# Carbon Capture, Usage, and Storage (CCUS): A Pathway to Decarbonization

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### Why in the News?

In its commitment to achieve **net-zero emissions by 2070**, India has prioritized the development of **Carbon Capture, Usage, and Storage (CCUS)** technologies. CCUS emerged as a key theme during **COP28** (held in Dubai, 2023), signaling global recognition of its potential in mitigating climate change.

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### What is CCUS?

**Carbon Capture, Usage, and Storage (CCUS)** is a group of **technological solutions** that capture carbon dioxide (**$CO_2$**) emissions from **large industrial sources** like:

- Thermal power plants
- Cement and steel factories
- Oil refineries

Once captured, $CO_2$ is either:

- **Stored underground** in geological formations, or
- **Utilized** in producing commercially valuable products.

Thus, CCUS helps prevent $CO_2$ from entering the atmosphere while enabling a

**circular carbon economy**.

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### Stages of CCUS Technology

#### 1. Carbon Capture

This is the **first step**, involving the separation of $CO_2$ from gas emissions at the source. The method used depends on $CO_2$ concentration:

- **Chemical Solvent-based Capture**
  - Ideal for low-concentration $CO_2$ streams (e.g., natural gas processing).
  - Common solvents: Amine-based compounds.
- **Physical Solvent Methods**
  - Effective for high-concentration $CO_2$ streams (e.g., pre-combustion in industrial plants).
  - Uses solvents like Selexol or Rectisol.
- **Adsorption Techniques**
  - Suitable for moderate $CO_2$ concentrations, like in **Steam Methane Reforming (SMR)**.
  - Uses solid materials like activated carbon or zeolites to trap $CO_2$.

#### 2. Carbon Utilization

In this stage, the captured $CO_2$ is **repurposed** into products such as:

- **Green urea** (for fertilizers)
- **Dry ice** (used in cooling)

- **Carbonated beverages**
- **Building materials** (e.g., carbon-infused concrete)
- **Industrial chemicals** and **biofuels**

### 3. Carbon Storage

Unutilized $CO_2$ is **injected deep underground** for long-term isolation. Common storage sites include:

- **Depleted oil and gas fields**
- **Deep saline aquifers**
- **Basalt formations** and other secure geological layers

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### Potentials of CCUS for India

1. **Direct Emission Reductions**
    - CCUS captures $CO_2$ **before** it reaches the atmosphere, directly cutting emissions at the source.
2. **Decarbonizing Industrial Sectors**
    - Crucial for **hard-to-abate sectors** like cement, steel, and coal-powered industries, which contribute significantly to India's emissions.
3. **Production of Green Fuels**
    - $CO_2$ can be converted into **clean fuels** like **hydrogen**, **methane**, and **green ammonia**, enabling energy transition.
4. **Supports Renewable Energy Goals**

- CCUS complements **solar and wind power**, especially in sectors where renewable alternatives are not yet viable.

5. **Climate Change Mitigation**
   - Helps slow global warming by reducing **greenhouse gas concentrations**.
6. **Job Creation**
   - New opportunities arise in **construction**, **engineering**, **R&D**, **operations**, and **supply chain management** of CCUS facilities.

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### Challenges in CCUS Deployment

1. **High Capital Costs**
   - Significant investment is required for:
     - Capture units
     - $CO_2$ pipelines
     - Underground storage sites
2. **Nascent Technology**
   - Advanced forms like **Direct Air Capture (DAC)**—which captures $CO_2$ from ambient air—are still in the early stages and costly.
3. **Limited Investment**
   - Private sector interest is low due to **uncertain returns**, long gestation periods, and lack of policy clarity.
4. **Infrastructure Bottlenecks**

- $CO_2$ needs **dedicated pipelines** for safe transport. Existing pipelines (designed for oil/gas) may not be compatible.
- Impurities in $CO_2$ can cause **pipeline corrosion**.

5. **Storage Site Identification**
   - Suitable geological sites are:
     - **Unevenly distributed**
     - Often **far from emission sources**
     - Require detailed geotechnical studies
6. **Regulatory and Legal Uncertainty**
   - There is **no comprehensive framework** governing $CO_2$ capture, transportation, storage, and liability in India.

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### Way Forward

1. **Launch of a National CCUS Mission**
   - Focused on **hard-to-abate sectors** like power, cement, and steel.
   - Aim to scale up CCUS deployment with clear roadmaps and targets.
2. **Incentivization Mechanisms**
   - Provide **Viability Gap Funding (VGF)** to make CCUS projects financially viable.
   - Introduce **Production-Linked Incentives (PLI)** and **carbon credits** for industries using CCUS.

- Offer **tax credits/subsidies** for early adopters.

3. **Policy and Regulatory Support**
   - Frame clear **guidelines and safety standards** for $CO_2$ capture, storage, and reuse.
   - Create **monitoring and verification frameworks** for long-term storage.
4. **Investment in R&D**
   - Support innovation to improve **capture efficiency**, **cost reduction**, and **new utilization pathways**.
   - Encourage collaboration between **government, academia, and industry**.
5. **Capacity Building and Awareness**
   - Train professionals and sensitize industries and the public on the importance and potential of CCUS.

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### Conclusion

**Carbon Capture, Usage, and Storage (CCUS)** represents a **critical bridge technology** that enables India to achieve its **net-zero by 2070 goal**, while supporting economic growth. Despite current challenges—costs, infrastructure, and regulation—the strategic importance of CCUS in **decarbonizing heavy industries**, creating **green jobs**, and ensuring **energy security** is immense. With the right policy push, technological innovation, and public-private collaboration, CCUS can become a cornerstone of India's climate action strategy.