School of Industrial and Information Engineering

Course 096125 (095857)

Introduction to Green and Sustainable Chemistry

POLITECNICO DI MILANO

# Introduction to Pollution Prevention.

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https://iscamapweb.chem.polimi.it/citterio/education/course-topics/

# Wastes and Pollution.

Waste in EU is defined by Directive 2008/98/EC Article 3(1)* as "any substance or object which the holder discards or intends or is required to discard", potentially represents an enormous loss of resources in the form of both materials and energy; in addition, the management and disposal of waste can have serious environmental impacts. Landfills, for example, take up land space and may cause air, water and soil pollution, while incineration may result in emissions of dangerous air pollutants, unless properly regulated.

Waste can produce, if not adequately managed, pollution of:

- Air , Water, and Soil

A mandatory summary of Toxic Release Inventory of Industrial and Municipal Wastes is required and helpful to define issues and solutions related to this relevant area.

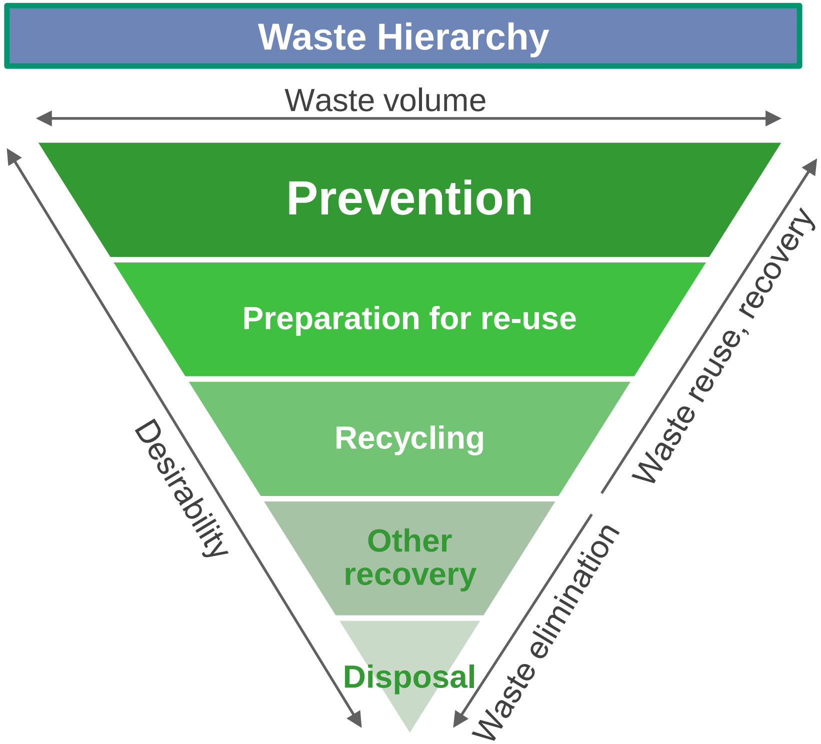
On 2 July 2014, the EU Commission adopted a legislative proposal and annex to review recycling and other waste-related targets in the EU Waste Framework Directive 2008/98/EC, the Landfill Directive 1999//31/EC and the Packaging and Packaging Waste Directive 94/62/EC.

http://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=JVV0T2HQSj6ykBx8hXhwRzKzpyFgpy49TLLnpCyQ8vZnvyckT2y1!-1416663925?uri=CELEX:02002R2150-20090420

# The Waste Hierarchy.

The EU Directive 2008/98/Ce of November 2008, has defined the «waste hierarchy» establishing in general a «priority order» of what represent the «best environmental option in the law and in the waste policy».

First in the hierarchy appears the prevention, then follows the preparing for re-use, subsequently the recycling (i.e. any recovery operation), then follows the **recovery** different from recycling (e.g. energy recovery), and, finally, the disposal consisting in any operation other than recovery (i.e. landfill and incineration without energy recovery).



# Industrial and Municipal Waste.

- Industrial waste is process waste associated with manufacturing.
  - This waste is classified as either municipal waste or hazardous waste, depending on the composition.
  - Regulatory programs for managing industrial waste vary widely among countries
  - The EU's approach to waste management is based on 3 principles: waste prevention, recycling/reuse, and improving final disposal and monitoring.

- Each year, industrial facilities in EU generate and manage 2 400 million ton of nonhazardous industrial waste in land application units whereas 101.3 million ton (4.0 % of the total) were classified as hazardous waste. (see table in next slide)

- Municipal waste in EU accounts for only about 10 % of total waste generated. However, it has a very high political profile because of its complex character, due to its composition, its distribution among many sources of waste, and its link to consumption patterns.

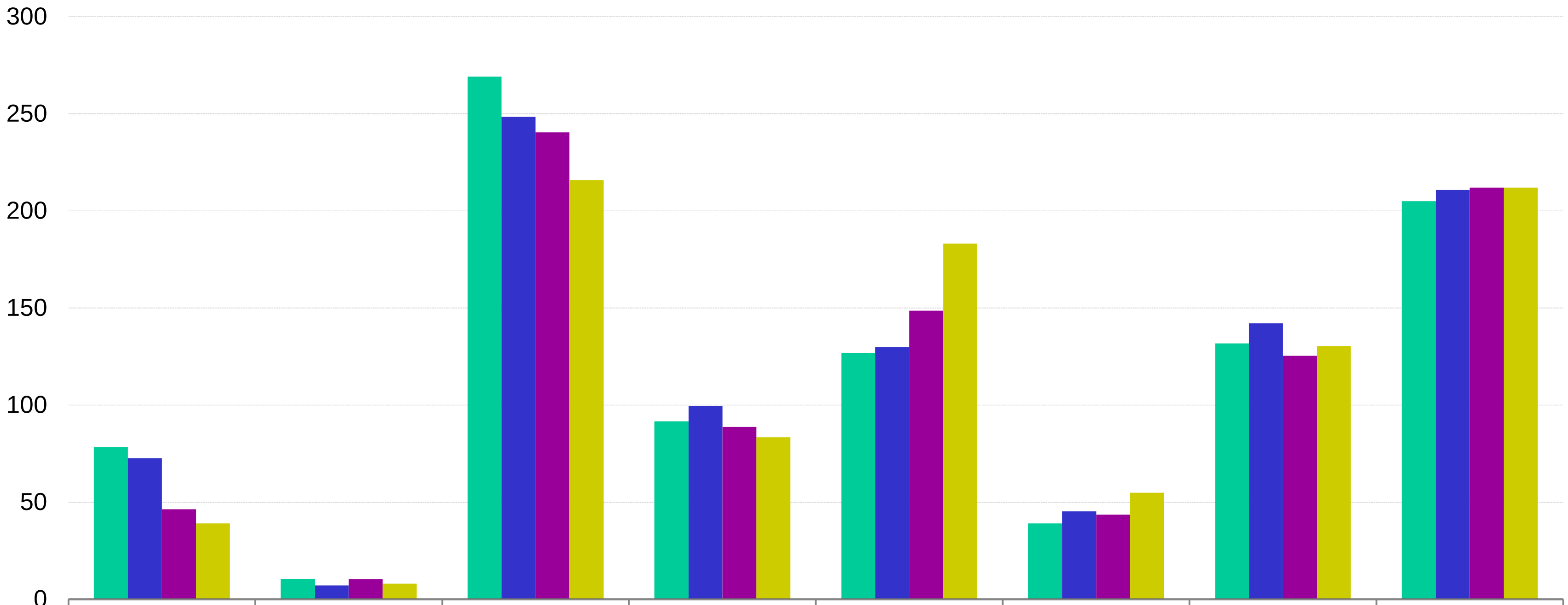
# EU Waste Generation, 2010 (1 000 tons).

| | Waste from economic activities and households | | Agriculture, forestry & fishing (Section A) | Mining & quarrying (Section B) | Manufacturing (Section C) | Energy (Section D) | Construction & demolition (Section F) | Other economic activities (Sections E and G to U) | Households |
|---|---|---|---|---|---|---|---|---|---|
| | Total | of which, hazardous | | | | | | | |
| EU-28 | 2 505 400 | 101 370 | 39 440 | 671 780 | 275 580 | 86 040 | 859 740 | 354 230 | 218 590 |
| EU-27 | 2 502 240 | 101 300 | 39 420 | 671 750 | 274 950 | 85 930 | 859 730 | 351 870 | 218 590 |
| Belgium | 62 537 | 4 479 | 231 | 1 701 | 14 543 | 1 210 | 18 165 | 22 008 | 4 679 |
| Bulgaria | 167 203 | 13 542 | 618 | 150 214 | 3 306 | 8 032 | 79 | 2 557 | 2 396 |
| Czech Republic | 23 758 | 1 363 | 114 | 115 | 4 202 | 1 540 | 9 354 | 5 099 | 3 334 |
| Denmark | 20 965 | 1 784 | 201 | 41 | 1 919 | 517 | 3 176 | 12 676 | 2 436 |
| Germany | 363 545 | 19 931 | 256 | 24 493 | 48 981 | 9 087 | 190 990 | 53 426 | 36 312 |
| Estonia | 19 000 | 8 962 | 110 | 6 453 | 3 716 | 6 534 | 436 | 1 320 | 430 |
| Ireland | 19 808 | 1 972 | 101 | 2 196 | 3 259 | 334 | 1 610 | 10 578 | 1 730 |
| Greece | 70 433 | 292 | 5 | 44 793 | 4 941 | 11 029 | 2 086 | 2 381 | 5 198 |
| Spain | 137 519 | 2 991 | 5 817 | 31 732 | 16 480 | 2 339 | 37 947 | 20 006 | 23 198 |
| France | 355 081 | 11 538 | 1 682 | 1 053 | 20 382 | 993 | 260 226 | 41 439 | 29 307 |
| Croatia | 3 158 | 73 | 14 | 29 | 634 | 108 | 8 | 2 365 | 0 |
| Italy | 158 628 | 8 543 | 311 | 706 | 35 928 | 2 660 | 59 340 | 27 204 | 32 479 |
| Cyprus | 2 373 | 37 | 129 | 382 | 132 | 3 | 1 068 | 198 | 461 |
| Latvia | 1 498 | 68 | 68 | 1 | 375 | 25 | 22 | 314 | 694 |
| Lithuania | 5 583 | 110 | 456 | 7 | 2 653 | 68 | 357 | 782 | 1 261 |
| Luxembourg | 10 440 | 379 | 3 | 18 | 498 | 2 | 8 731 | 803 | 385 |
| Hungary | 15 735 | 541 | 488 | 87 | 3 134 | 2 718 | 3 072 | 3 372 | 2 865 |
| Malta | 1 288 | 17 | 3 | 0 | 9 | 1 | 989 | 149 | 138 |
| Netherlands | 119 255 | 4 421 | 3 948 | 184 | 14 094 | 1 156 | 78 064 | 12 737 | 9 072 |
| Austria | 34 883 | 1 473 | 550 | 269 | 2 958 | 453 | 9 010 | 17 019 | 4 623 |
| Poland | 159 458 | 1 492 | 1 543 | 61 547 | 28 618 | 20 291 | 20 818 | 17 751 | 8 890 |
| Portugal | 38 347 | 1 625 | 193 | 1 206 | 9 766 | 456 | 11 071 | 10 193 | 5 464 |
| Romania | 219 310 | 666 | 18 353 | 177 404 | 7 862 | 5 888 | 238 | 3 438 | 6 127 |
| Slovenia | 5 159 | 120 | 141 | 12 | 1 517 | 558 | 1 509 | 694 | 728 |
| Slovakia | 9 384 | 415 | 526 | 166 | 2 669 | 878 | 1 786 | 1 641 | 1 719 |
| Finland | 104 337 | 2 559 | 2 772 | 54 851 | 15 211 | 1 445 | 24 645 | 3 732 | 1 681 |
| Sweden | 117 645 | 2 528 | 309 | 89 026 | 7 823 | 1 479 | 9 381 | 5 589 | 4 038 |
| United Kingdom | 259 068 | 9 447 | 494 | 23 092 | 19 970 | 6 239 | 105 560 | 74 764 | 28 949 |
| Liechtenstein | 312 | 8 | 0 | 12 | 32 | 0 | 0 | 268 | 0 |
| Norway | 9 433 | 1 763 | 195 | 366 | 2 687 | 28 | 1 543 | 2 385 | 2 229 |
| FYR of Macedonia | 2 328 | 150 | 0 | 855 | 1 017 | 4 | 0 | 0 | 451 |
| Serbia | 33 623 | 11 145 | 0 | 26 458 | 1 146 | 6 019 | 0 | 0 | 0 |
| Turkey | 783 423 | 0 | 0 | 723 791 | 11 406 | 18 578 | 0 | 60 | 29 587 |

*Source:* Eurostat (online data code: env_wasgen)

Source: Eurostat 2014 (env_wasgen)

# Waste generation, excluding major mineral wastes, EU-27, 2004–10.




| | Agriculture | Mining & quarrying | Manufacturing | Energy | Waste/ water | Construction | Other sectors | Households |
|---|---|---|---|---|---|---|---|---|
| 2004 | 78,3 | 10,4 | 269,2 | 91,7 | 126,7 | 39,0 | 131,7 | 205,0 |
| 2006 | 72,7 | 7,1 | 248,4 | 99,5 | 129,8 | 45,2 | 142,0 | 210,9 |
| 2008 | 46,3 | 10,3 | 240,5 | 88,7 | 148,7 | 43,6 | 125,4 | 212,0 |
| 2010 (1) | 39,1 | 8,0 | 215,8 | 83,4 | 183,1 | 54,8 | 130,4 | 212,1 |

2004 2006 2008 2010 (1)

(1) Source: Eurostat (online data code: env_wasgen)

# Waste Treatment in EU, 2010.

| | Total | Energy recovery | Incineration without energy recovery | Recovery other than energy recovery | Disposal other than incineration |
|---|---|---|---|---|---|
| EU-28 | 2.338.730 | 89.650 | 42.280 | 1.145.110 | 1.061.680 |
| EU-27 | 2.336.140 | 89.530 | 42.260 | 1.144.710 | 1.059.640 |
| Belgium | 30.358 | 4.797 | 1.975 | 20.414 | 3.172 |
| Bulgaria | 159.852 | 144 | 2 | 1.819 | 157.886 |
| Czech Republic | 18.247 | 767 | 55 | 13.220 | 4.204 |
| Denmark | 11.343 | 2.749 | 0 | 6.767 | 1.828 |
| Germany | 349.564 | 28.423 | 12.646 | 241.563 | 66.932 |
| Estonia | 17.953 | 336 | 0 | 5.956 | 11.661 |
| Ireland | 9.421 | 168 | 43 | 3.356 | 5.854 |
| Greece | 70.390 | 126 | 21 | 11.722 | 58.520 |
| Spain | 132.688 | 2.523 | 412 | 80.289 | 49.464 |
| France | 336.021 | 14.241 | 7.809 | 200.677 | 113.294 |
| Croatia | 2.585 | 110 | 24 | 403 | 2.048 |
| Italy | 127.156 | 2.373 | 6.092 | 93.037 | 25.655 |
| Cyprus | 2.371 | 7 | 7 | 1.381 | 976 |
| Latvia | 1.006 | 63 | 0 | 312 | 630 |
| Lithuania | 4.546 | 111 | 2 | 1.062 | 3.371 |
| Luxembourg | 12.546 | 32 | 124 | 6.286 | 6.105 |
| Hungary | 13.424 | 859 | 82 | 5.125 | 7.357 |
| Malta | 1.202 | 0 | 7 | 129 | 1.065 |
| Netherlands | 113.640 | 5.835 | 3.552 | 57.563 | 46.691 |
| Austria | 29.751 | 1.364 | 1.649 | 14.982 | 11.756 |
| Poland | 146.580 | 3.804 | 369 | 109.695 | 32.712 |
| Portugal | 20.115 | 2.343 | 419 | 7.583 | 9.771 |
| Romania | 212.858 | 1.507 | 75 | 16.561 | 194.716 |
| Slovenia | 5.638 | 282 | 35 | 3.885 | 1.436 |
| Slovakia | 7.692 | 255 | 66 | 3.559 | 3.812 |
| Finland | 105.630 | 9.847 | 389 | 31.999 | 63.395 |
| Sweden | 110.476 | 6.261 | 87 | 16.587 | 87.541 |
| United Kingdom | 285.674 | 316 | 6.343 | 189.183 | 89.832 |
| Norway | 6.292 | 1.280 | 276 | 2.566 | 2.170 |
| FYR of Macedonia | 2.106 | 0 | 1 | 331 | 1.775 |
| Serbia | 33.059 | 26 | 1 | 565 | 32.466 |
| Turkey | 777.471 | 126 | 27 | 197.216 | 580.102 |

Source: Eurostat (online data code:,

# Air Pollution.

Pollution in air is due to the release of volatile compounds from different sources and has several relevant effects on environment and humans:

- greenhouse effect
- ozone depletion
- acidification
- smog formation
- eutrophication
- human health
- ecosystem health

**TYPES OF AIR POLLUTION**

1. **Primary pollutants**: emitted directly into the air
2. **Secondary pollutants**: existing pollutants react with air to form new compounds

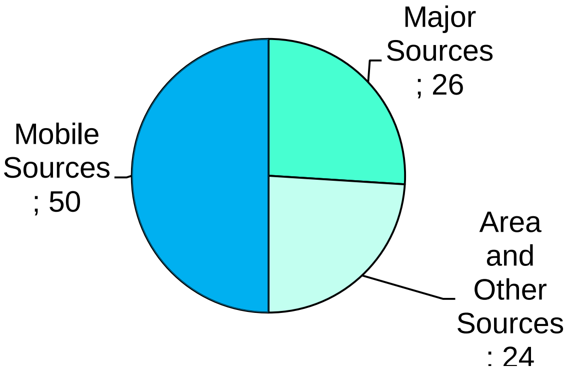
# Sources of Air Toxics.

*Routine Emissions from Stationary Sources*

*Each year, millions of tons of toxic pollutants are released into the air from both natural and manmade sources*

*Mobile Sources*

*Accidental release*




*Fires*

# Emission Chemical Species.

- **Main pollutants (gaseous)**
  - CO
  - $NH_3$
  - NM-VOC (nonmetallic volatile organic compounds)
  - $NO_x$
  - $SO_x$
- **Heavy Metals**
  - As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- **POP (persistent organic pollutants)**
  - PAH, benzo(a)pyrene, benzo(b)pyrene, DDT, …
- **PM (particulate matter)**
  - PM10, PM2.5, TSP

# Criteria Air Pollutants.

EPA uses six "criteria pollutants" as indicators of air quality:

- Nitrogen Dioxide: **$NO_2$**
  - brownish gas irritates the respiratory system originates from combustion ($N_2$ in air is oxidized); $NO_x$ sum of NO, $NO_2$, other oxides of N
- Ozone: ground level **$O_3$**
  - primary constituent of urban smog by reaction of VOC + $NO_x$ with heat +sun light
- Carbon monoxide: **CO**
  - product of incomplete combustion, reduces bloods ability to carry $O_2$
- Lead: **Pb**
  - toxic to liver, kidney, blood forming organs (tetraethyl lead in gasoline has been phased out but leaded Particulate Matter (PM10-2.5) again present
- Sulfur Dioxide: **$SO_2$**
  - formed when fuel (coal, oil) containing S is burned and metal smelting, is the precursor to acid rain along with $NO_x$ (via $H_2SO_4$ and $HNO_3$)

# Emissions Classification
## http://www.eea.europa.eu/publications/EMEPCORINAIR4.

| S. sectors | Description |
|---|---|
| 1 | Combustion Energy sector, utilities, refineries |
| 2 | Combustion small sources (residential) |
| 3 | Combustion in industry |
| 4 | Process emissions (industry) |
| 5 | Mining and extraction of fossil fuels |
| 6 | Use of solvents, use of products |
| 7 | Road transport |
| 71 | Road transport gasoline |
| 72 | Road transport diesel |
| 73 | Road transport diesel |
| 74[1)] | Road transport diesel - exhaust (volatilization) |
| 75[2)] | Road transport non-exhaust (tire, break and road wear |
| 8 | Non-road transport |
| 9 | Waste processing |
| 10 | Agriculture |

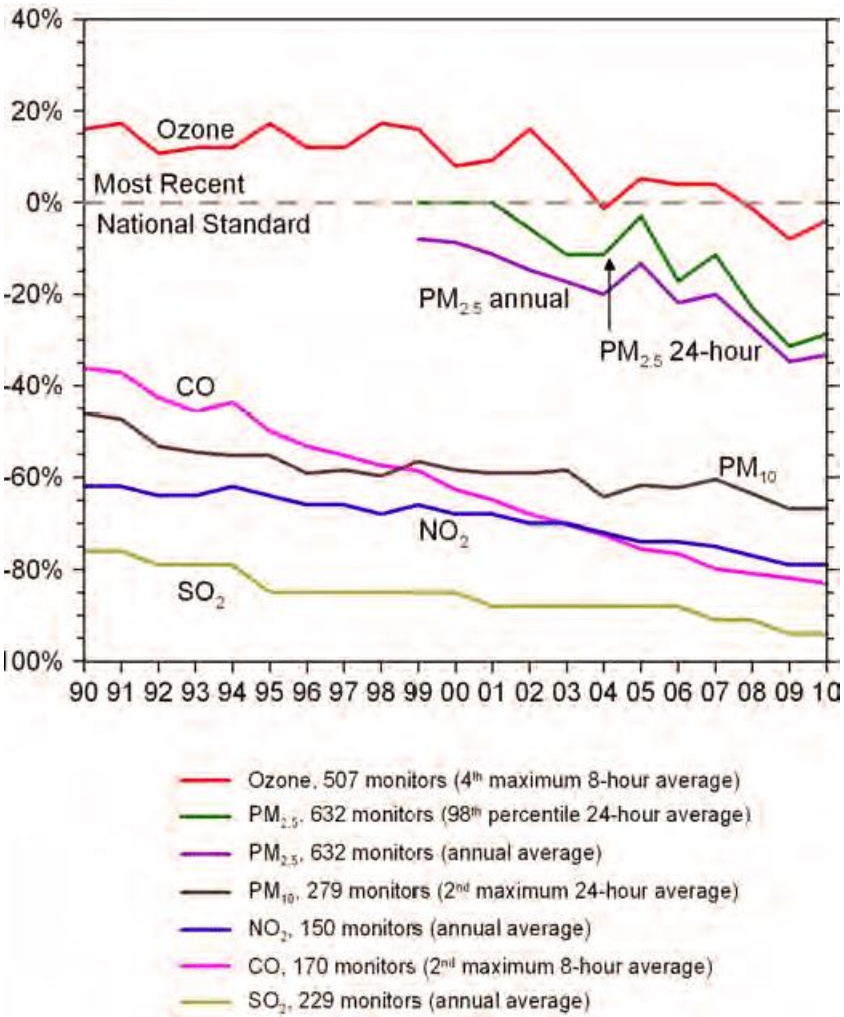
[1)] Relevant for NMVOC emissions
[2)] Relevant for PM emissions

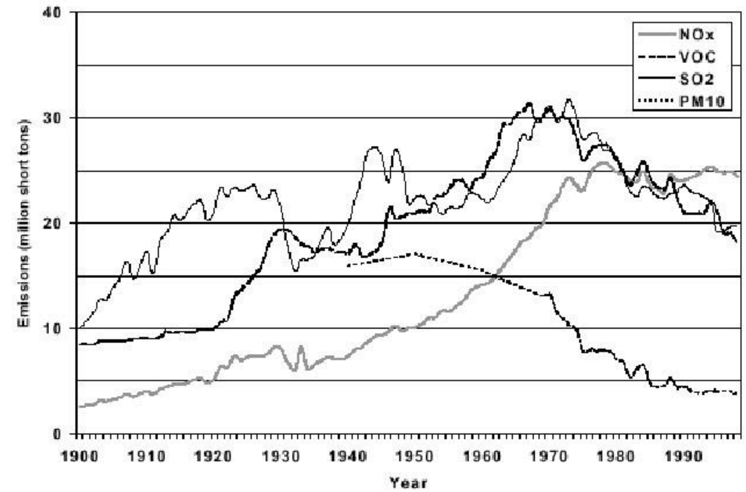
"SNAP" Selected Nomenclature for sources of Air Pollution

| | |
|---|---|
| 0-50 | Good |
| 51-100 | Moderate |
| 101-150 | Unhealthy for sensitive groups |
| 151-200 | Unhealthy |
| 201-300 | Very Unhealthy |
| 300-500 | Hazardous |

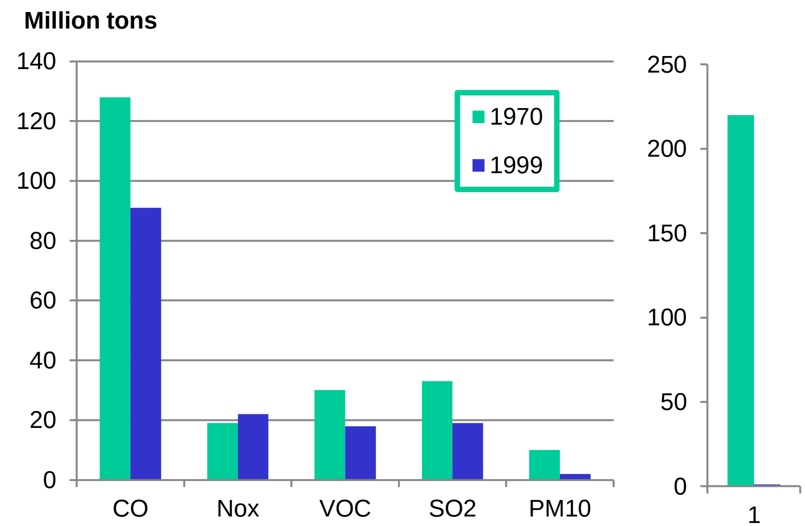
http://www.airnow.gov

# Trend in Emissions of $NO_x$, VOC, $SO_2$, and $PM_{10}$ (1940-2010 US).



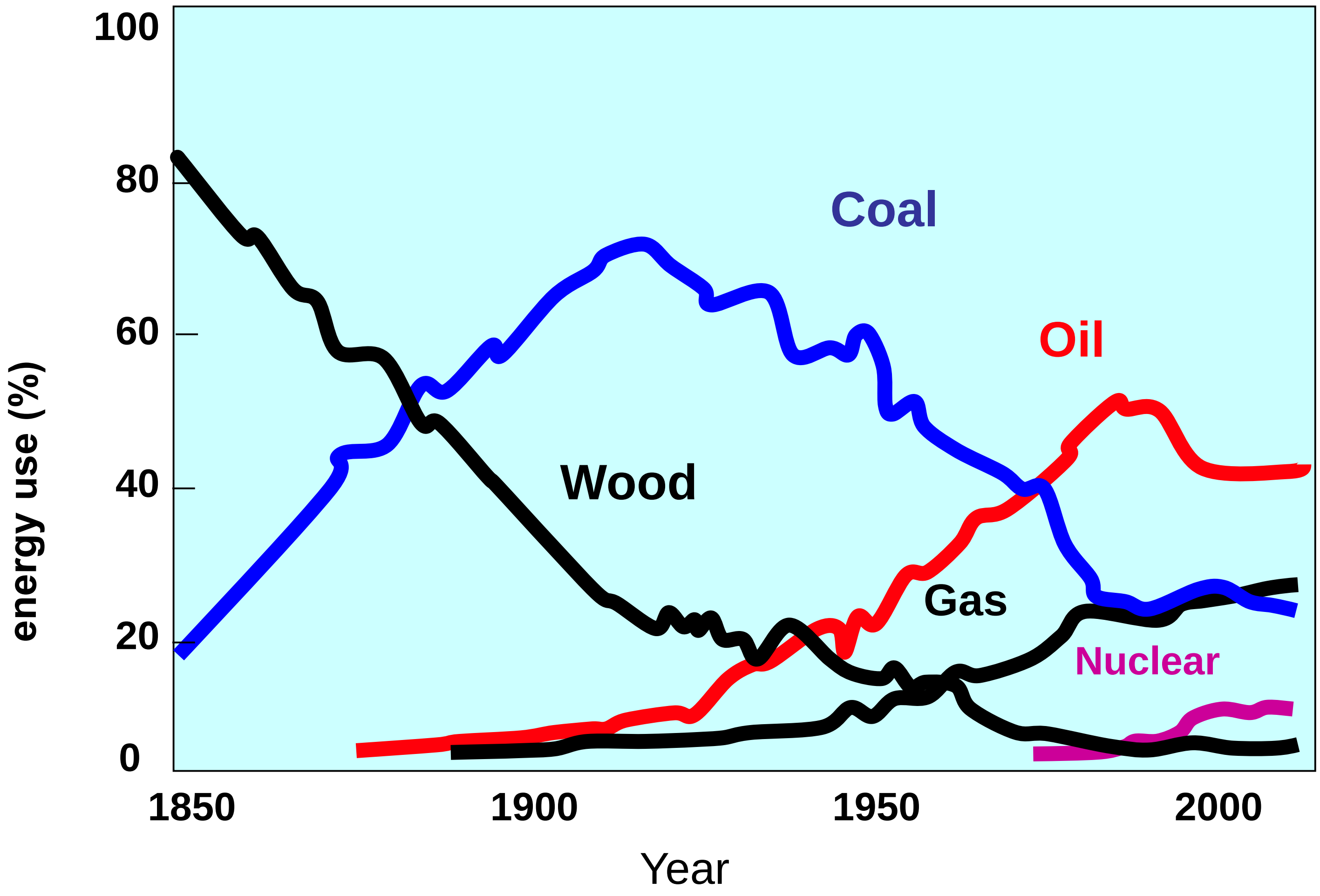




**Comparison of 1970 and 1999 Emissions**



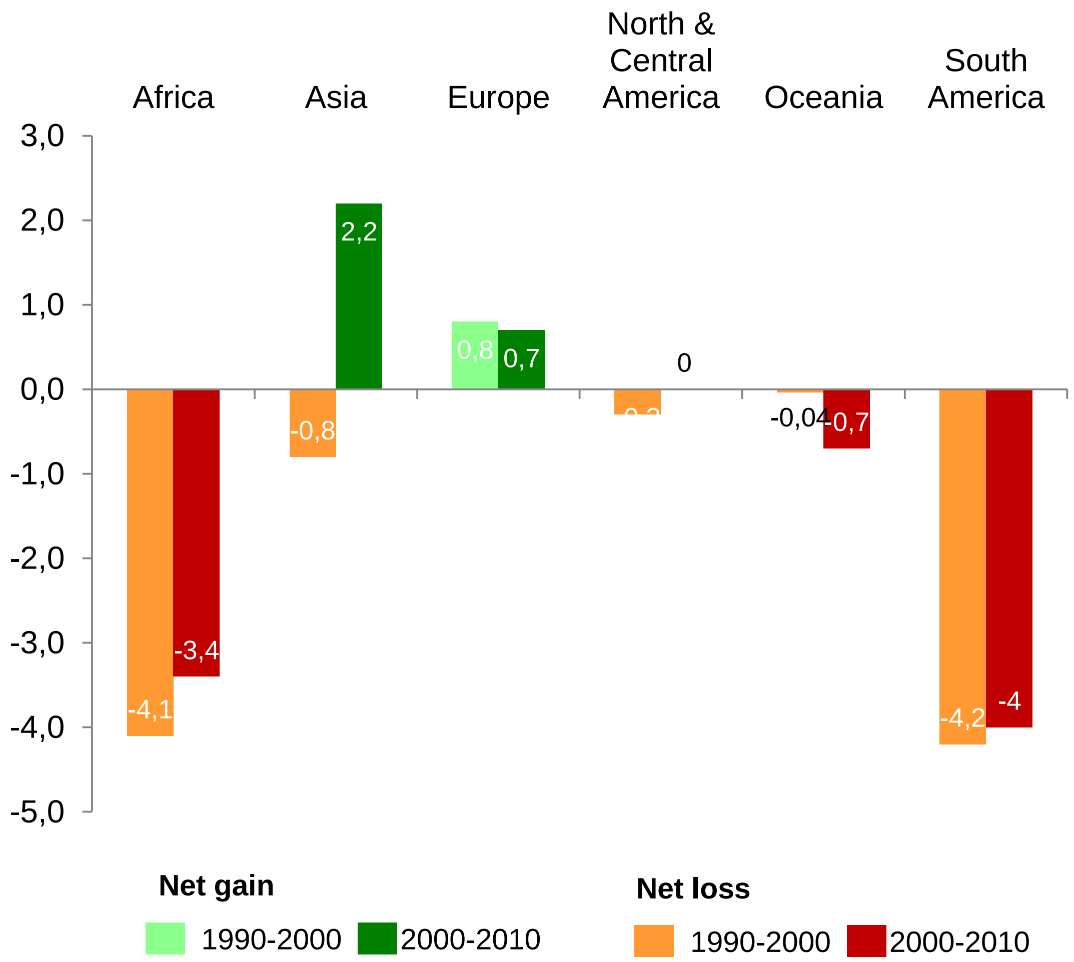

Source: Latest Findings on National Air Quality: 1999 Status and Trends EPA EPA-454/F-00-002

# Main Source of Air Pollution: Combustion as Energy Source Used by Humans – Historical Trend.



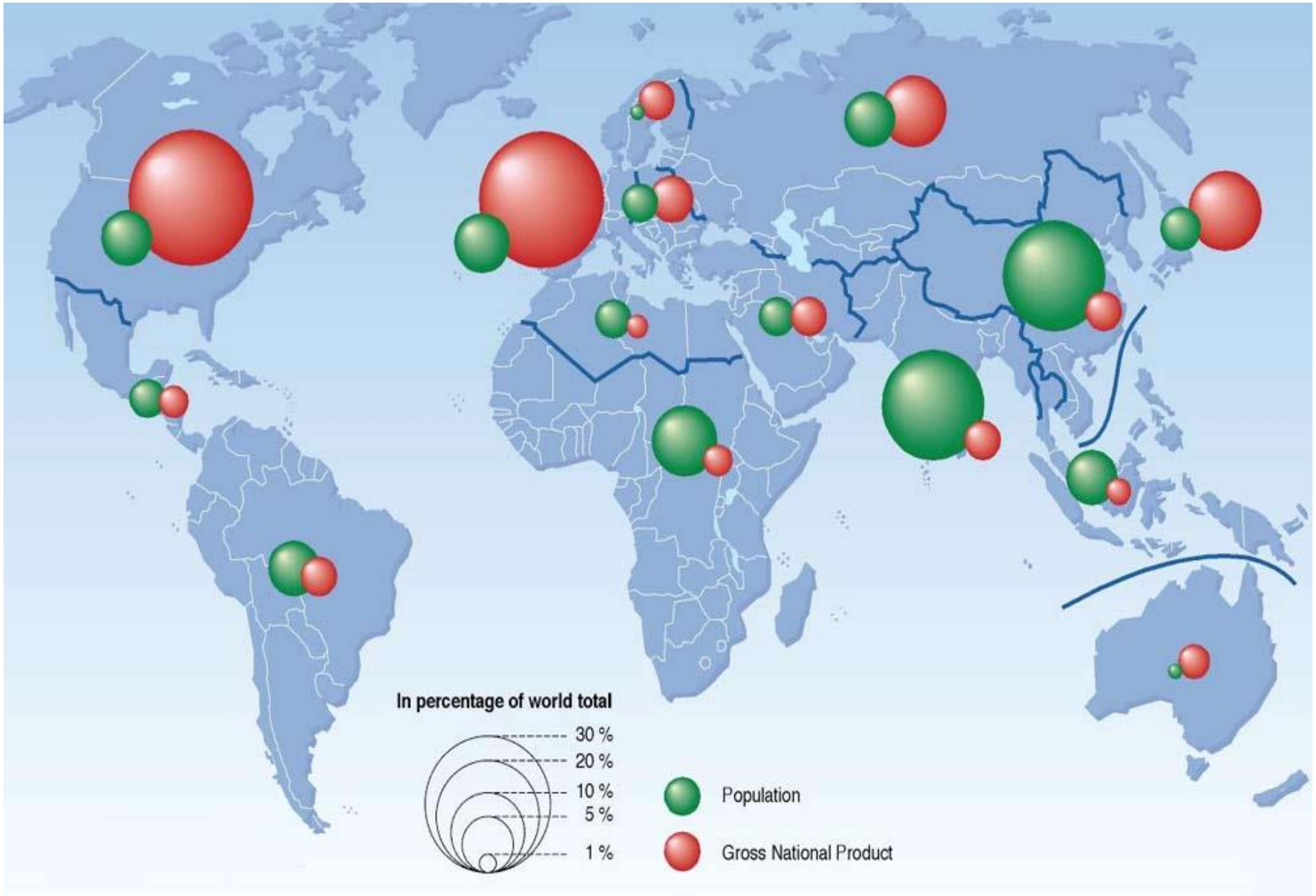
# Forested Area Trends.

Net change in forested area between 1990 and 2000 and between 2000 and 2010 (Million hectares per year)

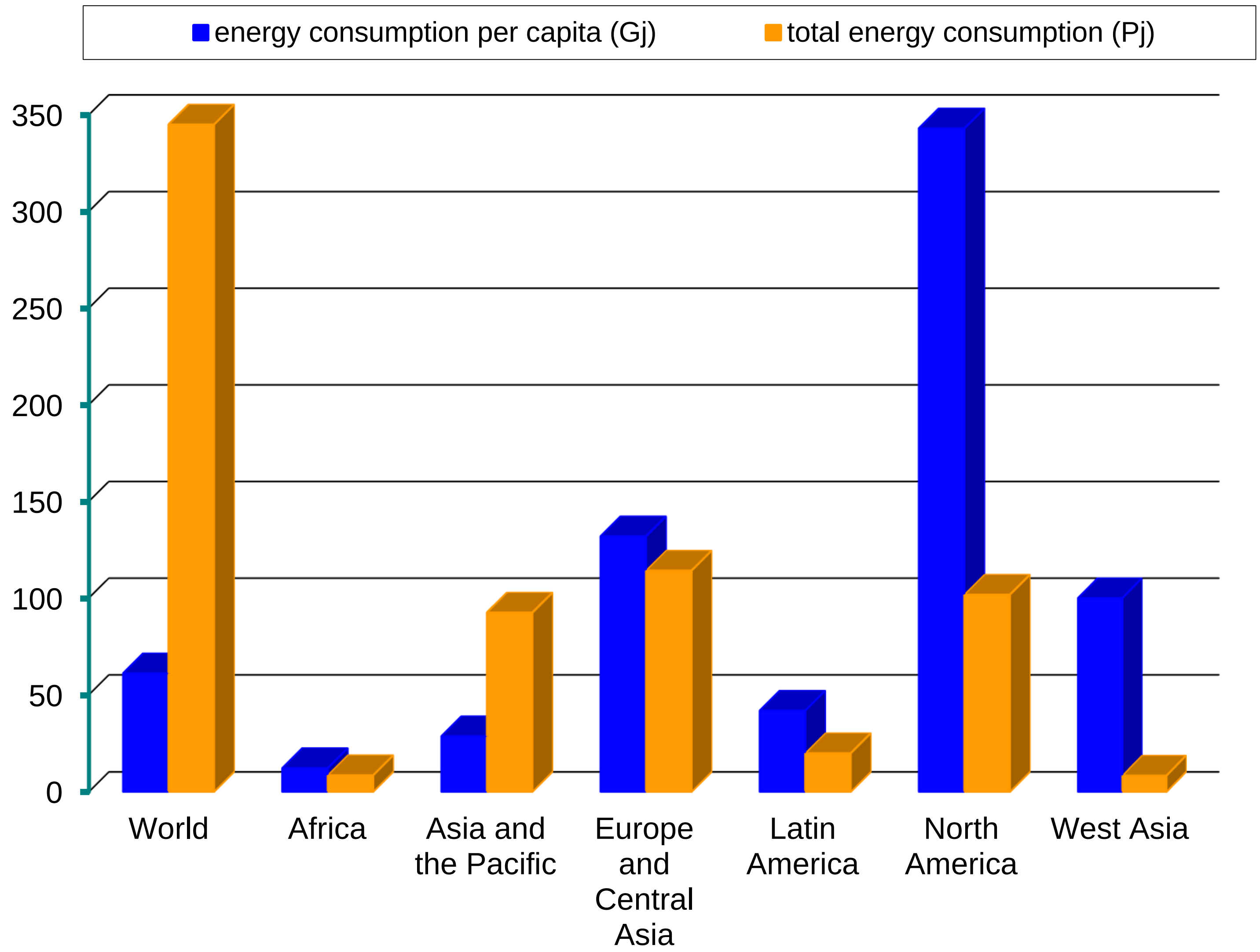



Fonte: ONU report 2011

# Population and GNP Distribution in the World (2011).

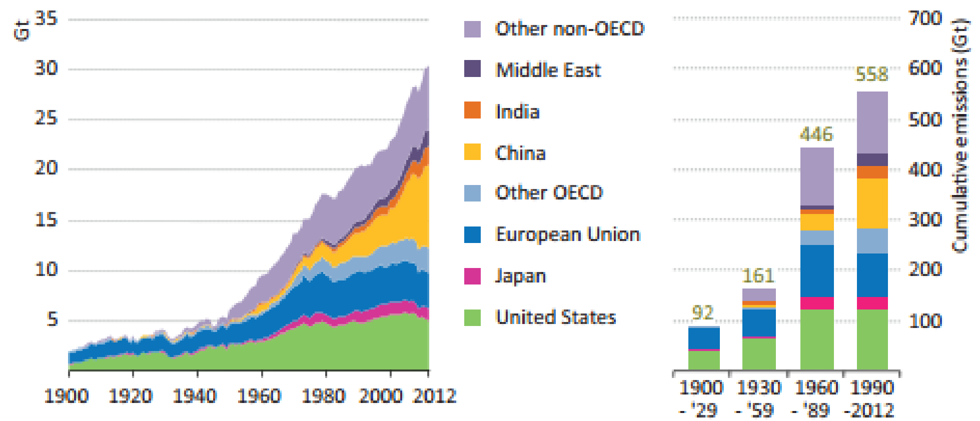


# Per Capita Energy Consumption by Region (2010).



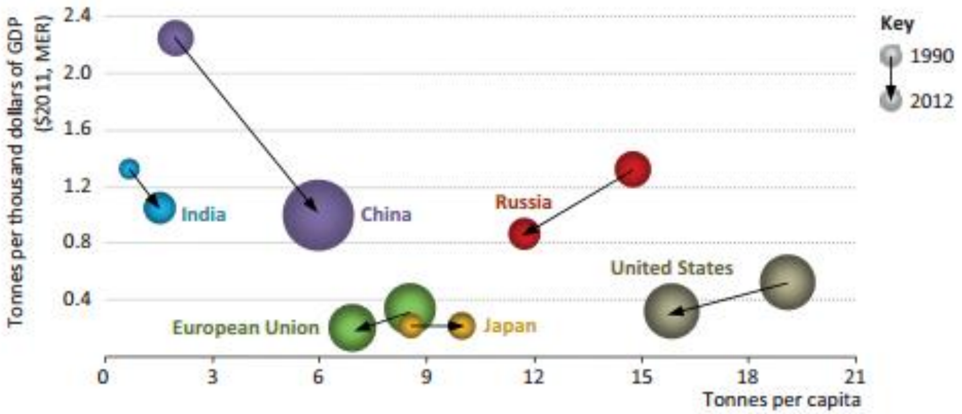
# Per Capita $CO_2$ Emissions by Country (2012).

**Figure 1.11** ▷ Energy-related $CO_2$ emissions by country




Sources: IEA databases and analysis; Boden *et al.*, (2013).

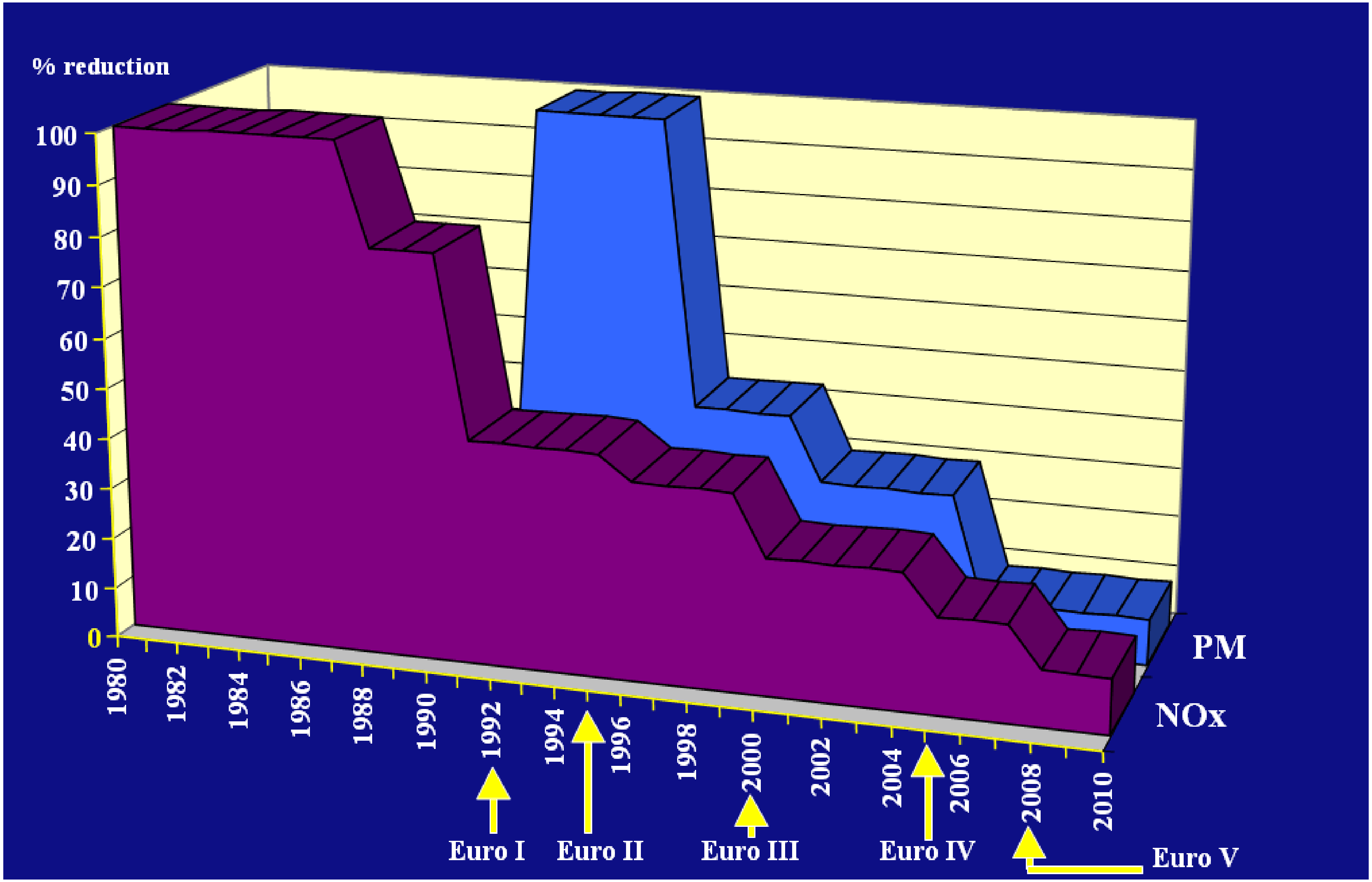
**Figure 1.14** ▷ Energy-related $CO_2$ emissions per capita and $CO_2$ intensity in selected regions



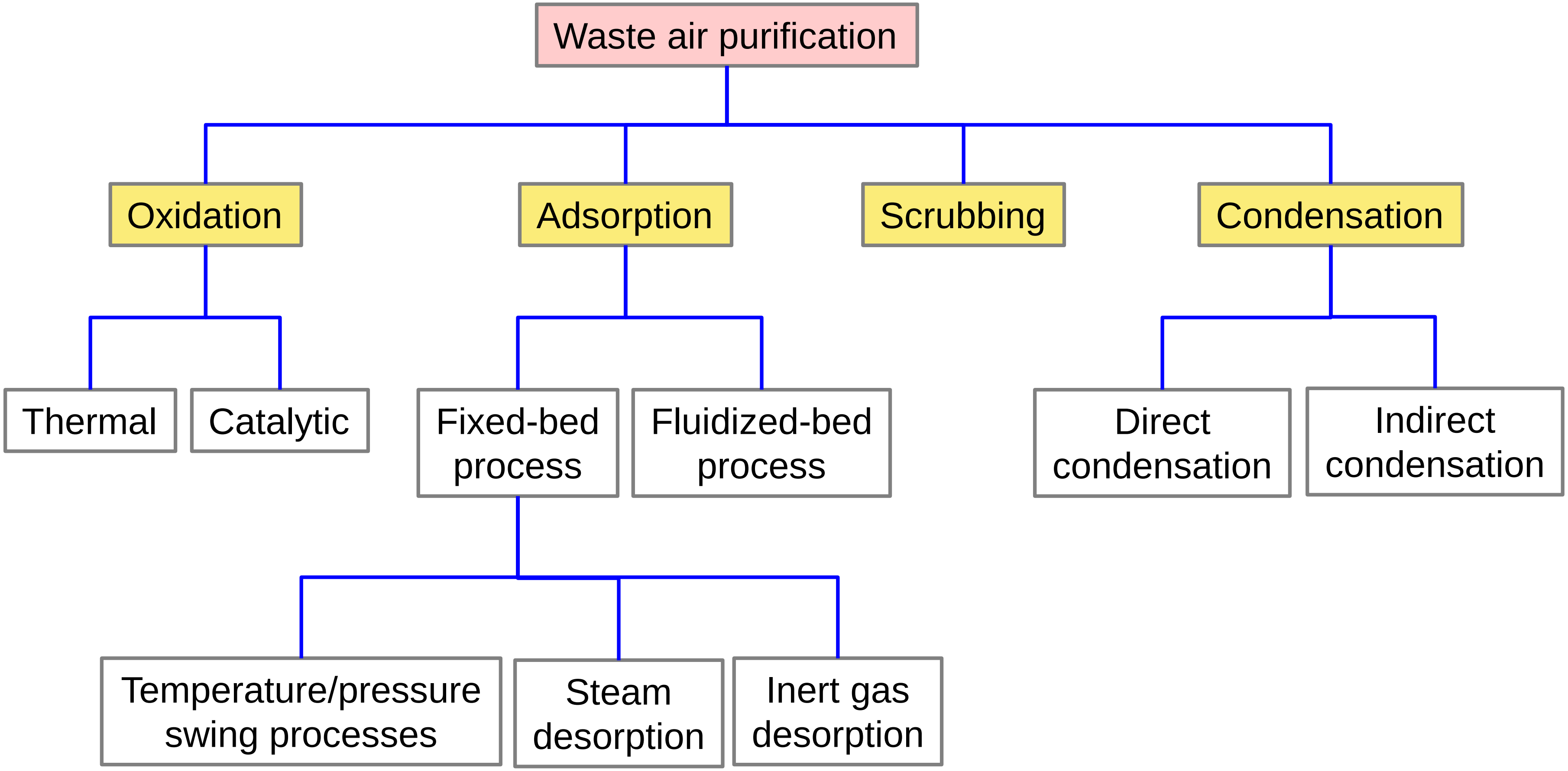

Notes: Bubble area indicates total annual energy-related $CO_2$ emissions in that region. MER = market exchange rate.

www.worldenergyoutlook.org/energyclimatemap

# Trends in Heavy- duty Vehicles Emission Reduction in EU from 1980 to 2010.



# Possible Techniques for Cleaning up Air Contaminated with VOC.



# Water Pollution.

Almost all human activities can and do impact adversely upon the water.

Water quality is influenced by both direct point source and diffuse pollution which come from urban and rural populations, industrial emissions and farming. Diffuse pollution from farming and point source pollution from sewage treatment and industrial discharge are the main sources. For agriculture, the key pollutants include nutrients, pesticides, sediment and fecal microbes.

Oxygen consuming substances and hazardous chemicals are more associated with point source discharges.

Based on current water quality standards, over 70% of rivers and estuaries and 60% of lakes now meet legislatively mandated goals.

- Some of the risks include:
  - pollutant runoff from agricultural lands
  - storm water flows from cities
  - Improperly managed landfill

# Point and Nonpoint Sources of Pollution.

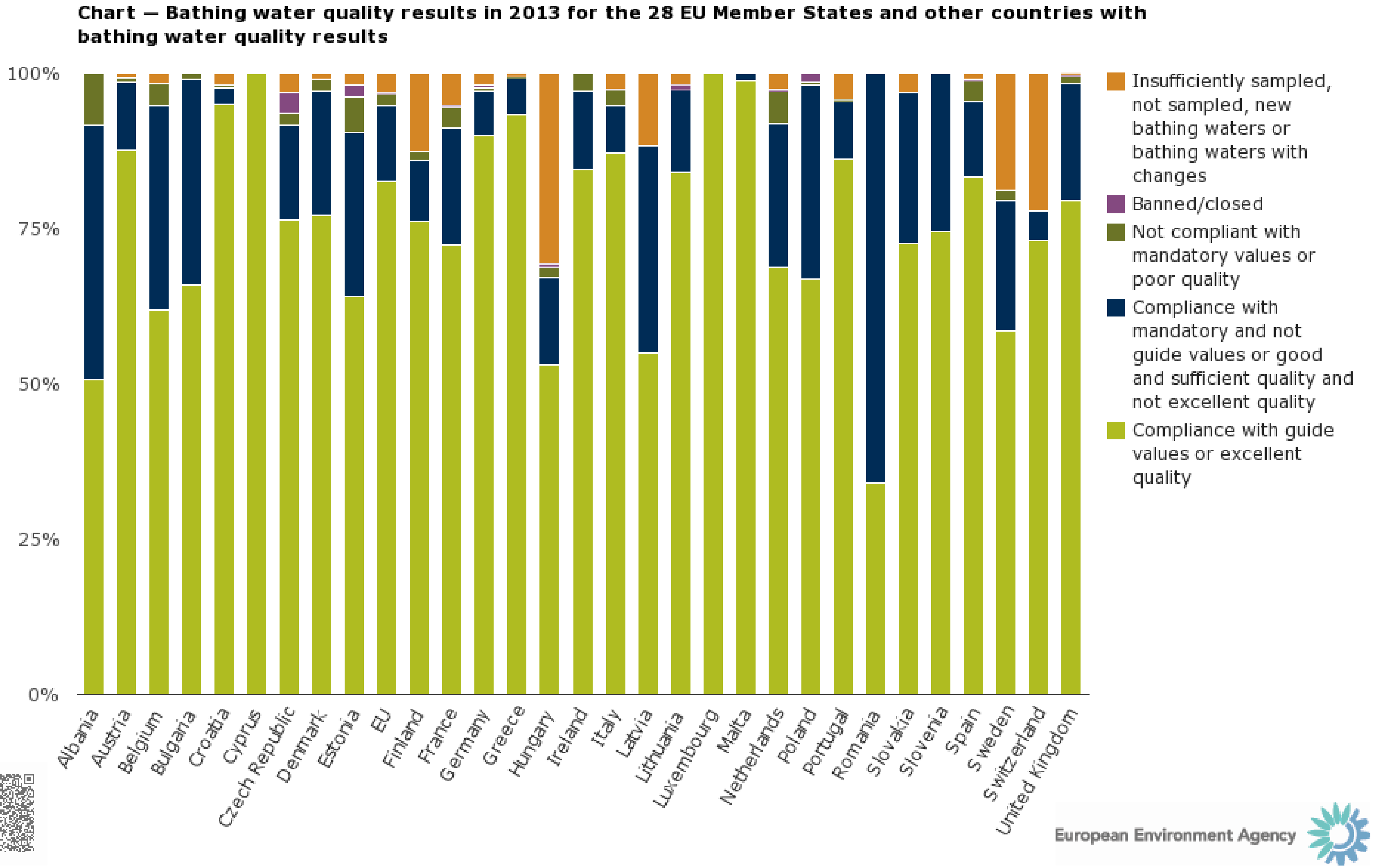
## POINT SOURCES

- Wastewater effluent, both municipal and industrial
- Runoff and leachate from waste disposal sites
- Runoff and infiltration from animal feed lots
- Runoff from mines, oil fields, and unswered industrial sites
- Storm sewer outfalls from cities with high (> 100 000) population
- Runoff from large construction sites
- Overflows of combined storm and sanitary sewers

## NONPOINT SOURCES

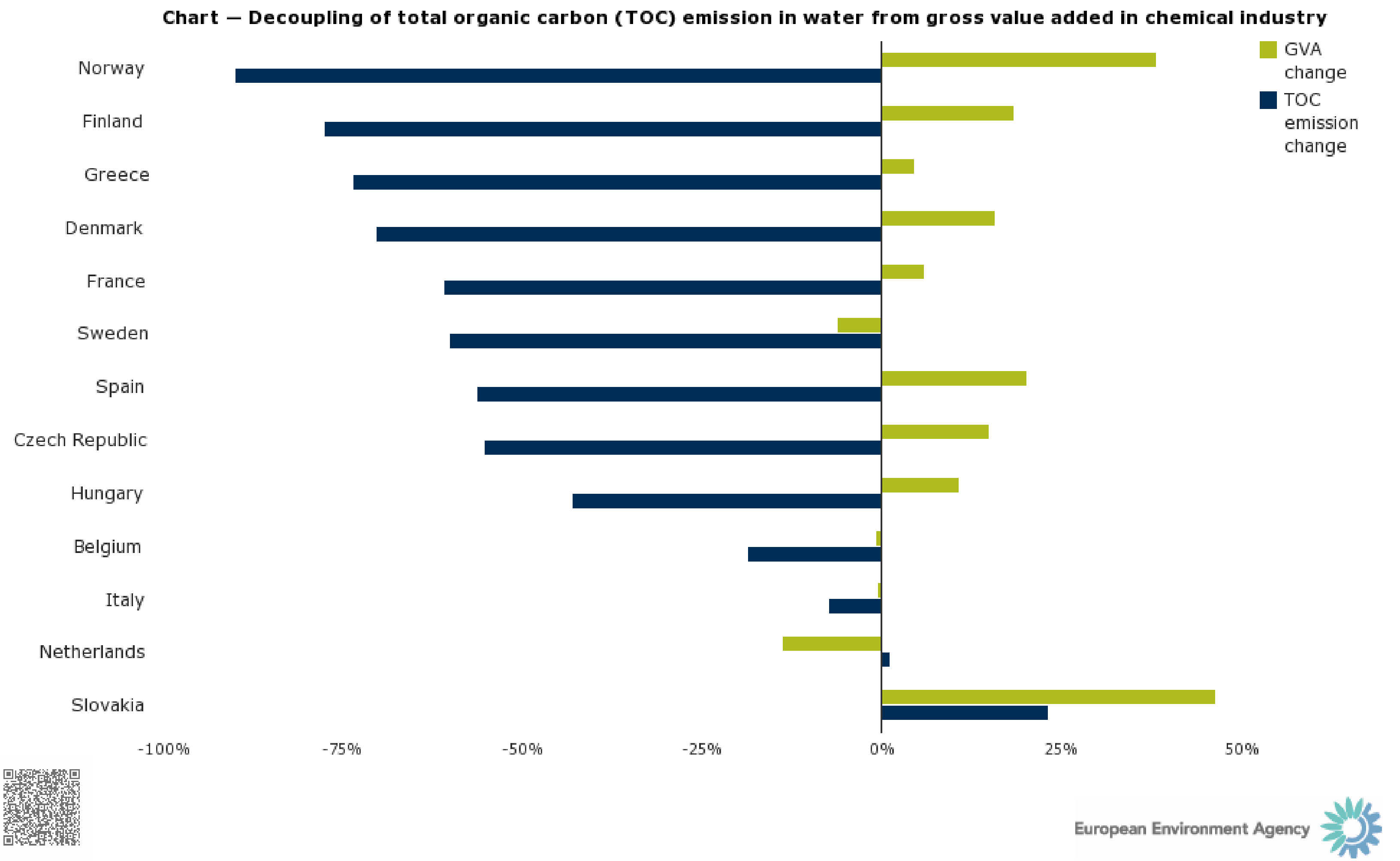
- Runoff from agriculture including return flow from irrigated fields
- Runoff from pasture and range
- Urban runoff from answered and sewered areas (>100 000 p)
- Septic leachate and runoff from failed septic systems
- Runoff from small construction sites
- Runoff from abandoned mines
- Atmospheric deposition over a water surface
- Activities on land that generate contaminants.

# Bathing Water Quality in EU (2013).




http://www.eea.europa.eu/data-and-maps/data/bathing-water-directive-status-of-bathing-water-6

# Decoupling of TOC emission in water (EU) from gross value added in chemical industry (2012).

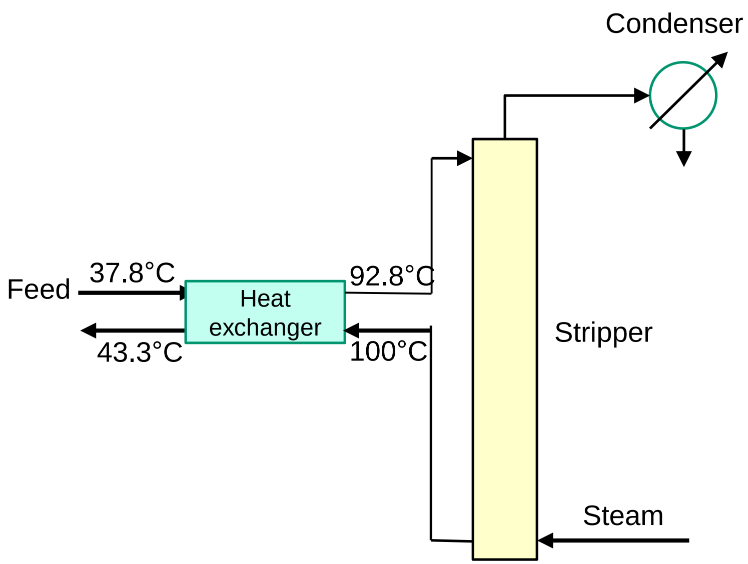



http://www.eea.europa.eu/data-and-maps/data/member-states-reporting-art-7-under-the-european-pollutant-release-and-transfer-register-e-prtr-regulation-7

# Possible Techniques for Cleaning Water Contaminated with Solvents.

The choice of processes leading to possible recover of solvents from dilute solutions are:

- decanting
- solvent extraction
- membrane separation
- adsorption
- air stripping
- steam stripping




Steam-stripping system for waste water clean-up.

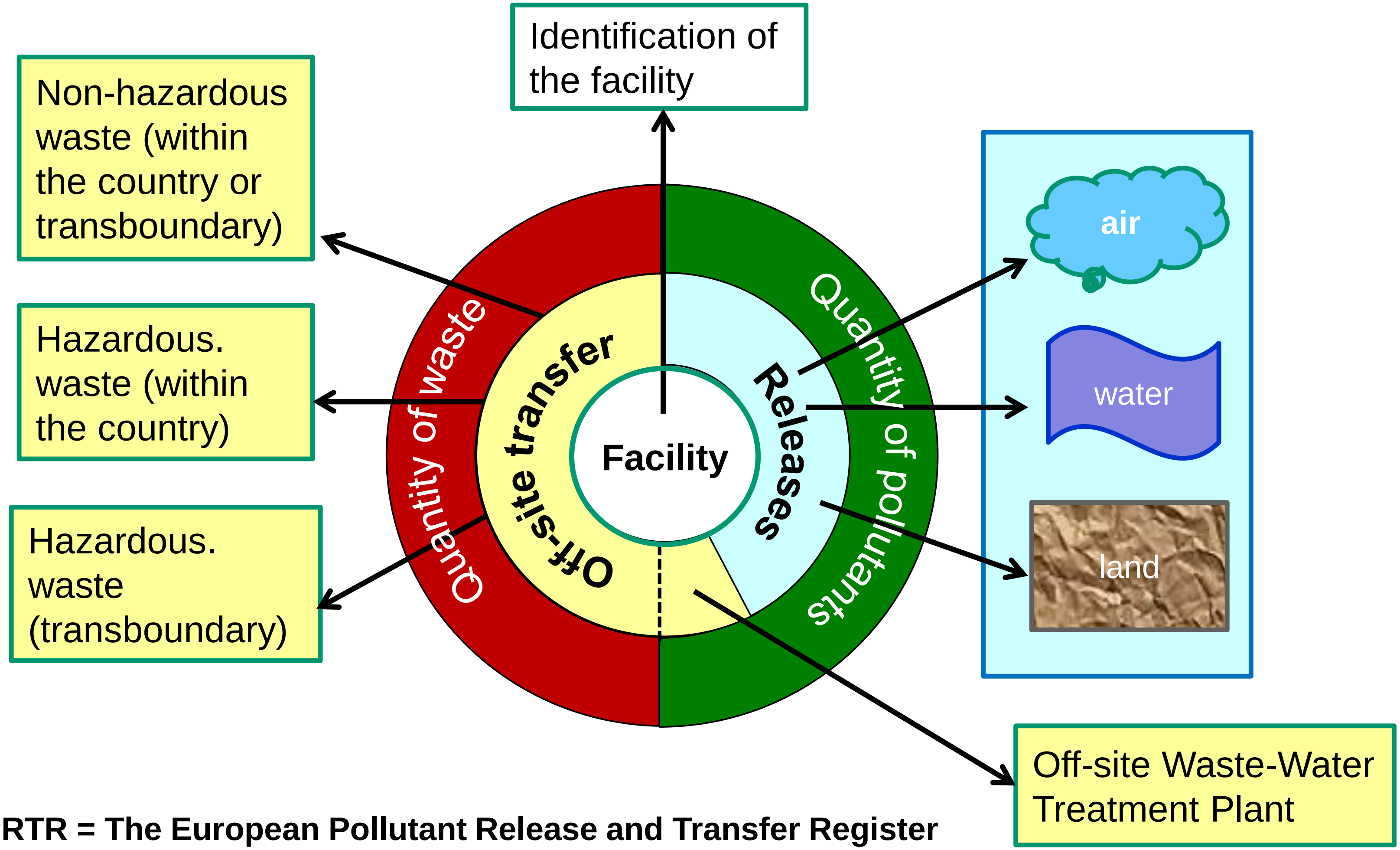
# Solid Waste (Industrial and Municipal) Pollution.

Solid Waste is defined in EU by Directive 2008/98/EC Article 3(1)* and classified according to the waste classification code, also referred to as EWC (European Waste Catalogue) code.

- **Industrial Solid Waste**
  - is process waste associated with manufacturing at all levels.
- **Municipal Solid Waste**
  - includes wastes such as durable goods, nondurable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic wastes from residential, commercial, institutional, and industrial sources.

*http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32008L0098

# E-PRTR Regulation, Recital 21.




**E-PRTR = The European Pollutant Release and Transfer Register**

EU - Guidance Document for the implementation of the European PRTR, 2006

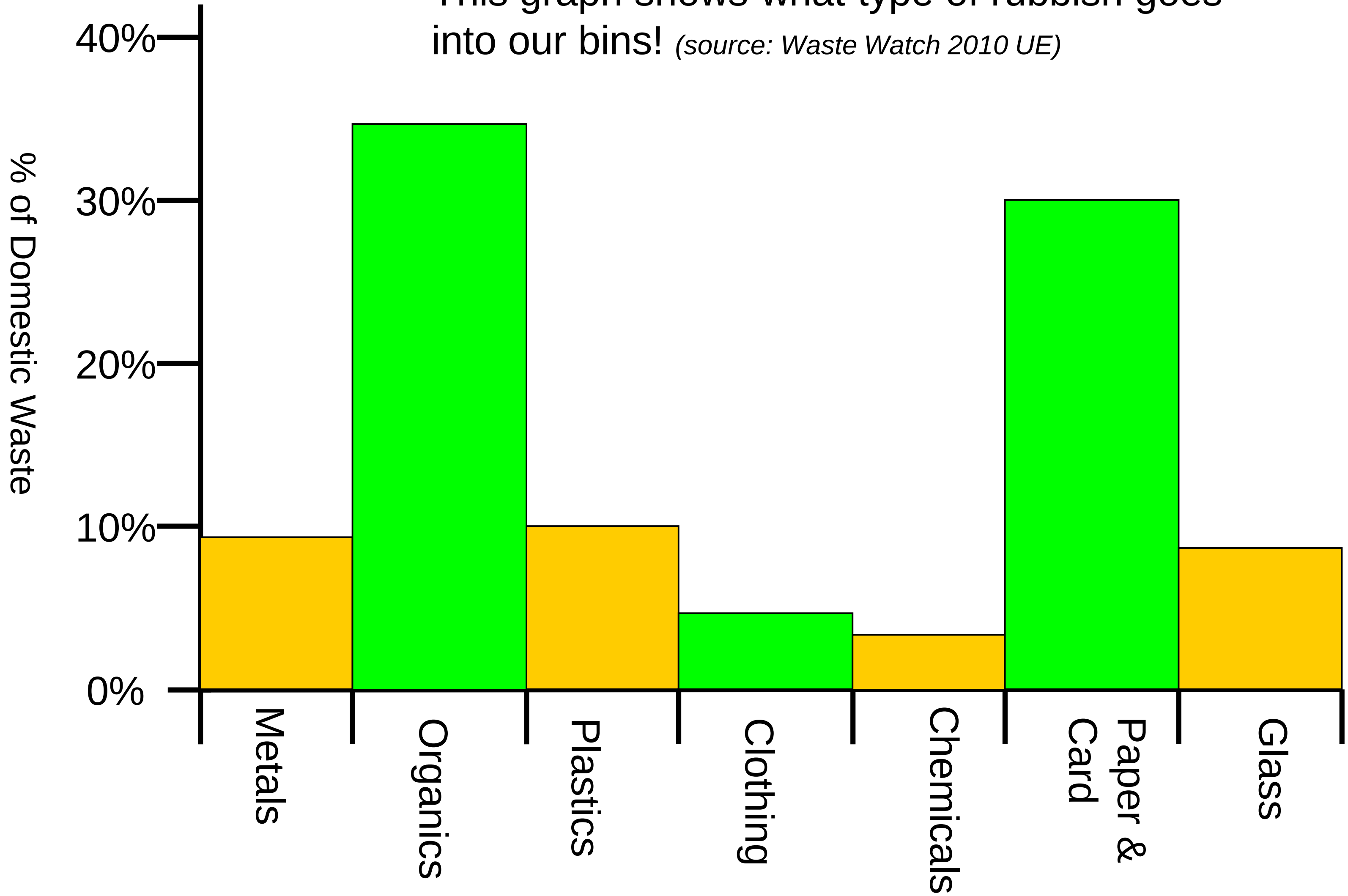
# Overview on the Reporting Requirements for Facilities under the E-PRTR.

| Releases | | Quantity[1] | M/C/E[3] | Method used | | |
|---|---|---|---|---|---|---|
| | to air | **kg/year** | X | X | | |
| | to water | **kg/year** | X | X | | |
| | to land | **kg/year** | X | X | | |
| **Off site transfers of:** | | **Quantity[1]** | **M/C/E[3]** | **Method used** | **Name and address of recovered/ disposer** | **Address of actual recovery/disposal site receiving the transfer** |
| Pollutants in wastewater[5] | | **kg/year** | X | x | | |
| Non-hazardous waste | for disposal (D) | **t/year** | x | x | | |
| | for recovery (R) | **t/year** | x | x | | |
| Hazardous waste within the country | for disposal (D) | **t/year** | x | x | | |
| | for recovery (R) | **t/year** | x | x | | |
| Hazardous waste transboundary | for disposal (D) | **t/year** | x | x | x | x |
| | for recovery (R) | **t/year** | x | x | x | x |

[1)] Quantities are totals of releases from all deliberate, accidental, routine and non-routine activities at the site of the facility or of off-site transfers. [2)] The total quantity of each pollutant that exceeds the threshold value specified in Annex II; **in addition, any data that relate to accidental releases have to be reported separately whenever available.** [3)] It has to be indicated whether the reported information is based on measurement (M), calculation (C) or estimation (E). See chapter 1.1.11 of this guide. [4)] Where data are measured or calculated, the method of measurement and/or the method for calculation shall be indicated. For further sub-division of this column see chapter 1.1.11.5 of this guide. [5)] Off-site transfer of each pollutant destined for waste-water treatment that exceeds the threshold value specified in Annex II.

# Types of House Waste.

This graph shows what type of rubbish goes into our bins! *(source: Waste Watch 2010 UE)*



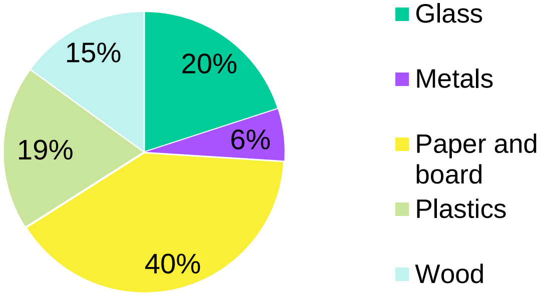
# EU trends in Solid Waste.

Municipal and industrial management: from simple collection to complex post-collection phases (sorting, recycling, disposal).

- Requires investment, management skills and technology
- Trend toward vertical integration (e.g. collection > incineration) and horizontal integration (e.g. management of municipal and industrial waste)

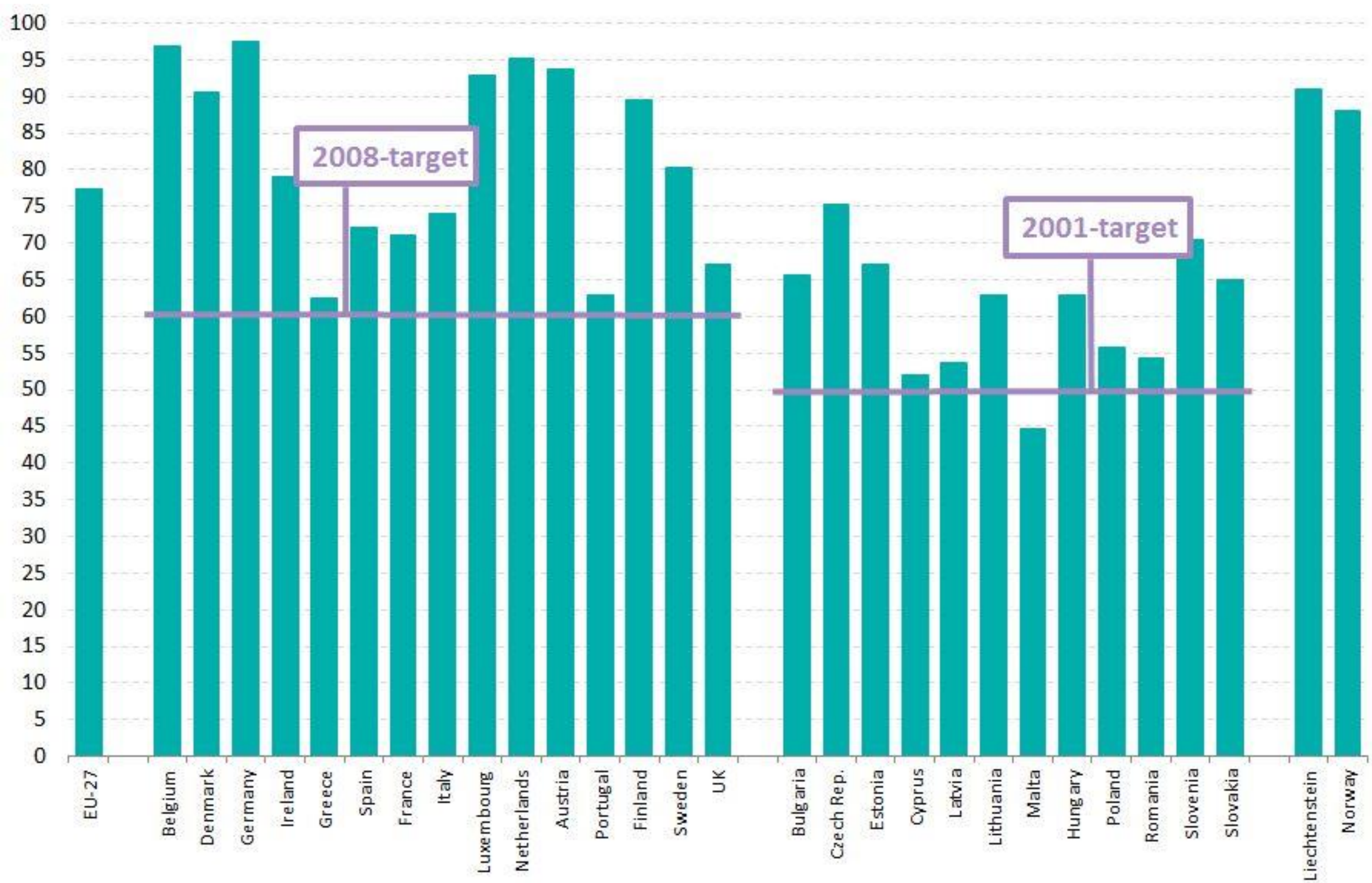
- Private Sector
  - From small contractors to large integrated companies
  - Trend towards concentration with greater market share

- Public Sector
  - Often organized through corporate structures, some grow through mergers and expand into other municipalities.
  - Some re-municipalization




CIRIEC WP11/07

# Reported Performance of Member States, Recycling of Packaging Waste (%, 2011 Data).



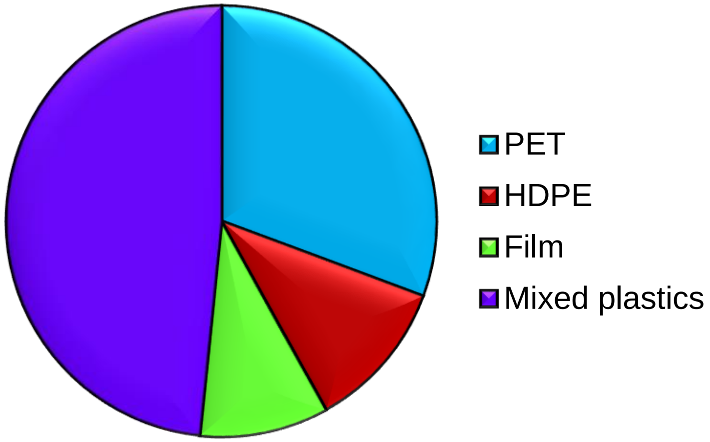

Source: Eurostat.

http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Packaging_waste_statistics

# Some Aspects of Municipal Waste Recovery of Plastics (Italy 2014).

Total recovery per capita 2014:

North Italy 14.5 *kg*
Central Italy 8.3 *kg*
South Italy 6.3 *kg*




Increase of recovery 2010 vs. 2009: 4%

In 2014 in Italy were collected 615.000 *ton* of plastic packaging (210 *kton* from MULTI and 404 *kton* from MONO), equivalent to:

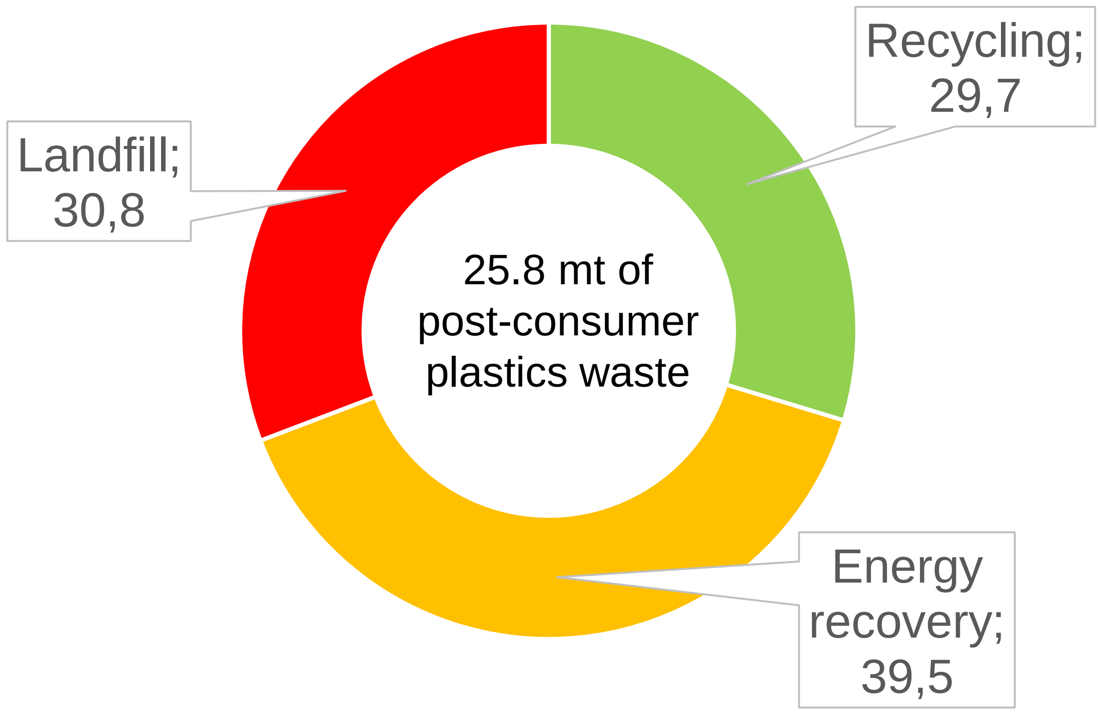
7 times the volume of Big Pyramid of Egypt.

Source: COREPLA

# Some Aspects of Recovery of Plastics (Europe 2014).

**In 2014 plastics recycling and energy recovery reached 69.2%**

In 2014, 25.8 million tonnes of post-consumer plastics waste ended up in the waste upstream. 69.2% was recovered through recycling and energy recovery processes while 30.8% still went to landfill.

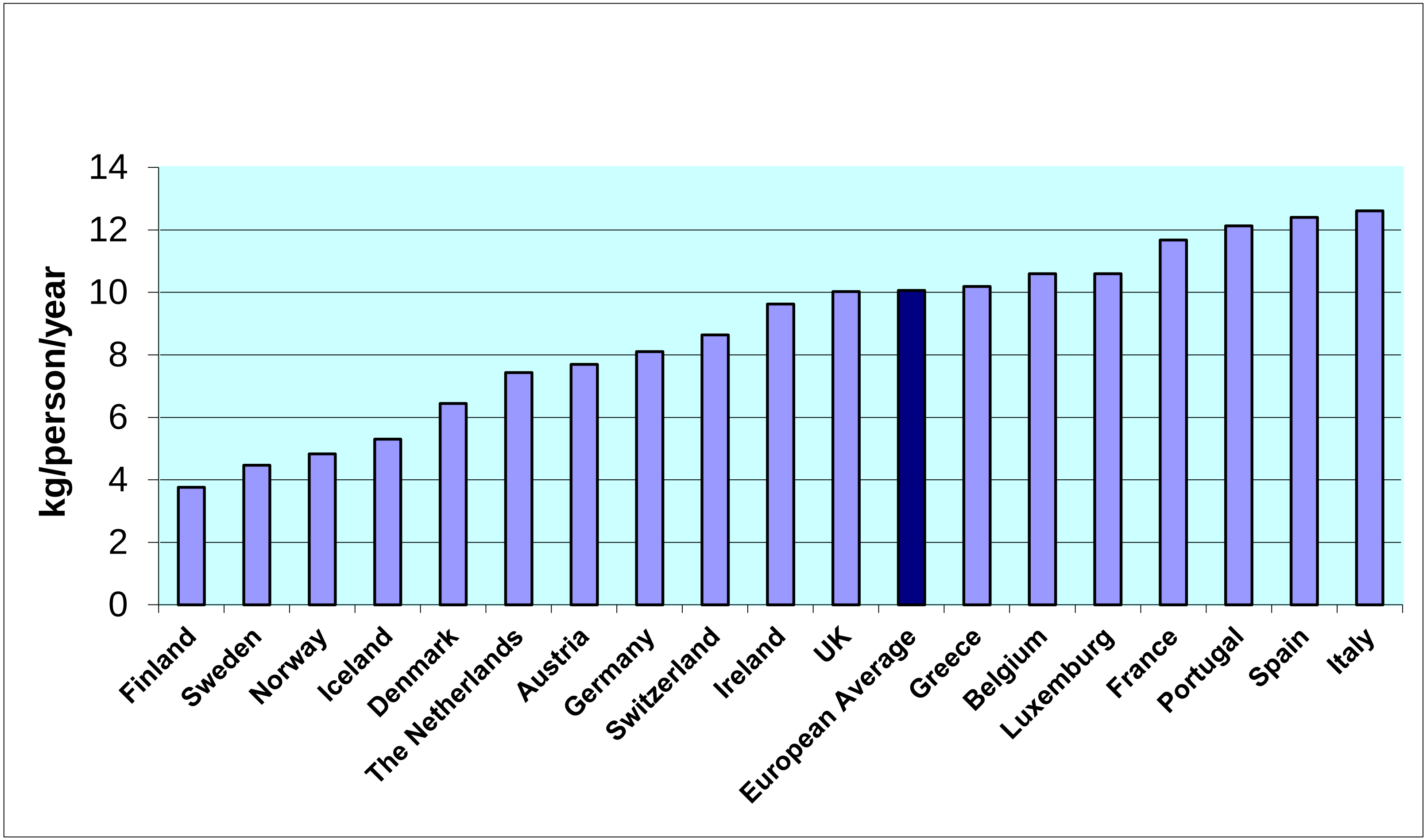



Plastics – the Facts 2015 – Plastic Europe

# Origin and Fate of Pharmaceutical and Personal Chemical Products (PPCPs) in the Environment.

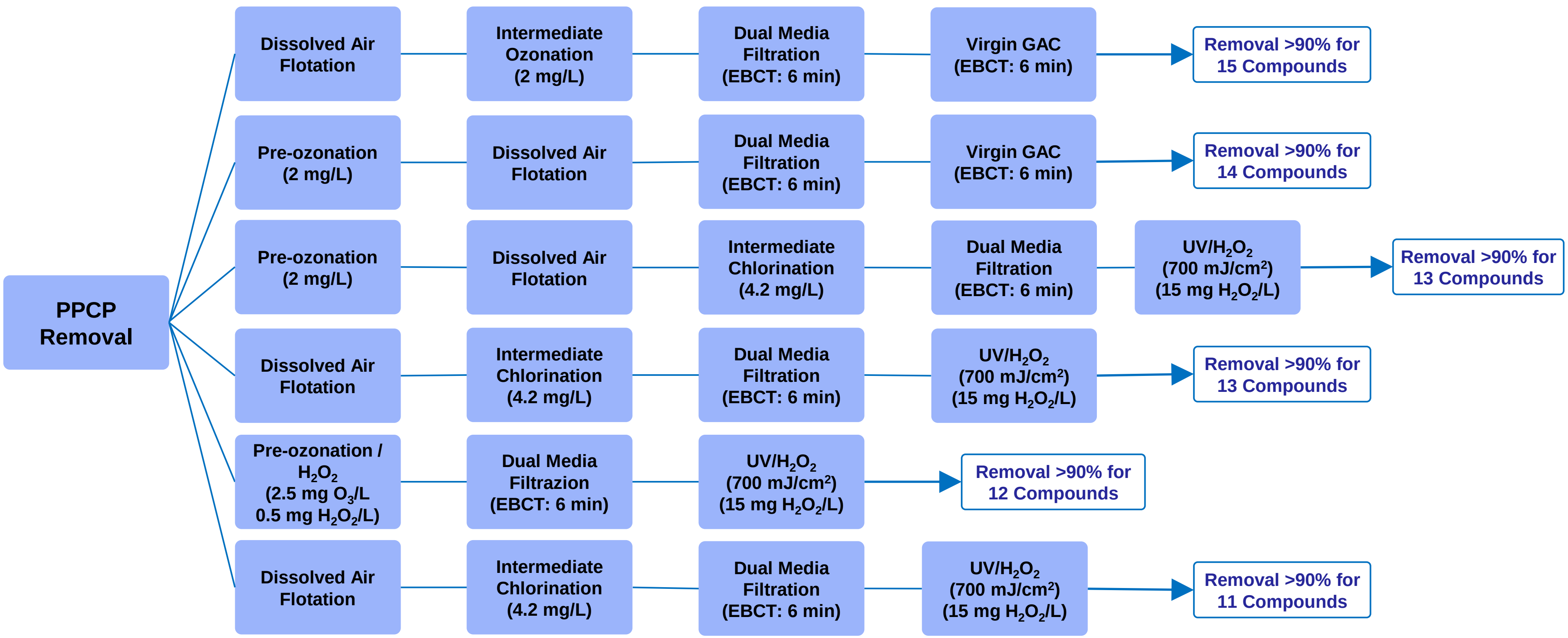

http://www.epa.gov/ppcp/

# Detergent Consumption per capita in Eighteen European Countries (2000-2010).



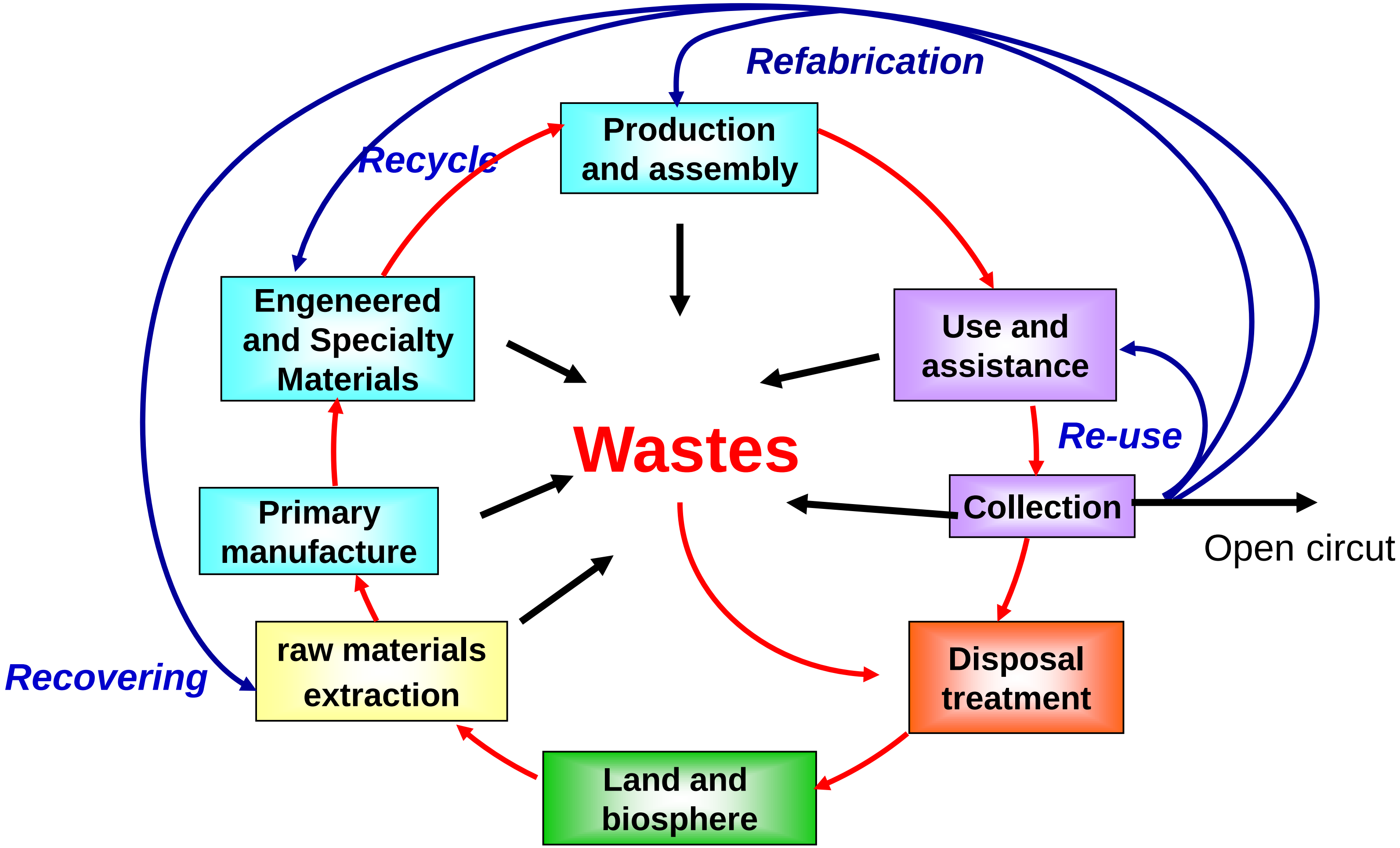
# Pharmaceutical and Personal Care Products (PPCPs) in Wastewaters.

With widespread occurrence of pharmaceuticals and personal care products (PPCPs) in the water cycle, their presence in source water has led to the need to better understand their treatability and removal efficiency in treatment processes. A possible treatment scheme has been recently proposed.*

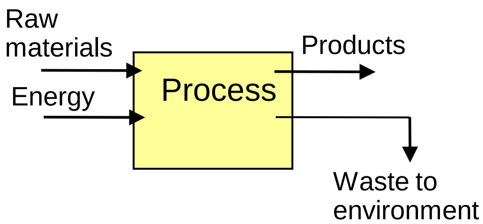



S. Zhang et al. Water Research, 2016, 105, 85-96.

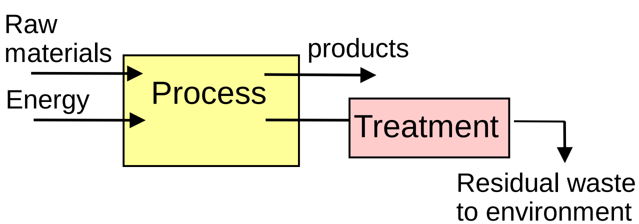
# Integration of Waste Separation – From Industrial Production to Re-employ.



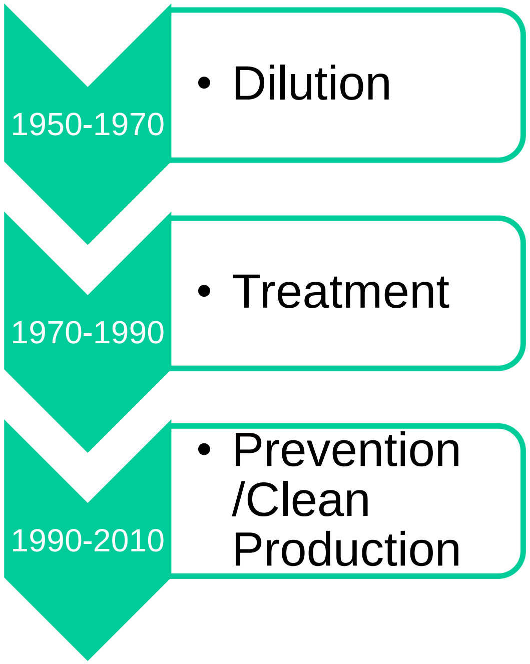
# History of Waste Management.

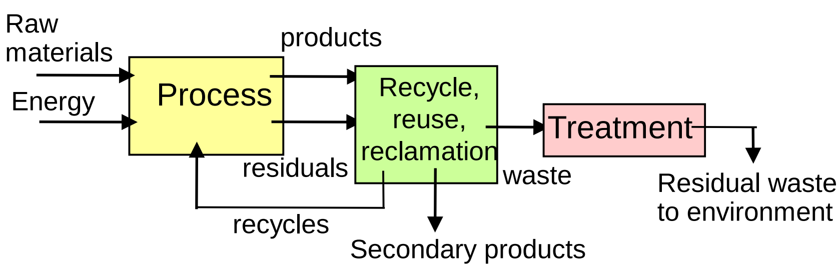



(a) Past industrial practices

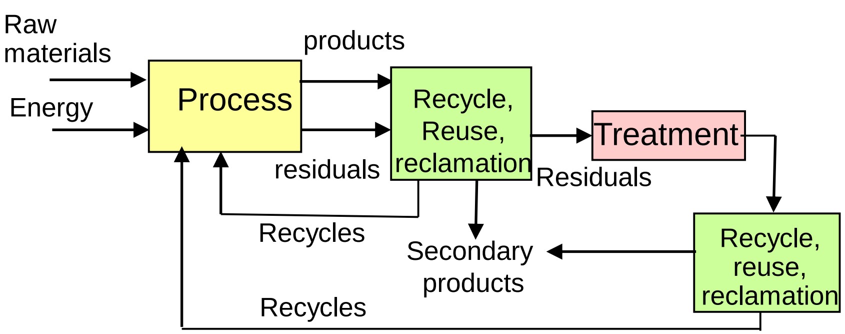



(b) Recent industrial practices



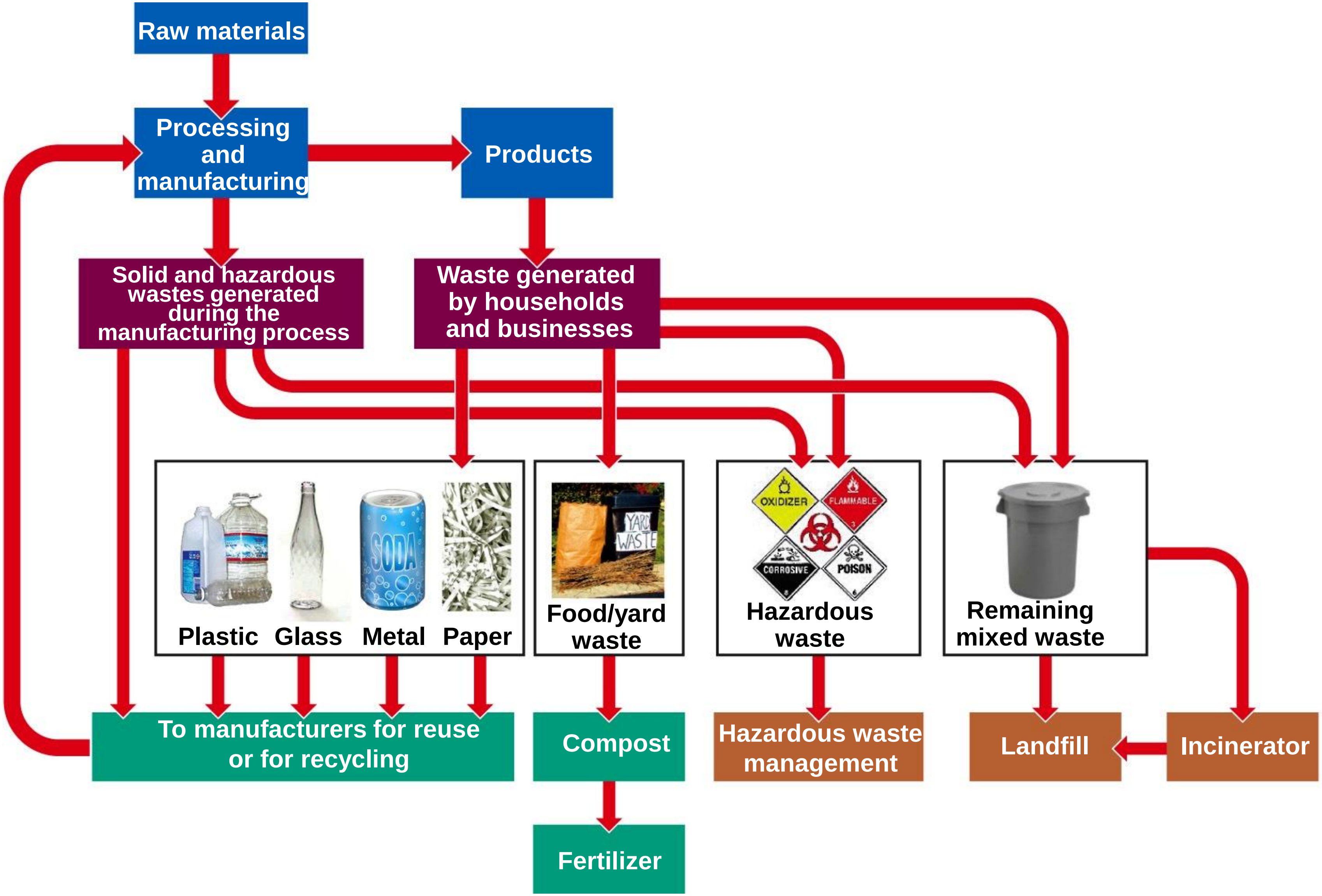




(c) Current pollution prevention practices

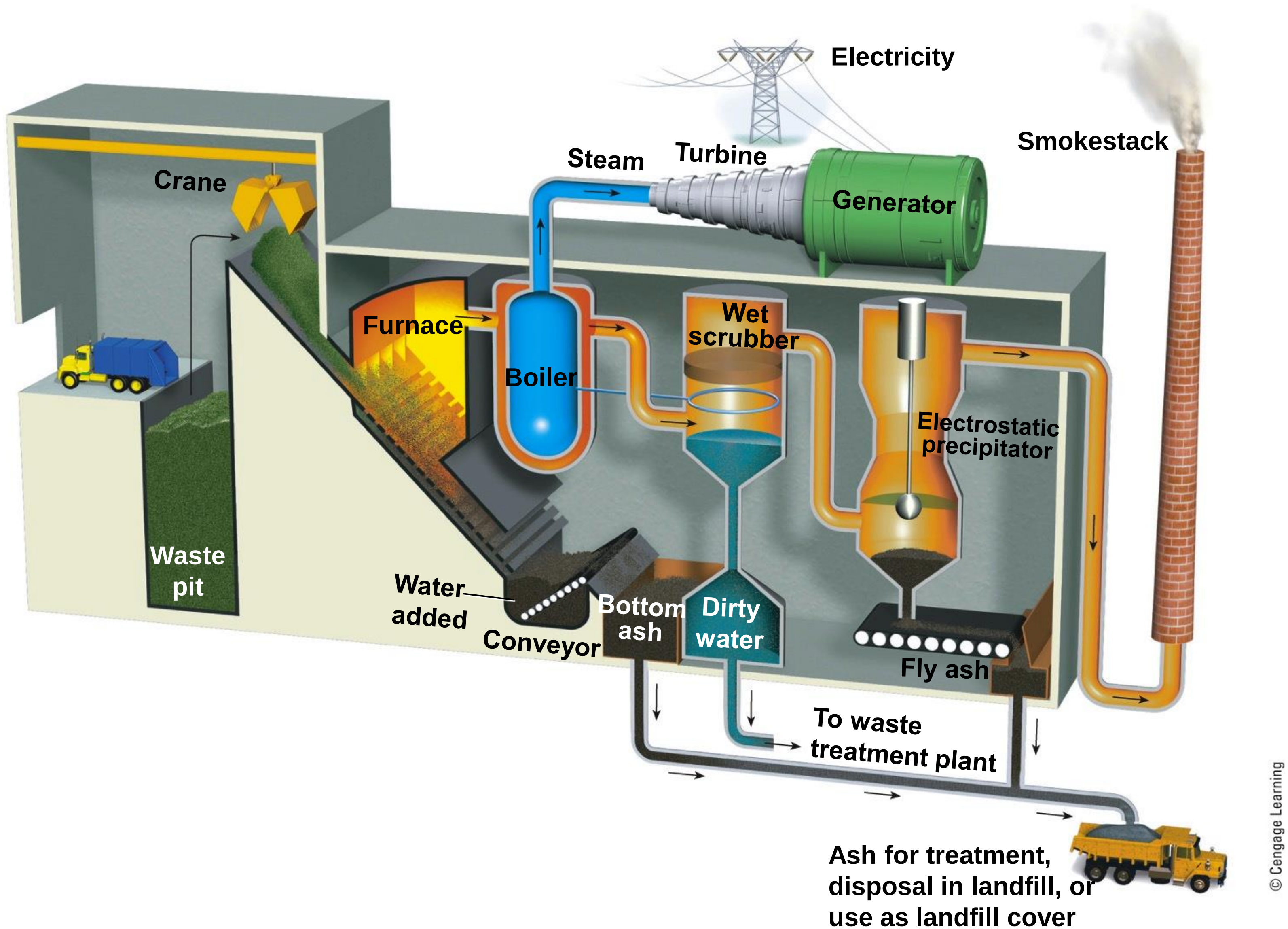



(d) Ideal future industrial practices

# Integrated Waste Management.



# Incineration of Organic Wastes.



# Waste-to-Energy Incineration.

## Advantages

**Reduces trash volume**

**Produces energy**

**Concentrates hazardous substances into ash for burial**

**Sale of energy reduces cost**

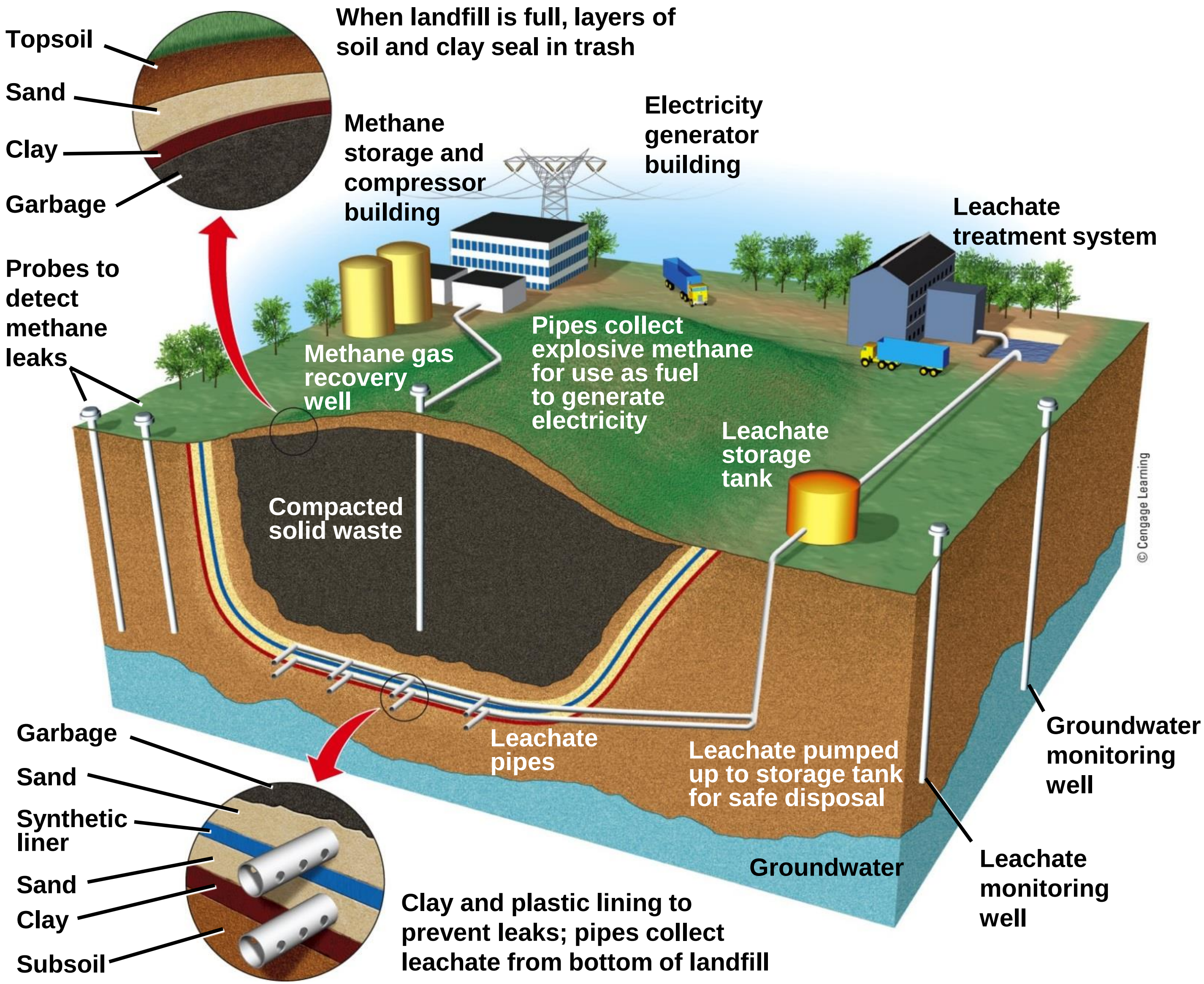
## Disadvantages

**Expensive to build**

**Produces a hazardous waste**

**Encourages waste production**

# Sanitary Landfill.



# Landfill Garbage.

## Advantages

Low operating costs

Can handle large amounts of waste

Filled land can be used for other purposes

No shortage of landfill space in many areas

## Disadvantages

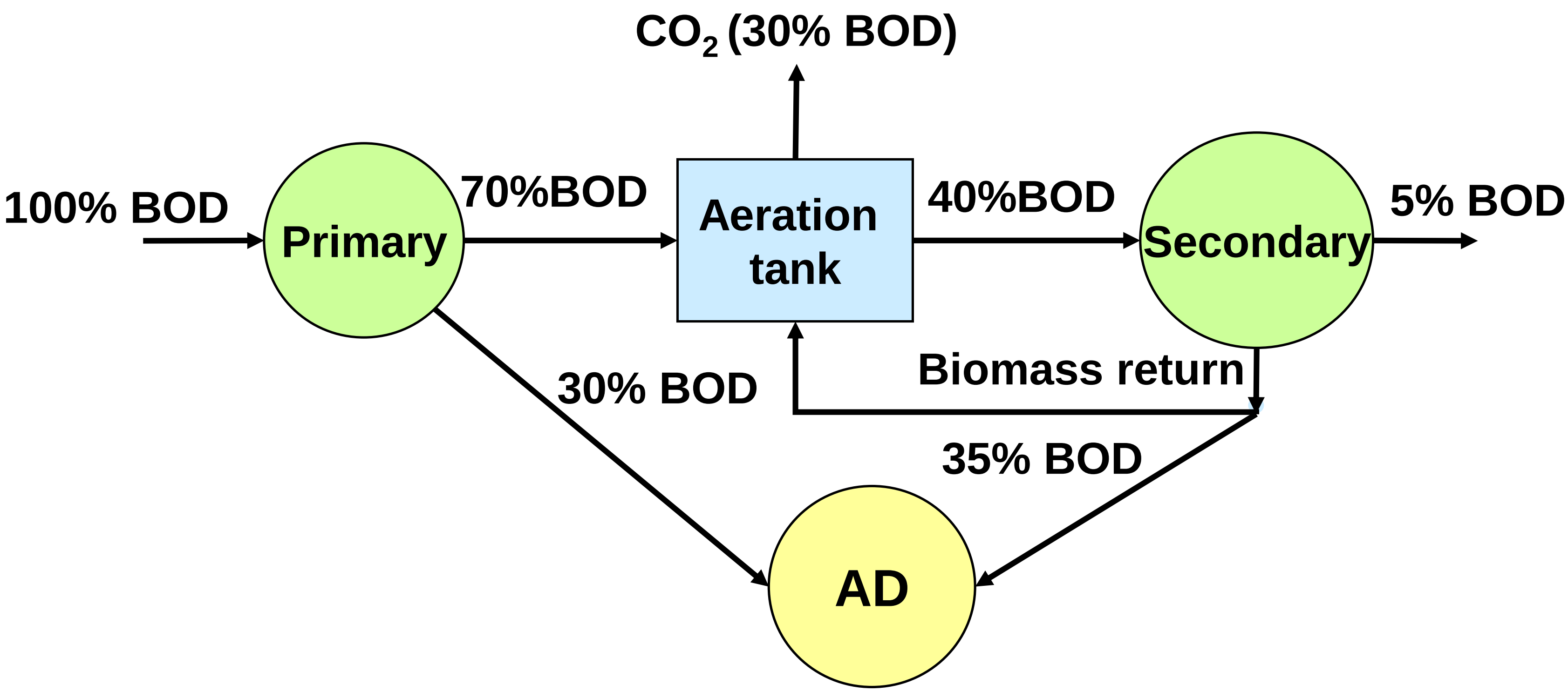
Noise, traffic, and dust

Releases greenhouse gases (methane and $CO_2$) unless they are collected

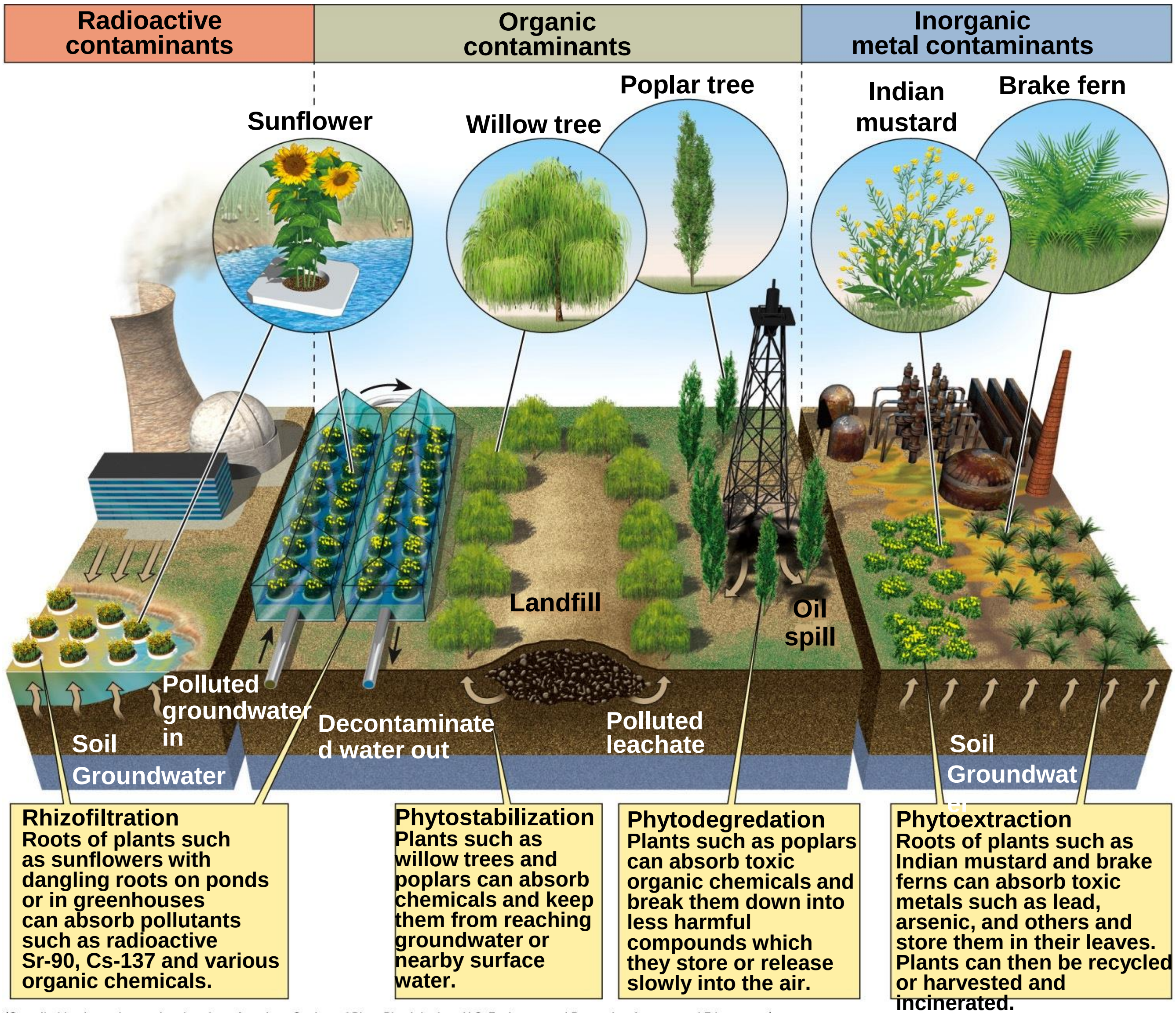
Output approach that encourages waste production

Eventually leaks and can contaminate groundwater

# Waste Management (Bioconversion).

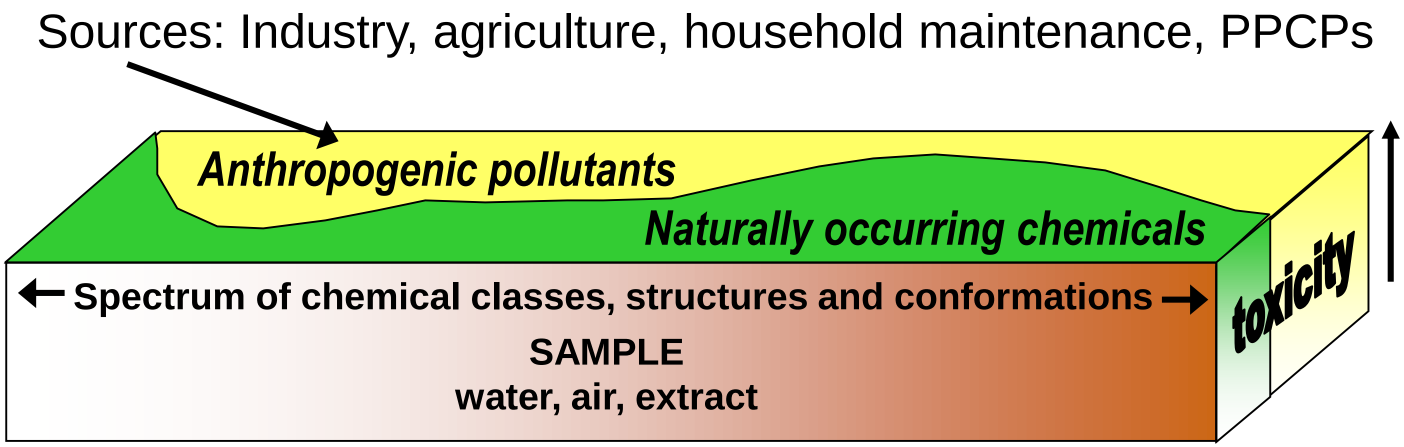


# Phytoremediation.




(Compiled by the authors using data from American Society of Plant Physiologists, U.S. Environmental Protection Agency, and Edenspace.)

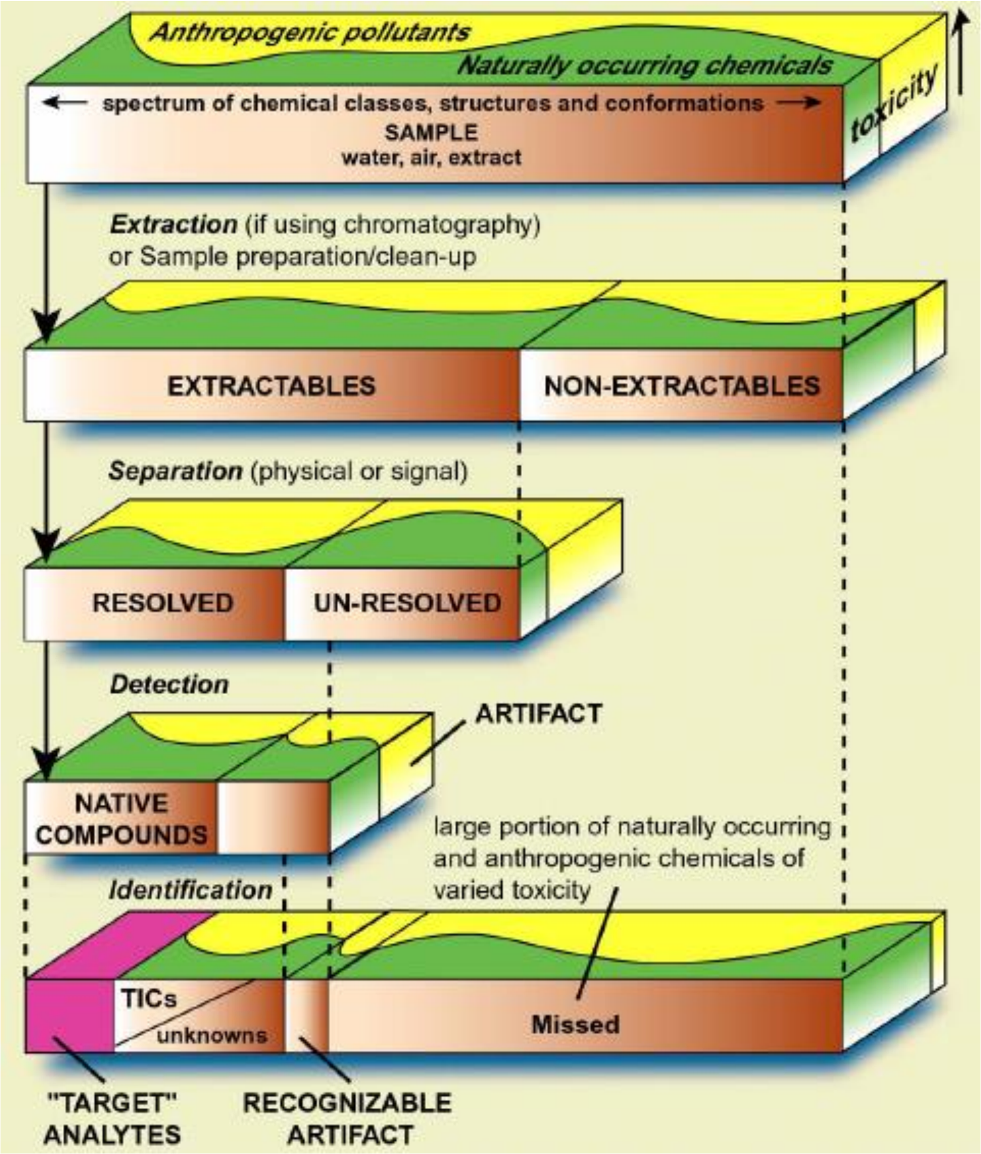
# Universe of Chemicals in the Environment.




"Not everything that can be counted counts, and not everything that counts can be counted."

(oft attributed to Albert Einstein)

# Limitations and Complexity of Environmental Chemical Analysis.




TIC = tentatively Identified compound

C.G. Daughton
U.S. EPA July 2002

# History of Waste Management (Cont.).

- **Dilution**: Relies on assimilative capacity of natural systems
  - Too much waste in industrially and urban concentrated areas, assimilative capacity exceeded easily.

- **Treatment**: Waste management after it is generated
  - Treatment usually changes the form of pollutant and the polluted medium.
  - Increased regulatory pressure demands higher treatment efficiency - may not be possible with treatment only.
  - Treatment cost was systematically increasing - US and EC spent about $150 and $50 Billion, respectively, in 2010 for treatment
  - Pollution becoming more complex and persistent
  - Need for prevention and recycling.

# Pollution Prevention Definition.

United Nations Environment Program (UNEP) defined "cleaner production" officially in 1989 as:

**"… the continuous application of an integrated preventive environmental strategy applied to processes, products, and services to increase eco-efficiency and to reduce risks to humans and the environment."**

**The Europe 2020 Strategy seeks the following Priority Objectives**:

1: To protect, conserve and enhance the Union's natural capital

2: To promote sustainable growth by developing a more competitive low-carbon economy that makes efficient, sustainable use of resources

3: To safeguard the Union's citizens from environment-related pressures and risks to health and well-being.

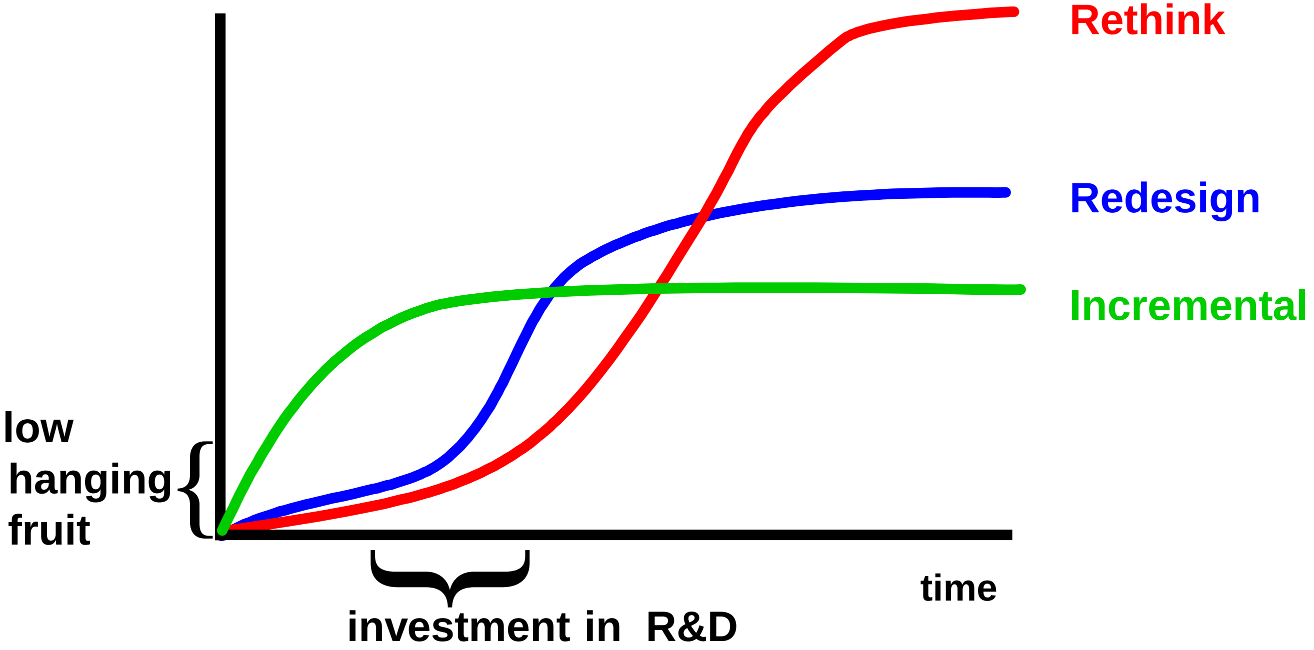
4: To maximise the benefits of Union environment legislation by improving implementation.

# Pollution Prevention (PP) Definition (Cont.).

- EPA defines PP as "source reduction," and other practices that reduce or eliminate the creation of pollutants through;
  - increased efficiency in the use of raw materials, energy, water, or other resources, or
  - protection of natural resources by conservation.
- The Pollution Prevention Act defines "source reduction" to mean any practice which:
  - reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal;
  - reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants.

# Pollution Prevention Synonyms and Technology Performance.

- Cleaner production (CP)
- Waste minimization
- Source reduction
- Eco-efficiency



# Pollution Prevention Terminology.

## Eco-efficiency:

- Delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity.

'doing more with less'

## Cleaner production (CP):

- Continuous application of an integrated preventative environmental strategy applied to processes, products and services.
- Embodies:
  1. More efficient use of natural resources and thereby minimization of waste and pollution as well as risks to human health and safety.
  2. Addressing pollution issues at their source rather than at the end of the production process, *i.e.* avoidance of 'end-of-pipe' approach.

# Seven components of Eco-efficiency:

1. Reduce material intensity of goods and services
2. Reduce energy intensity of goods and services
3. Reduce toxic dispersion
4. Enhance material recyclability
5. Maximize sustainable use of renewable resources
6. Extend product durability
7. Increase the service intensity of goods and services

# Pollution Prevention Terminology (3).

## Cleaner production includes:

*For processes*:

- conserving raw materials and energy, eliminating the use of toxic raw materials and reducing the quantity and toxicity of all emissions and wastes.

*For products*:

- reducing the negative effects of the product throughout its life-cycle, from the extraction of the raw materials right through to the product's ultimate disposal (“cradle to grave” approach).

*For services*:

- incorporating environmental concerns into designing and delivering services.

# Pollution Prevention Terminology (4).

“Tools" for eco-efficiency and cleaner production includes:

1. Life Cycle Assessment (Analysis)
2. Design for the environment
3. Environmental management systems
4. Environmental audits
5. Environmental accounting
6. Performance based contracting
7. Environmental labeling
8. Public environmental reporting
9. Industrial ecology
10. Environmental taxes

# Pollution Prevention Terminology (5).

## Life cycle assessment:

- Life Cycle Assessment (**LCA**) measures, and thus provides the opportunity for comparison, the environmental impacts of products or services relative to each other.
- Most LCA measurements are made by summing the "units of energy consumed" in the extraction of raw materials, transport, manufacture, distribution and final disposal of a product or service. Additional summations are made of emissions to air, land or water resulting from the creation and disposal of the product or service.

## Design for the Environment:

- Design for the environment (**DFE**) or 'eco-design' examines a product's entire lifecycle and proposes changes to how the product is designed to minimize its environmental impact during its lifetime.

# Pollution Prevention Terminology (6).

## Environmental management systems (**EMS**):

- A structured approach to planning and implementing environmental protection measures that enable organizations to measure their environmental performance, and then regularly evaluate their performance and improvement.
- To develop an EMS, an organization has to assess its environmental impacts, set targets to reduce these impacts, and plan how to achieve the targets.

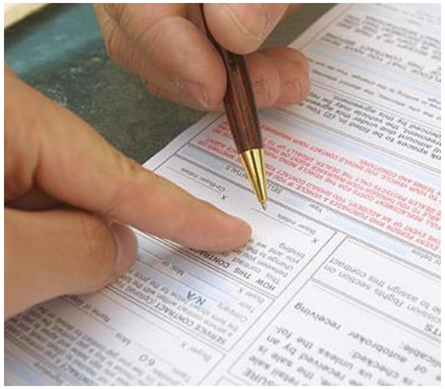
## Environmental audits:

- Identification of all the environmental impacts made by a firm so that changes to processes and practices can be assessed and implemented.
- Once an audit is undertaken, the firm will be able to implement cleaner production and eco-efficiency improvements based on the audit findings.

# Pollution Prevention Terminology (7).

## Environmental accounting:

- Gathering the required information by an organization to understand the full spectrum of its environmental costs and to integrate these costs into decision making.



## Performance based contracting (PCB):

- Is a technique mainly utilized in the energy industry, but has great potential for being applied to many parts of business activity. Under PBC, a third party contractor takes responsibility for the management of a specific part of the business. The contractor adopts the risk for managing that business but also gains financial rewards for making it more efficient (with gains shared).
- In the energy industry Performance Based Contractors approach firms with proposals to improve their energy efficiency over a period of time, at no cost to the firms. The savings made by the energy efficiency improvements are used to pay the contractor and also are returned to the firm. It is clear that such an approach can be used for many aspects of a firm's inputs and outputs — water, transport, waste, chemicals and such.

# Pollution Prevention Terminology (8).

Environmental labeling ('eco-labeling‘):

- Labeling consumer products which have environmental benefits, or at least a lower impact than their alternatives. Environmental labels assist consumers, both organizations and individuals, to make responsible product choices, by informing them of the environmental impacts of products and providing a standardized means of comparing products.

Public environmental reporting:

- A process by which organizations, including governments, can examine their environmental performance over a specified reporting period and disseminate that information to a wide audience. Results are published, either as a stand-alone document or as part of other publications, such as an annual report. The inclusion of an independent verification can help to establish the credibility of a report.

# Pollution Prevention Terminology (9).

Industrial ecology (**IE**):

- Sitting of symbiotic or complementary industries in the same areas. This way, through thoughtful land-use planning and the design of individual plants, cleaner production can be said to be incorporated at the beginning of industrial activity, rather than being added afterwards.
- This type of development, also known as "industrial ecology parks," can facilitate improved recycling of outputs from one industry by other industries, rather than those outputs simply being treated as waste and sent to landfill. Such recycling reduces waste and increases profits, not only for the creator of outputs, but also the buyer.
- This design also reduces transport costs and the environmental effects of transport. Any improvements in land planning which reduces the need for transporting materials will lead to reduced air pollution in metropolitan air sheds.

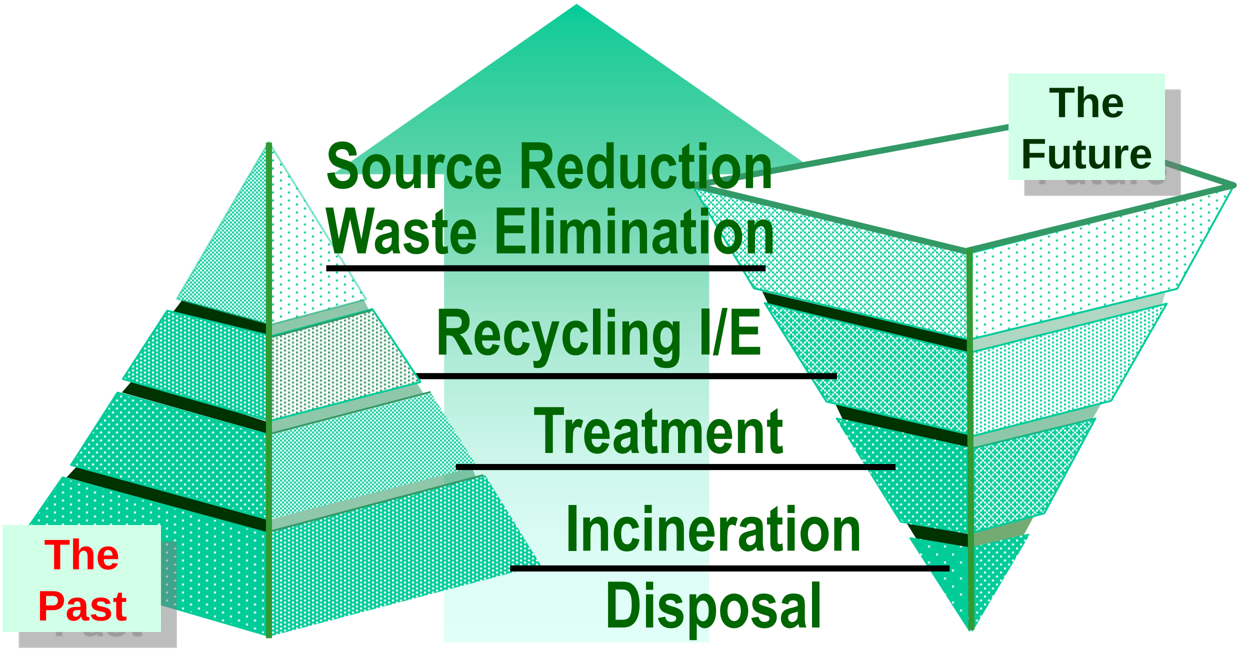
# Pollution Prevention Terminology (10).

## Environmental taxes:

- Environmental Taxes are a means of encouraging optimal resource use, equity and the minimization of pollution. Three types of environmental tax are:

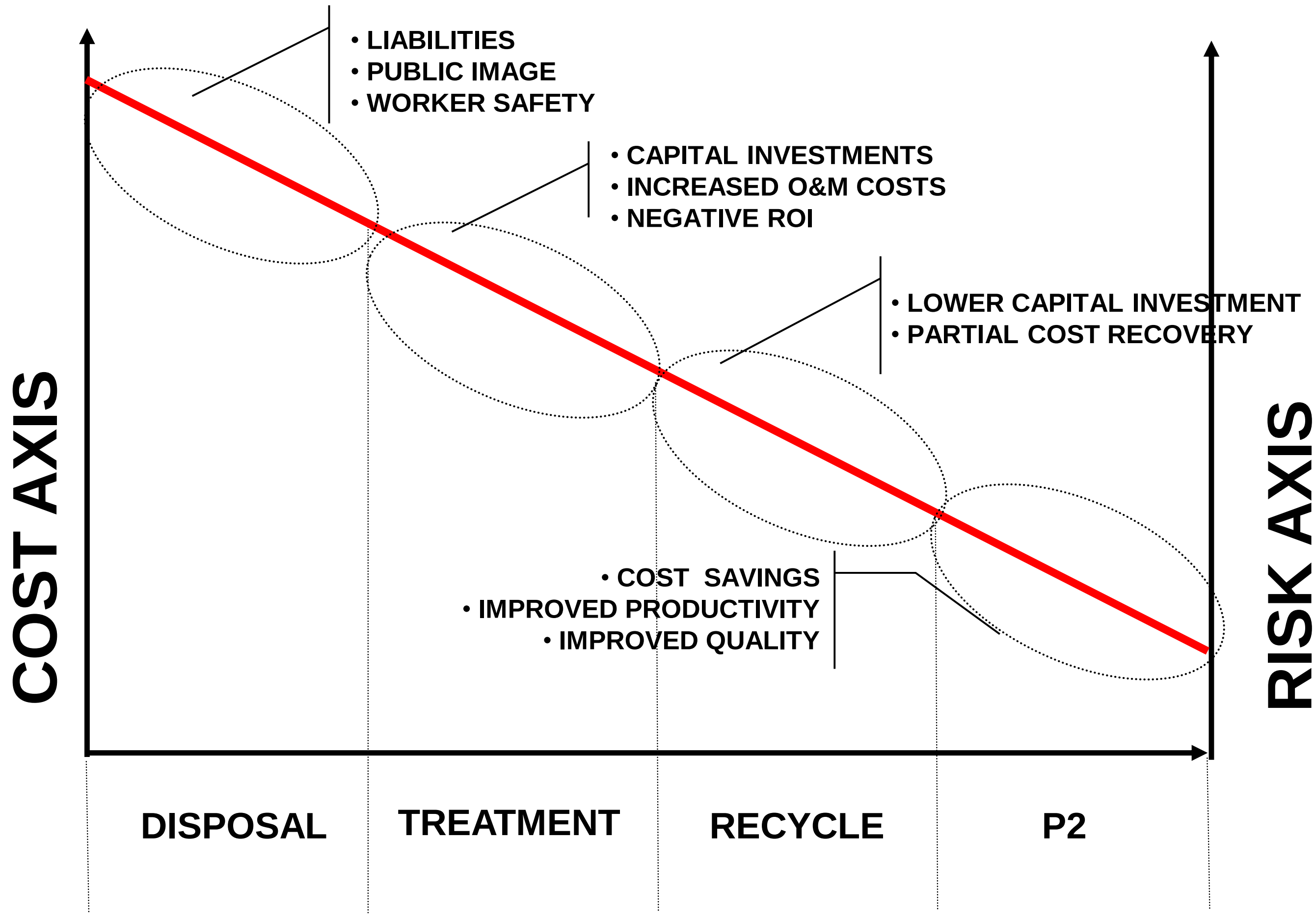
1. Emission taxes on measurable emission to air, water and land, or the generation of noise.
2. Consumption or product taxes levied on particular products that are considered damaging to the environment.
3. Tax differentiation in existing indirect taxes such as excise duties, sales taxes or value added taxes for Environmental ends, for example, the reduction in the excise on unleaded gasoline.

# Pollution Prevention Hierarchy.




- First level of action should be source reduction- prevent or reduce pollution at the source whenever feasible.
- Pollution that cannot be prevented should then be recycled in an environmentally safe manner whenever feasible.
- What is non-recyclable should be treated
- What remains after treatment should be disposed.

# Pollution Management Hierarchy (2).



# EU Environmental Policy Instruments.

| Type | | Description/Examples |
| --- | --- | --- |
| 1. | Regulative instruments | Command and control, permits, technological prescription |
| 2. | Market-based instruments | Taxes, tariffs, subsidies, tradable permits |
| 3. | Procedural instruments | Auditing programs, environmental impact assessment |
| 4. | Co-operative instruments | Commitments and agreements, roundtables, action plans, harmonization, research |
| 5. | Persuasive instruments Information | education, public campaigns, appeals, eco labels |

Source: Böcher and Töller (2007).

# EU Air Pollution Control Instruments, 1970-2011.

Overall, there are a total of 29 different policy instruments, the majority of which pertain to the most interventionist category, i.e. regulative instruments (51%). The two most common measures in this category are technical requirements for polluting activities (excluding transportation) and the issuance of limit values, with 72 and 40 instruments respectively. The procedural instruments are the second most common instrument type - monitoring and reporting requirements stand out the most, occupying shares of 12.1 % and 10.9 %, respectively. Overall the two explain for 80%.

| Instrument types | Number | Share of total |
|---|---|---|
| *Regulative* | 165 | 51.24 |
| Allocation of emission allowances | 4 | 1.24 |
| Approval of procedures | 2 | 0.62 |
| Implementation requirements | 19 | 5.90 |
| Limit values | 40 | 12.42 |
| Mandatory targets | 5 | 1.55 |
| National allocation plans | 11 | 3.42 |
| Restrictions (on production or trade) | 12 | 3.73 |
| Technical requirements | 72 | 22.36 |
| *Market-based* | 17 | 5.28 |
| Auctioning of allowances | 1 | 0.31 |
| Investment prescription | 1 | 0.31 |
| Premium | 1 | 0.31 |
| Tax | 1 | 0.31 |
| Trading scheme | 13 | 4.04 |
| *Procedural* | 87 | 27.02 |
| Audit | 1 | 0.31 |
| Authorization procedures | 1 | 0.31 |
| Evaluation | 4 | 1.24 |
| Monitoring | 39 | 12.11 |
| Registration requirements | 5 | 1.55 |
| Reporting | 35 | 10.87 |
| Specification of inventory system | 2 | 0.62 |
| *Co-operative* | 36 | 11.18 |
| Action plans | 13 | 4.04 |
| Adaptation of legislation | 3 | 0.93 |
| Financial support (demonstration projects) | 2 | 0.62 |
| Harmonization | 5 | 1.55 |
| Information exchange | 8 | 2.48 |
| Research and development | 5 | 1.55 |
| *Persuasive* | 17 | 5.28 |
| Access to information | 7 | 2.17 |
| Labelling | 9 | 2.80 |
| Training | 1 | 0.31 |
| **Sum** | 322 | 100.00 |

Source: Own illustration based on data obtained from EUR-Lex (2011)

# International Treaties Have Reduced Hazardous Waste.

**Basel Convention**

1992 – in effect

1995 amendment – bans all transfers of hazardous wastes from industrialized countries to less-developed countries

2012 – ratified by 179 countries, but not the United States

2000 – delegates from 122 countries completed a global treaty

Control 12 persistent organic pollutants (POPs)

Include DDT, PCBs, dioxins

Discovered that everyone on earth has POPs in blood

2000 – Swedish Parliament law

By 2020 ban all chemicals that are persistent and can accumulate in living tissue

Norway, Austria, and the Netherlands: Committed to reduce resource waste by 75%

# Actors and their Roles in P2.

| Actor | Role |
|---|---|
| The company<br>• employers<br>• employees | • responsibility and internal control<br>• prevention teams and organization<br>• change in work routines<br>• participation and influence |
| The network of the company<br>• consultants<br>• suppliers<br>• educational institutions<br>• trade unions | • cleaner working procedures<br>• cleaner process technologies<br>• changes in design and construction<br>• clean technologies<br>• learn prevention strategies<br>• new courses and further training<br>• working conditions versus environment<br>• 'cleaner' wage-bargaining system<br>• diffusion of knowledge about prevention |
| The authorities<br>• municipality<br>• central government | • green wastewater plan<br>• health and safety<br>• environmental certification<br>• trade agreements/action plans<br>•initiate methods of promoting clean technologies |
| The public<br>• citizen<br>• media | • motivation to prevention<br>• information<br>• change of consumer behaviour and debate |

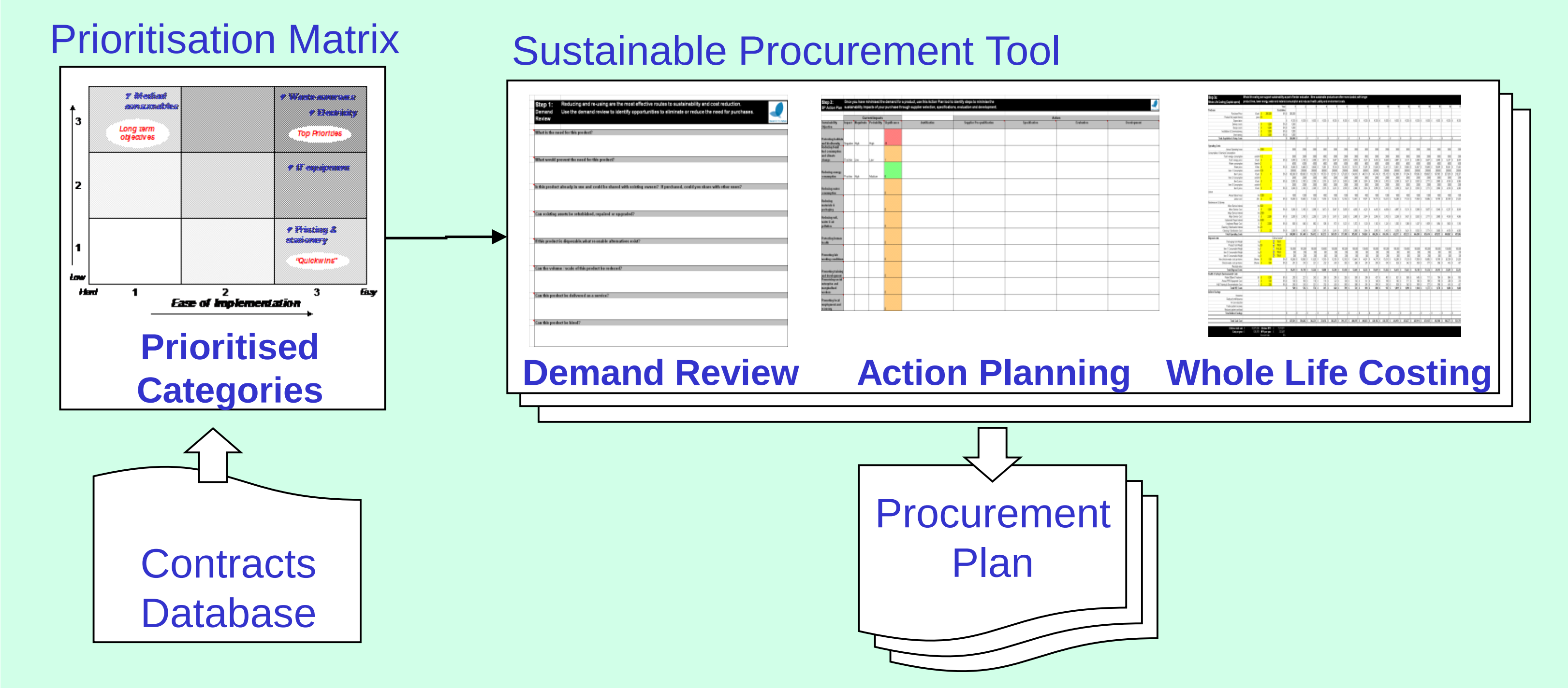
# Process Elements for P2.

- Change input materials
- Technology change
- Good house keeping
- Product change
- On-site use
- Recycle/recovery

## Change in input materials:

- Accomplishes P2 by reducing or eliminating the hazardous materials that enter the production process. Changes in input materials can also be made to avoid the generation of hazardous wastes.

  1. material purification   2. material substitution.



# Process Elements for P2 (3).

## Technological change:

- Oriented toward process and equipment modifications to reduce waste, primarily in a production setting. Technology changes can range from minor alterations that can be implemented in a matter of days at low cost, to the replacement of processes involving large capital costs.
  - changes in the production process
  - equipment, layout, or piping changes
  - use of automation
  - changes in process conditions (e.g., flow rates, temperatures, pressures, and residence times).

# Process Elements for P2 (4).

## Good housekeeping:

- Procedural, administrative, or institutional measures that a company can use to minimize waste. Many of these measures are used in industry largely as efficiency improvements and good management practices. Good housekeeping practices can often be implemented with little cost. These practices can be implemented in all areas of the plant, including production, maintenance operations, and in raw material and product storage.

*Good operating practices include*:

- P2 programs
- management and personnel practices
- material handling and inventory practices
- loss prevention
- waste segregation
- cost accounting practices
- production scheduling

# Process Elements for P2 (5).

Product change:

- Performed by the manufacturer of a product with the intent of reducing waste resulting from a product's use.

  Product changes include:

  - product substitution
  - product conservation
  - changes in product composition.

On-site reuse:

- Recycling via use and/or reuse involves the return of a waste material either to the originating process as a substitute for an input material, or to another process as an input material.

# Waste Reduction Policy.

**Greenhouse Gases:**

- Biomass IGCC nearly zero net GHGs
- Average coal system: ~1,000 g CO2-equiv/kWh
- NGCC system: ~500 g CO2-equiv/kWh
- Today's biomass systems remove GHGs from atmosphere

**Energy:**

- Coal and natural gas: negative system energy balance
- Even neglecting the energy content of coal and natural gas, biomass systems are more energy efficient
- NGCC: natural gas extraction and losses account for 21% of total energy

**Air emissions:**

- Biomass: few particulates, $SO_2$, $NO_x$, and methane
- Coal: upstream CO and NMHC emissions lower
- NGCC: system methane emissions high

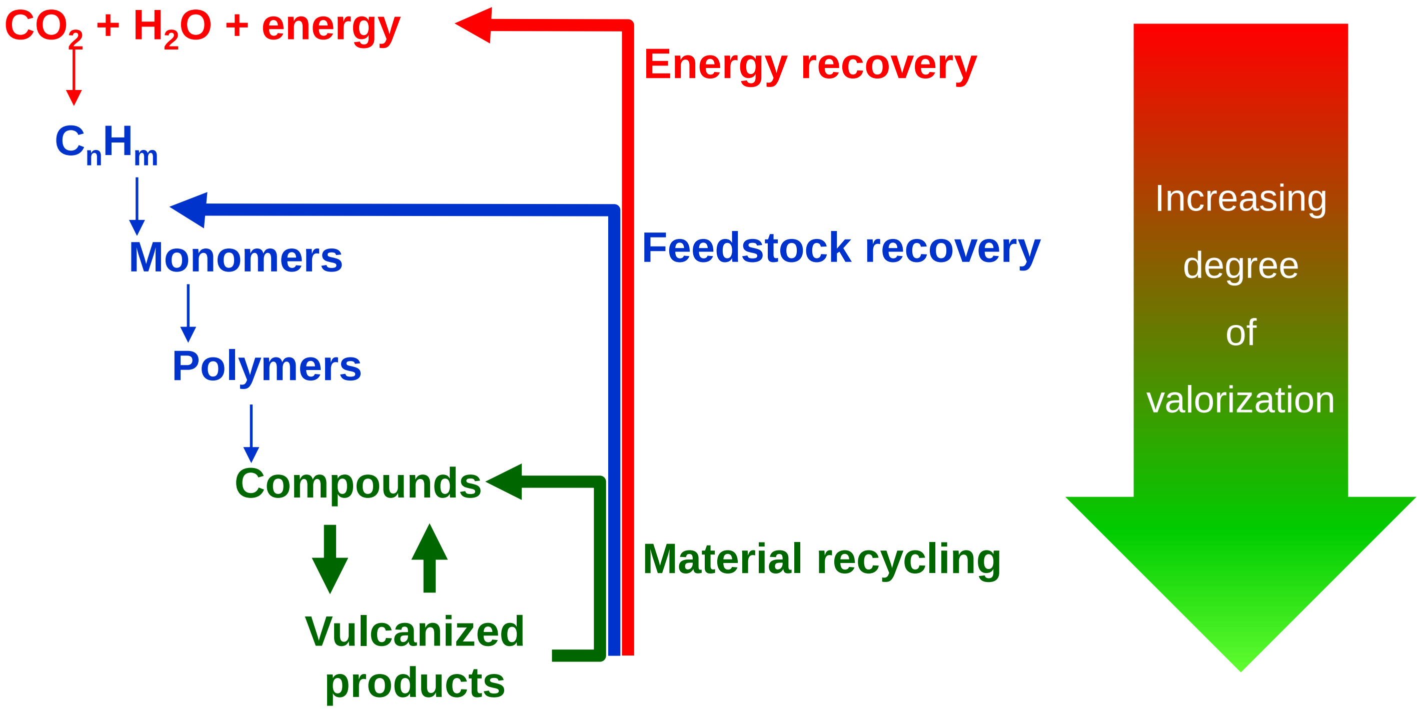
**Resource consumption:**

- Biomass systems << fossil systems

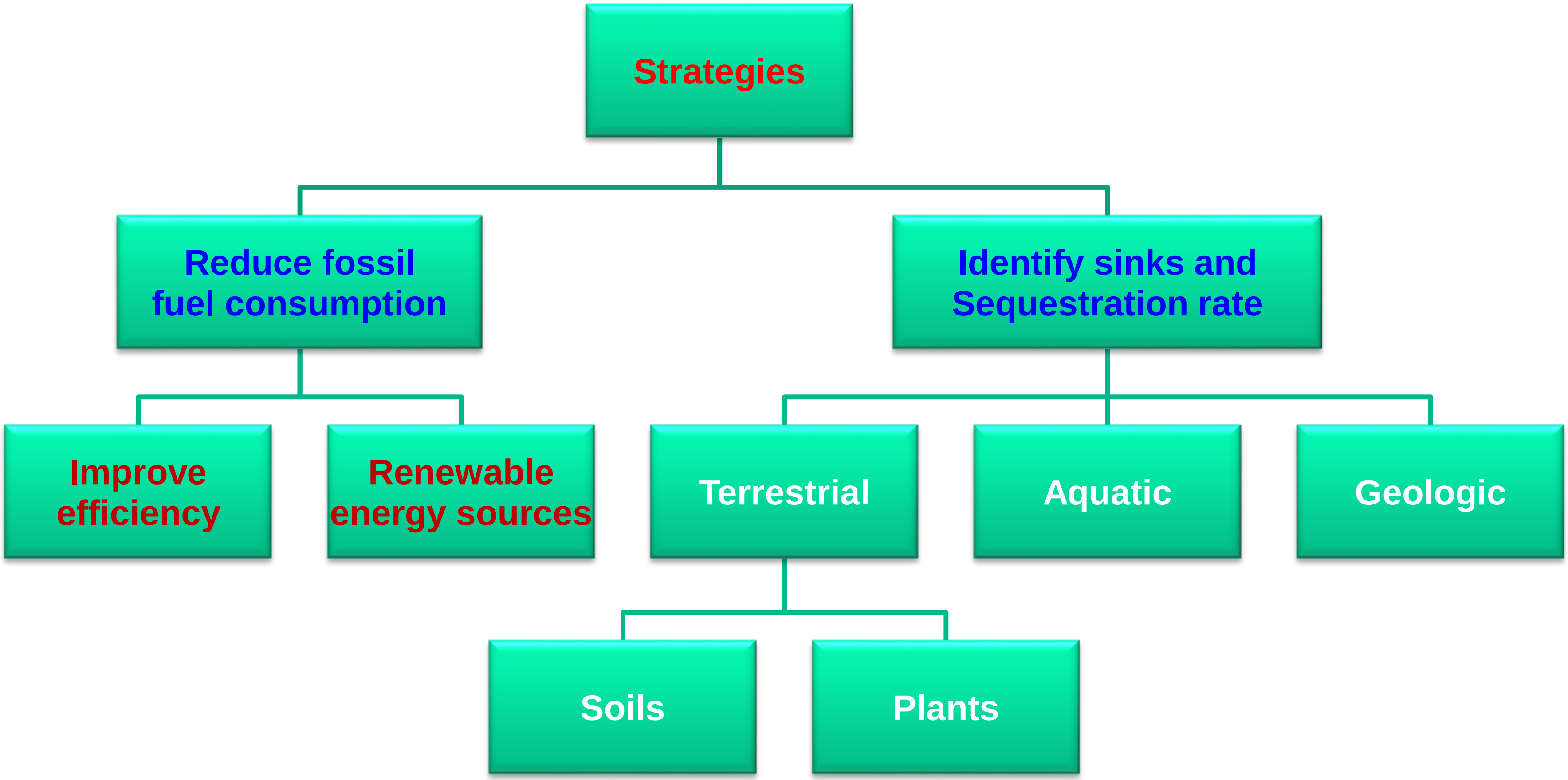
**Co-firing:**

- 15% co-firing reduces GWP of coal system by 18%
- Reduction in emissions, resource consumption, and energy use

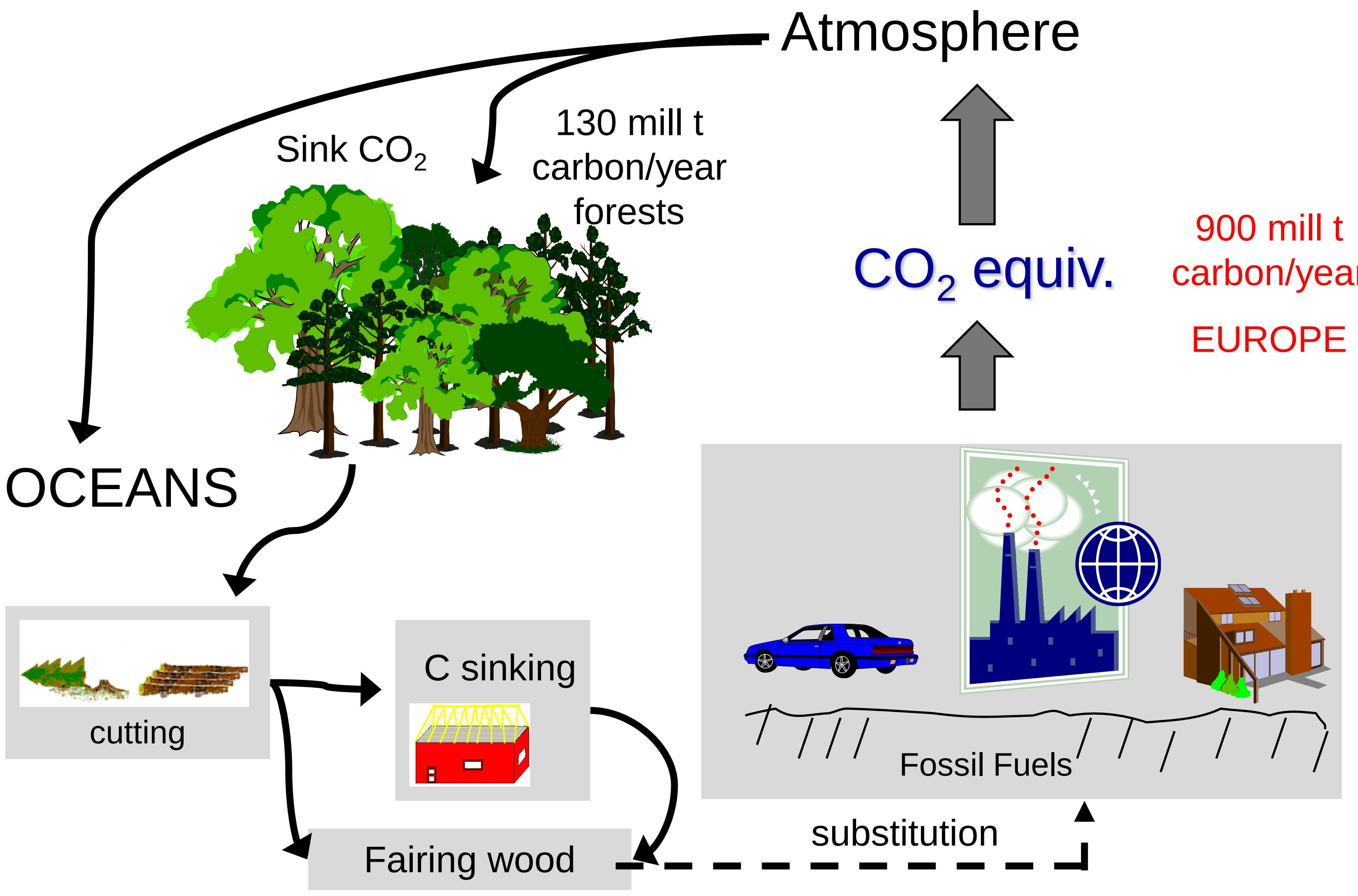
# Recycling/Recovery Valorization Chain.



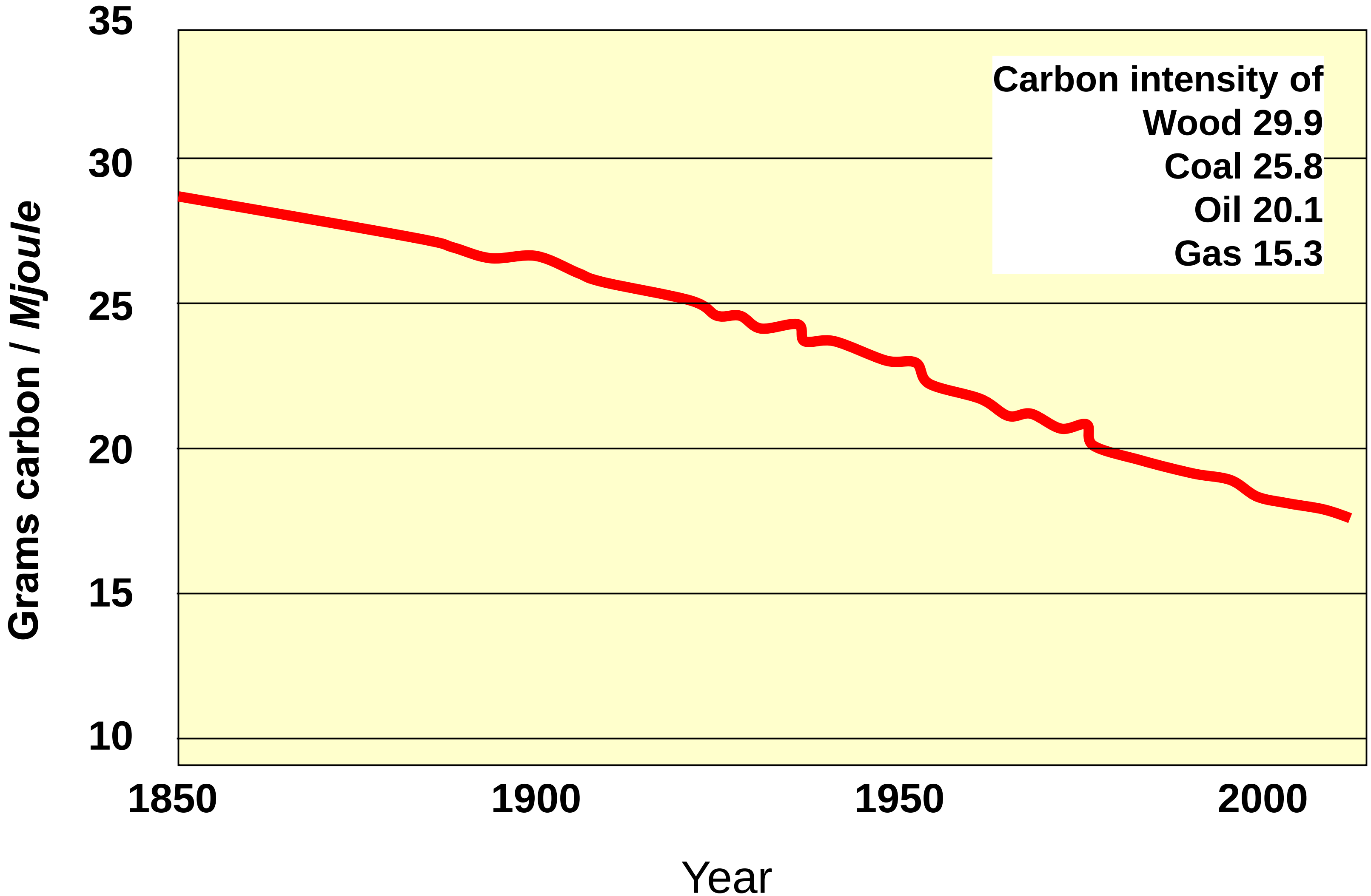
# Example of PP: Strategies to Cut down Atmospheric $CO_2$.



# Closing the Carbon Cycle.

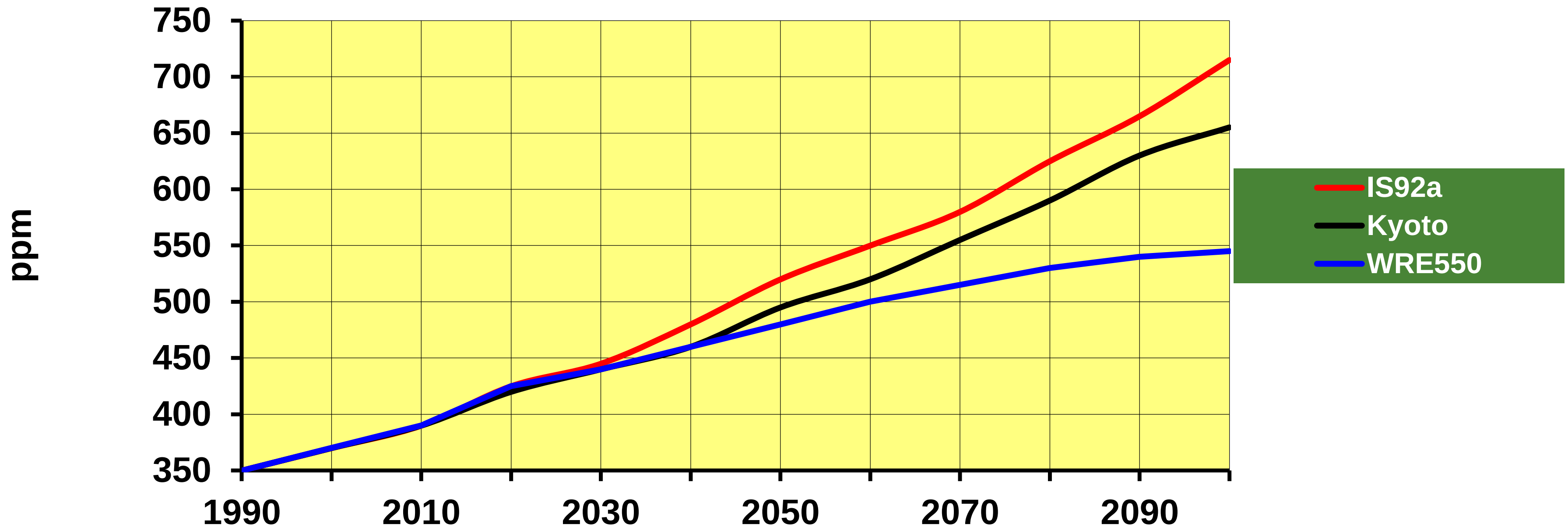


# Reducing Carbon.



# Potential Impact of Kyoto Protocol.

**Kyoto = Annex 1 Parties constant after 2010**




**Full Compliance to the Kyoto Protocol - 440 ppm**
**Non Compliance - 450 ppm at 2030**

# $CO_2$ Balance.

**Combustion**

$$\{CH_2O\} + O_2 \longrightarrow CO_2 + H_2O \qquad \Delta H = -440\ kJ$$

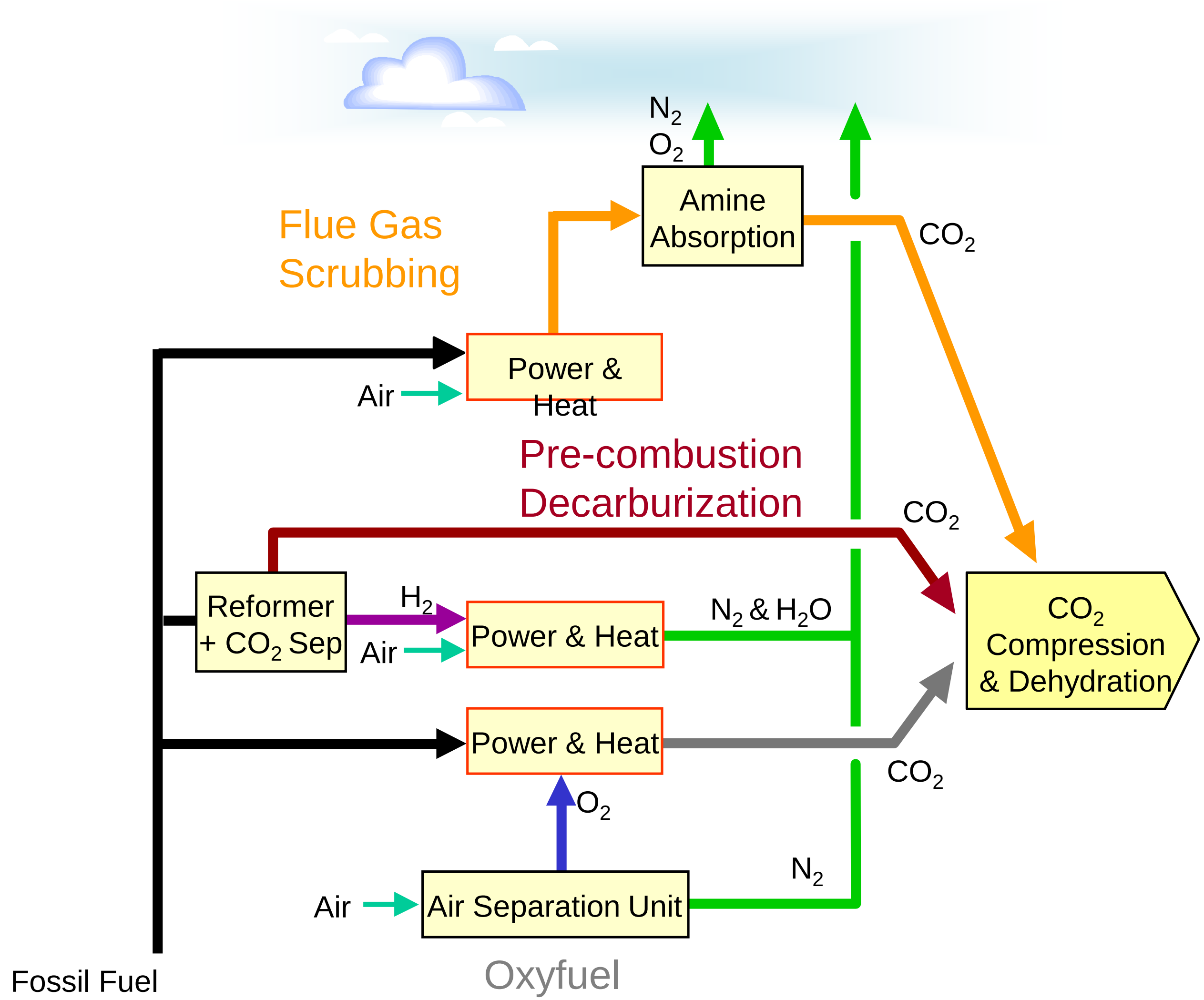
**Photosynthesis**

$$CO_2 + H_2O \xrightarrow{h\nu} \{CH_2O\} + O_2 \qquad \Delta H = +440\ kJ$$

**Closed cycle - <u>but unbalanced</u> in the production of $CO_2$.**

**Need for mitigating actions of $CO_2$ capture!**

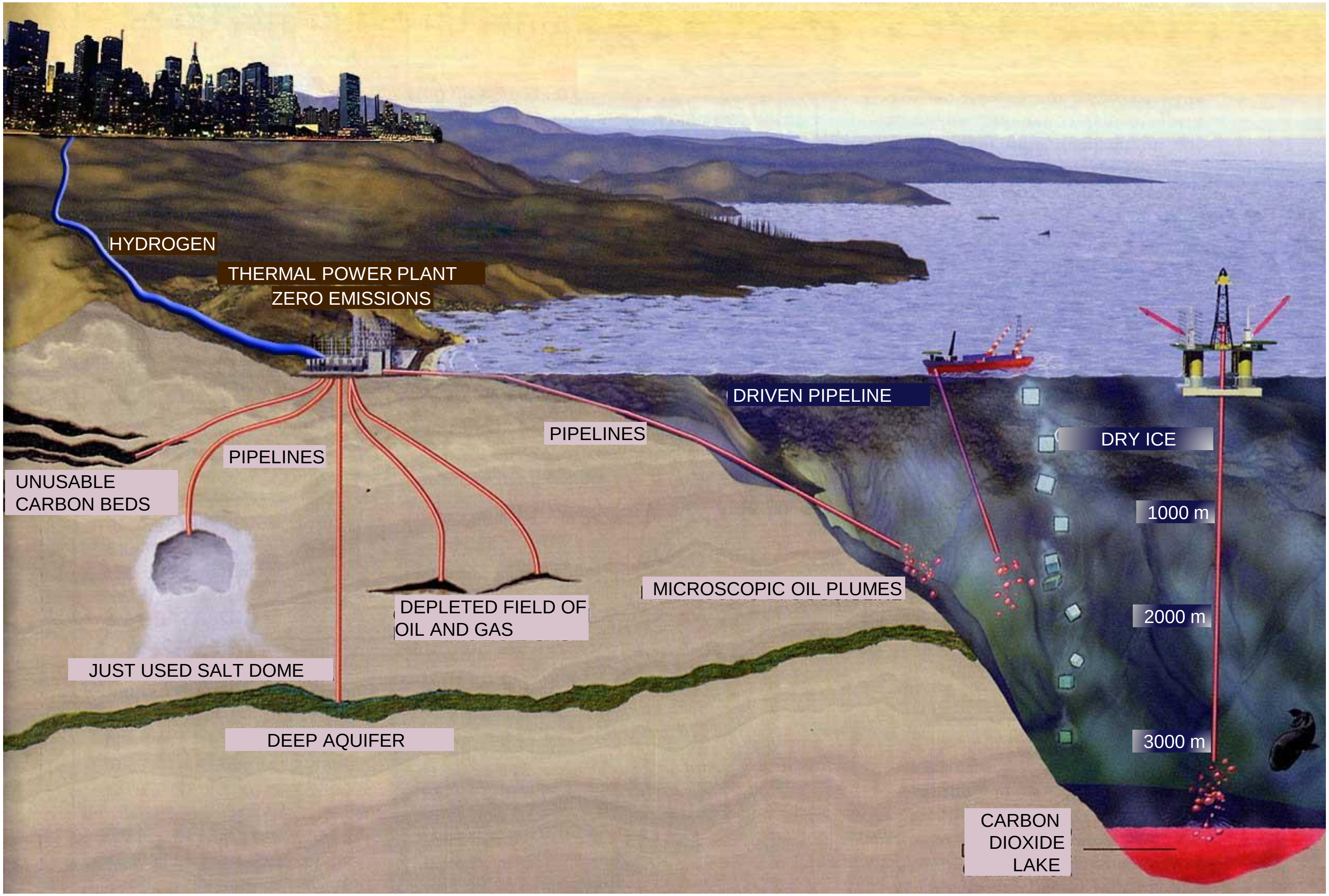
- **Biological**
- **Chemical/geochemical (pre-concentration)**
  - **Deep see**
  - **Recovery coal and petroleum**
  - **Green Chemistry**




Geologic Storage

- Enhanced Oil Recovery
- Enhanced Coal Bed Methane
- Depleted Oil/Gas Reservoirs
- Saline Formations

# $CO_2$ Possible Uses from Thermal Plants: Carbon Sequestration - Geologic Storage.



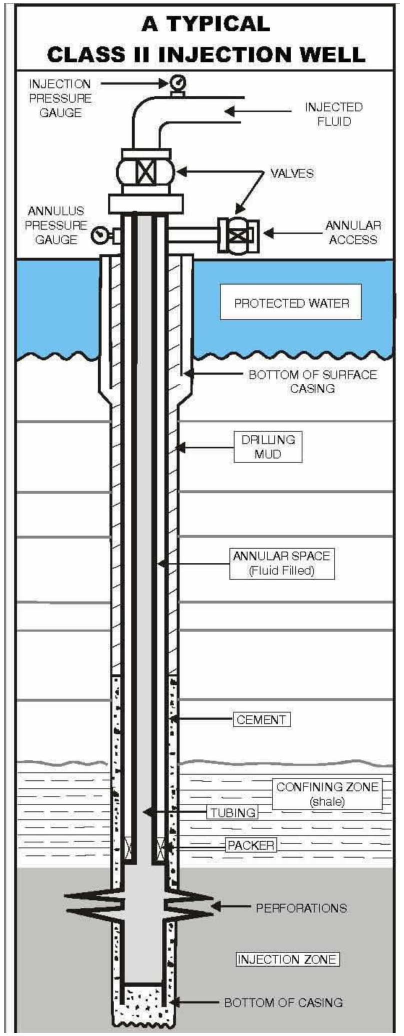
# Deep-well Disposal.

## Advantages

Safe if sites are chosen carefully

Wastes can often be retrieved

Low cost




## Disadvantages

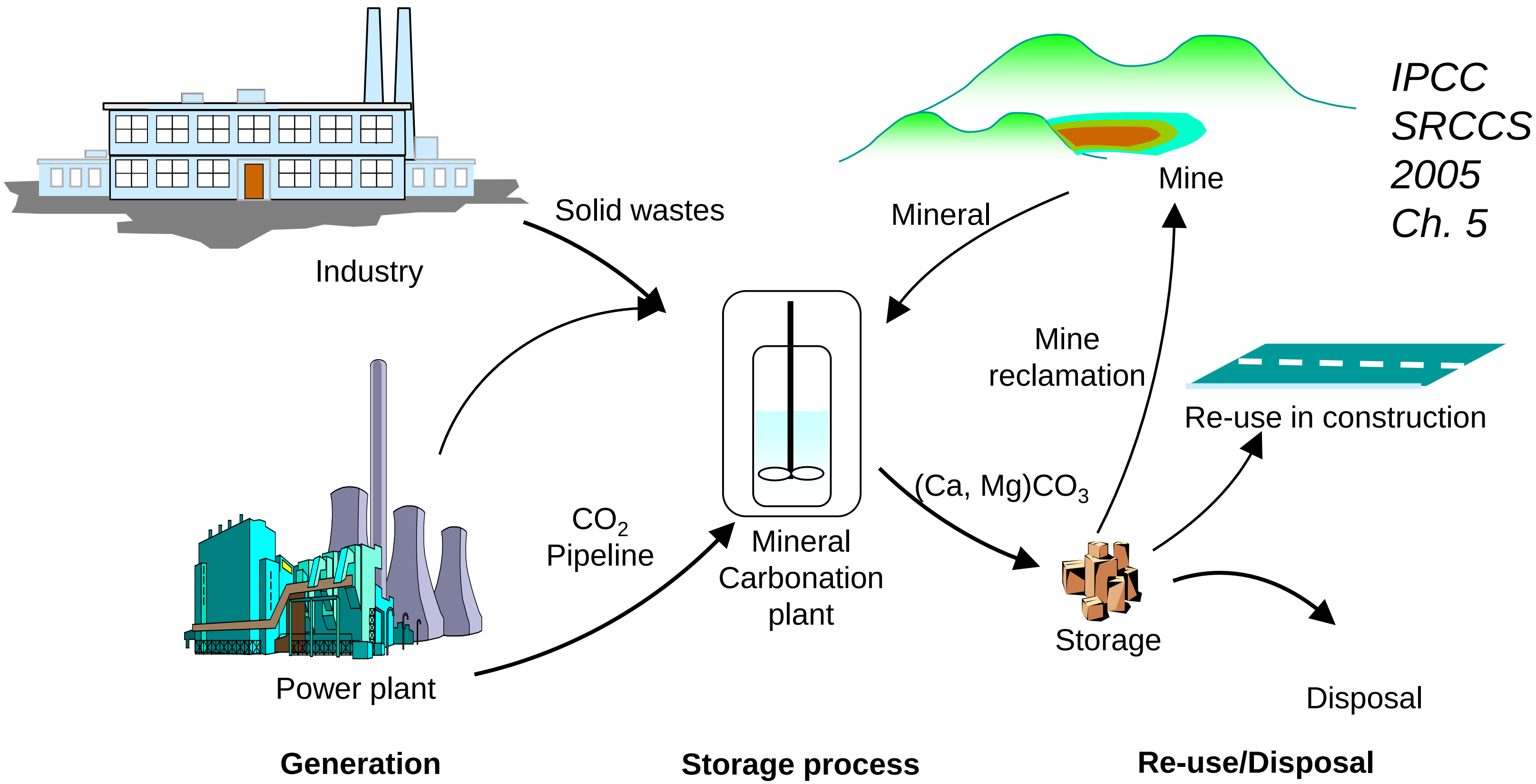
Leaks from corrosion of well casing

Emits $CO_2$ and other air pollutants

Output approach that encourages waste production

# $CO_2$ Fixation by Mineral Matter.

Alternatives in the $CO_2$ mineralization:




**Overall carbonation chemistry, with M = Mg or Ca (or Fe, …)**

$$MO\cdot ySiO_2\cdot zH_2O(s) + CO_2(g) \rightleftarrows MCO_3(s) + y\,SiO_2(s) + z\,H_2O(l) + Heat$$

# $CO_2$ Mineralization as CCS Option.

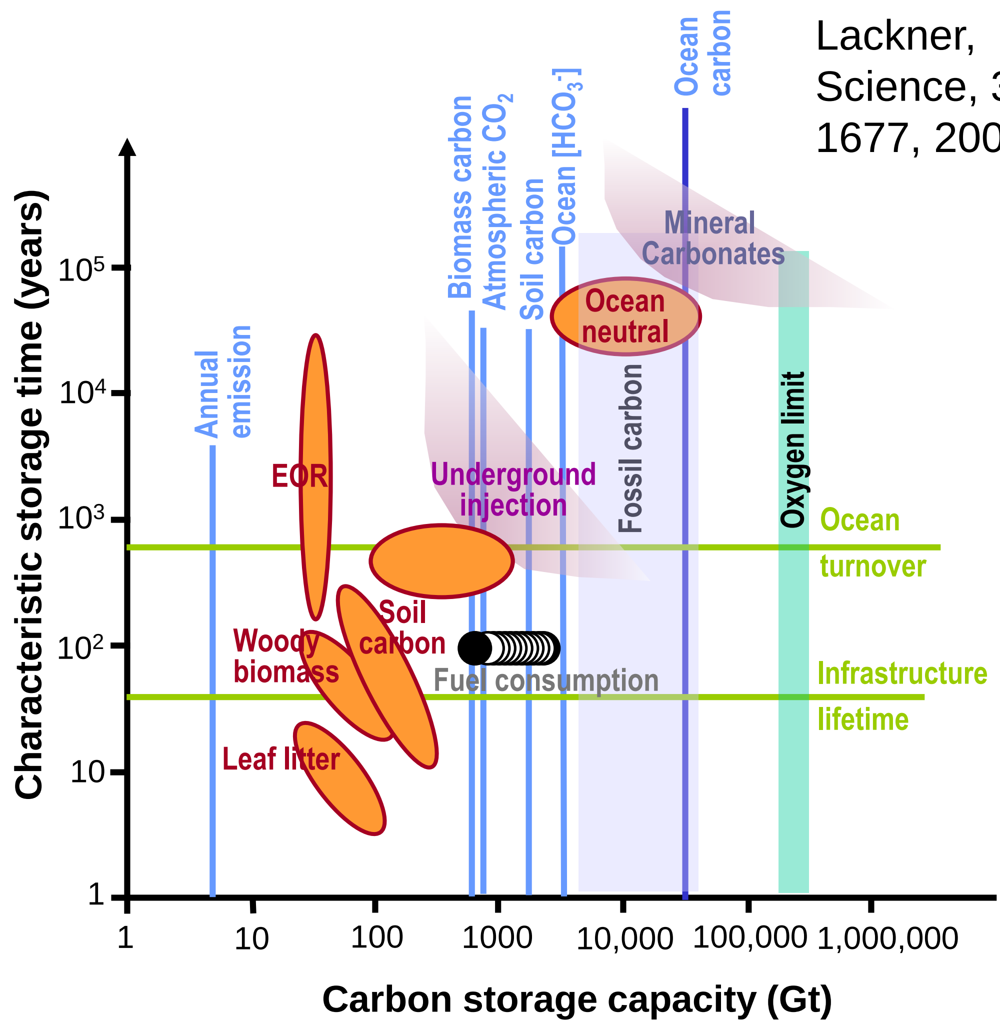
Carbon (dioxide) capture and storage (CCS) options:

- Carbon capture and geological storage (CCGS) often taken for "CCS" – *i.e. EC proposal for a directive on CCGS, 1/2008*
- Carbon capture and mineral carbonation (CCMC)
- Carbon capture and ocean storage (CCOS)
- Carbon capture and export (CCE)

- CCGS receives by far the most publicity and industrial support. Primarily from oil/gas sector
- According IEAs CCS report (2008) " It is unlikely that mineralization will offer an opportunity for sequestering large volume of $CO_2$"

# Mineralization Storage Potential.

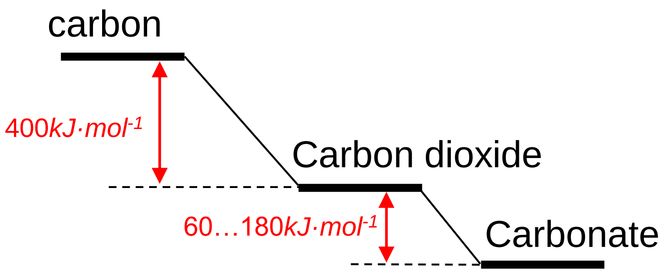
- **Much larger potential than other CCS options**
- **Could bind all fossil carbon**
- **Available word-wide, hence increasing attention**
- **No "leakage" problems from carbonates**
- **Worldwide capacity > 5000 Gt $CO_2$**




Lackner, Science, 30, 1677, 2003

# $CO_2$ Demineralization: Benefit and Limits.

- Enormous capacity, widely spread
- Negligible leakage: Dissolution produces $Mg^{2+}$ + $HCO_3^-$ ions, post-CCS monitoring not needed
- Overall exothermic chemistry; potential for energy neutral process
- A lot of iron by-product

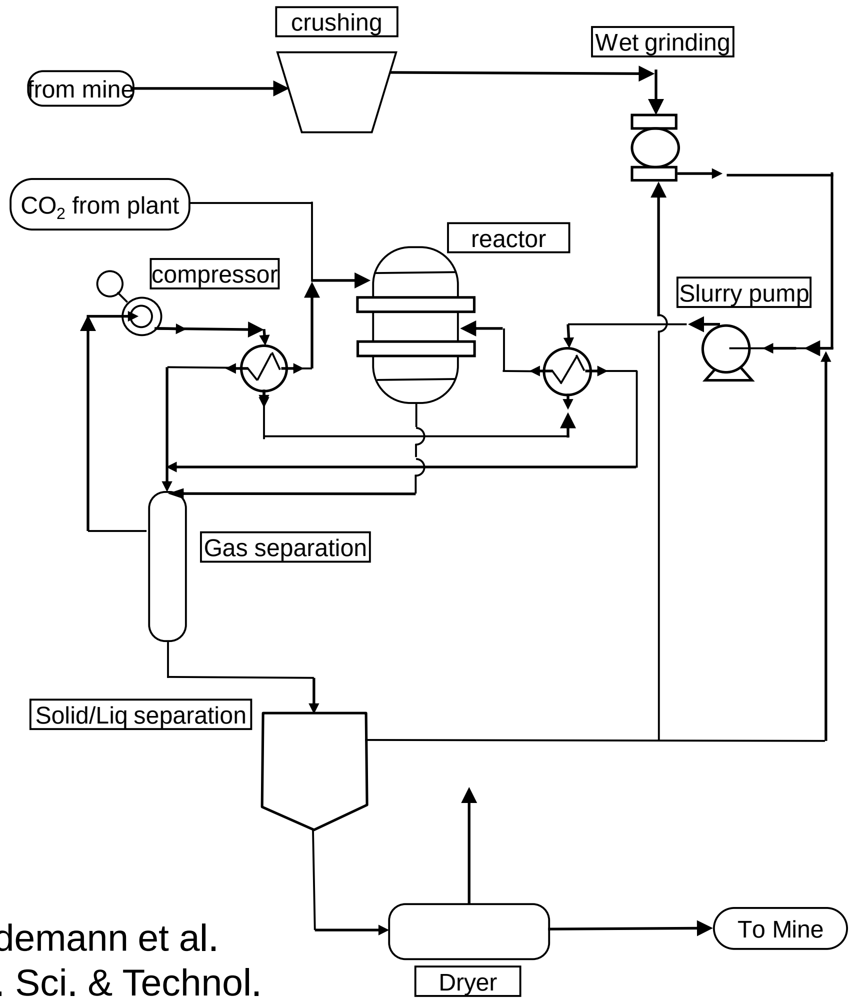



- Large amounts of materials needed: ~3 *tons* per *ton* $CO_2$, ~8 *tons* per *ton* of coal
- Product amounts large but not problematic; low value $MgCO_3$
- Slow chemistry, staged processing needed
- Slow – due to lack of manpower, funding and publicity – technology development

# $CO_2$ Mineralization: Aqueous Solution-based Process.

- *P* = 40-159 *bar*; *T* = 185°C; NaCl, $NaHCO_3$ for controlling ion strength, ….
- Costs 55-75 *US$/ton* $CO_2$
- Energy input 10-400 *kWh/ton* $CO_2$ (preheat, crush/grind)
- Increased rates with $KHCO_3$ reported
- Dissolution chemistry and silica layer still hot issues
- Note: reported energy are grossly over-estimated

**heat ≠ power !!!**



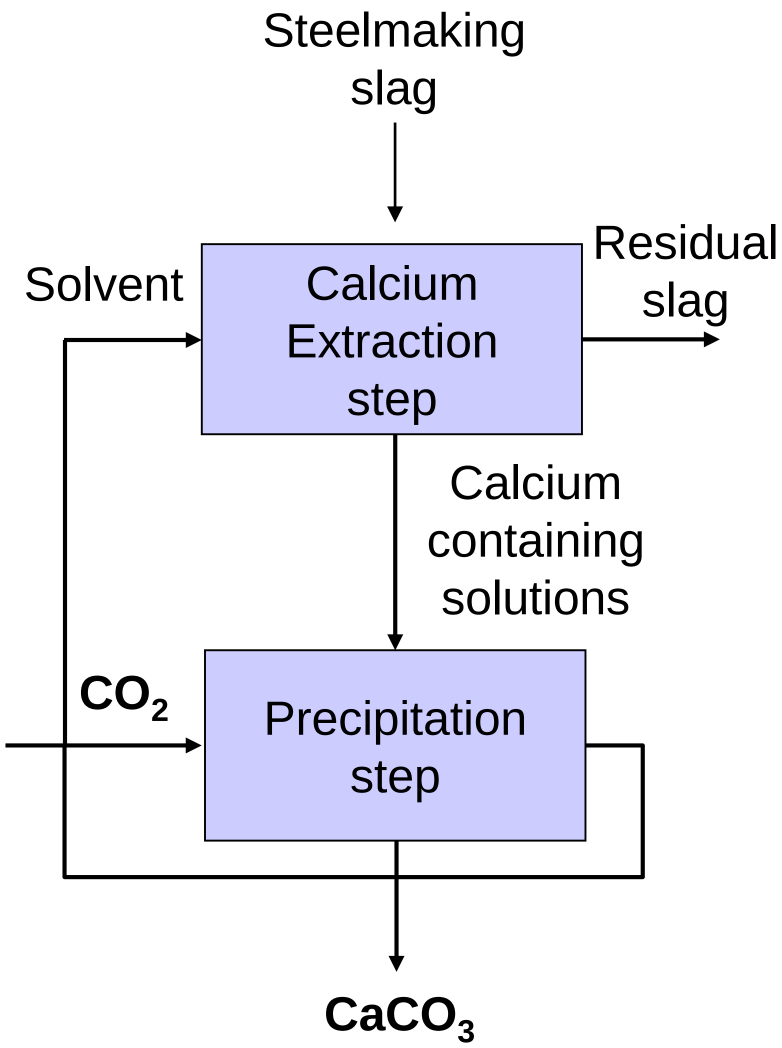

Getdemann et al. Env. Sci. & Technol. 41 (2007) 2587.

# Other Possible Technologies.

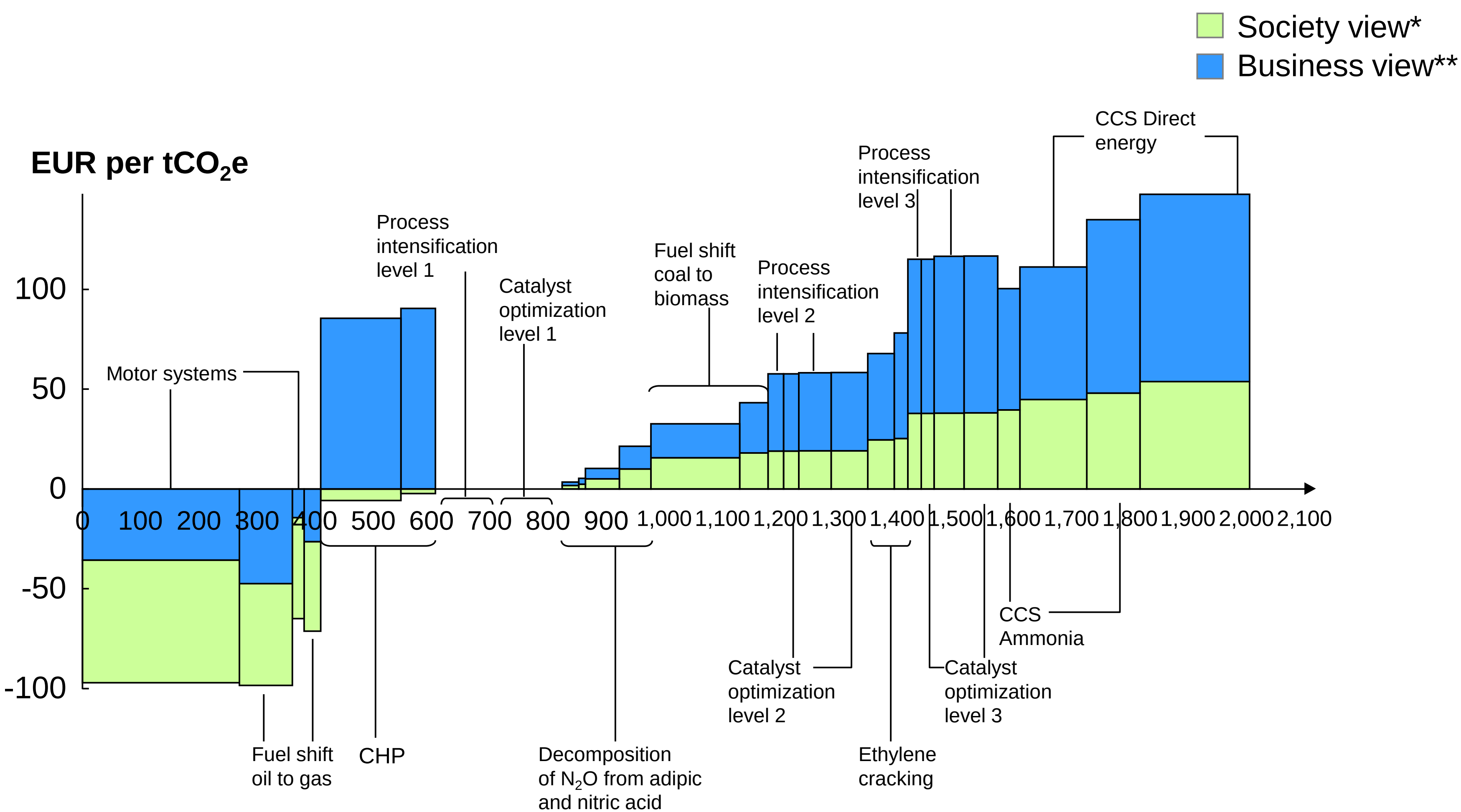
- Olivine containing rocks enhancing natural sequestration (0.1 *Mt/a* of $CO_2$ 100 ×)
- Mg,Ca-containing oil shale ash can be carbonated (10-15 *Mt/a*)
- Calcium carbonate for use in paper industry can be obtained from steelmaking slag (limited CCS potential)
- $Mg(OH)_2$ production from serpentine mineral followed by gas-solid carbonation (Finland).
- Injection of $CO_2$ into basaltic rock (Iceland)
- Spreading fine olivine powder of land and trapping $CO_2$ from air.

# Mineralization Storage Potential / 2.

- **March 2009 estimate USA: “more than 500 years of U.S. $CO_2$ production” (~7 Gt/a).**
- **Finland 2008: 200-300 years of Kyoto protocol excess ~12 Mt/a, i.e. 2.5-3.1 Gt $CO_2$ in central Finland.**
- **Worldwide capacity > 5000 Gt $CO_2$**



# GHG Abatement Cost Curve for the Chemical Industry.




Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below EUR 60 per $tCO_2e$ (society view) if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play

* 4% interest rate, depreciation over life time of equipment

** 10% interest rate, depreciation over 10 years

Source: ICCA/ McKinsey analysis

# Key Learning Points.

- Problems of waste include inefficient use of resources & capital as well as risks to welfare and the environment
- Most developed countries have waste minimization programs - recycling, energy efficiency
- At the process level, process flow sheets are invaluable in highlighting sources of waste.
- Most chemical products end up in the environment - they should be designed for recycle or degradation.