GREENZO ENERGY INDIA LIMITED
ISO 9001-14001

Green Hydrogen
Hydrogenation Processes in
Chemical Industry

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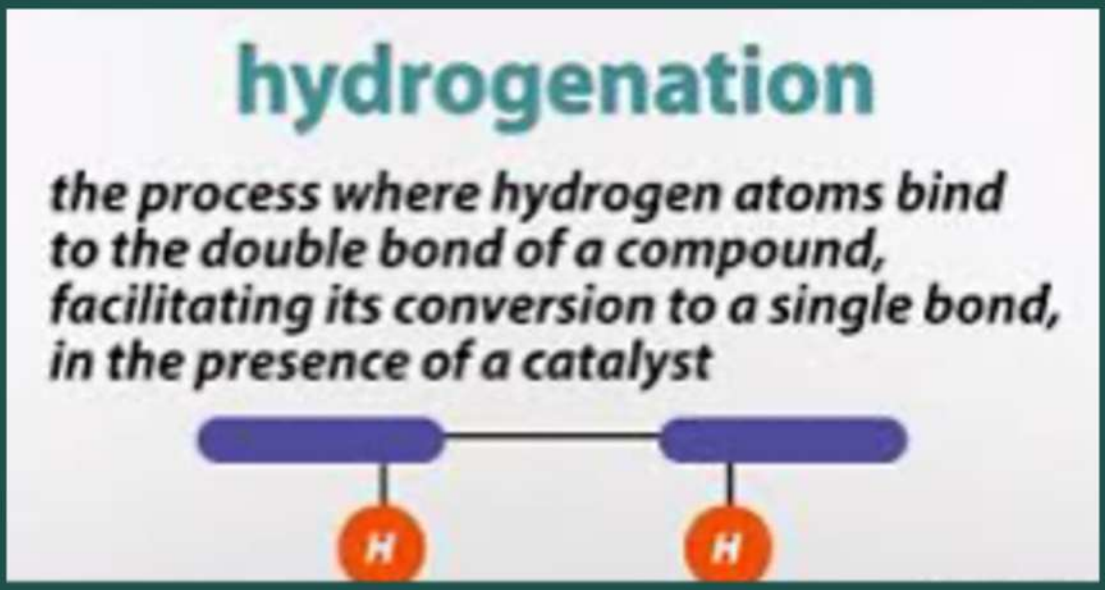
Message from MD

Green hydrogen is reshaping the chemical industry by enabling cleaner, more efficient hydrogenation processes. From bulk chemicals to pharmaceuticals and agrochemicals, its role enhances sustainability while supporting innovation. At Greenzo Energy, we are committed to advancing green hydrogen solutions that not only decarbonize industrial operations but also strengthen India's position in the global clean energy transition.

Sandeep Agarwal
Founder & Managing Director

Hydrogen and the Chemical Industry



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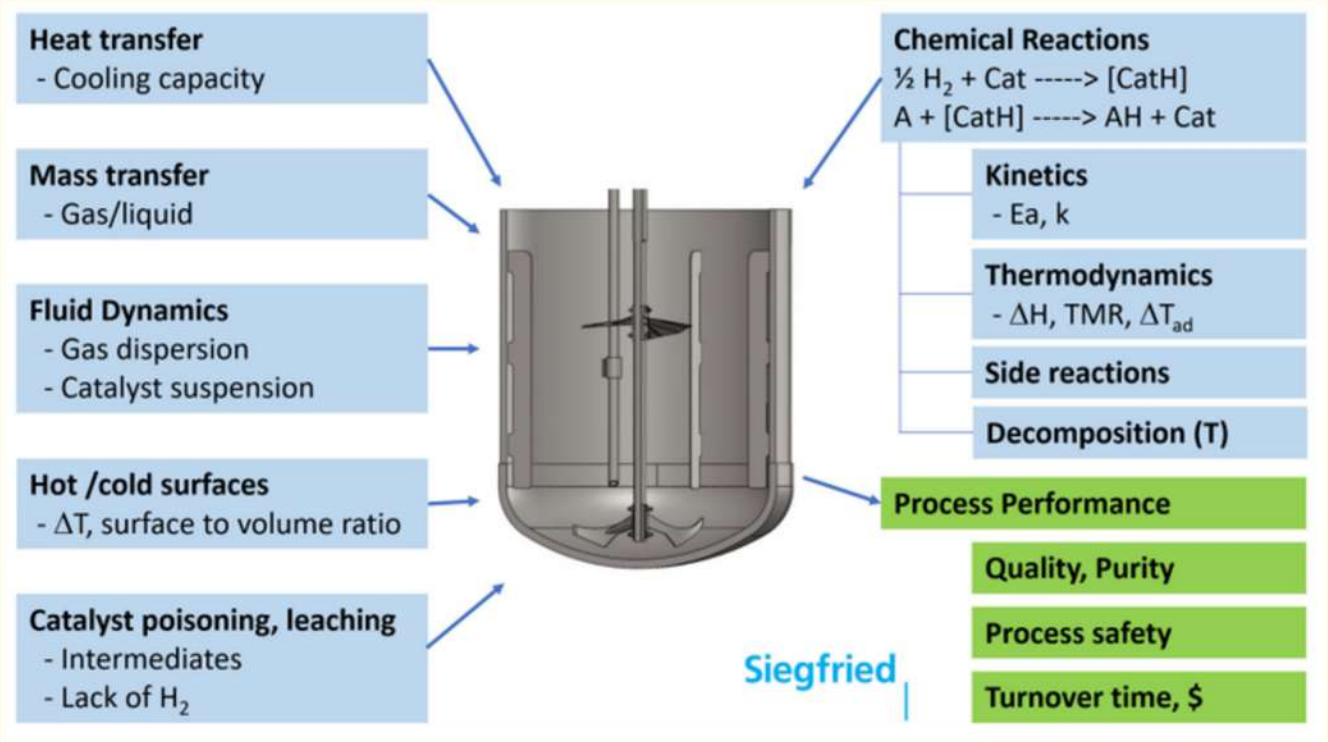
Green Hydrogen uses in Industrial Hydrogenation Processes in Chemical Industry

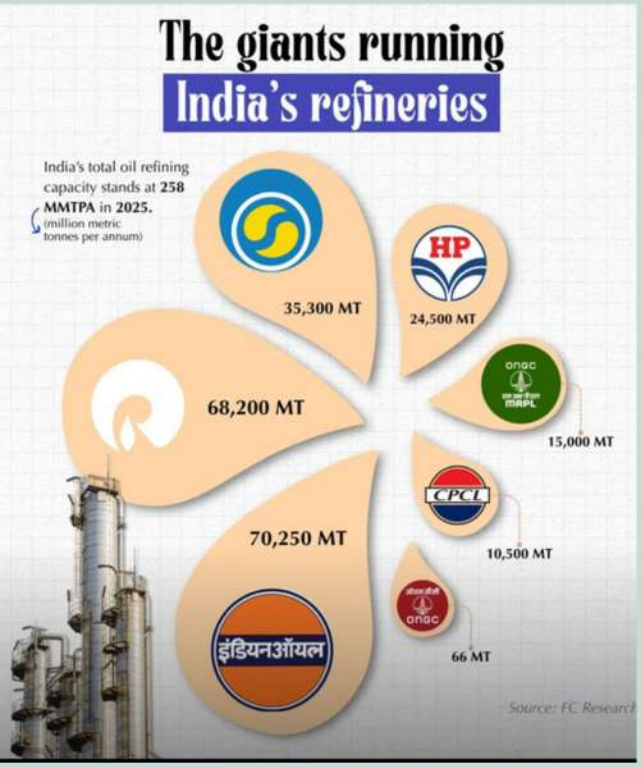
1. Executive Summary

Green Hydrogen is one of the most important raw materials in the chemical industry. Among its many uses, its role in hydrogenation processes is fundamental. Hydrogenation refers to the chemical reaction where hydrogen gas (H_2) is added to an unsaturated bond or functional group, usually in the presence of a catalyst. This reaction is widely used in the manufacture of bulk chemicals, specialty chemicals, pharmaceuticals, and agrochemicals, thereby improving stability, modifying functionality, or achieving desired physical properties.



2. Mechanistic Steps

Hydrogenation is a catalytic process that generally follows three key stages:



2.1 Hydrogen Adsorption and Activation

Molecular hydrogen (H_2) adsorbs onto the active sites of the catalyst surface, where it undergoes dissociation into atomic hydrogen. These activated hydrogen atoms are highly reactive intermediates.

2.2 Substrate Adsorption

The unsaturated compound—such as an alkene, alkyne, nitro compound, or carbonyl derivative—adsorbs onto the same catalyst surface. The interaction aligns the reactive double or triple bonds for subsequent hydrogen addition.

2.3 Surface Reaction and Desorption

Stepwise transfer of atomic hydrogen to the adsorbed substrate occurs, reducing the unsaturated bond. The fully hydrogenated product is then desorbed from the catalyst surface, regenerating the active sites for the next catalytic cycle.

3. Typical Reaction Conditions

- **Catalysts:** Heterogeneous catalysts such as Nickel (Ni), Palladium on Carbon (Pd/C), Platinum (Pt), Ruthenium (Ru), Raney Nickel, or homogeneous catalysts like Wilkinson's catalyst (Rh-based).
- **Temperature:** Generally, between 50–300 °C, depending on the reactivity of the substrate and the selectivity required.
- **Pressure:** Operates under elevated hydrogen pressures, typically 5–200 bar, with higher pressures favouring faster reaction rates and complete hydrogenation.

4. Major Classes of Hydrogenation in the Chemical Industry

a) Hydrogenation of Unsaturated Hydrocarbons

- Converts alkenes and alkynes into saturated alkanes.

Example: $CH_2 = CH_2 + H_2 \xrightarrow{Ni} CH_3–CH_3$

Ethylene → Ethane

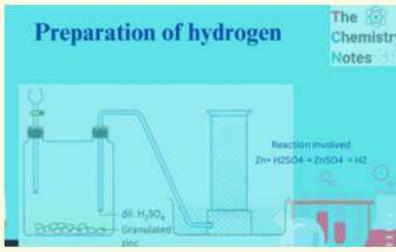
- **Applications:**
  - o Production of saturated hydrocarbons.
  - o Modification of polymers and fuels.
  - o Hydrogenation of vegetable oils into margarine and shortenings.

b) Reduction of Nitro Compounds to Amines

- Nitro groups are reduced to amines, which are important intermediates for dyes, pharmaceuticals, and agrochemicals.

Example: $C_6H_5NO_2 + 3H_2 \xrightarrow{Pd} C_6H_5NH_2 + 2H_2O$

Nitrobenzene → Aniline



- **Applications:**
  - o Manufacture of herbicides and insecticides.
  - o Intermediates for polyurethane foams, dyes, and pigments.
  - o Building blocks for active pharmaceutical ingredients (APIs).

c) Hydrogenation of Carbonyl Compounds

- Aldehydes and ketones reduce to alcohols.

Example: $CH_3CHO + H_2 \xrightarrow{Ni} CH_3CH_2OH$

Acetaldehyde → Ethanol

- **Applications:**
  - o Production of solvents.
  - o Manufacture of fine chemicals and fragrances.
  - o Stabilization of intermediates in specialty chemistry.

d) Hydrogenolysis

- Cleavage of single bonds (C–O, C–N, C–Cl, etc.) in the presence of hydrogen.

Example: $C_6H_5CH_2Cl + H2 \xrightarrow{Pd} C_6H_5CH_3 + HCl$

Benzyl chloride → Toluene

- **Applications:**
  - o Deprotection of intermediates in pharmaceutical synthesis.
  - o Removal of halogen substituents.
  - o Conversion of oxygenates into pure hydrocarbons in refining.

5. Industrial Importance of Hydrogenation

1. **Agrochemicals:** Many herbicides, insecticides, and fungicides are derived from hydrogenated amines and aromatic intermediates.
2. **Pharmaceuticals:** Hydrogenation is used to synthesize APIs (Active Pharmaceutical Ingredients), e.g., antihistamines, antidepressants, antibiotics.
3. **Specialty Chemicals:** Production of dyes, pigments, and polymer additives.
4. **Food Industry:** Hydrogenation of vegetable oils to produce margarine and shortenings.
5. **Environmental Applications:** Saturation of unsaturated compounds in waste streams to make them stable and less toxic.

6. Advantages of Hydrogenation Processes

- High selectivity and yield when properly catalysed.
- Cleaner alternative to older chemical reduction methods (e.g., iron filings, tin/HCl), avoiding large volumes of by-products.
- Compatible with continuous processing for large-scale industrial plants.
- Enables sustainability by integrating with green hydrogen supply from electrolysis, reducing carbon footprint.

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