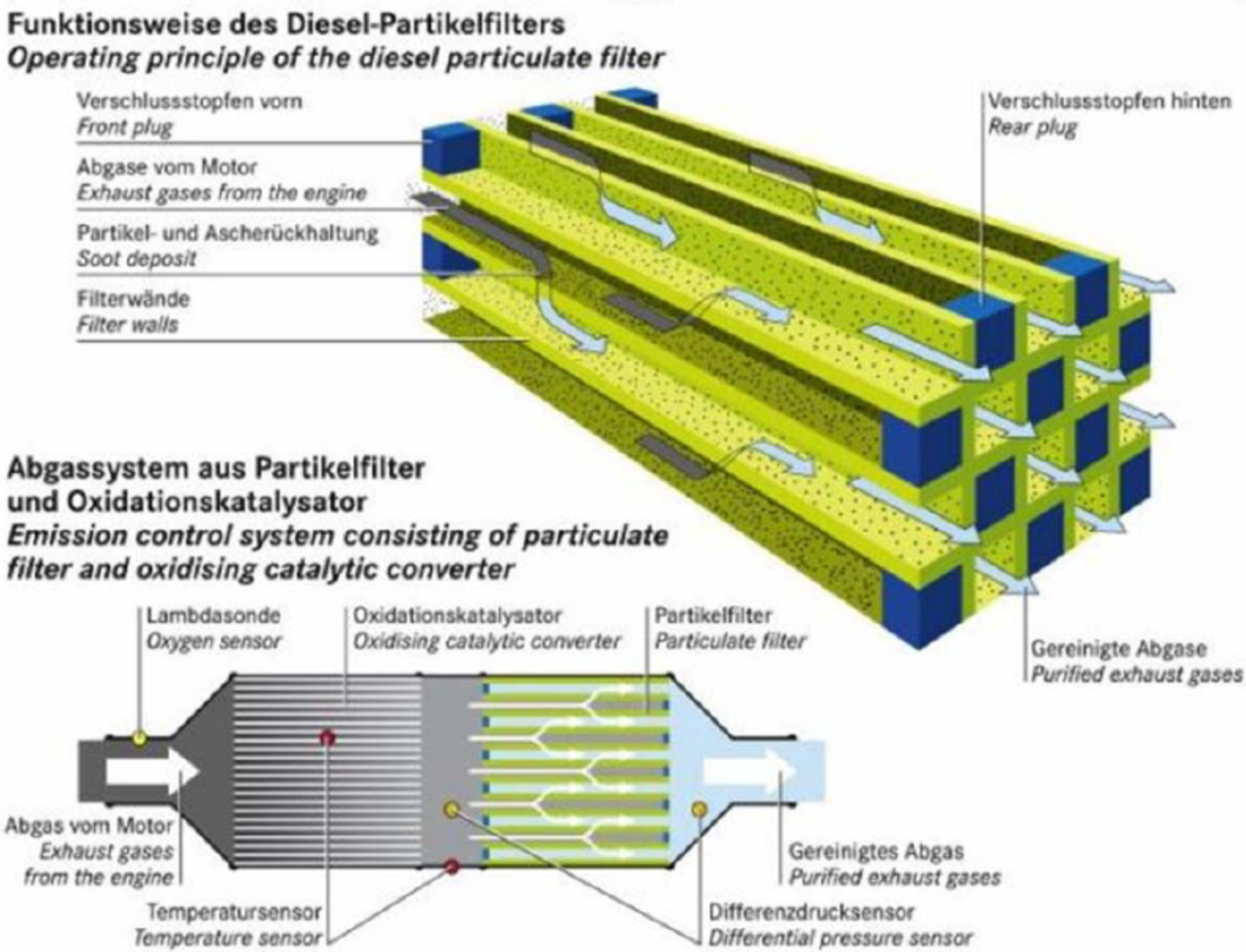
Electrostatic Precipitator for removing dust from the flue gas



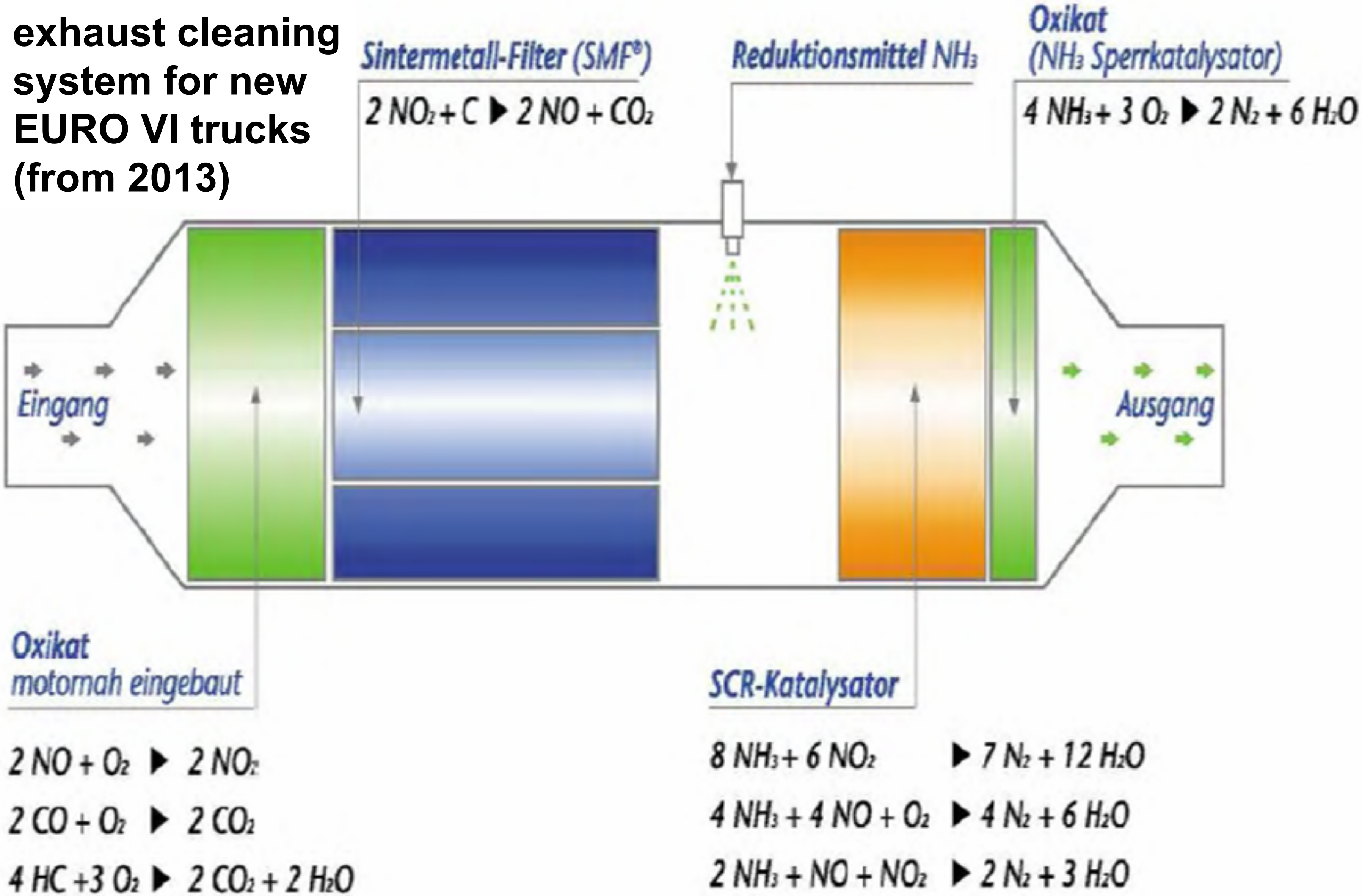


Technical options for the removal of PM from exhaust gas - set-up of a tubular bag filter

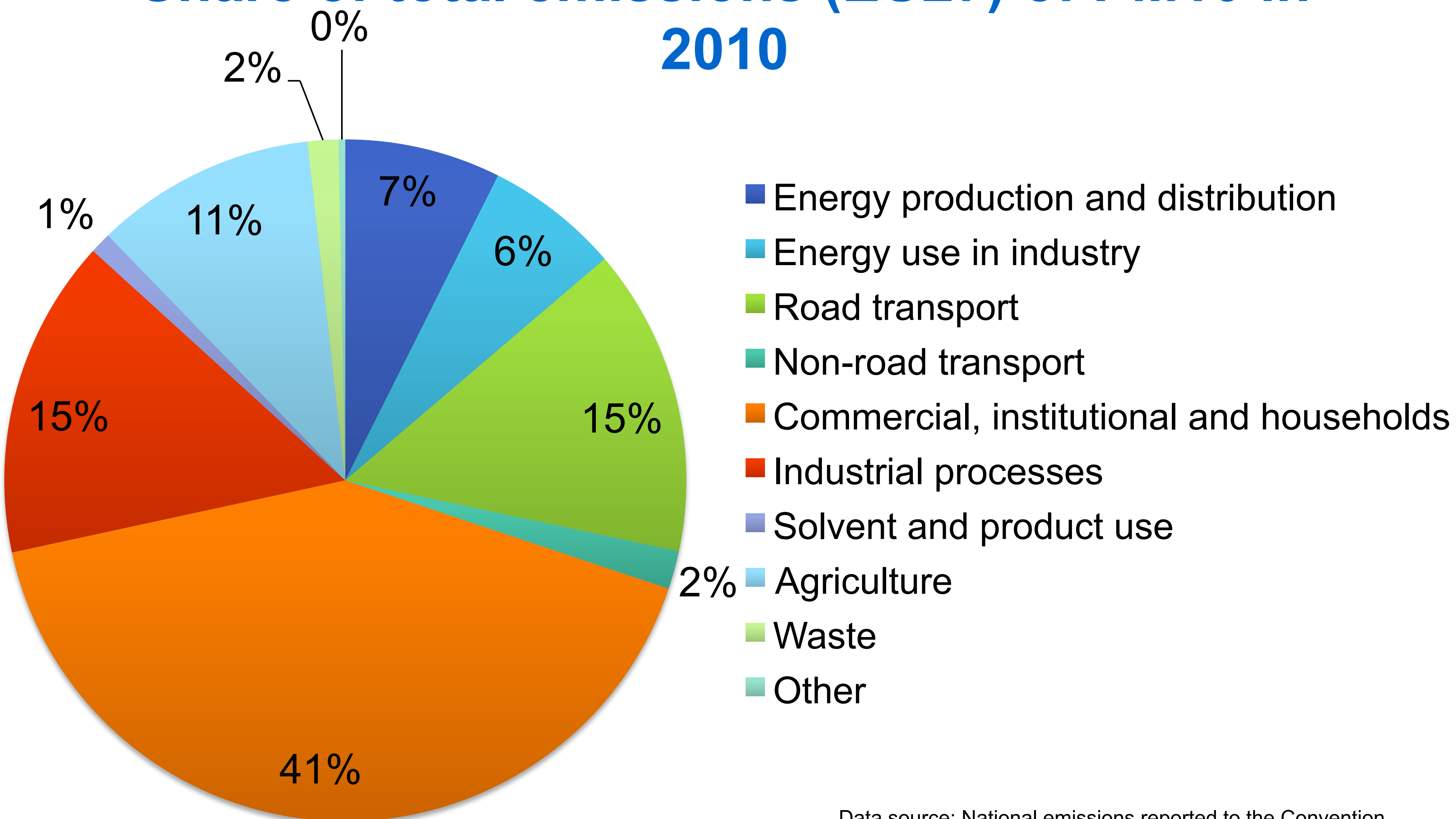
Source: Baumbach 1996


Funktionsweise des Diesel-Partikelfilters
Operating principle of the diesel particulate filter
Verschlussstopfen vorn
Front plug
Abgase vom Motor
Exhaust gases from the engine
Partikel- und Ascherückhaltung
Soot deposit
Filterwände
Filter walls
Verschlussstopfen hinten
Rear plug
Gereinigte Abgase
Purified exhaust gases
Abgassystem aus Partikelfilter
und Oxidationskatalysator
Emission control system consisting of particulate
filter and oxidising catalytic converter
Lambdasonde
Oxygen sensor
Oxidationskatalysator
Oxidising catalytic converter
Partikelfilter
Particulate filter
Abgas vom Motor
Exhaust gases
from the engine
Gereinigtes Abgas
Purified exhaust gases
Temperatursensor
Temperature sensor
Differenzdrucksensor
Differential pressure sensor

exhaust cleaning system for new EURO VI trucks (from 2013)



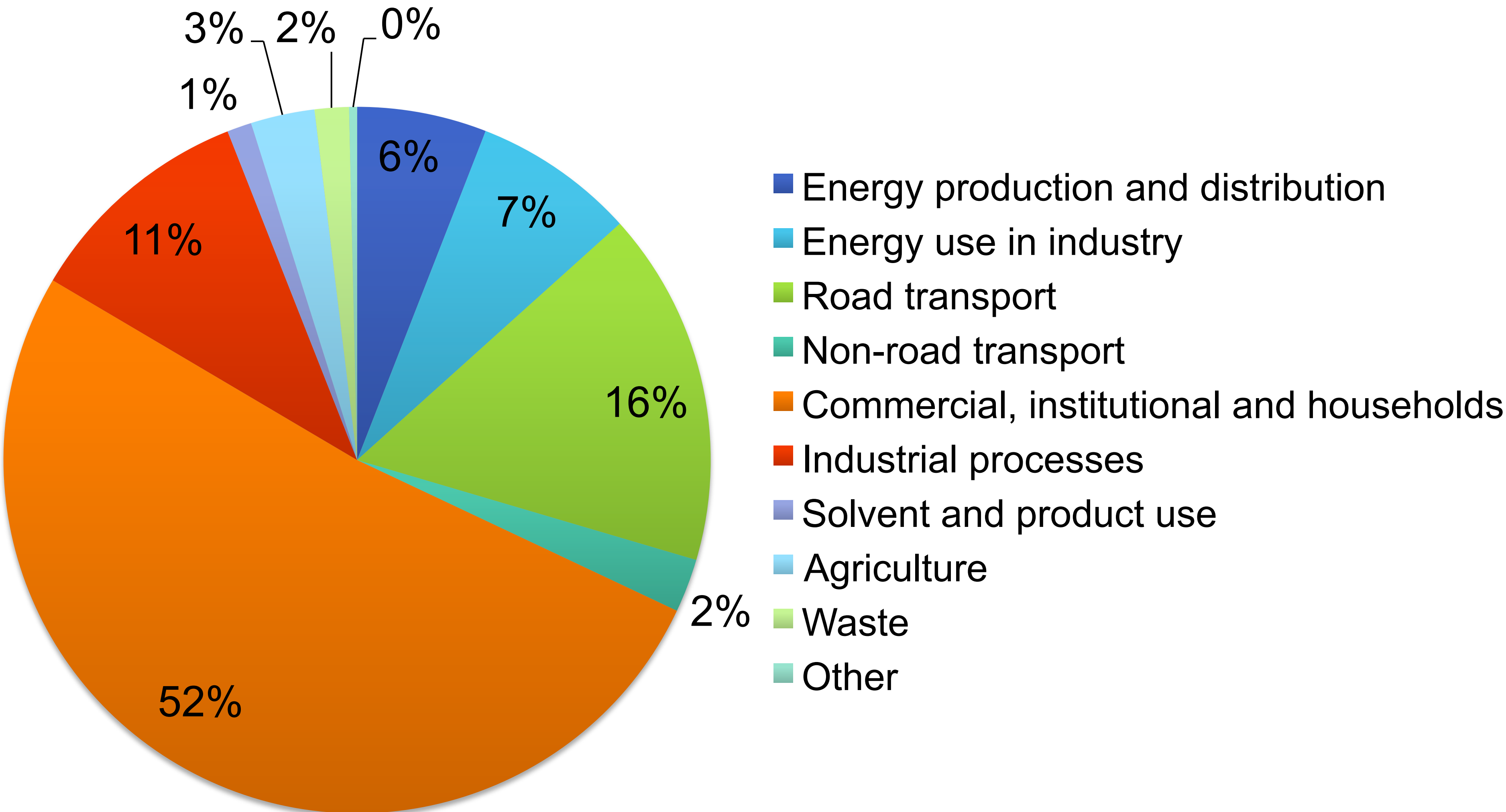
Share of total emissions (EU27) of PM10 in 2010



Data source: National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention)

Total amount of PM10 for EU27: **1969** Gg (kt)

Share of total emissions (EU27) of PM2.5 in 2010



Total amount of PM2.5 for EU27: **1333** Gg (kt)

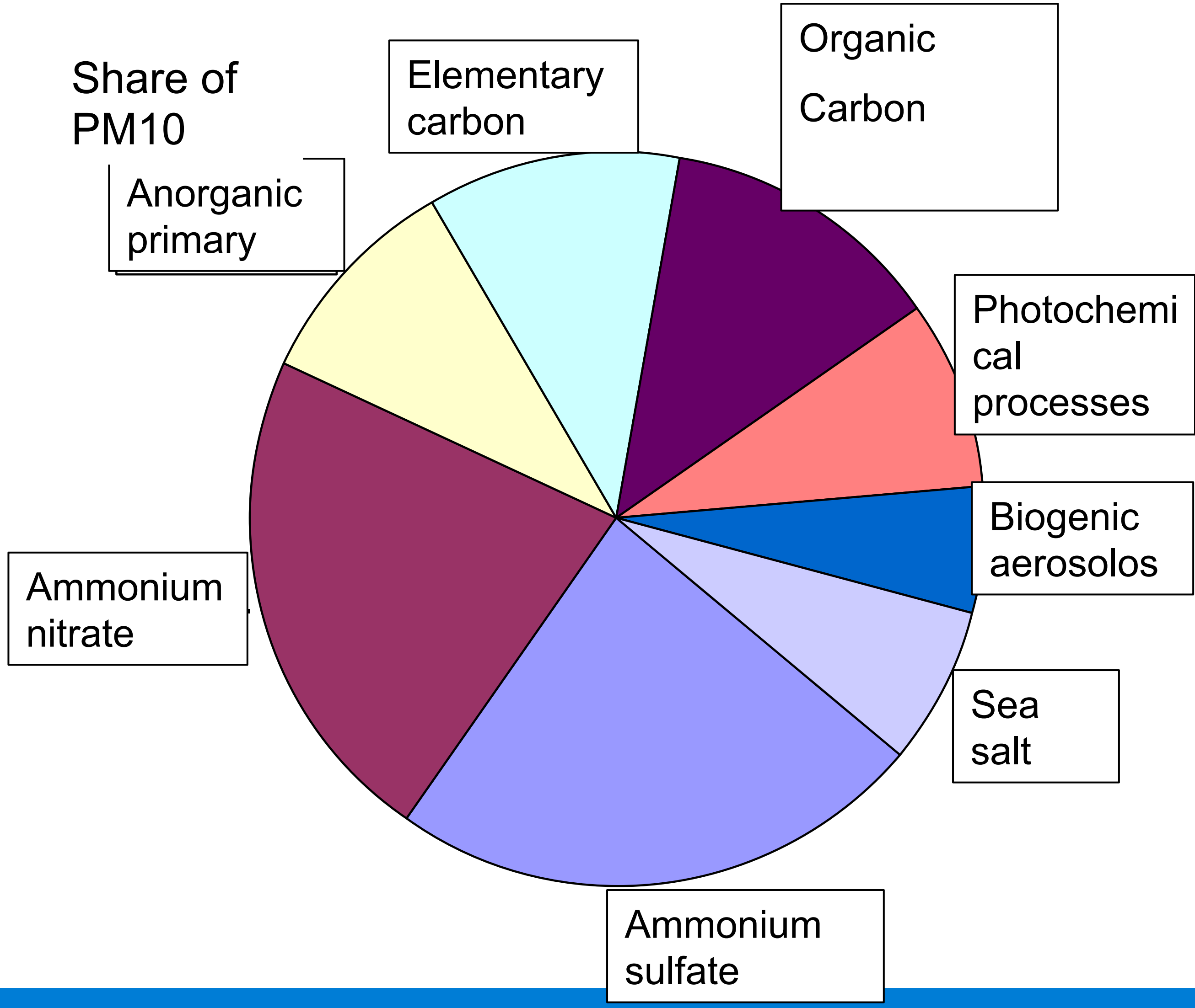
Data source: National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention)

Composition of the anthropogenic PM10 concentration – rural background

Share of anthropogenic primary particles ca. 30 %

urban/near streets up to 70 %

Source Schneider 1999



Generation of secondary aerosols

Ammonia (NH_3), sulfur dioxide (SO_2), nitrogen oxides (NO_X)

Gaseous precursors

Volatile organic compounds (NMVOC)

SO_2 => HSO_3 => H_2SO_4

H_2SO_4 + 2 NH3 = $(NH_4)_2SO_4$

NO_2 => HNO_3

HNO_3 + NH3 = NH_4NO_3

concentrations
temperature
atmosph. stability
humidity
rain
radiation

Complex oxidation processes

caused by formation of radicals

(O_3, OH, NO_3)

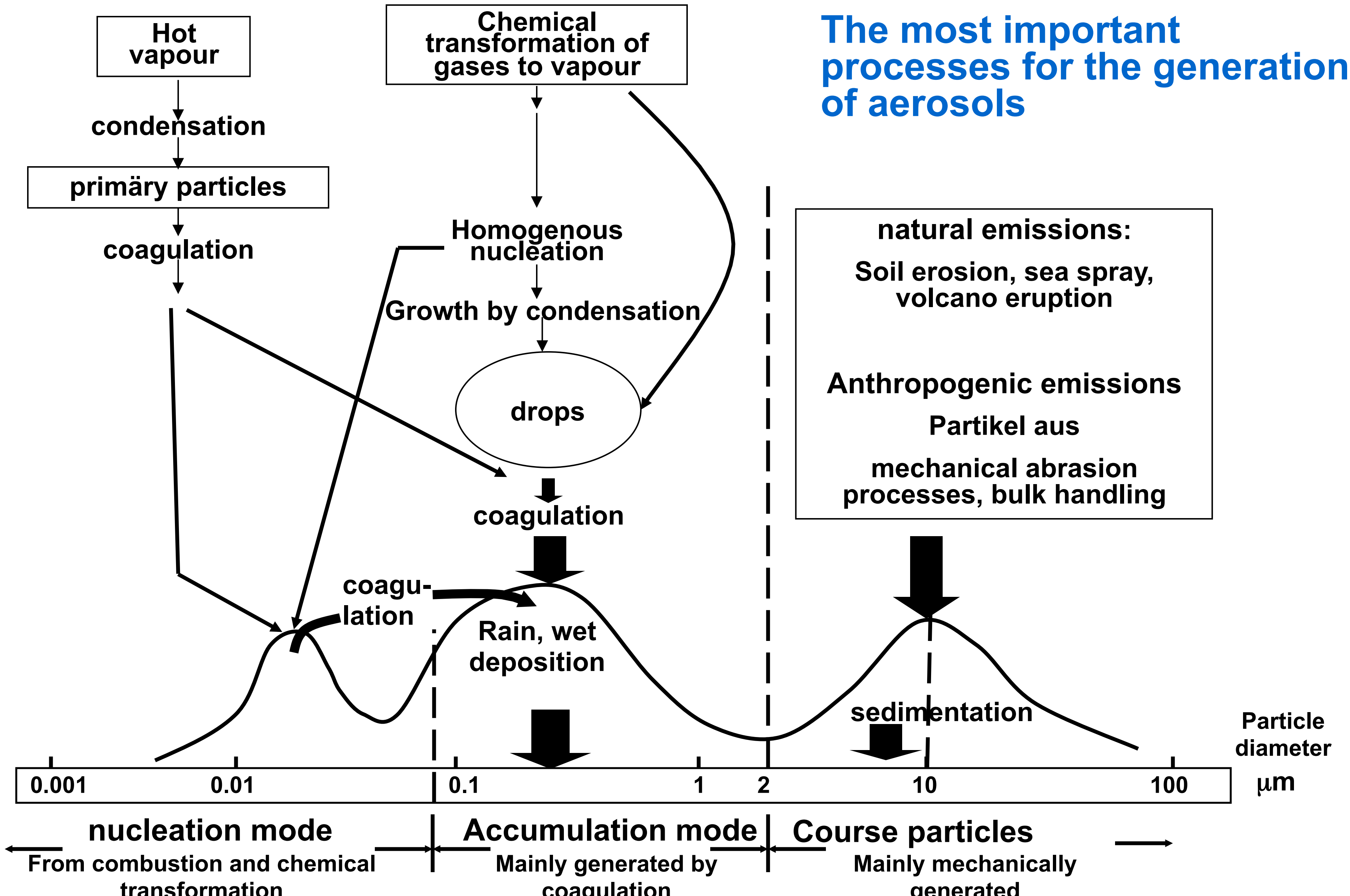
Inorganic secondary aerosols (ammonium sulfate und nitrate)

Organic secondary aerosols

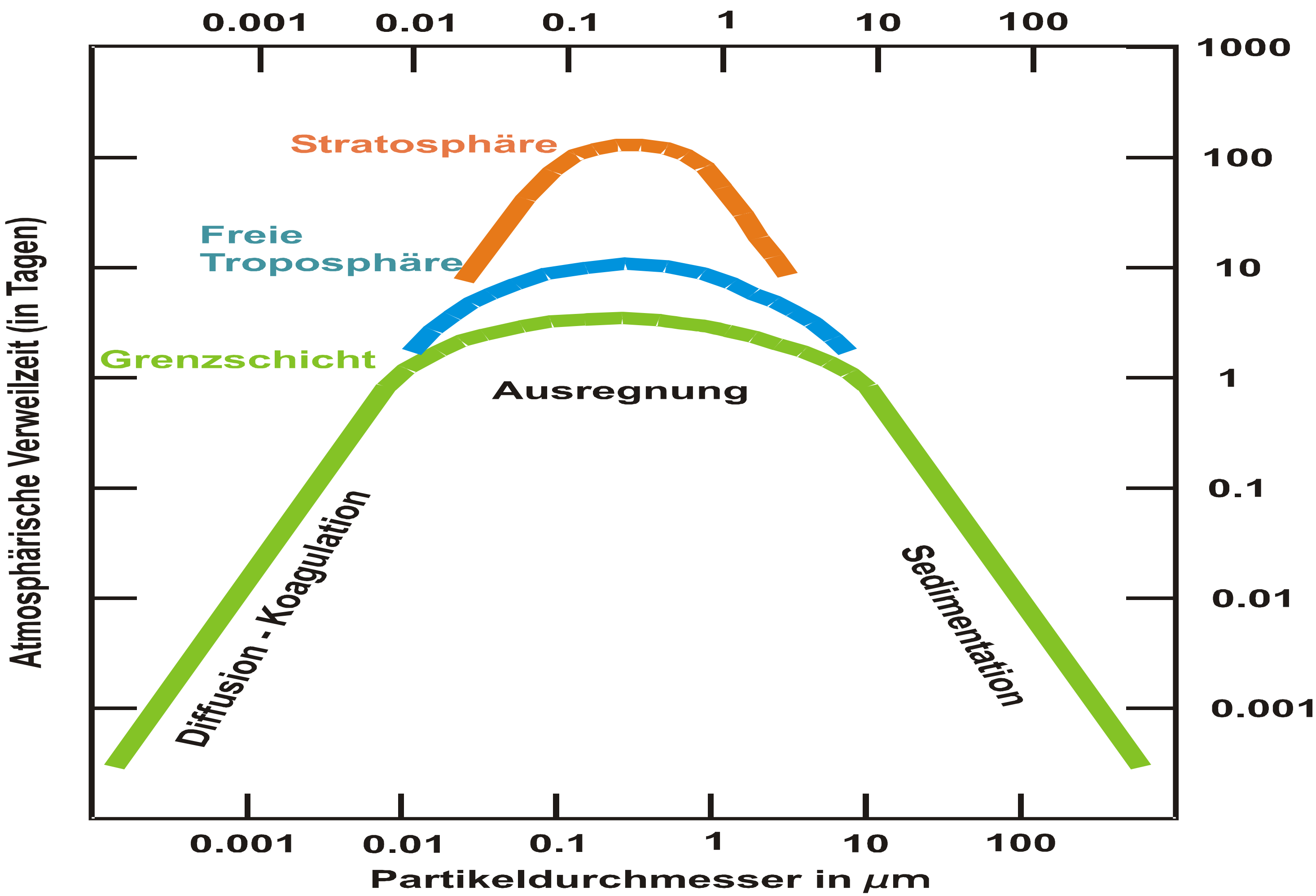
NH_4HSO_4 $(NH_4)_2SO_4$ NH_4NO_3

Many different species

The most important processes for the generation of aerosols

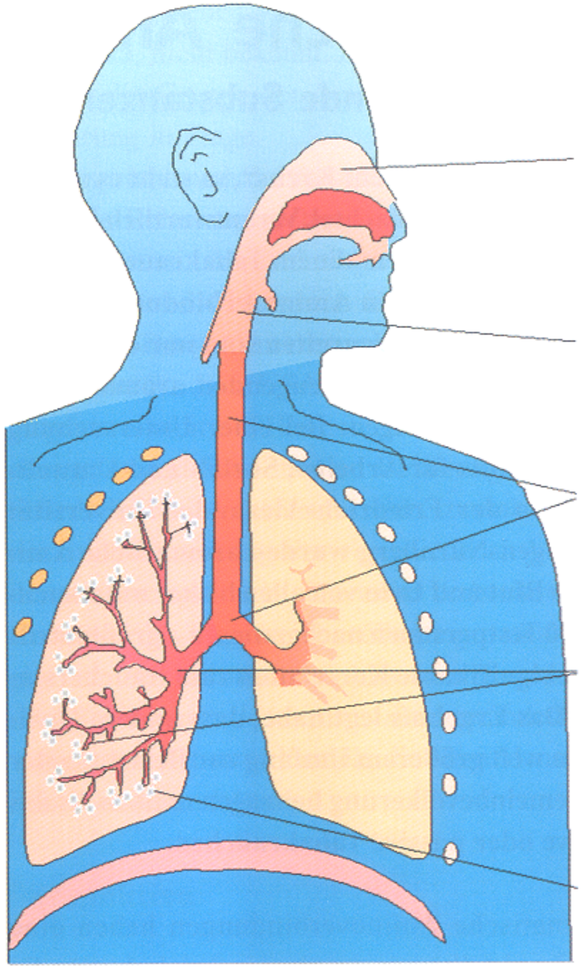


Relation between particle size (x- axis) and atmospheric life time (y-axis, in days)



source: Ad-hoc Arbeitsgruppe des DECHEMA/GDCh/DBG Arbeitsausschusses "Chemie der Atmosphäre"

Separation rate of inhaled particles in the human respiratory tract, depending on its diameter



Separation rate > 50% in

Nasal mucus skins and pharynx
> 10 µm

Larynx
>4.7 – 5.8 µm

Airpipes and main bronchia
> 3.3 – 4.7 µm

Secondary and terminal bronchia
> 1.1 – 3.3 µm

Alveoli
< 1.1 µm

Source: Umweltforschung Journal 2004

Mechanisms of how Particles Effect Human Health

pulmonary alveoli contain

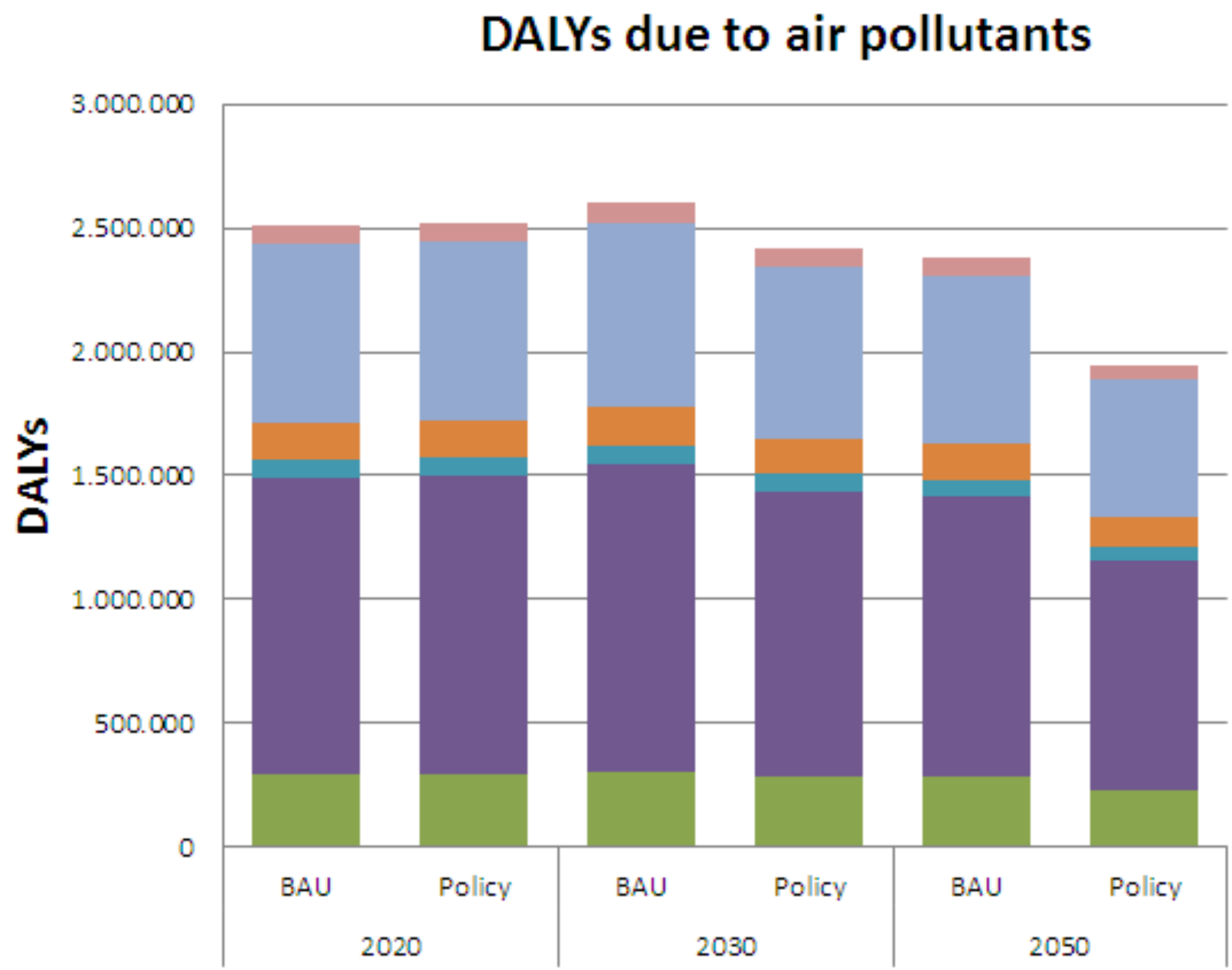
- **particles (PM 2,5)** ... .AM.... ......
- **Epitheliel (upper skin layer)**
- **Interstitium (intermed.layer)**
- **Endothel**
- **Blood vessel** T ....PMN .. .. M

1) irritation of autonomic nervous system	2) transport of PM 0,1 in arteries	3) inflammation of lung tissue
⇓	⇓	⇓
accelerated pulse-beat;		activation of body‘s defences
	inflammation ⇘	⇓
⇓	⇓	blood gets viscous, clots faster
cardiac disrythmia ⇙	less flexible arteries	⇓
disturbance of blood circulation		arteriosklerosis, thrombosis

Source: GSF

AM = alveolärer Makrophage
PMN = neutrophile Granulozyten
T = Thrombozyten
M = Monozyten

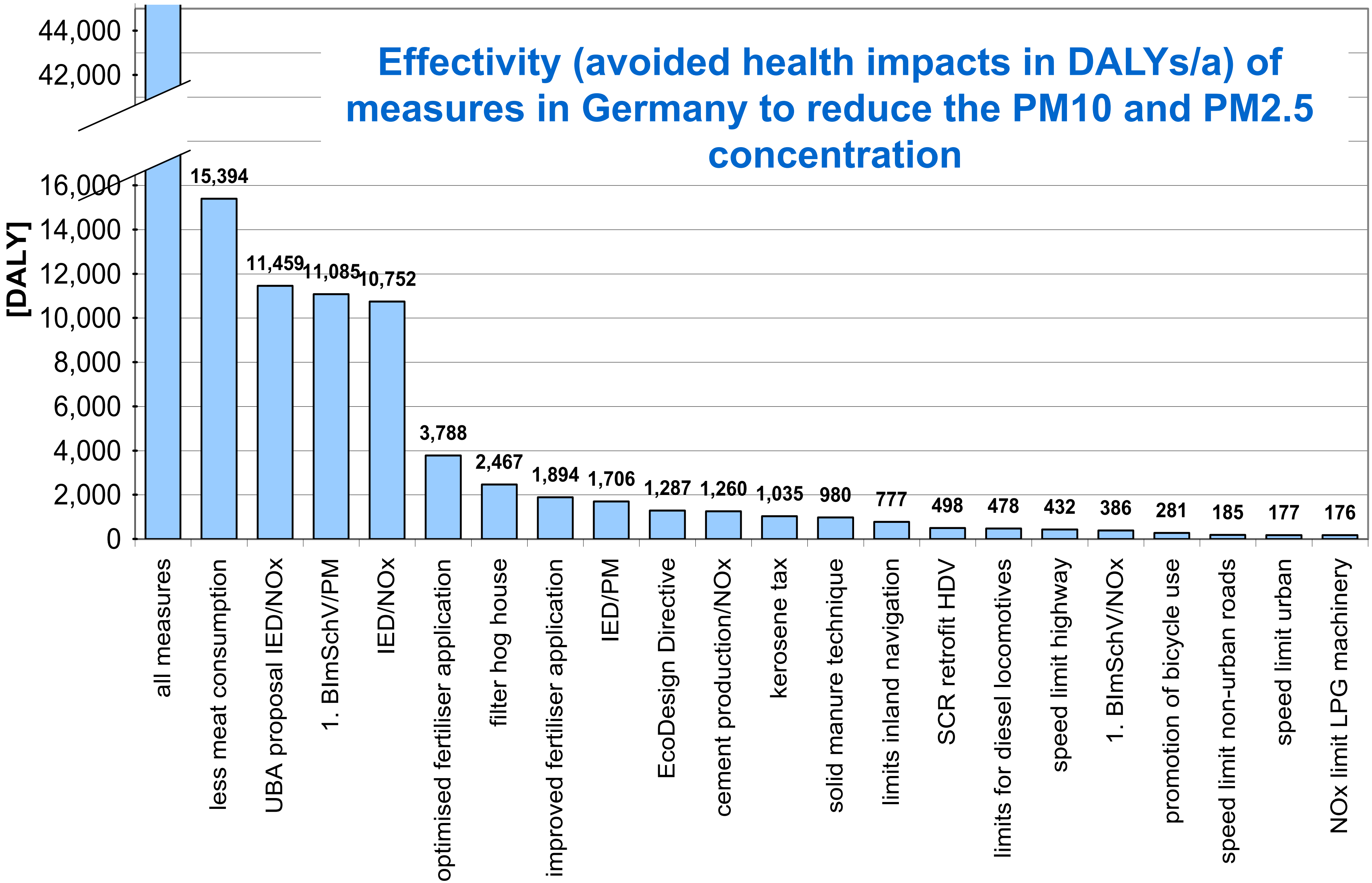
DALYs caused by one year of emissions of air pollutants in Europe (except NO2 impacts)



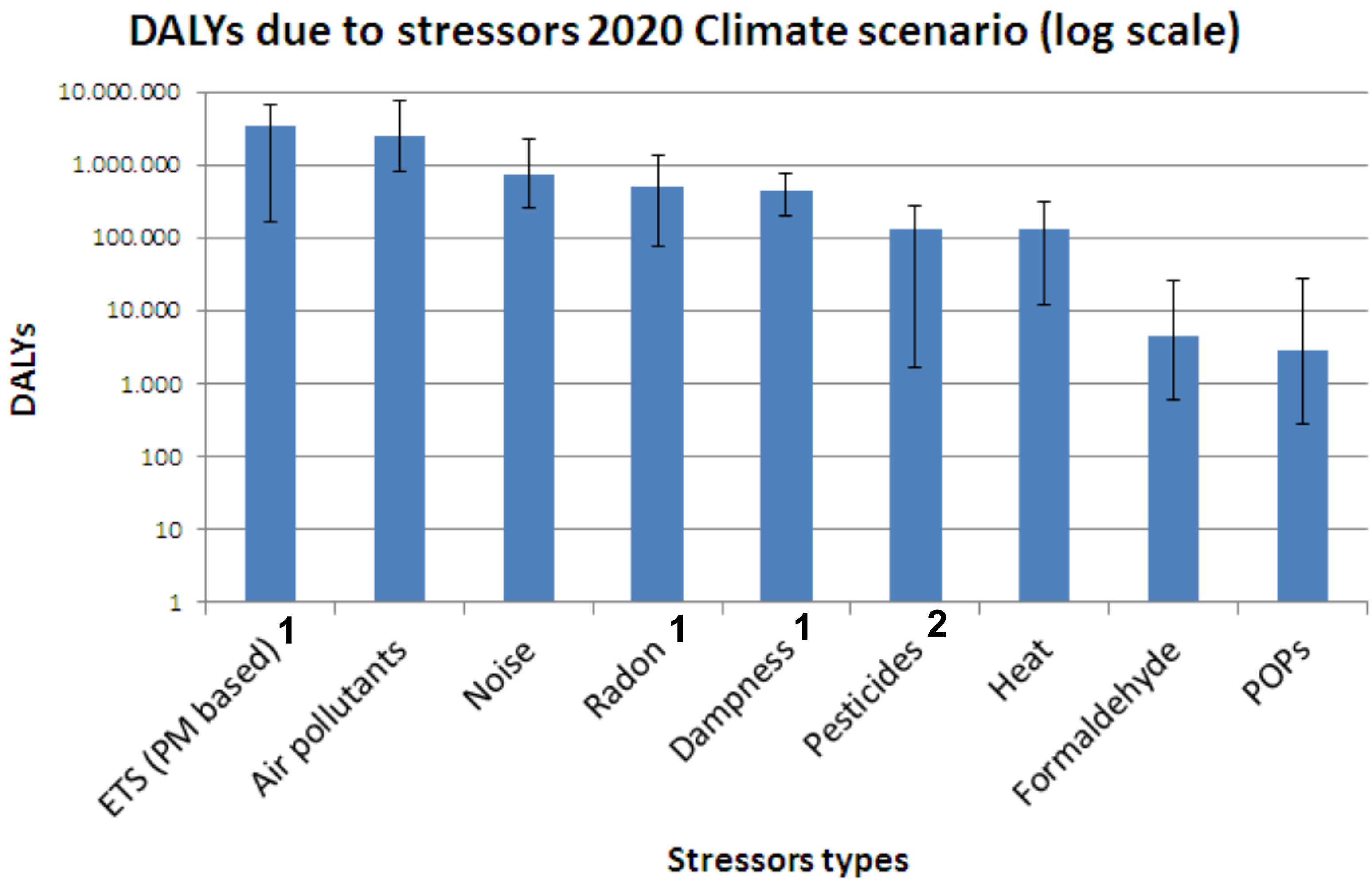
~ 1,7 days/ person*a

~ 3 months/ person over life time

Effectivity (avoided health impacts in DALYs/a) of measures in Germany to reduce the PM10 and PM2.5 concentration



DALYs due to all stressors for ‚2020 Climate'

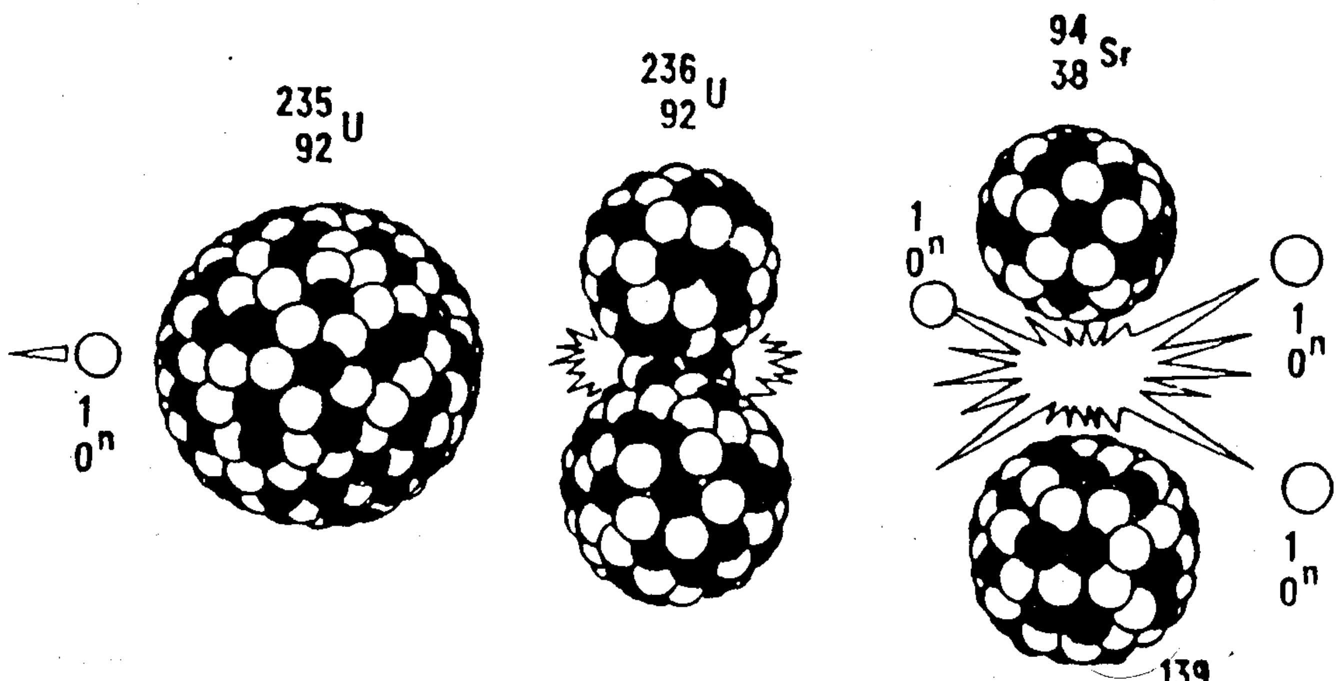


1 If no additional measures to improve air exchange rate in buildings are implemented.
2 Results from the Exiopol project.

C) Nuclear accidents

Generation of Energy with Nuclear Fission

Fission of the nucleus of an uranium – U^{235} atom



$$ {}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{236}_{92}U \longrightarrow {}^{139}_{54}Xe + {}^{94}_{38}Sr + 3\,{}^{1}_{0}n + 200\ \mathrm{MeV} $$

Thermal power of a nuclear reactor after shut down

100 s	ca. 160 MW
300 s	ca. 110 MW
10 min	ca. 90 MW
1 h	ca. 64 MW
24 h	ca. 52 MW

Because of radiation stemming from

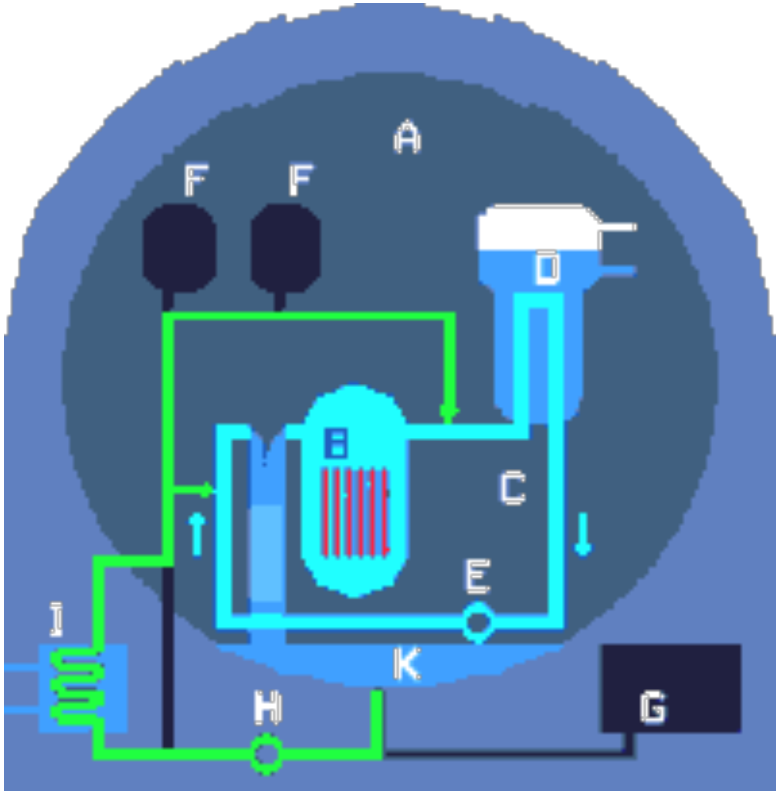
- **Fission products: e.g. Strontium90 (28 a), Jod 131 (8 a), Jod133 (20 h)**
- **Activated material: by irradiation of of the reactor container, e.g. Fe59, Co60**
- **Conversion products (Pu239)**

Emergency cooling system (example: Break in the main coolant line)

1) Use accumulator tank F (high pressure)

2) Use flood tank G

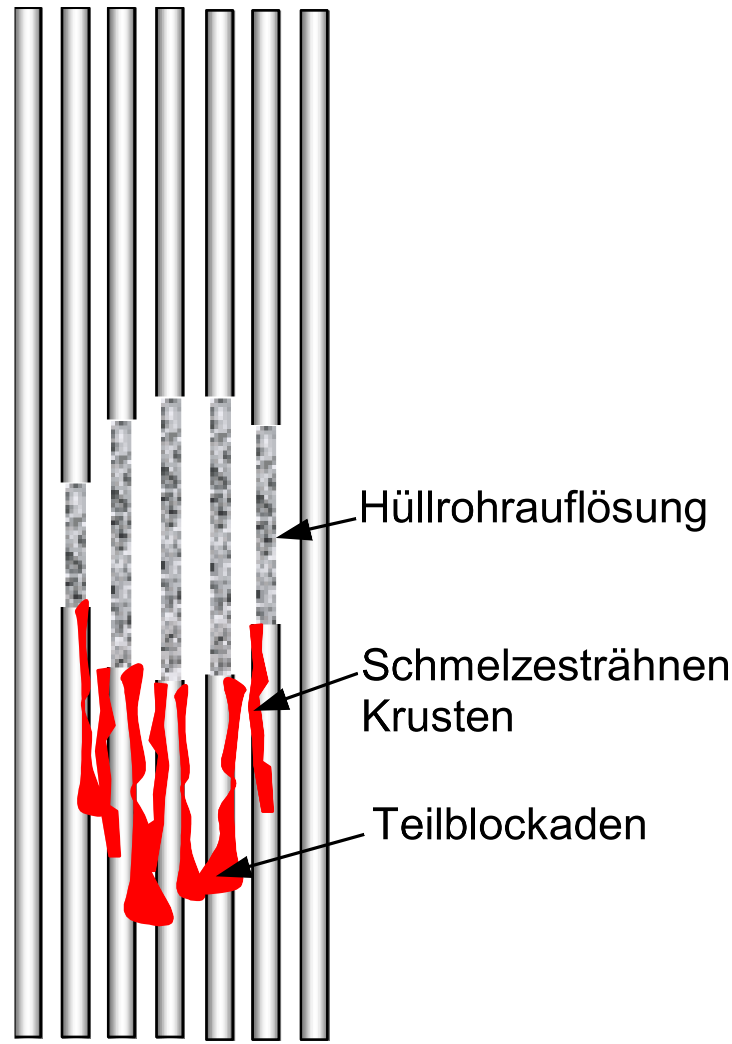
3) Pump water from reactor sump



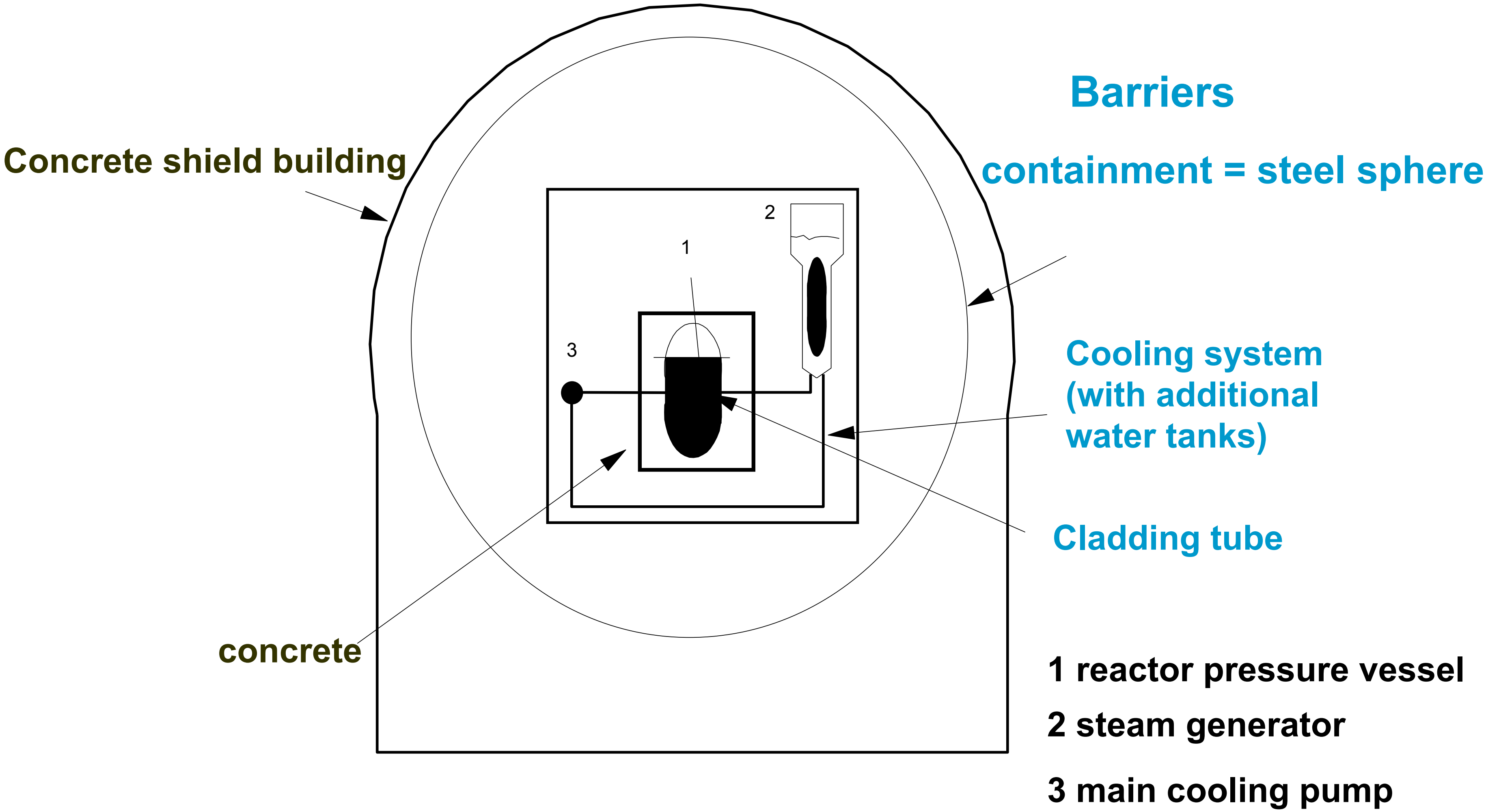
Core Melting

Insufficient cooling

- Heating and vaporisation of remaining water
- >1200°C: production of hydrogen caused by oxidising the zirkaloy of the cladding tube
- Melting of cladding tubes and content of tubes (



Quelle Starflinger


Barriers
Concrete shield building
containment = steel sphere
1
2
3
Cooling system
(with additional
water tanks)
Cladding tube
concrete
1 reactor pressure vessel
2 steam generator
3 main cooling pump

Pathways to the release of radioactive substances

1) **Heating -> pressure increases -> controlled pressure release through filter**
2) **Hydrogen oxidisation / explosion of the oxygen hydrogen mixture (catalytic recombiners in containment)**
3) **Water vapour explosion (concrete structure)**
4) **Molten radioactive substances melt through the concrete at the bottom of reactor**

Estimation of health impacts caused by nuclear accident in Southern Germany; impacts occur within 200 years after accident

Type of accident	Early impacts	Latent health risks			
	Immediate fatalities	Collective dose pers.Sv	Fatal cancers	Non-fatal cancers	Genetic defects
DRSB 1	164	$1{,}04\ 10^{6}$	52 000	124 800	10 400
DRSB 2	63	$6{,}4\ 10^{5}$	32 000	76 800	6 400
DRSB 3	-	$1{,}7\ 10^{5}$	8 500	20 400	1 700
DRSB 4	-	$6{,}1\ 10^{4}$	3 050	7 320	610
DRSB 5	-	$6{,}8\ 10^{3}$	340	816	68
DRSB 6	-	$6{,}8\ 10^{2}$	34	82	7

For comparison: in total 22 Mio deaths from cancer (all causes) in Germany over 100 years

source Riskostudie B, 1989

Area for evacuation and resettlement after a large nuclear accident

(berechnet mit RODOS, Quelle: Bundestagsdrucksache 17/2871)

Weather: wind direction; wind speed precipitation.	Area for evacu-ation km²	Equal to circle with radius km	Area for resetlle-ment km²	Equal to circle with radius km
strong variing dry	110	6	80	5
strong constant dry	500	13	400	11
moderate variing dry	270	9	160	7
moderate constant dry	900	17	1200	20
weak variing dry	500	13	350	11
weak variing dry	800	16	700	15
strong variing 1 mm/h	4800	39	22900	85
strong constant 1 mm/h	5800	43	9900	56
moderate variing 1 mm/h	4500	38	15600	71
moderate constant 1 mm/h	3000	31	6200	44
weak variing 1 mm/h	4300	37	10100	57
weak constant 1 mm/h	1500	22	2700	29

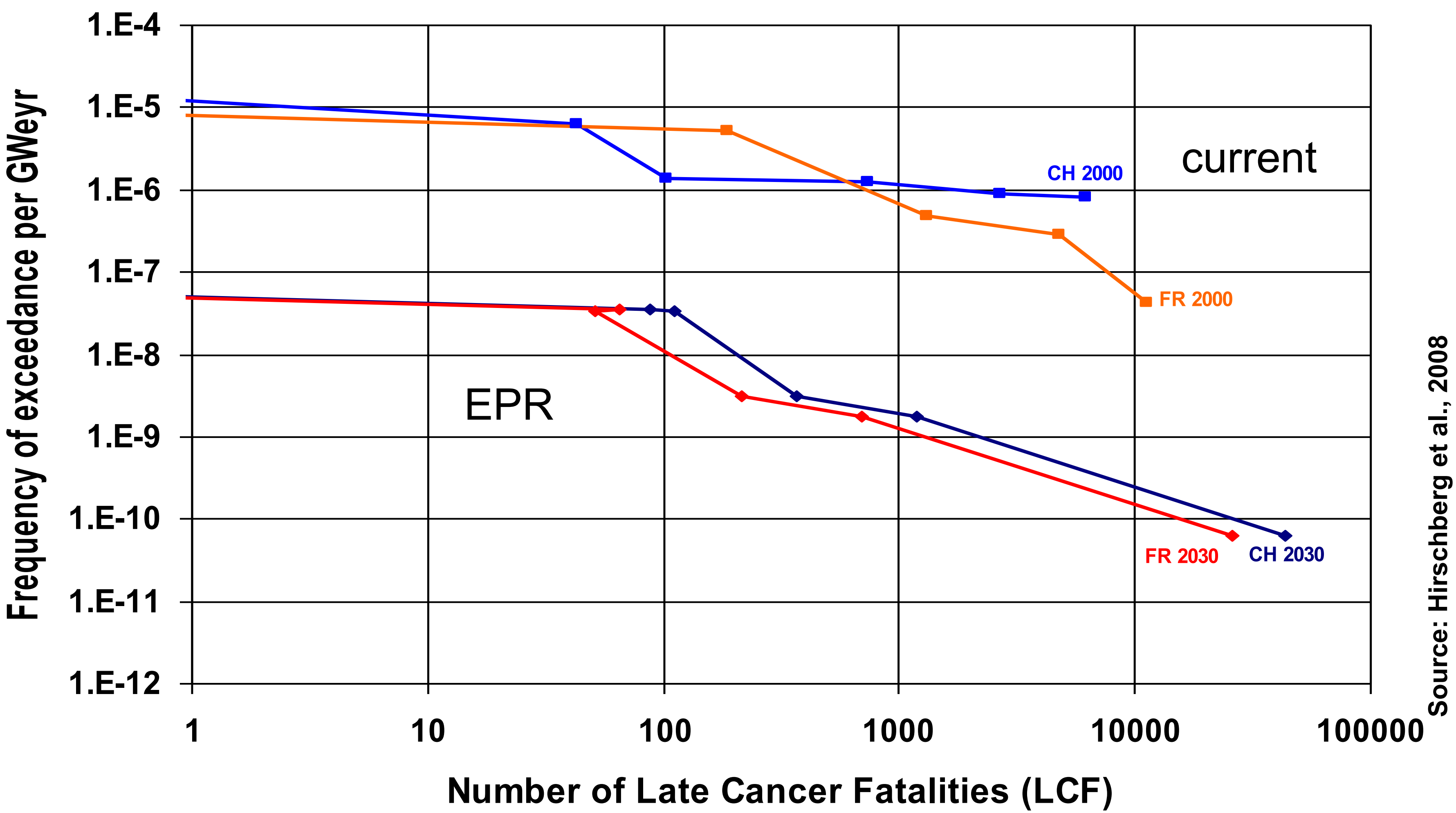
Population around nuclear power plants in Germany (in 1000 persons)

Radius	10 km	20 km	30 km	40 km
Biblis A	126	568	1580	2724
Gundremmingen B	43	196	514	1092

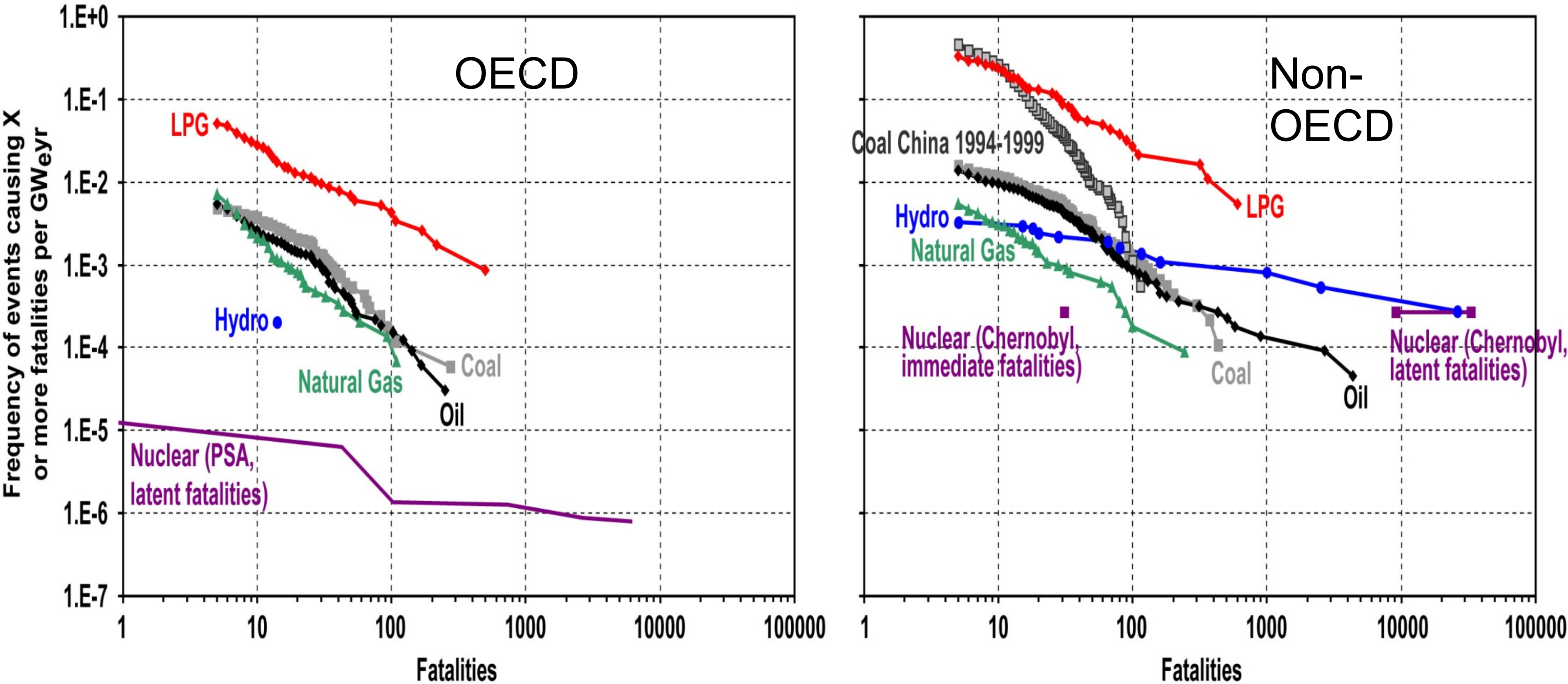
Total damage ca. 250 billion € to 2000 billion € per accident with large release of radioactive substances, using willingness to pay and material damage. Compensation much smaller (estimation of requests for compensation to TEPCO for Fukushima accident ca . 25 – 90 billion €)

For comparison: GDP (gross domestic poduct) of Germany: 2 500 billion €/ a;

F-N Curves: Latent Cancer Fatalities (LCF) for current nuclear power plants and EPR (European Pressurized Reactor)



Frequency and Fatalities due to large accidents 1970 – 2005, source: Hirschberg, PSI



- **High probability for LPG (liquid petrol gas) and in coal mines in China.**
- **Break of dams in developing countries may cause thousands of deaths, last break of a dam in OECD countries > 1000 deaths 1963 in Vaiont, Italy; 1917 deaths).**

source: Hirschberg, PSI

Risk of a large nuclear accident:

- **Risk = frequency * damage = expectation value of damage**
- Frequency: with PSA: 10^{-7} bis 10^{-8} /(year and plant)
  statistical frequency: 10^{-4} /(year and plant)
- Individual risk ca 10^{-11}/a*plant resp. 10^{-8}/a*plant
- Rough estimation of damage : 450 – 1 000 billion € per large accident (including intangible costs)
- Risk with PSA: (0,45 - 1* 10^{12} €)* (10^{-7} /a - 10^{-8} /a) / (9,4 * 10^{9} kWh/a) = **0,000021 – 0,00000027 €/kWh, for EPR Factor 1000 maller**
- Risk with statistical frequency: (0,45 bis 1* 10^{12} €)* (10^{-4} /a) / (9,4 * 10^{9} kWh/a) = **0,01 – 0,005 €/kWh**

→ **Low expectation value of damage**

Assessment as Damocles risk/ social risk

- **High damage with very low probability (a Damocles risk) is seen as worse than the same risk, but with lower damage and higher probability by many people (risk aversion)**
- **Approaches to address this quantitatively:**

  Switzerland: Factor 100

  Netherlands: tolerable risk $10^{-3}/N^2$ (N = number of deterministic fatalities), not for probabilistic damages (e.g. nuclear accidents),
- **No discussion or decision in most countries (e.g. Germany).**
- **In Germany law that forbids nuclear phase out -> obviously seen as intolerable risk.**
- **Leads to reduction of social/Damocles risks, but increases health impacts and has negative economic and social impacts.**

4) Integrated Assessment for Supporting Decision Making with Multiple Criteria

- Why quantitative assessment and comparison of impacts, risks and benefits of options?

- **Integrated Assessment (IA):** a multidisciplinary process of synthesizing knowledge across scientific disciplines with the purpose of providing all relevant information to decision makers to help to make decisions.

How do we form opinions and make decisions?

- **We have two mechanisms**

The intuitive system produces answers/opinions qickly and effortlessly. It works automaticly and unconsciously.

The logical system tries to collect information, measures, checks and considers, but needs will power and high efforts. It can not deal with more than one issue and is exhaustible.

Usually we think, that our opinions and decisions are based on using the logical system, but we use the intuitive system.

-> problems with the intuitive system

Problems with decision making with our ‚intuitive system:

- **Opinions are based on the readily available information – even if important information is missing; coherence of the information (a good story) more important than quantity, quality and completeness.**
- **Framing effect – the presentation of information influences the opinion**
- **HALO effect: one positive (negative) characteristic of a person influences the perception of the other characteristics of a person**
- **Complex questions are unconsciously replaced by simpler questions**
- **Decisions/opinions of others (peers) influence our decisions/ opinions.**

Problems with Risk assessment

- **Low probabilities/frequencies are weighted over proportionally (risk aversion)**
- **Losses are seen as worse than gains**
- **Frequencies are estimated using the easiness of remembering an example for the damage.**

Thus:

- **At least for public decisions a quantitative assessment/decision support system necessary**

How to assess environmental impacts?

Use of environmental pressures (emissions) for the assessment not useful, as severity of the impacts per unit of release is not known, thus

no weighting/comparison between pressures and with economic and social indicators possible;

➡ **Pressures/ emissions can not be assessed.**

➡ **Impacts (damage, risks) caused by the pressures should be estimated.**

- **Integrated environmental impact assessment using the impact-pathway- or full chain approach**

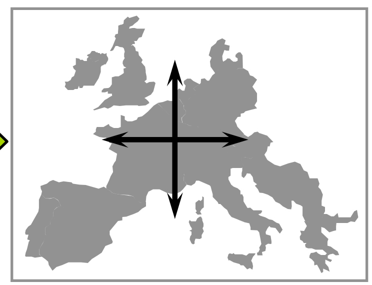
To weigh risks and benefits quantitatively they have to be transformed into a common unit, e.g. a monetary unit

Assessment of impacts is based on the preferences of the affected well-informed population

The Impact Pathway Approach

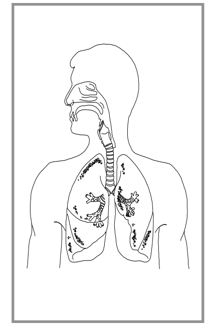
Pollutant Emissions

Transport and Chemical Transformation



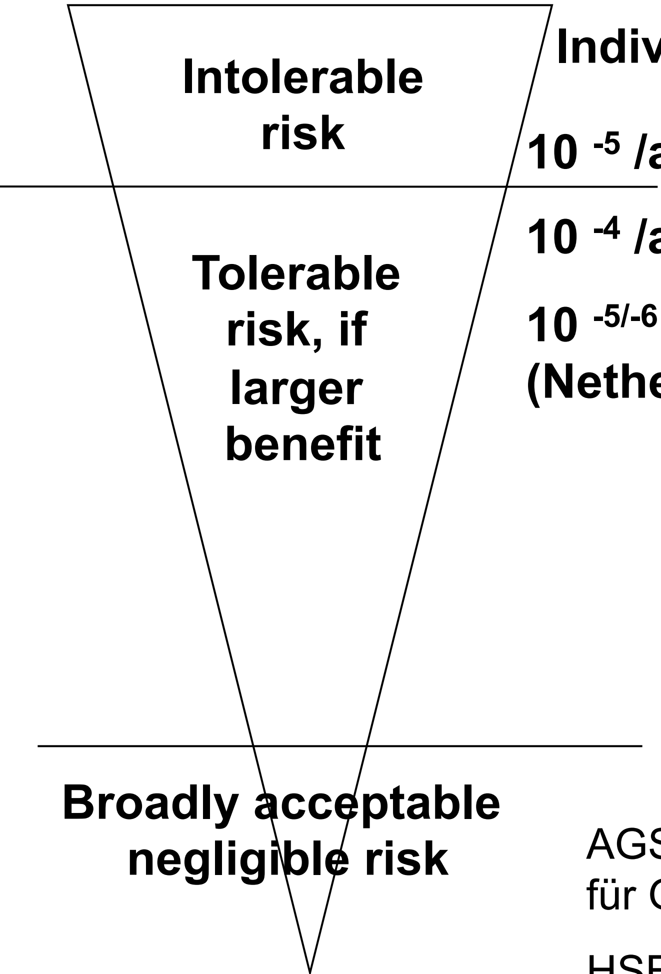
Calculation is made twice: with and without project!

Differences of Physical Impacts



monetary valuation

Assessment of Risks to Human Health



Individual risks:

10 $^{-5}$ /a (HSE UK);

10 $^{-4}$ /a (AGS)

10 $^{-5/-6}$ /a (Netherlands)

AGS = Ausschuss für Gefahrstoffe,

HSE = Health and Safety Executive

Step 1: Inacceptable intolerable risks have to be avoided by all means (e.g. via thresholds, bans).

Step 2: The assessment of tolerable risks is based on the measured preference of the affected well informed population.

Assessment of Damocles Risks (Societal Risks)

Risk = frequency * damage = expectation value of damage

Problem: very high damage with low probability often assessed as worse than same risk, but lower damage.

Currently there is no accepted methodology to include risk aversion, so the expectation value is used

(proposals in other countries:
Switzerland: factor 100, the Netherlands: tolerable risk 10^{-3} /N^2).

Monetary values of health endpoints (EUR 2010)

Health End-Point	Low	Central	High	per case
Increased mortality risk - VSLacute	1,121,433	1,121,433	5,607,164	Euro
Life expectancy reduction - Value of Life Years chronic	40,500	59,810	213,820	Euro
Sleep disturbance	400	1,045	1,320	Euro/year
Hypertension	740	800	930	Euro/year
Acute myocardial infarction	2,200	4,470	31,660	Euro
Lung cancer	69,080	719,212	4,187,879	Euro
Leukaemia	2,045,493	3,974,358	7,114,370	Euro
Neuro-development disorders	4,486	14,952	32,895	Euro
Skin cancer	10,953	13,906	26,765	Euro
Osteoporosis	2,990	5,682	8,074	Euro
Renal dysfunction	22,788	30,406	40,977	Euro
Anaemia	748	748	748	Euro

Values for Assessing Greenhouse Gas Emissions

[Euro 2010 per tonne CO2 eq]	2010	2015	2025	2035	2045	2050
MDC_NoEW	9	11	14	15	17	22
MDC meta analyis	24	26	32	39	48	58
Kyoto+	**26**	**30**	**36**	**42**	**74**	**87**
2° max	**36**	**46**	**73**	**119**	**194**	**250**

Kyoto/20%+ : fulfillment of the Kyoto aim 2010, 20% GHG reduction 2020 in EU and further considerable reduction after 2020

Max 2° : temperature increase of 2° not exceeded (source Kuik 2009)

MDC_NoEQ: quantifiable marginal damage costs without equity weighting, estimated with the FUND model develop by Tol

MDC meta analysis: meta analyis of studies estimating marginal damage costs (source Tol 2011)

An example for using the methodology :

Objective: rank different electricity generation techniques according to their contribution to a sustainable energy system

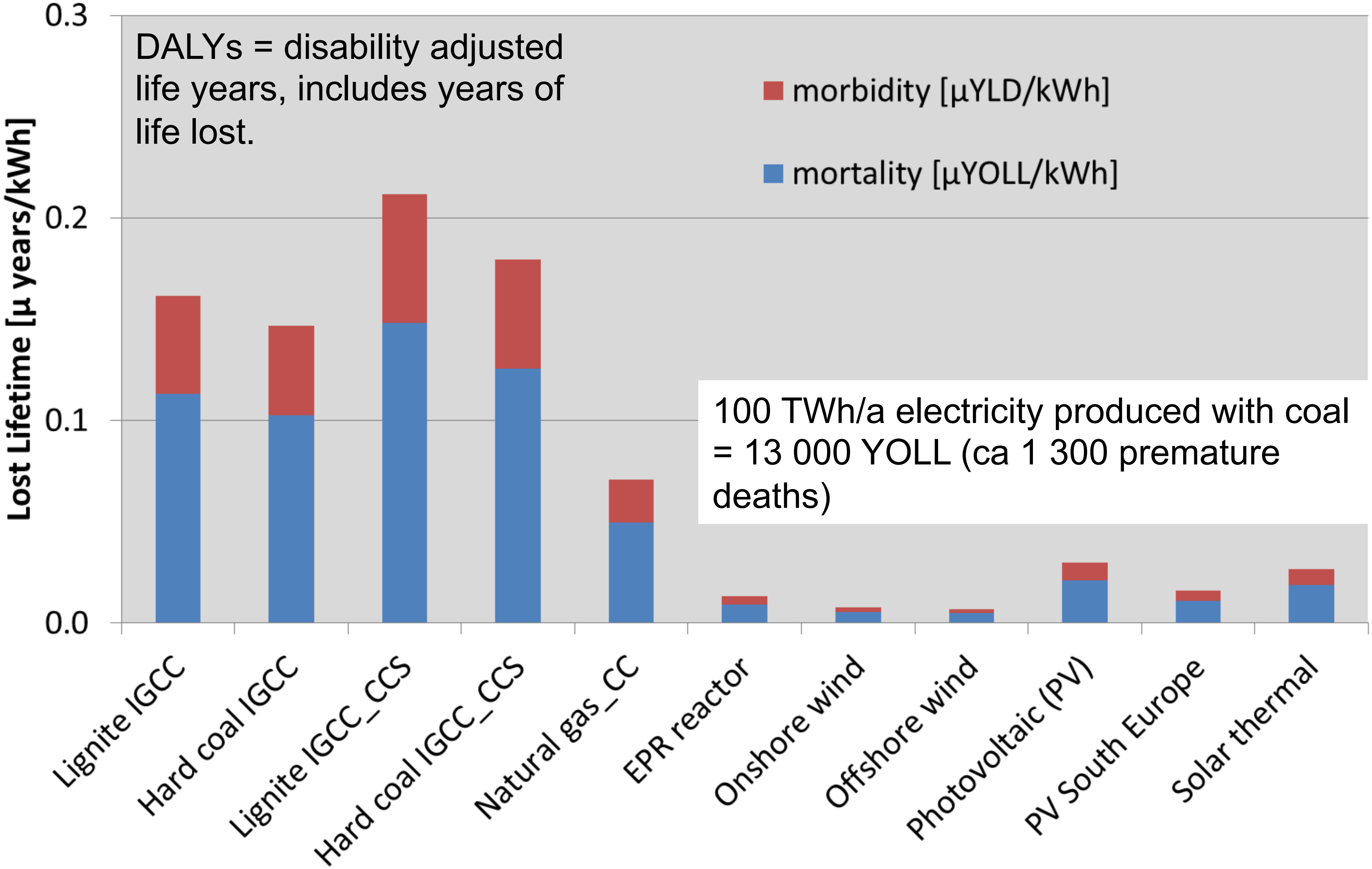
Main criteria for assessing the sustainability of electricity generation:

1) Risks for human health and biodiversity losses per kWh as low as possible – for the life cycle including as well normal operation as accidents

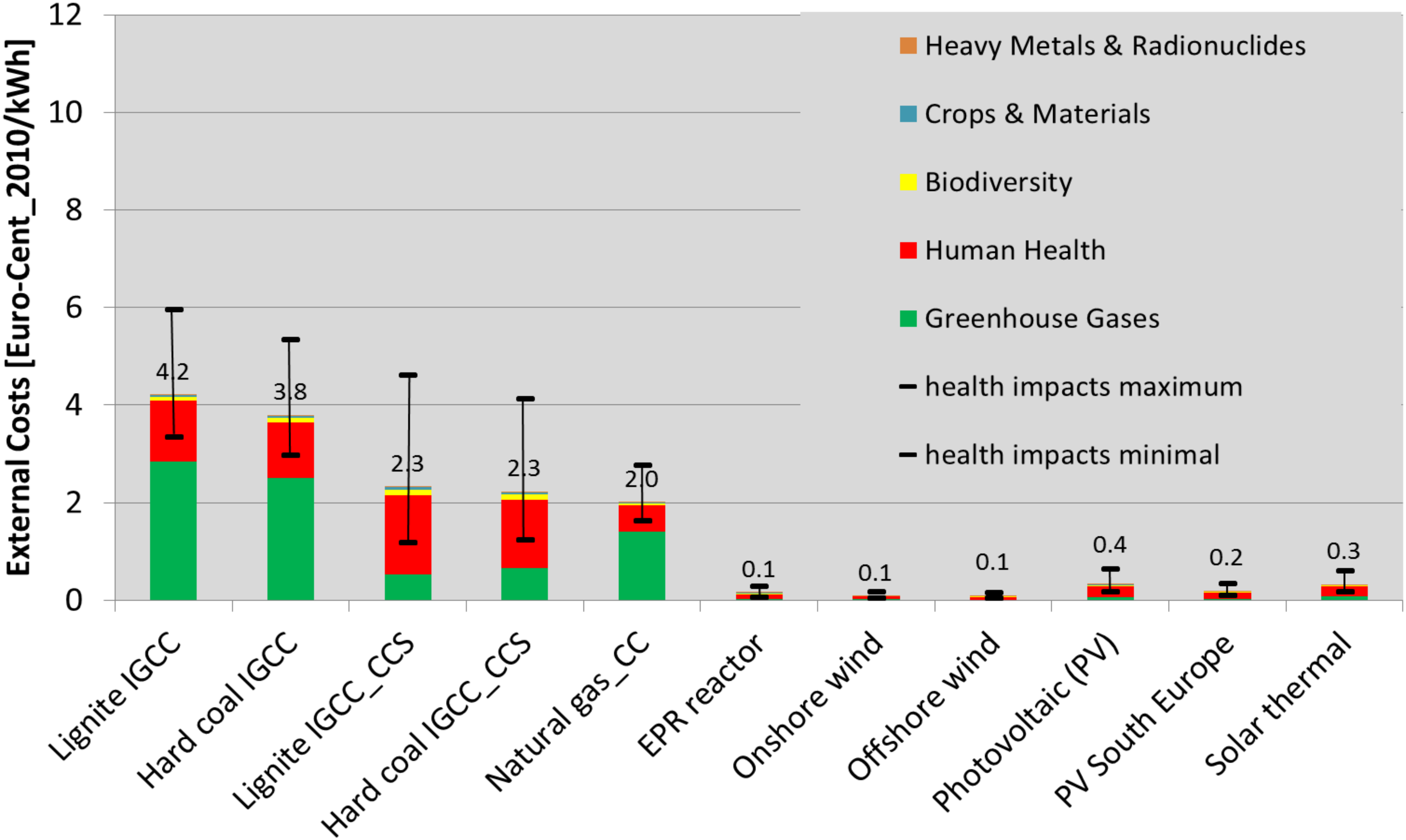
2) Greenhouse gas emissions per kWh as low as possible– for the whole life cycle

3) Generation costs per kWh as low as possible – including costs for back up and storage

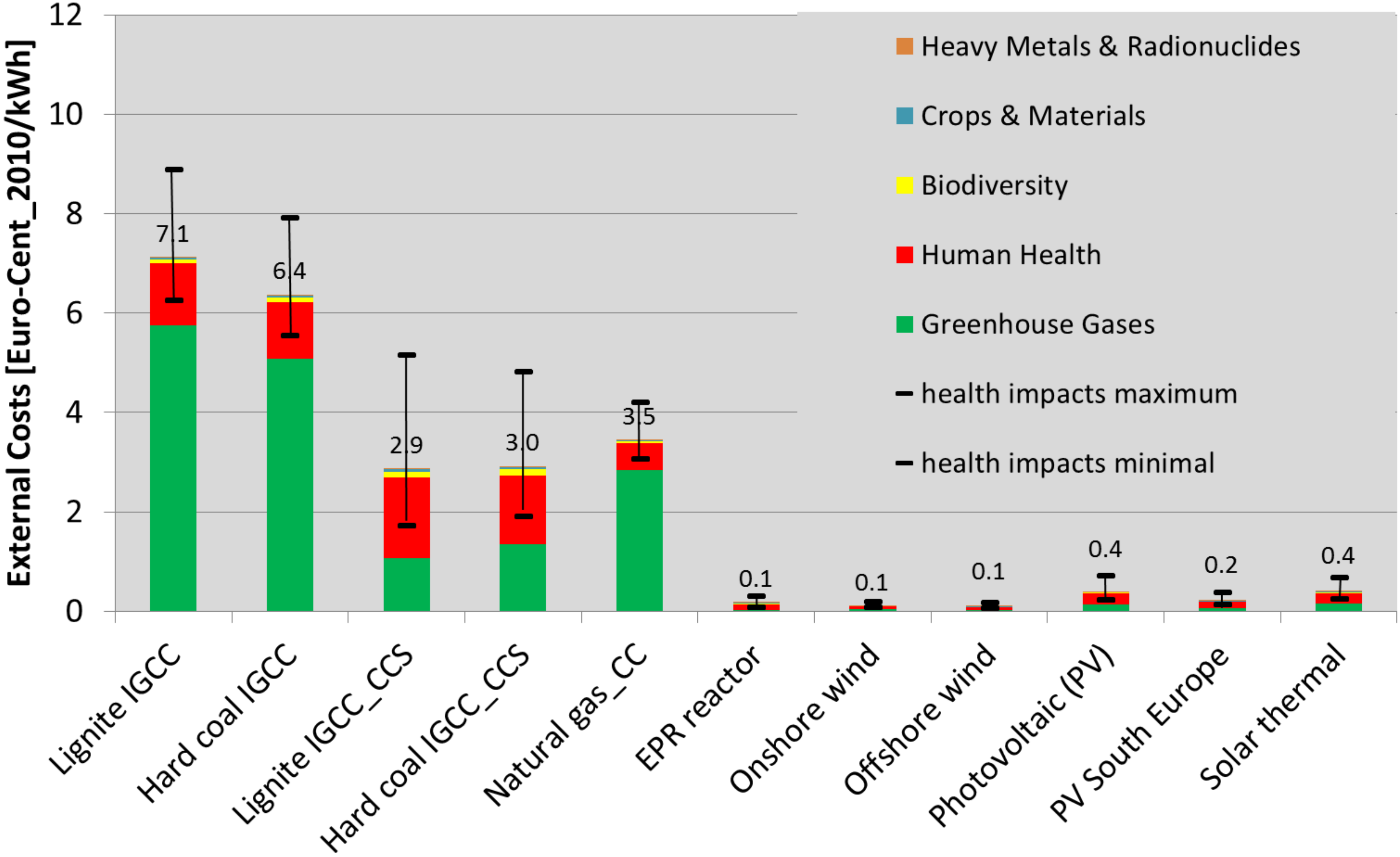
Risks to human health per kWh [DALYs per kWh]



External Costs, Kyoto+ Scenario



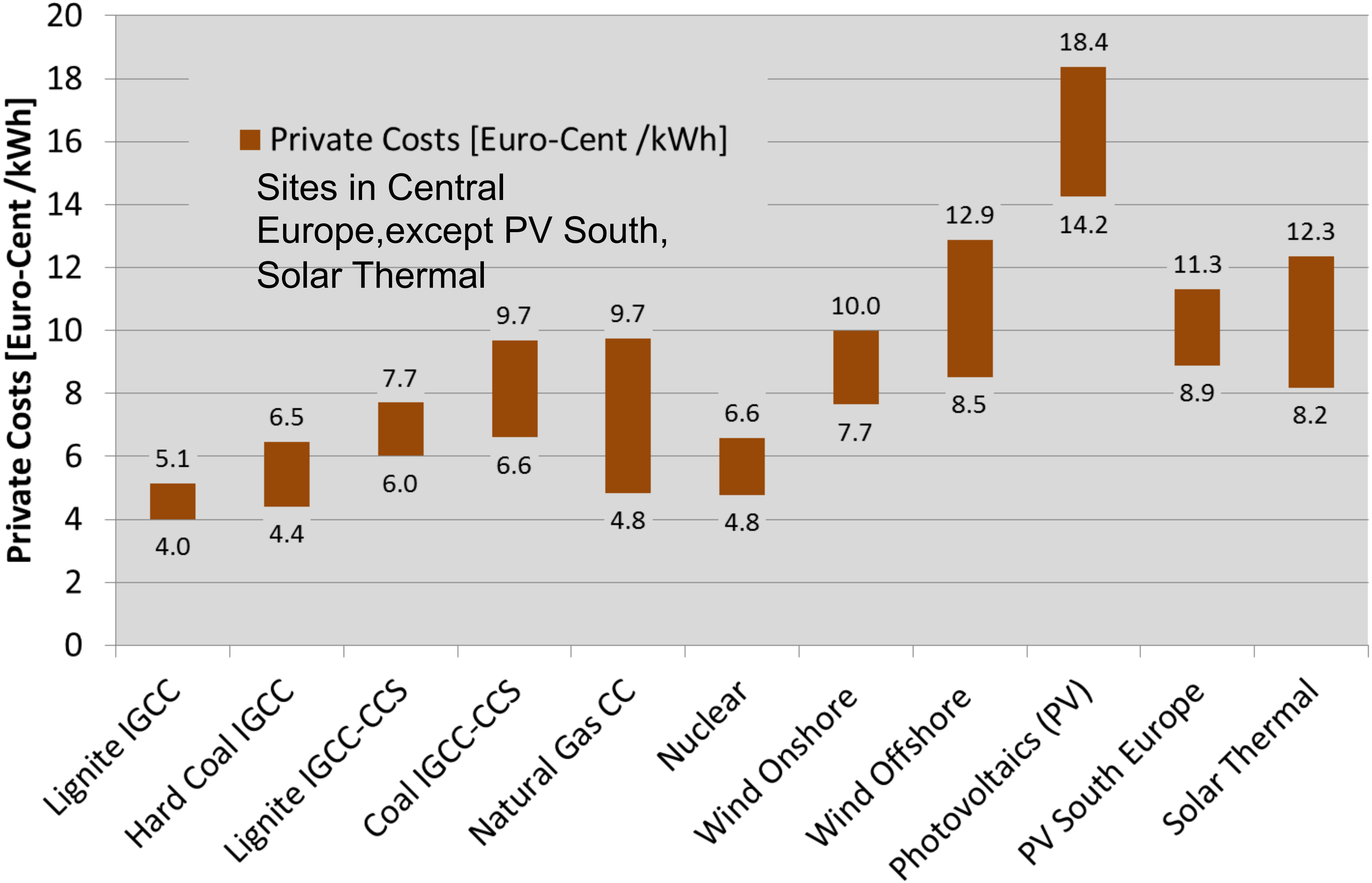
External Costs, 2° max Scenario



Private Costs

- private costs = all costs per kWh borne by the electricity producer, but without taxes (VAT) and subsidies
- includes investment, operation and maintenance, fuel, supplies and services, dismantling, waste disposal
- Includes back-up costs (provision of reserve capacity), estimated by comparing scenarios of energy systems with and without the assessed technology with the same supply security
- estimation/projection of costs for plants built 2030

Electricity Generation Costs first year of operation ca 2025

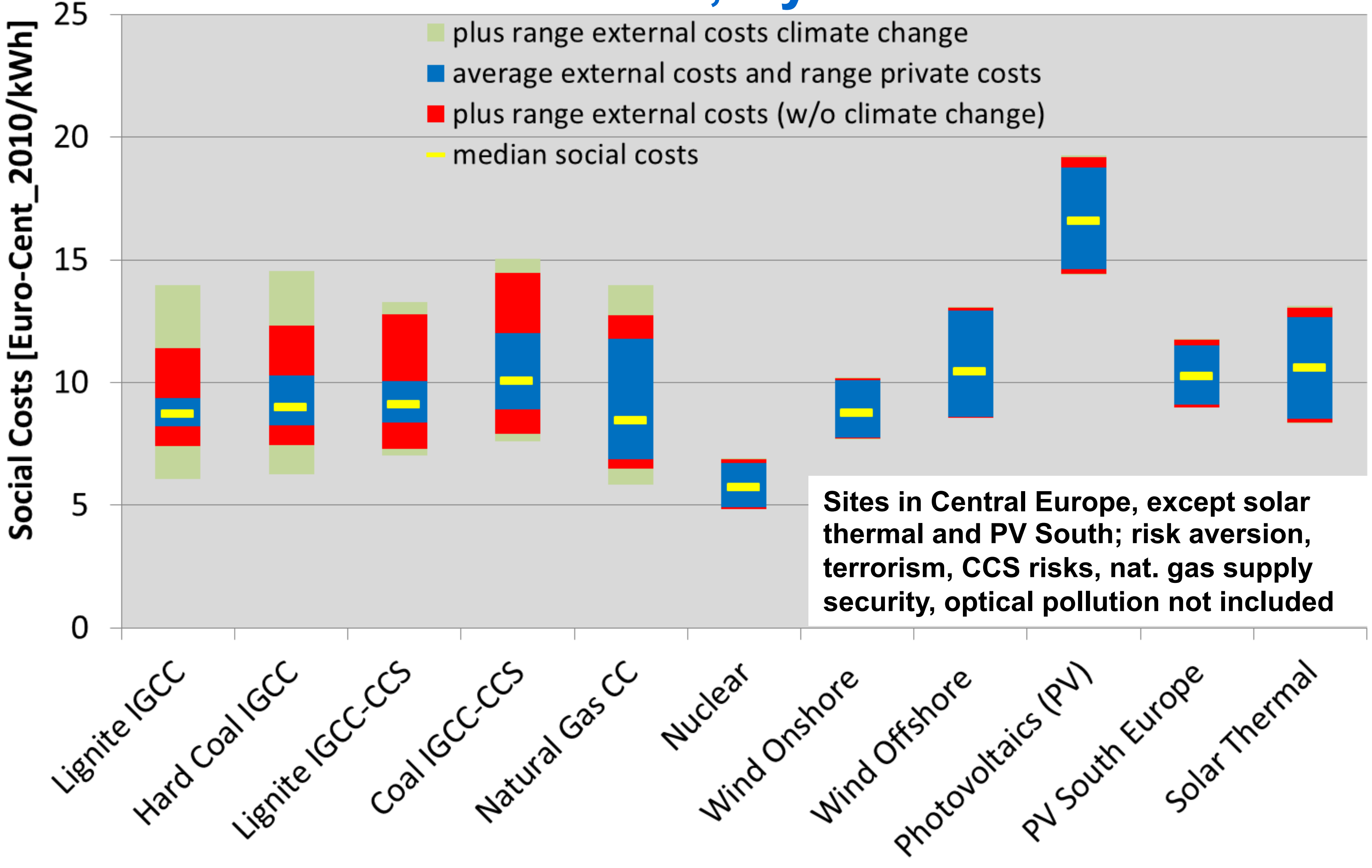


Which Effects Are Not Included ?

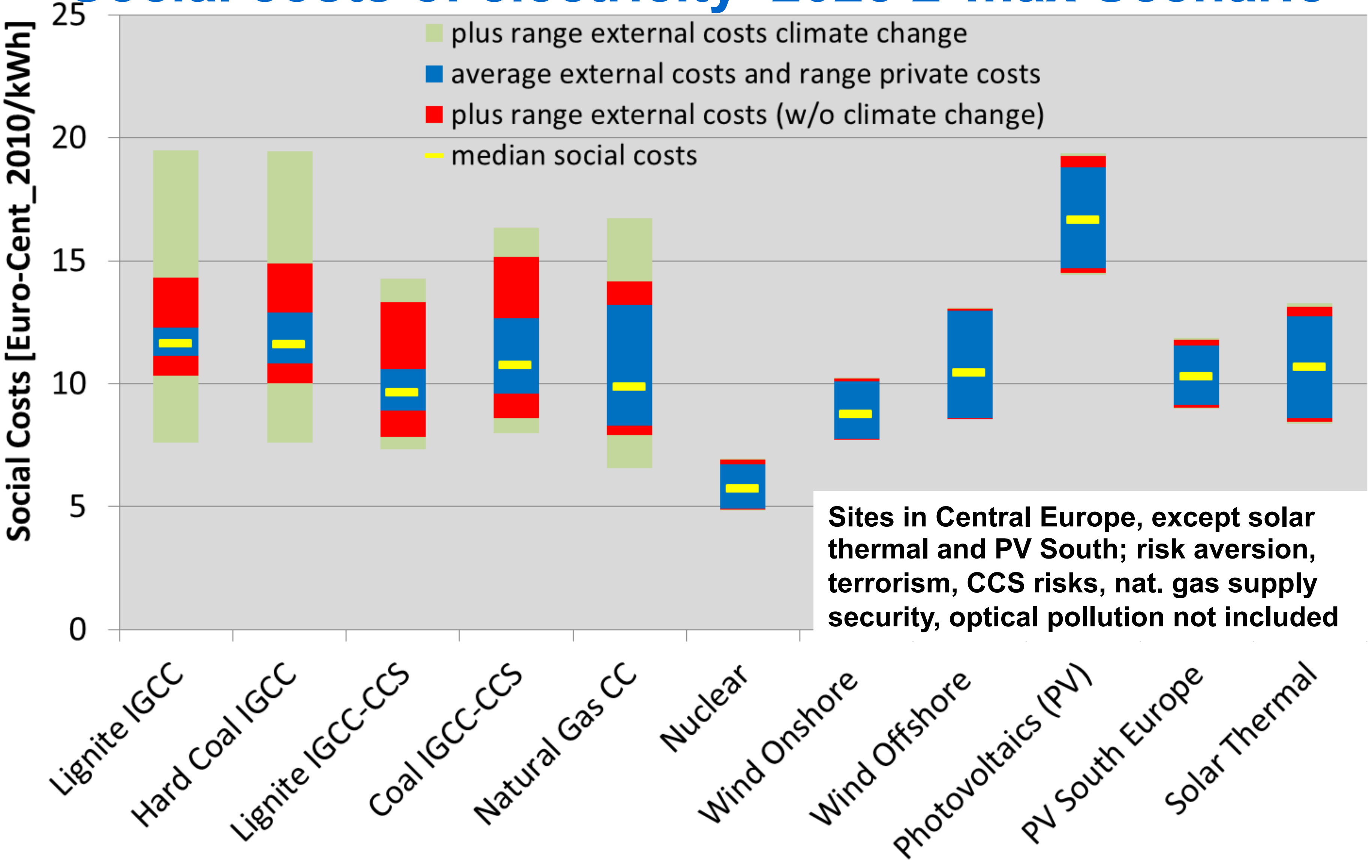
as agreed methods or reliable information are not available, though impacts on the result may be large :

- **Assessment of Damocles risks (low probability- high damage risks) – agreed method not available**
- **Risk caused by terrorism – information not publicly available**
- **Visual annoyance - large spatial and temporal variability, thus benefit transfer not possible**
- **Risk of carbon storage – no quantitative information yet available**
- **Security of supply for natural gas - methodology not available**

Social costs 2025, Kyoto+ Scenario



Social costs of electricity 2025 2°max Scenario



Conclusions I

- **Lowest social costs for an ambitious climate policy (2° aim):**

Nuclear, on shore wind, run-off water, lignite with CCS and natural gas.

However,

nuclear (EPR now, Generation IV after 2030) not accepted in some countries due to risk aversion; progress in transmutation of wastes helpful

wind and water have a limited potential, wind needs back-up capacity or storage;

supply security for natural gas is lower;

environmental and economic risks of carbon storage yet uncertain.

- **With a moderate climate strategy, lignite and hard coal without CCS will play a certain role.**

Conclusions II

- Biomass burnt in smaller plants has relatively high external and social costs (and is anyway needed for the production of liquid fuels). The use of residual biomass in large plants might be a favourable option.
- Electricity production with solar plants in North and Central Europe tend to have high quantifiable social costs at least until 2020, but become competitive in Southern Europe. PV plants in Mediterranean countries would be the next best option with high potential.

- **More information and tools:**
- **www.externe.info**
- **www.integrated–assessment.eu**
- **www.needs-project.org**