GREEN CHEMISTRY

SLIDE 3

PRINCIPLES OF GREEN CHEMISTRY (CONT.)

3. Prevention or Minimization of Hazardous Products

1. Hazardous product is Toxic or environmentally harmful.
2. The effect of hazardous substances if formed may be minimised for the workers by the use of protective clothing, engineering controls, respirator etc. This, however, adds to the cost of production.
3. It is found that sometimes the controls can fail and so there is much more risk involved.

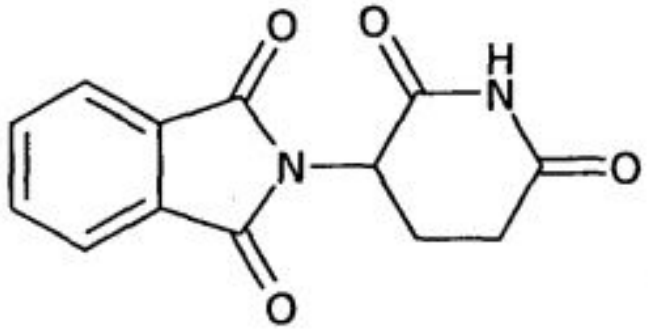
CHEMICAL SAFETY

- Transfer chemicals carefully!
- Keep lids on chemical containers when not in use
- When diluting an acid, pour the acid into water
- Consider **all** chemicals dangerous

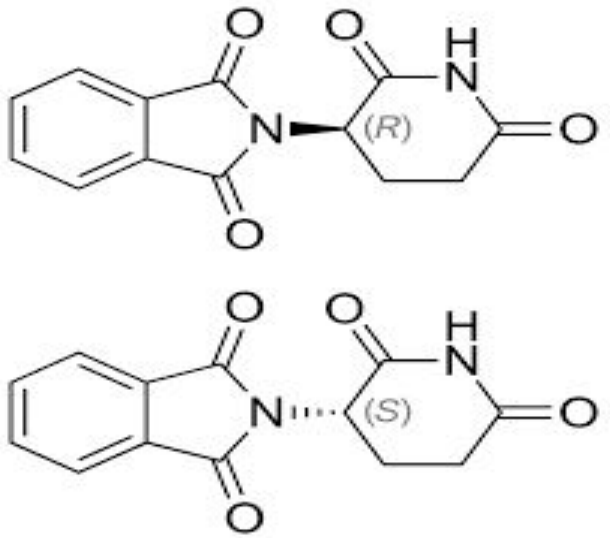
4. Designing Safer Chemicals

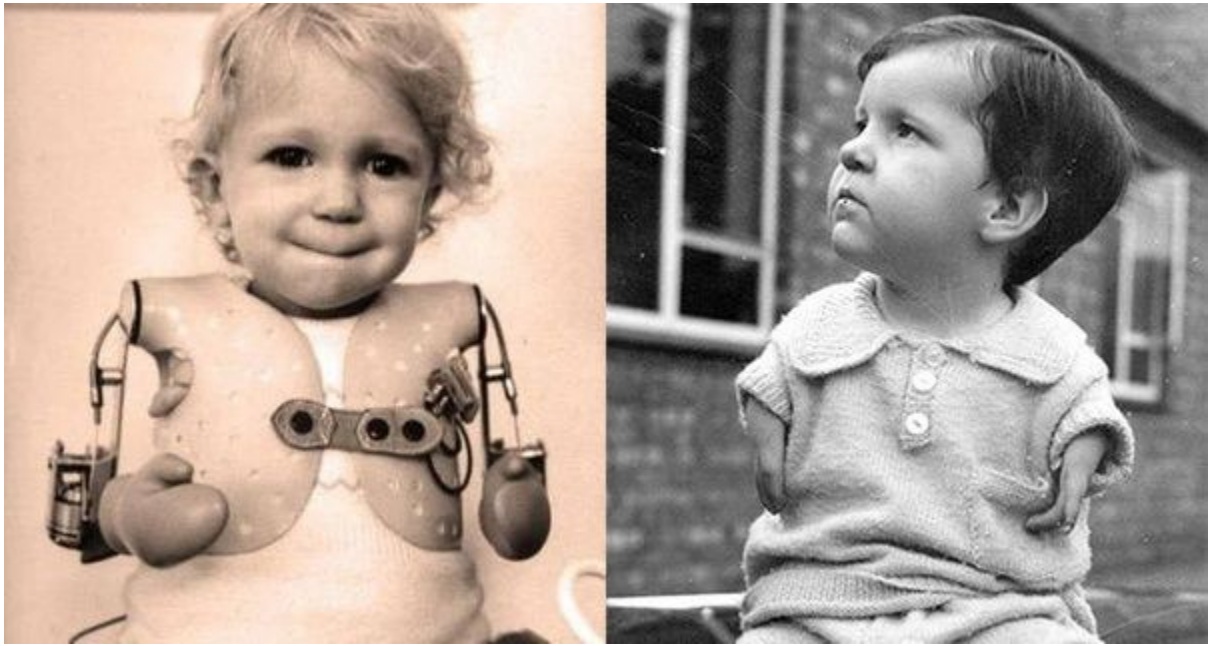
Chemical products should be designed to preserve efficacy of function while reducing toxicity.

Thalidomide (introduced in 1961) for lessening the effects of nausea and vomiting during pregnancy (morning sickness).

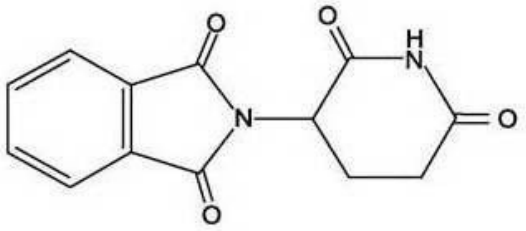


Thalidomide

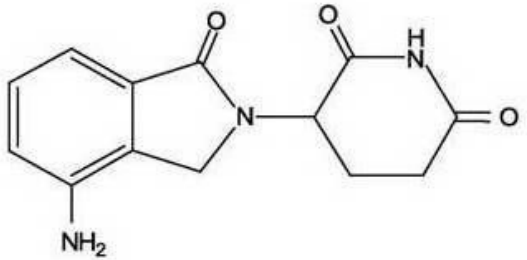




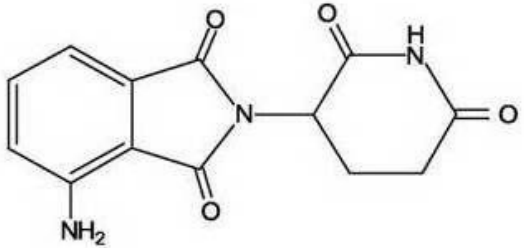
Thalidomide: 2-(2, 6-dioxopiperidin-3-yl)-1*H*-isoindole-1, 3(2*H*)- dione



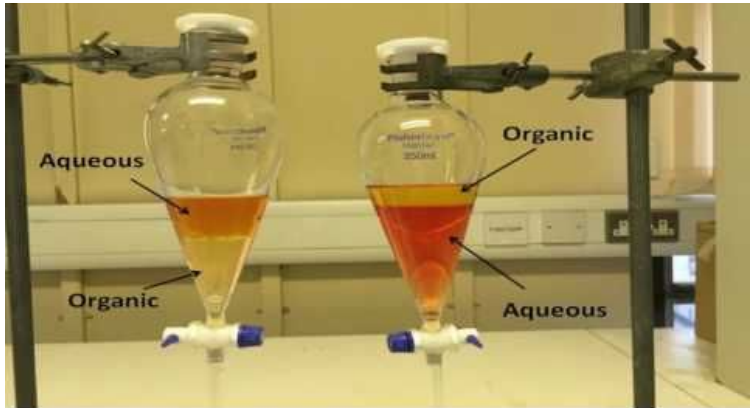
Lenalidomide: 3-(4-amino-1-oxo 1, 3-dihydro-2*H*-isoindol-2-yl) piperidine-2, 6-dione

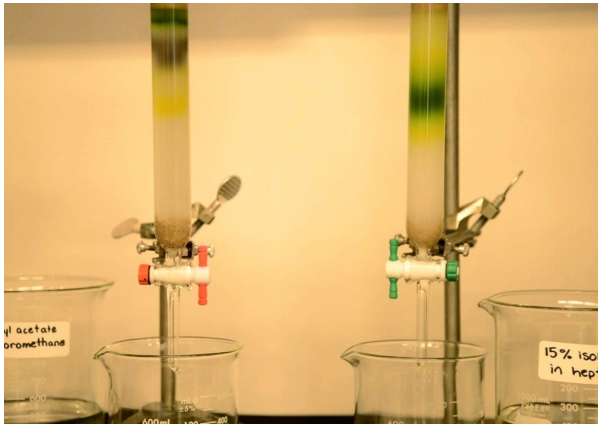


Pomalidomide: 4-Amino-2-(2, 6-dioxopiperidin-3-yl) isoindole-1, 3-dione



5. The use of auxiliary substances (eg. solvents, separating agents) should be made unnecessary wherever possibles and innocuous when used.

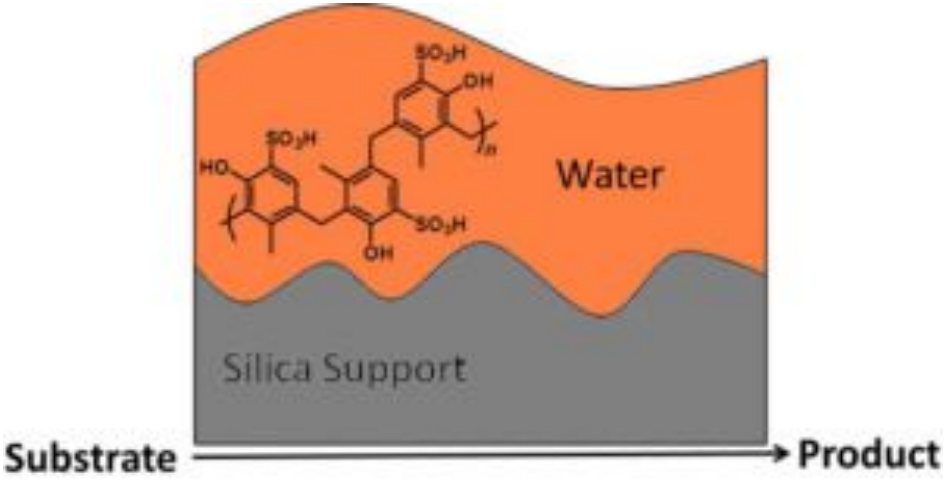




SELECTION OF APPROPRIATE SOLVENT

1. Use of **immobilised solvents**. The immobilised solvent maintains the solvency of the material, but it is non-volatile and does not expose humans or the environment to the hazards of that substance. This can be done by tethering the solid molecule to a solid support or by binding the solvent molecule directly on to the backbone of a polymer.
2. The use of liquid or **supercritical liquid** CO2 should be explored.
3. If possible, the reaction should be carried out in **aqueous phase** or without the use a of solvent (**solventless reactions**).

Supercritical liquid as a solvent (CO_2)



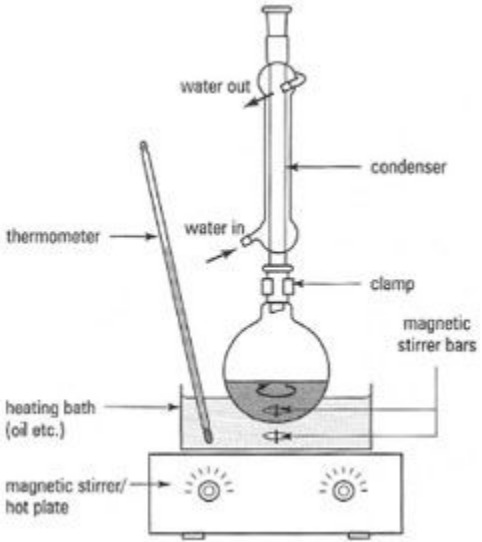
Salient features: low cost; easy to prepare; high efficiency; good recyclability and diverse applications in catalysis.

6. Design for Energy Efficiency

Energy requirements of chemical processes should be recognised for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

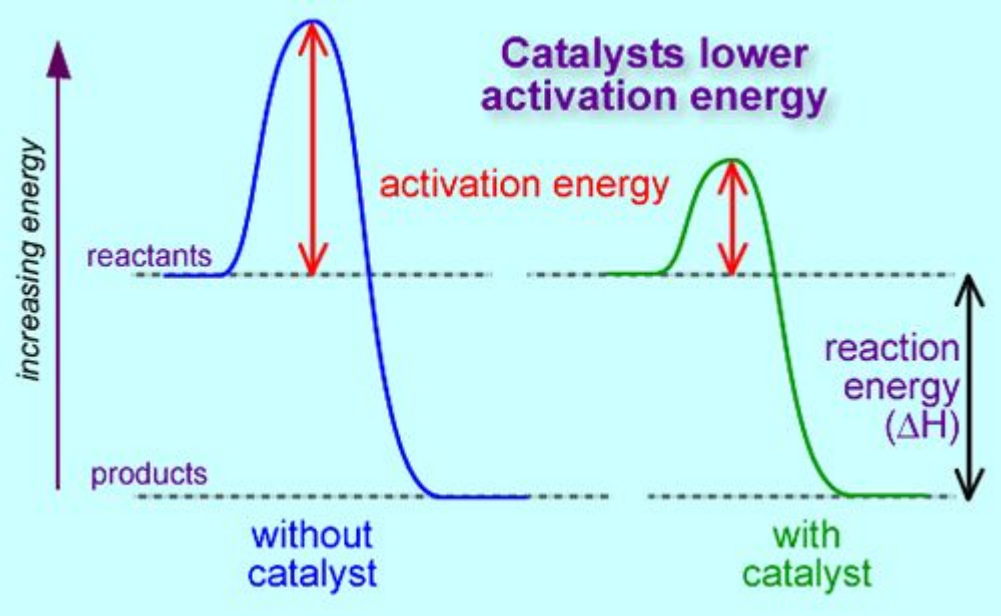
Challenges faced

- The reaction mixture has to be heated to **reflux** for the required time or until the reaction is complete. There is a lack of analysis of what heating requirements are during the design of a synthesis.



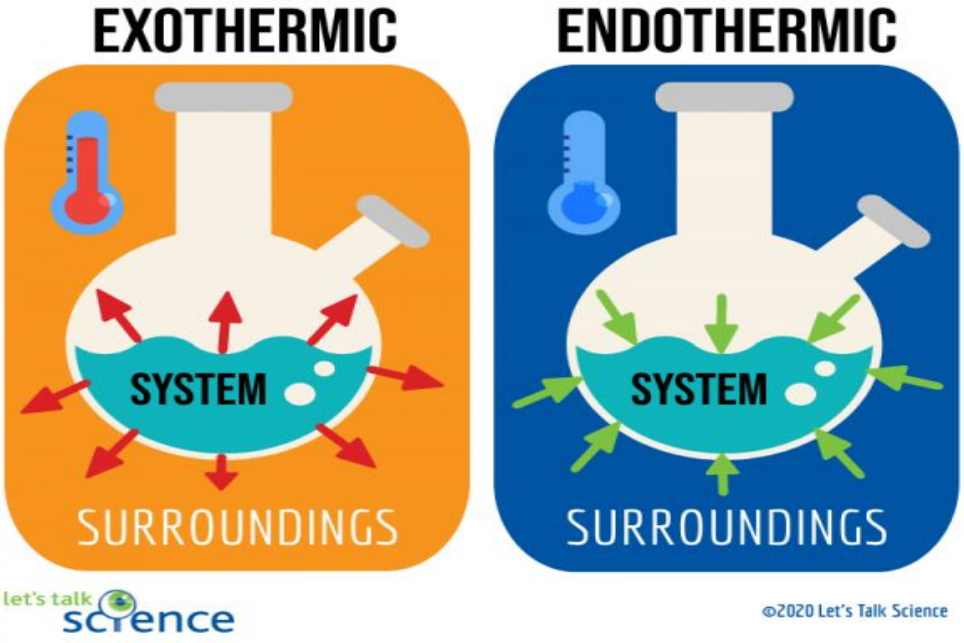
In case reaction is driven to its thermodynamic product, it generally requires the use of thermal energy achieved through heating in order to overcome energy barrier. How energy barrier can be reduced?

CATALYST

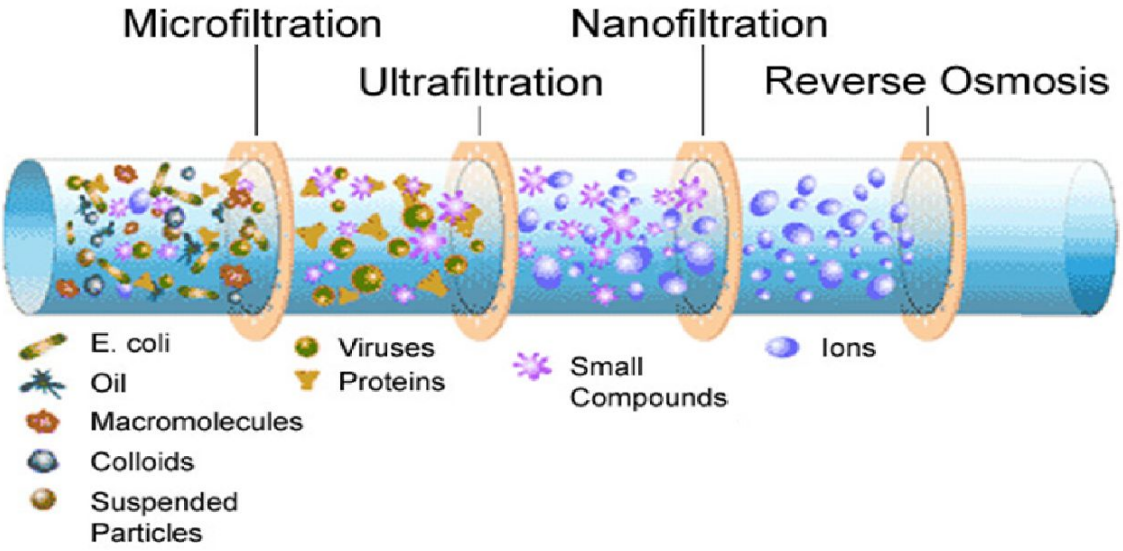

Catalysts lower activation energy
activation energy
increasing energy
reactants
products
reaction energy (ΔH)
without catalyst
with catalyst

HOW TO LOWER ENERGY IF REACTION IS EXOTHERMIC?

Extensive cooling is required.



If the final product is impure, it has to be purified by distillation, recrystallisation or ultrafiltration.



DRAWBACKS

All these steps involve the use of energy. By designing the process such that there is no need for separation or purification, the final energy requirements can be kept at the bare minimum.

Energy to a reaction can be supplied by photochemical means, microwave or sonication.

SONICATION

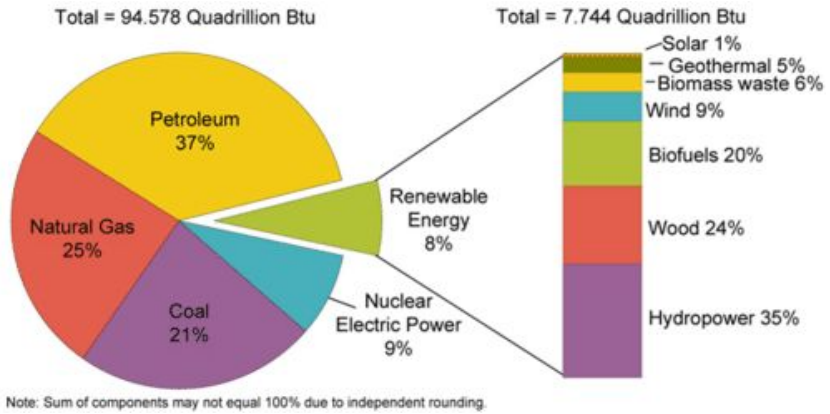
7. Selection of Starting Materials

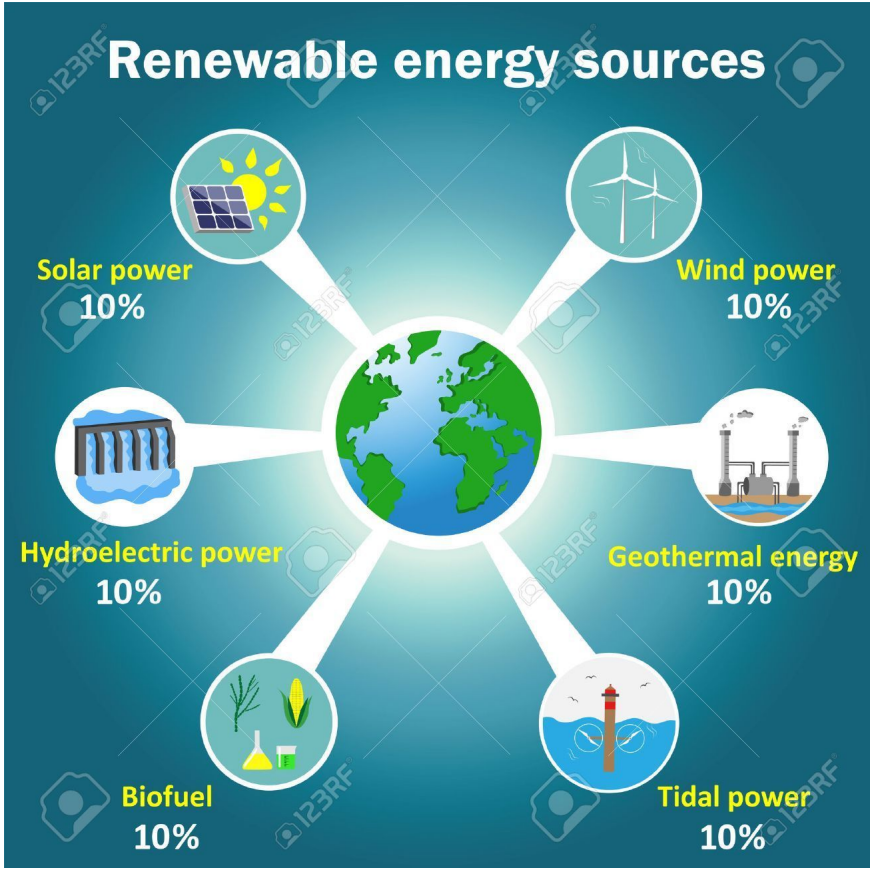
A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

What are renewable vs depleting feedstocks

Depleting resources: fossil fuels, Sun and solar power.

Fossil Fuels will require millions of years to reoccur so its considered as depleting and not renewable like vegetation.

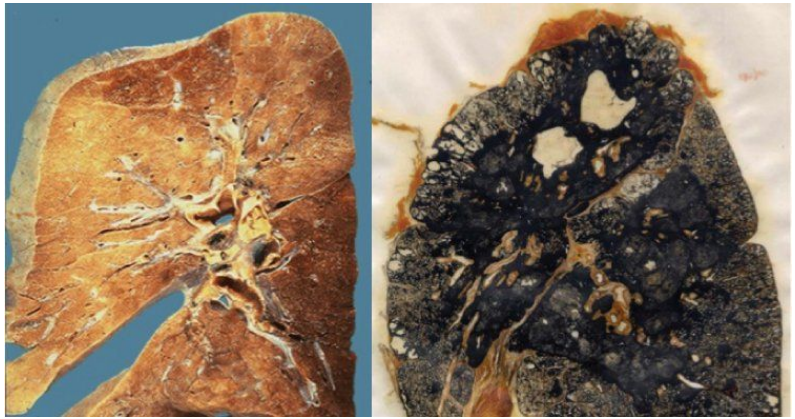




Although Sun is depleting but will take millions of years so it's considered as infinite source of energy.

Use of depleting or non renewable resources has the following impacts:

1. Coal mining leads to black lung disease and habitat destruction
2. Petroleum refining results in oil spills and air pollution

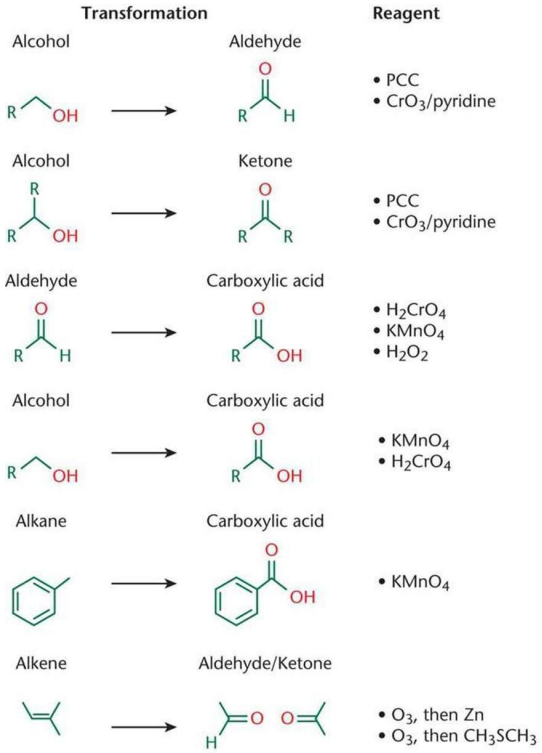


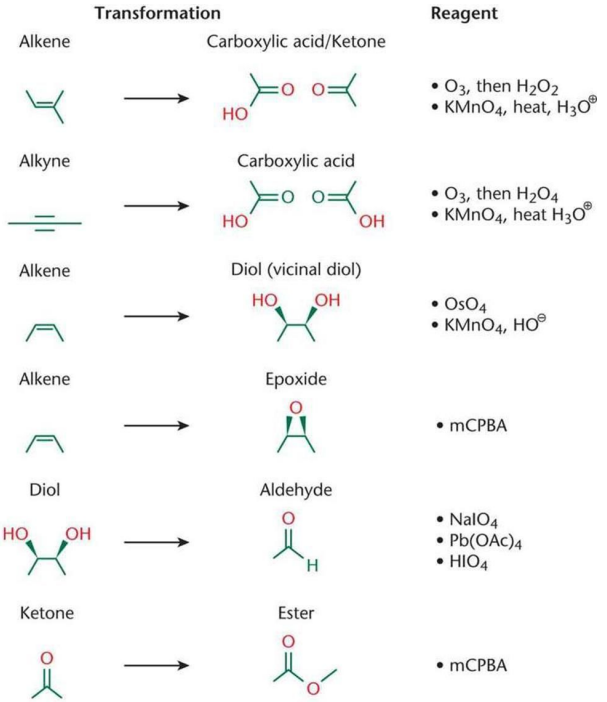
Black lung disease

oil spill

Petroleum hydrocarbons are generally in their fully reduced form and therefore require to be oxidized to functionalize and derivatize them in order to make a variety of other useful products.

Oxidation chemistry has been some of the most polluting chemistry that has attributed to the risk to human health through use of heavy metals as oxidizing agents.





Advantages of renewable resources

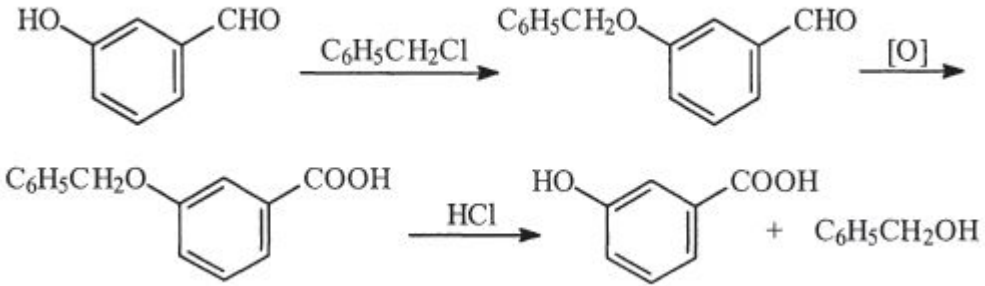
1. Generated quickly in real-time
2. Environmentally friendly
3. Cheaper

8. Reduce Derivatives/ Unnecessary Derivatization

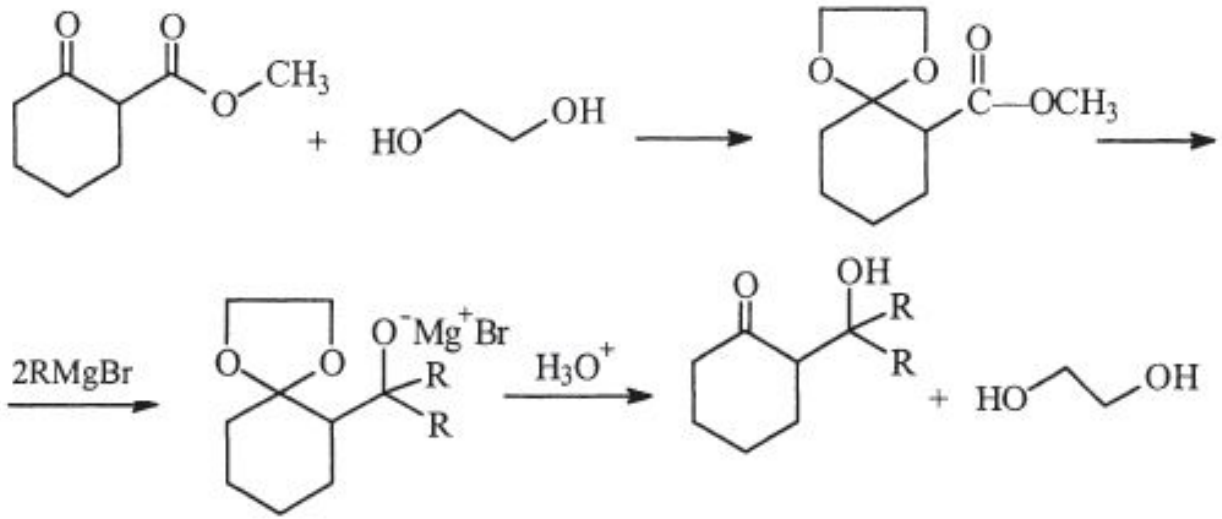
Unnecessary derivatization (use of blocking groups, protection/de-protection, and temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

Use of Protecting Groups

In case an organic molecule contains two reactive groups and you want to use only one of these groups, the other group has to be protected, the desired reaction completed and the protecting group removed.



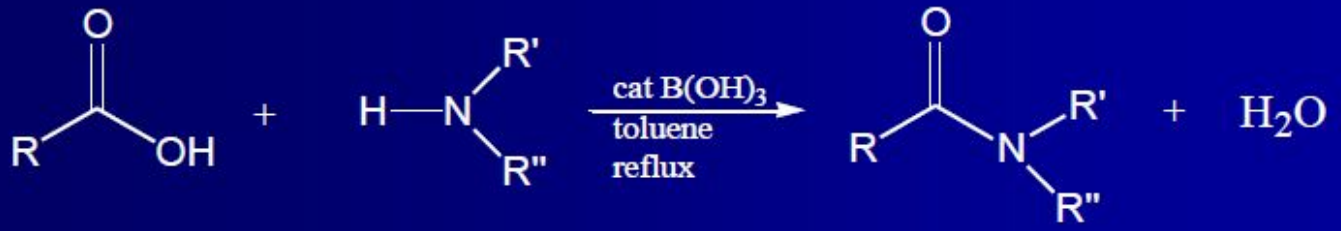
Another reaction involving protection of a keto function by using 1,2-ethanediol



Boric acid mediated amidation

- Direct amidation of carboxylic acids with amines
  - Boric acid: nontoxic, safe, inexpensive
  - Eliminates use of $SOCl_2$, PCl_3, phosgene
  - Widely applicable

Emisphere Technologies, Inc



The protecting groups that are needed to solve a chemoselectivity problem should be added to the reaction in stoichiometric amounts only and removed after the reaction is complete.

Since these protecting groups are not incorporated into the final product, their use makes a reaction less atom-economical.

In other words the use of protective group should be avoided whenever possible. Though atom-economy is a valuable criteria in evaluating a particular synthesis as 'green', other aspects of efficiency must

THANK YOU