Addressing the Challenges of Large-Scale Carbon Capture, Storage and Utilization

28 February 2024 | Technical Topic Webinar

Presented by:

Dr. Harisinh Parmar
EIT Lab Coordinator
About EIT

We are dedicated to ensuring that you receive a world-class education and gain skills that you can immediately implement in the workforce.

**Engineering Specialists**
EIT is one of the only institutes in the world specializing in Engineering. We deliver professional certificates, diplomas, advanced diplomas, undergraduate and graduate certificates, bachelor’s and master’s degrees, and a Doctorate of Engineering.

**Industry Oriented Programs**
Our programs are designed by industry experts, ensuring you graduate with cutting-edge skills that are valued by employers. Our program content remains current with rapidly changing technology and industry developments.

**World-Class Australia Accredited Education**
Our vocational programs and higher education degrees are registered and accredited by the Australian Government. We have programs that are also recognized under three international engineering accords.

**Industry Experienced Lecturers**
Our lecturers are highly experienced engineers and subject specialists with applied knowledge. The technologies employed by EIT, both online and on-campus, enable us to source our lecturers from a large, global pool of expertise.

**Unique Delivery Model**
We deliver our programs via a unique delivery methodology that makes use of live and interactive webinars, an international pool of expert lecturers, dedicated learning support officers, and state-of-the-art such as hands-on workshops, remote laboratories, and simulation software.
Dr. Harisinh Parmar

Harisinh is a chemical engineer with a strong background in CFD modeling involving multiphase flow. Currently, he is working as a lab coordinator and academic staff at EIT. Along with teaching bachelor’s and postgraduate students, Harisinh has recently been involved with Hydrogen Energy related teaching and modeling work. In his previous role at Curtin University, he modeled and designed a subsea settling tank using ANSYS Fluent and conducted pilot scale experiments to validate settling efficiency.
Survey

In your view, what are the three primary global challenges?
Content

• Carbon Cycle
• Carbon Budget
• CCS Plans around the world
• Carbon capture process
• Carbon storage
• Transportation
• Course outline
Carbon Cycle and CO₂

CO₂:
• Dominant anthropogenic, or human sourced, greenhouse gas (GHG).
• Generated by use of fossil fuels, biomass combustion, agriculture, and diffuse industrial and domestic sources.

How we reduce the Emission:
• Energy efficiency and
• Substitution of fossil fuels by renewable or nuclear energy.
• To achieve net zero emissions, any surplus emissions need to be captured and securely stored.
Global Carbon Budget 2022

• The carbon budget is the amount of $CO_2$ that a human can emit while still having a chance to contain global warming within 1.5°C centigrade compared with preindustrial levels, as advocated by the Paris Agreement.

• Our planet can count on certain natural carbon sinks such as forests and oceans, but even these sinks can no longer keep up with the rate at which greenhouse gases are pouring into the atmosphere.
Global Carbon Budget 2022

The numbers that tell the truth about climate action. Global carbon emissions in 2022 remain at record levels.

There is a limited cumulative CO₂ emission budget for any given climate target.

If current emissions levels persist, there is now a 50% chance that global warming of 1.5°C will be exceeded in nine years.

Every un-emitted gigatons CO₂ matters. Every avoided tenth of degree of warming matters.
Global Carbon Budget 2022

Global CO₂ emissions must reach zero to limit global warming. World leaders must take meaningful action if we are to have any chance of limiting global warming close to 1.5°C.
Global Carbon Budget 2022

Sources = Sinks

**Sources**
- 35.2 GtCO$_2$/yr (89%)
  - 4.5 GtCO$_2$/yr (11%)

**Sinks**
- 19.1 GtCO$_2$/yr (48%)
- 11.4 GtCO$_2$/yr (29%)
- 10.5 GtCO$_2$/yr (26%)

**Budget Imbalance:**
- 3% (the difference between estimated sources & sinks)
- -1.2 GtCO$_2$/yr
How much worse will the problem get?

If we add up all the promises to cut emissions made by countries that are party to the Paris climate agreement, the world would still warm by more than 3°C by the end of this century.

*Emissions are in Gigatonnes of CO2 equivalent*
Fast-growing cities - worse climate risks

Population growth 2018-2035 over climate change vulnerability

- 95% of cities facing extreme climate risks are in Africa or Asia,
- 84 of the world's 100 fastest-growing cities face "extreme" risks from rising temperatures and extreme weather brought on by climate change.
Survey

What steps do we take as a matter of priority to reduce the carbon intensity?
Carbon Capture and its cost

Estimates of carbon capture costs by industry and category of capture technology, presented in 2021 U.S. dollars.
# Carbon Capture: Key Challenges

<table>
<thead>
<tr>
<th>Technical Issues</th>
<th>Legal/Social Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Capture Technology</td>
<td>• Regulatory Framework</td>
</tr>
<tr>
<td>- Existing Plants</td>
<td>- Permitting</td>
</tr>
<tr>
<td>- New Plants</td>
<td>- Treatment of CO₂</td>
</tr>
<tr>
<td>• Cost of CCS</td>
<td>- Policy incentives</td>
</tr>
<tr>
<td>• Sufficient Storage Capacity</td>
<td>- Infrastructure</td>
</tr>
<tr>
<td>• Best practices</td>
<td>- Human capital</td>
</tr>
<tr>
<td>- Storage site characterization</td>
<td>- Legal Framework</td>
</tr>
<tr>
<td>- Monitoring / Verification</td>
<td>- Liability</td>
</tr>
<tr>
<td>- Site Closure</td>
<td>- Ownership</td>
</tr>
<tr>
<td></td>
<td>- Pore Space</td>
</tr>
<tr>
<td></td>
<td>- CO₂</td>
</tr>
<tr>
<td></td>
<td>- Public Acceptance</td>
</tr>
</tbody>
</table>
# Carbon Capture: Pros Vs Cons

## PROS
- It can reduce emissions at source
  - Capable to remove 20% of total CO₂ emissions from industrial and energy production facilities
  - Capable of removing 90% of CO₂ from power plants
- Faster removing CO₂ than planting trees
  - A typical tree: capture around 21 kilograms (kg) of CO₂ per year - after 20 years
  - Over the first 20 years of a tree's life, it only actually absorbs 39kg of carbon dioxide
- Carbon capture, on the other hand, can reduce large amounts of CO₂ emissions at the source

## CONS
- Expensive
  - It currently costs an average of **$600 (£440)** per tons of CO₂ absorbed, which isn’t ideal, given humans emit 36 billion tons of CO₂ a year.
  - Treatment of CO₂
    - Expert are working to make more affordable
- Energy Intensive
  - more amount of thermal energy required
  - Compress CO₂ for storage
- Increase emission
- Significant risk involved
  - it can be harmful to human health.
  - Water bodies damage risk
CCS Plants operating/development

Global capture and storage capacity is now around 40MtCO₂/yr.
CCS Plants operating/development

- Natural gas processing uses well-established CO₂ separation technologies. Operations in Shute Creek (7MtCO₂/yr) and Century Plant (5MtCO₂/yr) in the USA as well as Gorgon (4MtCO₂/yr) in Australia.

- Coal-fired power with CCS using amine solvent for post-combustion capture of CO₂ used for EOR has performed safely and effectively at two power stations. The Boundary Dam plant in Saskatchewan (Canada) since 2014 and Petra Nova in Texas, since 2017.

- Gas-fired power with CCS has not yet been undertaken at scale, although small-scale CO₂ capture without permanent storage has been used commercially at a natural gas combined cycle plant in the USA ‘clean gas’ project at Teesside, North-East England, is now proposed, while two similar gas-power-CCS projects are being planned in the Humber region.

- Blue’ hydrogen production in the QUEST project in Alberta, Canada, uses amine solvent to capture 1MtCO₂/yr with 99.5% purity. The Port Arthur refinery in Texas, uses pressure swing adsorption to separate CO₂, leaving 99% pure hydrogen.
CCS Plants operating/development

- Cement production decarbonization, which accounts for 8% of the world’s CO₂ emissions, the EU Low Emissions Intensity Lime and Cement industry-research collaboration (LEILAC) has run a demonstration plant at Lixhe, Belgium, and is designing a scaled-up plant at Hannover, Germany.

- Norway’s Longship CCS programme includes capture of CO₂ from the Brevik cement plant and a waste-to-energy facility in the Oslofjord region, shipping it in liquid form to an onshore terminal on the coast, from where it will be piped to storage under the North Sea by the Northern Lights project.

- Emirates Steel Industries in Abu Dhabi, has developed the first iron and steel plant with CCS, using methane reformed to a hydrogen / carbon monoxide syngas for direct reduction of iron ore.
Carbon Capture Process

- Carbon Capture and Storage (CCS) is a way of reducing carbon emissions, that helps to tackle with global warming.
- CCS involves the capture of carbon dioxide (CO$_2$) emissions from industrial processes (steel and cement production) or burning of fossil fuels in power generation.
- This carbon is then transported from where it was produced, through shipping or in a pipeline and can be stored deep underground in geological formations.
Carbon Capture Process

1. **Capturing carbon dioxide** – CO2 is separated from other gases that are produced in industrial processes. There are three basic types of CO2 capture: pre-combustion, post-combustion, and oxyfuel post-combustion:
   - **Pre-combustion** – Converts fuel into a gaseous mixture of hydrogen and CO2. The hydrogen is separated and can be burnt without producing any CO2, and the CO2 can be compressed and stored.
   - **Post-combustion** – Separates CO2 from combustion-exhaust gases. The CO2 is captured using a liquid solvent or other separation methods. Once absorbed by the solvent, CO2 is then released and forms a “high-purity CO2 stream”.
   - **Oxyfuel combustion** – Uses oxygen rather than air for the combustion of fuel. This produces exhaust gas that is mainly water vapor and CO2, which can be easily separated to produce high-purity CO2.

2. **Transport** – The CO2 is then compressed and transported by road transport, ships, or through underground pipelines to a storage site.

3. **Storage** – Once it reaches the storage site, the CO2 is injected into rock formations underground, which typically run 1km deep. These storage sites are usually located at saline aquifers (geological formations) or depleted oil and gas reservoirs.
Carbon capture Process

- **Post-combustion**
  - Combustion
  - CO₂ containing flue gas
  - N₂ - CO₂ separation

- **Pre-combustion**
  - Gasification/reform
  - CO₂ containing Syngas
  - H₂ - CO₂ separation

- **Oxyfuel combustion**
  - Combustion
  - Air separation
  - O₂

- **Chemical-looping combustion**
  - Fuel reactor
  - Me
  - MeO
  - N₂
  - Air

Compression

- CO₂
- Heat & Power

- CO₂
- Heat & Power

- H₂
  - Heat & Power
  - Fuels/Chemicals

Compression

- CO₂
- Heat & Power
Pre combustion capture
Post combustion capture

1. Flue gas from coal or gas power plant.
2. The gas is cooled to 30-40 °C using water.
3. The gas rises inside the tower. Amines run downwards. CO₂ is bound to the amines, and the solution is collected at the bottom.
4. The solution is heated. At about 120 °C the amines release the CO₂. The amines sink, while the CO₂ rises to the top.

The exhaust gas is released at the top. 85-90% of the CO₂ has been removed.

Source: Nyeetskapplikke.no / ZERO

*chemical compound that binds to CO₂
Oxy-fuel combustion capture
Chemical looping capture
Novel capture Technologies

- Molten carbonate fuel cells (MCFC) use hydrogen from a fuel source such as natural gas along with CO\textsubscript{2} from flue gas to produce electricity, heat, and water. The captured CO\textsubscript{2} exits the fuel cell at a high concentration and can easily be separated.

- Advanced cycles for combustion: Techniques such as calcium and chemical looping – where an oxygen carrying substance is circulated through two reactors – work to improve the basic efficiency of the CO\textsubscript{2} capture process through better integration with the power supply process.

- Novel supercritical CO\textsubscript{2} (sCO\textsubscript{2}) techniques use CO\textsubscript{2} at or above its critical temperature and pressure, offering potential benefits such as higher efficiency, lower capital costs and higher CO\textsubscript{2} capture rates. One emerging sCO\textsubscript{2} process attracting significant interest is the Allam-Fetvedt Cycle which creates a new type of power station. Rather than fitting a CCS unit onto a current combined cycle gas turbine (CCGT) plant, the turbine burns gas in a single operation with oxygen, with pure CO\textsubscript{2} becoming the working internal fluid, before capture or recycling. An Allam-Fetvedt Cycle demonstrator in Texas has reported a net efficiency of 59%, similar to a conventional gas-fired plant.\textsuperscript{38}
Storage operations

• While much captured CO₂ is currently stored by means of enhanced oil recovery (EOR), geological storage has also been carried out and monitored to meet high performance standards for climate purposes.

• For example, 1.7MtCO₂/yr is stored in saline aquifers at the North Sea Sleipner and Snøhvit operations and 1MtCO₂/yr in an onshore aquifer from the Quest project. More than 12,000Gt of potential CO₂ storage resources have been identified worldwide and 400Gt have been evaluated as investable.
The Ocean- Carbon Sink

Atmospheric CO₂

Dissolved CO₂

Water movements enhancing gas exchanges

100m

Sequestration of carbon in the deep cold waters

ocean-climate.org
The Ocean - Biological Pump

- Solar energy
- Atmospheric CO₂
- Dissolved CO₂
- Phytoplankton, through photosynthesis, produces organic matter
- Plankton uses carbonate to produce its limestone protection
- Carbonate ion
- Organic matter
- Dead organisms sink to the bottom of the ocean
- Carbon storage by sedimentation
Direct CO$_2$ injection
Sequestration: Agriculture, Wetlands

Carbon sequestration in forests
• Depending on their characteristics and local circumstances, forests play different roles in the carbon cycle, from net emitters to net sinks of carbon.

• Forests sequester carbon by capturing carbon dioxide from the atmosphere and transforming it into biomass through photosynthesis. Sequestered carbon is then accumulated in the form of biomass, deadwood, litter and in forest soils.

• Release of carbon from forest ecosystems results from natural processes like respiration and oxidation as well as deliberate or unintended results of human activities.

• The contribution of forests to carbon cycles has to be evaluated taking also into account the use of harvested wood.
Compression & transportation of CO$_2$

- Carbon dioxide (CO$_2$) captured from coal flue gas or synthesis gas must be compressed.

- Compression of CO$_2$ is challenging because it represents a potentially large auxiliary power load on the overall power plant system.

- In August 2007 study conducted for NETL, CO$_2$ compression was accomplished using a six-stage centrifugal compressor with inter-stage cooling that required an auxiliary load of approximately 7.5% of the gross power output of a subcritical pressure, coal-fired power plant.

- CO$_2$ can be transported via trucks or ships, but the most common and efficient method is by pipeline.

- In a supercritical state, CO$_2$ has the density of a liquid but the viscosity (thickness) of a gas and is, therefore, easier to transport through pipelines.

- To enable the safe use of CO$_2$ pipelines, CCS projects must ensure captured CO$_2$ complies with strict purity and temperature specifications, as well as making sure CO$_2$ is dry and free from impurities that could impact pipelines’ operations.
Transportation via pipeline and marine
# Carbon Capture, Utilisation & Storage

## Program Structure

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Introduction</td>
</tr>
<tr>
<td>2.</td>
<td>CCS over the Entire Economy</td>
</tr>
<tr>
<td>3.</td>
<td>Capturing Carbon for Power Industry</td>
</tr>
<tr>
<td>4.</td>
<td>Carbon capture from industrial operations</td>
</tr>
<tr>
<td>5.</td>
<td>Absorption capture systems</td>
</tr>
<tr>
<td>6.</td>
<td>Adsorption capture systems</td>
</tr>
<tr>
<td>7.</td>
<td>Membrane Technology in CCS</td>
</tr>
<tr>
<td>8.</td>
<td>Geological Carbon Storage</td>
</tr>
<tr>
<td>9.</td>
<td>Ocean Storage</td>
</tr>
<tr>
<td>10.</td>
<td>Terrestrial ecosystem storage</td>
</tr>
<tr>
<td>11.</td>
<td>Carbon Dioxide Transportation</td>
</tr>
<tr>
<td>12.</td>
<td>Economic &amp; Social Perspective</td>
</tr>
</tbody>
</table>
Thank You!
We have a range of courses in Renewable Energy Engineering.

<table>
<thead>
<tr>
<th>Courses</th>
<th>Start Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional Certificate of Competency in Smart Grids</td>
<td>12 March 2024</td>
</tr>
<tr>
<td>52910WA Graduate Certificate in Hydrogen Engineering and Management</td>
<td>7 May 2024</td>
</tr>
<tr>
<td>52859WA Graduate Certificate in Renewable Energy Technologies</td>
<td>4 June 2024</td>
</tr>
<tr>
<td>52894WA Advanced Diploma of Applied Electrical Engineering (Renewable Energy)</td>
<td>2 July 2024</td>
</tr>
<tr>
<td>Professional Certificate of Competency in Hydrogen Energy – Production, Delivery, Storage, and Use</td>
<td>9 July 2024</td>
</tr>
<tr>
<td>Professional Certificate of Competency in Battery Energy Storage and Applications</td>
<td>10 September 2024</td>
</tr>
<tr>
<td>Professional Certificate of Competency in Renewable Energy Systems</td>
<td>10 September 2024</td>
</tr>
</tbody>
</table>

Upcoming Webinars

All upcoming Events & Webinars:
www.eit.edu.au/news-events/events/

Insights Into EIT’s Advanced Diplomas and Other Vocational Programs
29 Feb 2024

Internet of Things (IoT) for Engineering
06 Mar 2024

Sustainable Materials and Practices in Civil Engineering
06 Mar 2024

Power Quality Challenges with High Penetration of Renewable Systems
13 Mar 2024

Hydrogen Technology Engineering and Management Towards the Net-Zero Emission
14 Mar 2024
Certificate of Attendance

To receive your digital certificate of attendance for participating in this webinar, please fill out the form and survey here (or scan the QR Code):

https://qrco.de/beptXn

Kindly note that this form will close on Monday the 4th of March, 5:00am UTC and no further requests for certificates will be accepted after the form has closed.
Q&A