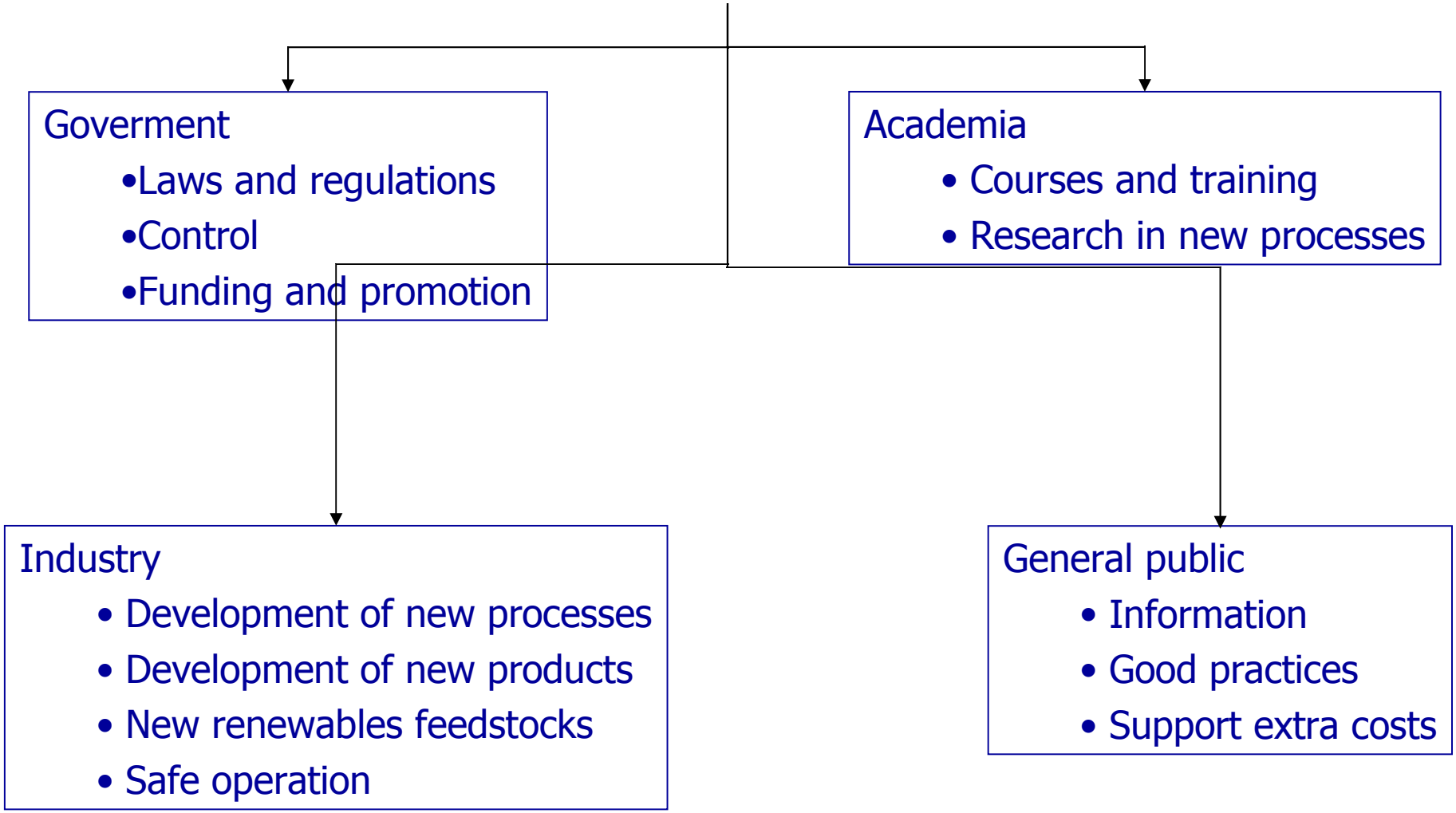
Actions aiming at Green Chemistry



The ACS/EPA Cooperative Agreement

- What is the EPA?
- What is ACS?
- EPA/ACS collaboration
  - Propose nominations to the Presidential Green Chemistry Challenge Awards Program
  - Highlights the concerns with current products and processes
  - Presents a green chemistry solution
  - Real-World Cases in Green Chemistry

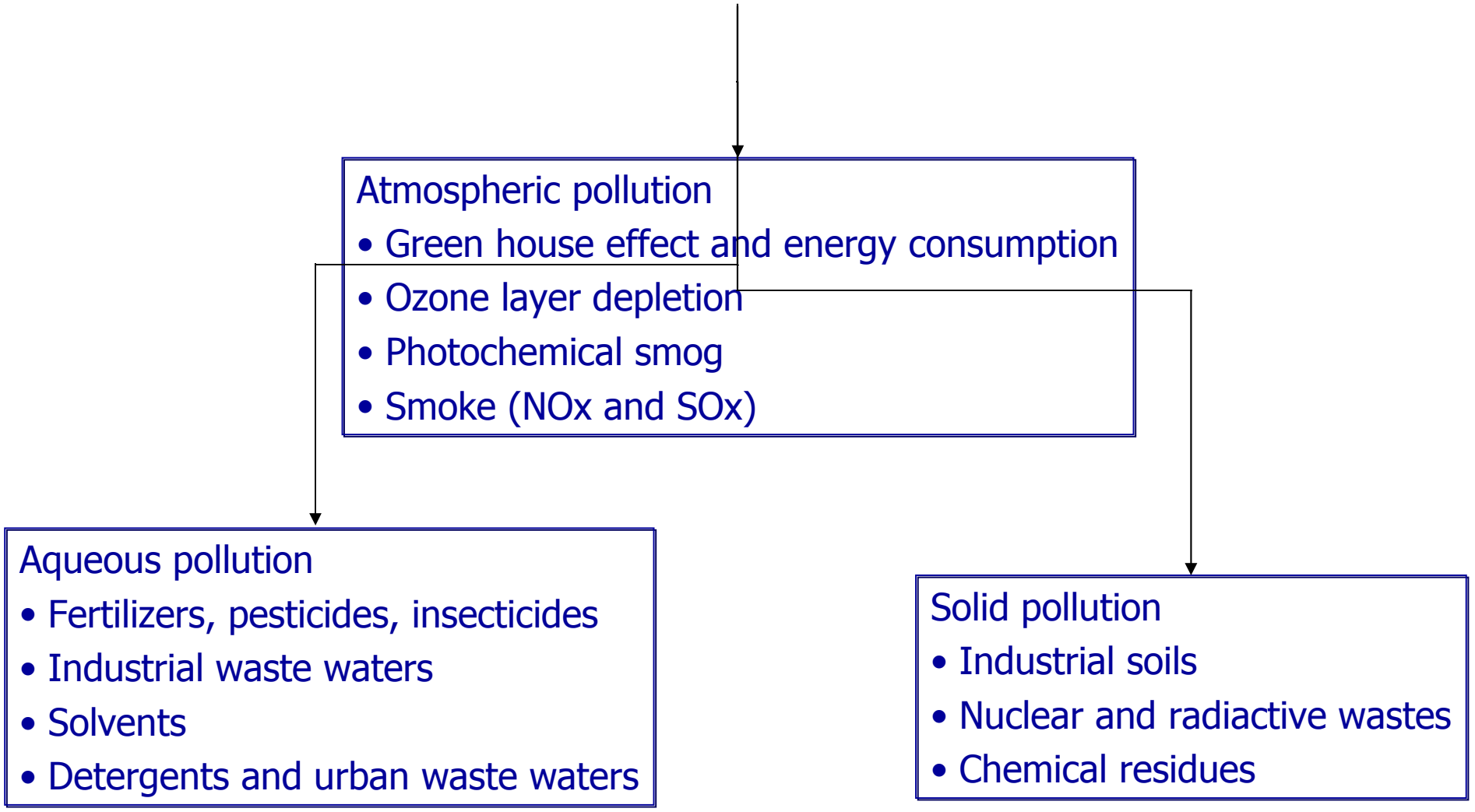
ACS Activities

- Earth Day Program
- Green chemistry in the curriculum (books)
- Green chemistry summer school
- National Chemistry Week
- Interactive Teaching Units

Europe and Japan

- Royal Society of Chemistry
- Venice (7th Summer school in green chemistry)
- Barcelona (Green Chemistry PhD course)
- European Commission (Cost Actions)
- York and other European Universities
- Japan is developing very strong initiatives

Can the Chemistry be Dirty?

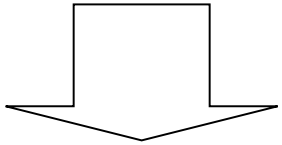


Examples of Chemical Products of the 20th Century

- Thalidomide.
- DDT.
- CFCs.
- Endocrine disruptors.
- Bioaccumulating substances.
- Persistent/non-biodegradable materials.

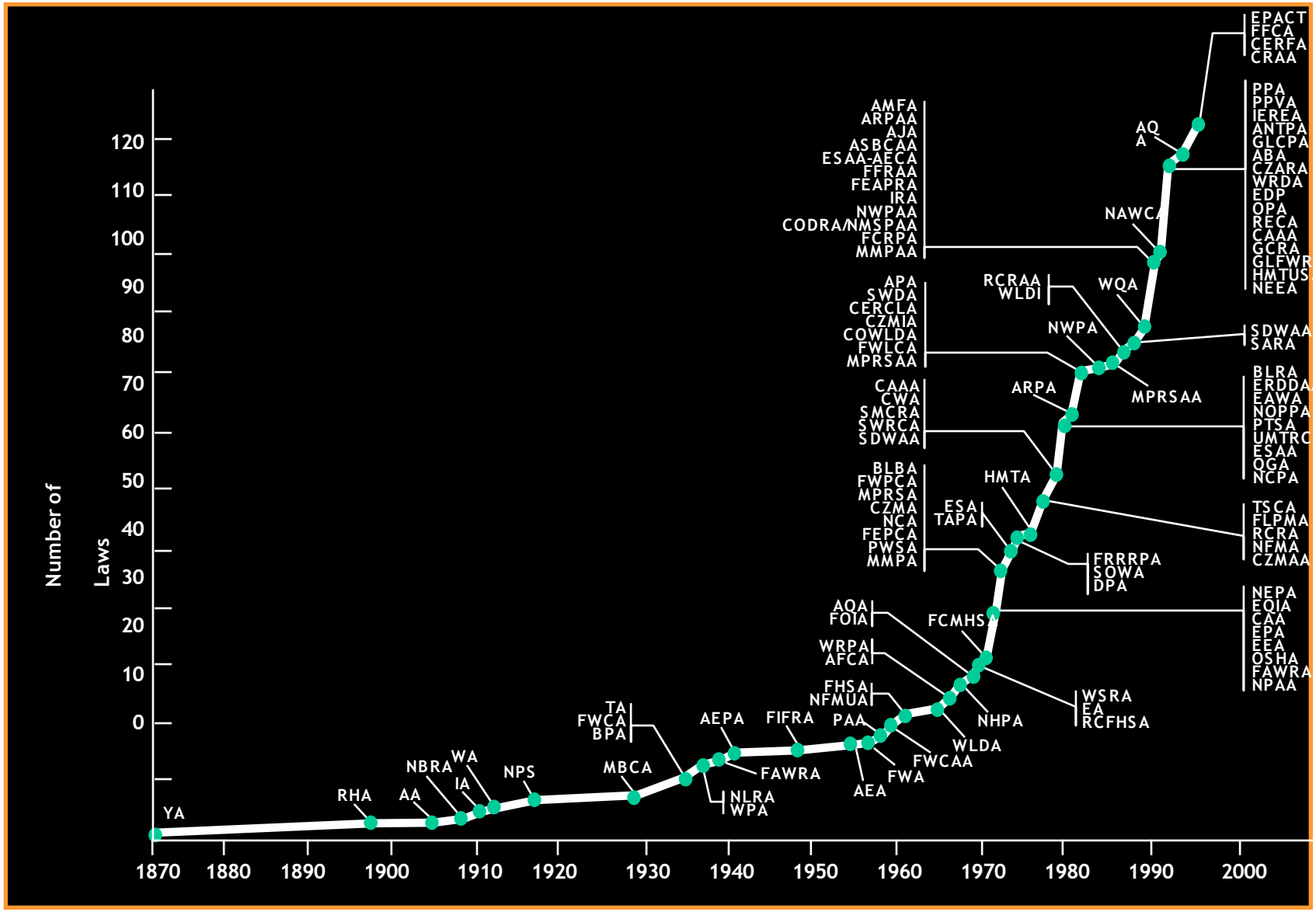
Why the chemistry is dirty?

- Provides energy
- Provides materials (plastics, paper, etc)
- Provides commodities (sprays, detergents, paints, dyes)
- Provides fertilizers, insecticides, pesticides
- Provides drugs and pharmaceuticals



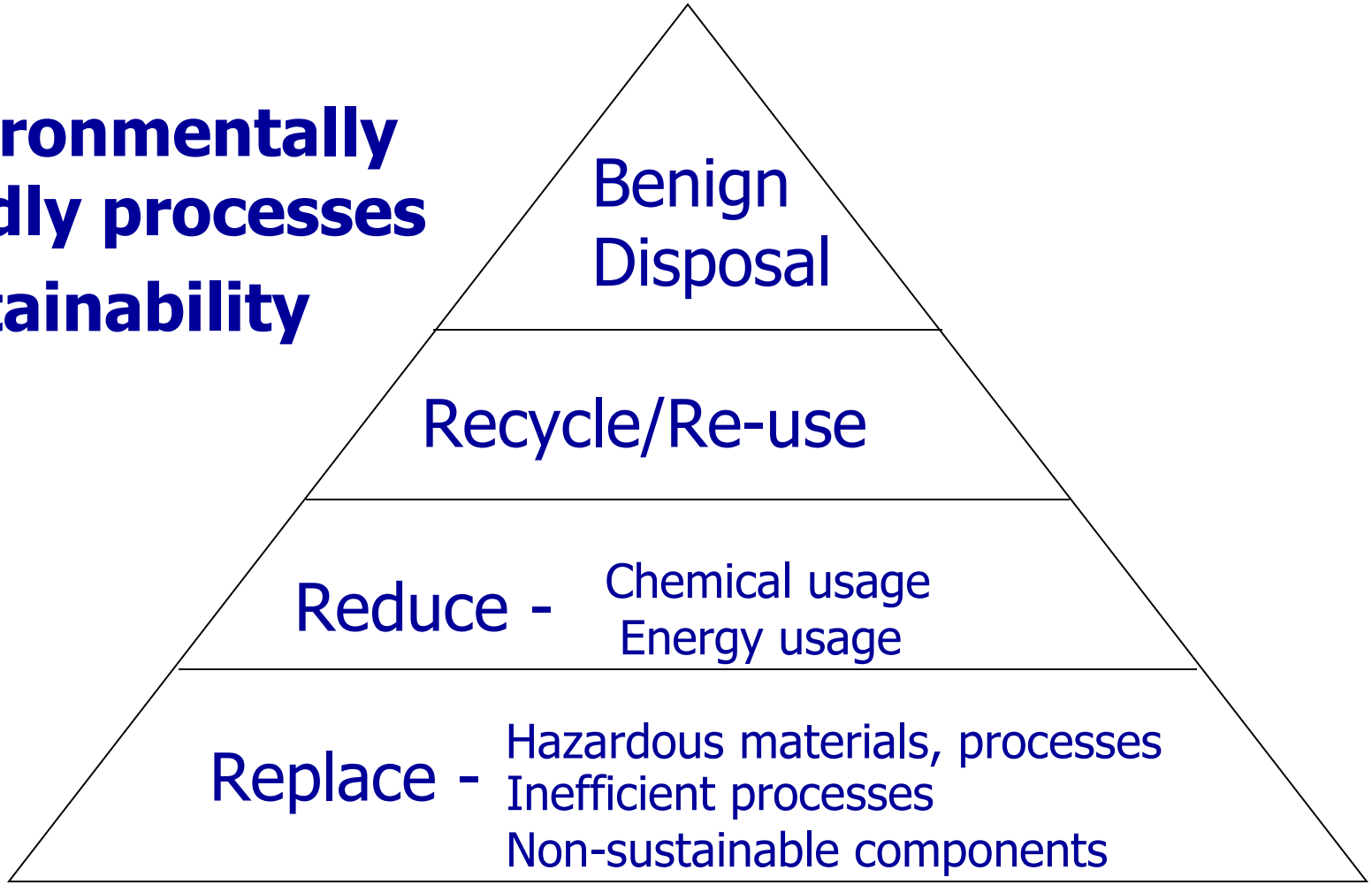
- Social demand
- Social complain

Growth of Legal Regulation



What is Green Chemistry?

- **Environmentally friendly processes**
- **Sustainability**



Green Chemistry Technologies and Solutions

- What is Green Chemistry?
  - Chemistry to provide commodities being environmentally friendly and sustainable
- How do we know what is Green?
- A dip into the Clean/Green technology Pool with some examples.

How do we know what is Green?

Metrics in Green Chemistry

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science" William Thompson, Lord Kelvin, (1891)

"If you don't keep score then you are only practising"

Metrics in Green Chemistry

How do we know what progress we are making?

⇒ E - Factor

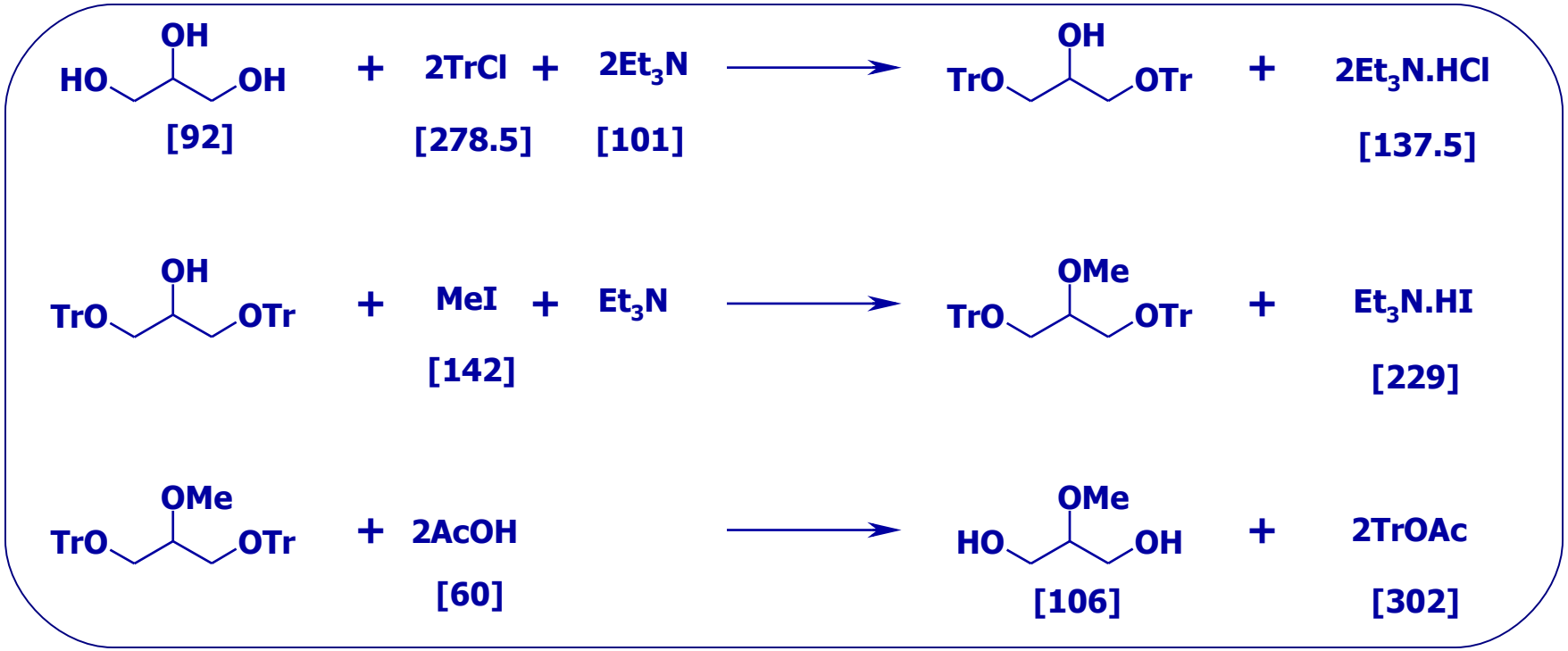
Amount of waste/kg product:

	Product tonnage	E Factor
Bulk Chemicals	10^4-10^6	<1 - 5
Fine chemical Industry	10^2-10^4	5 - >50
Pharmaceutical Industry	10-10^3	25 - >100

R.A. Sheldon, *Chem & Ind,* **1997**,*12*

Metrics in Green Chemistry

Preparation of 2-methoxypropane-1,3-diol from glycerol

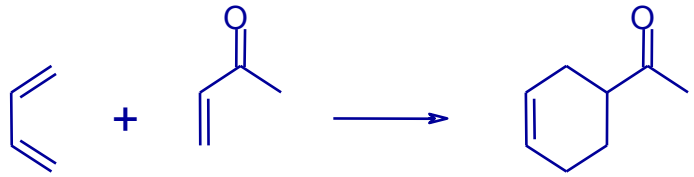


Assuming 100% yields, no reaction or work-up solvents and no reagent excesses 1 kg glycerol produces 1.15 kg 2-methyl ether and 12.04 kg of waste!

Atom Economy

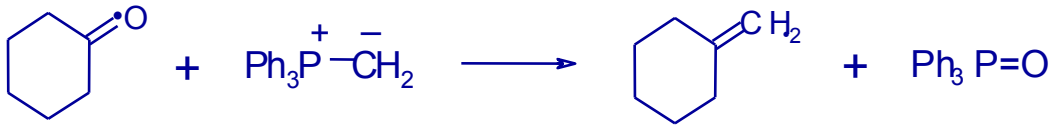
$$\text{Atom economy} = \frac{\text{MW of desired product}}{\Sigma\ \text{MWs of all substances produced}}$$

- **Diels-Alder Reaction**



100% Atom economy

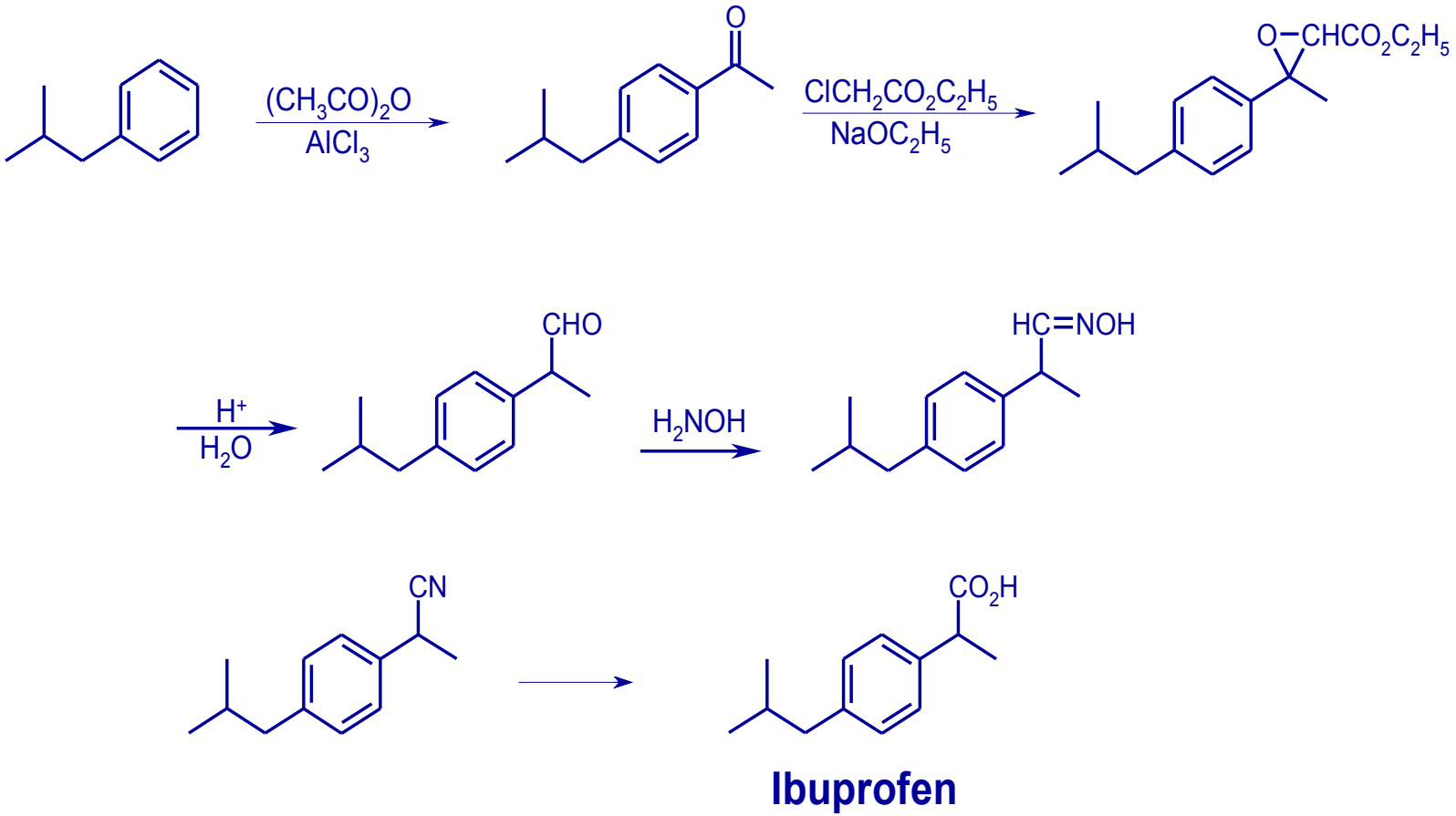
- **Wittig Reaction**



35% Atom economy

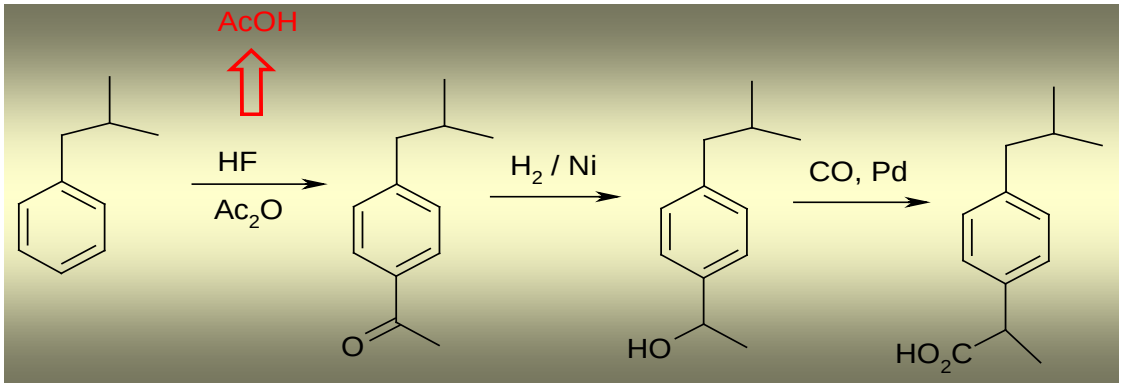
Pharmaceutical Applications

Traditional synthesis of ibuprofen



Ibuprofen

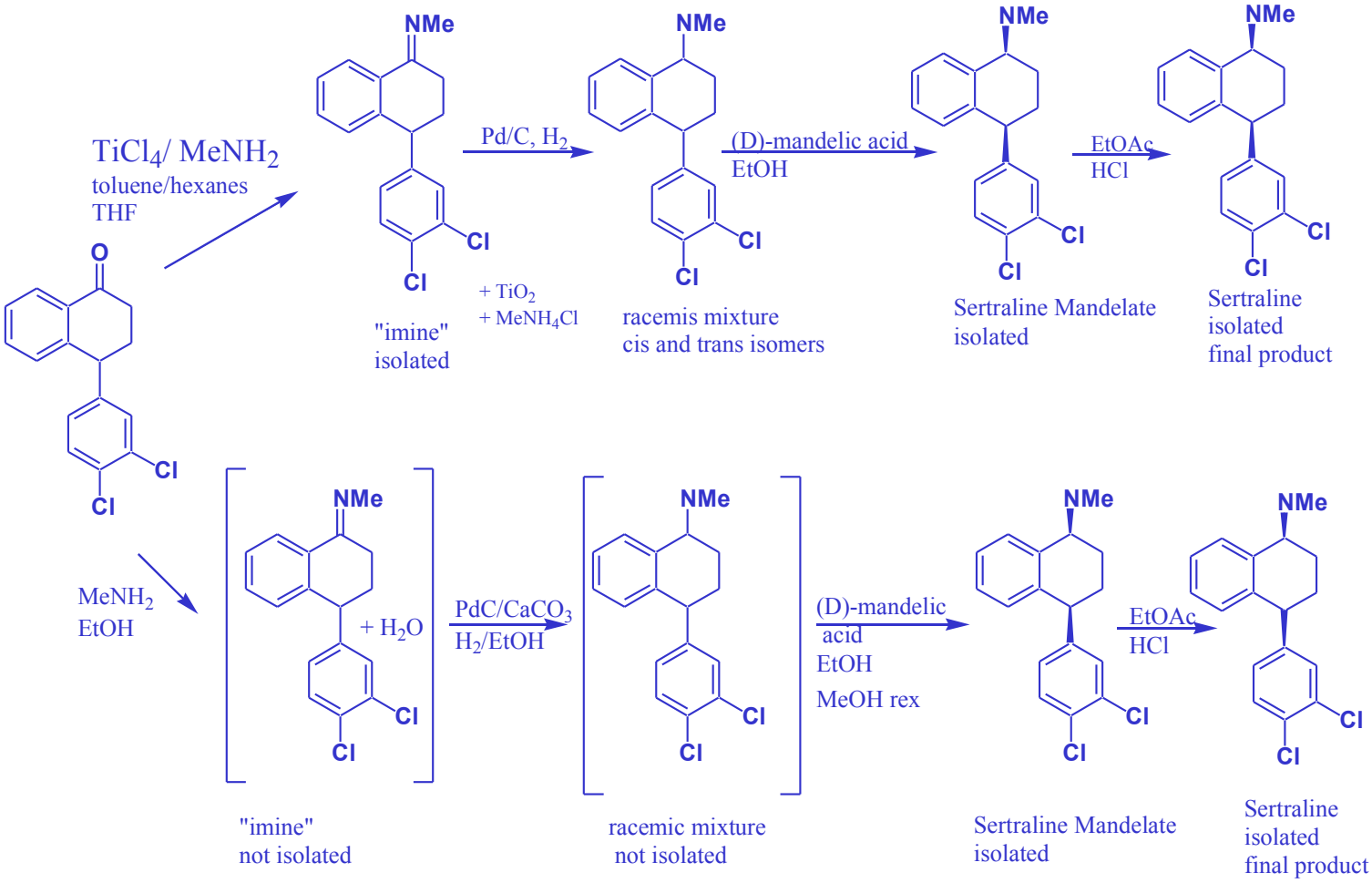
Boots & Hoechst Synthesis of Ibuprofen – Green Route



Developed to improve production:

* 3 steps
* No solvents
* Catalytic vs. stoichiometric reagents
* Recycling, reuse and recovery of byproducts and reagents (**acetic acid >99%; HF >99.9%)**

Redesign of the Sertraline Process



Alternative Synthetic Pathways

- Sodium iminodisuccinate
  - Biodegradable, environmentally friendly chelating agent
  - Synthesized in a waste-free process
  - Eliminates use of hydrogen cyanide

Bayer Corporation and Bayer AG

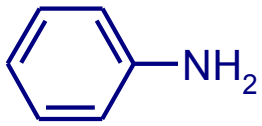
2001 Alternative Synthetic Pathways Award Winner

New Chemistry: Synthesis of 4-ADPA

Monsanto's new route: rubber antidegradant

130,000 M tonnes/annum

Starting Material: Aniline



Traditional Chemistry

Organo-halogens used.

Hazardous Solvent used.

High Waste levels.

Green Chemistry

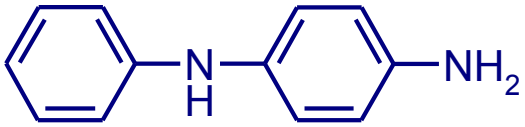
Safer.

No Organo-halogens.

Waste Minimised -74% less organic, 99% less water.

Reusable catalyst employed.

Reduced Cost.



Product: 4-ADPA