RECENT ADVANCESS IN CARBON CAPTURE, UTILIZATION AND STORAGE (CCUS) TECHNOLOGY, POLICY AND REGULATIONS: TOWARDS A NET ZERO STRATEGY

INDIGENIZED ADSORBENT BASED CARBON CAPTURE TECHNOLOGY FROM POINT SOURCE AND DIRECT AIR

Dr. Ravi Babu V
Senior Scientist
CSIR-CECRI

Acknowledgement

Dr. VK Saraswat
Member, NITI Aayog

Message from " Padma Bhushan" Dr. V.K. Saraswat, Hon'ble Member, NITI Aayog

Visit to CECRI after many years has been an eye opener. The quality of research in energy-based electrochemistry is of the highest order. I could witness that the canvas of CECRI has expanded from a mere electroplating lab to development of Li-ion batteries, PEM /Alkaline Fuel Cells and Elecrtrolyzers and production of green Hydrogen. Work in the area of direct Air Capture of CO_2 is path breaking and can revolutionize the carbon Capture Process in the Country. Use of electro chemical sensors for bio-sensing is also very promising.

The major point of inflection is the translation of Research work into commercial product and involvement of Industries in R&D to market.

There is a passion and sense of pride in the work being done with young Scientists under the leadership of a very dynamic Director and very competent and experienced Scientists. I think the work of CECRI is worth emulation by many other CSIR labs.

Congratulations !

I wish them all the best in all future endeavors.

God Bless You

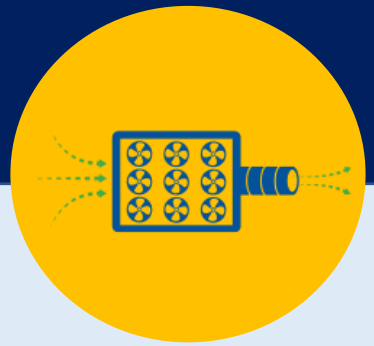
V. K. Saraswat

Acknowledgement

Secretary, DSIR and Director General, CSIR

Director, CSIR-CECRI

CO_2 Capture under flue gas condition



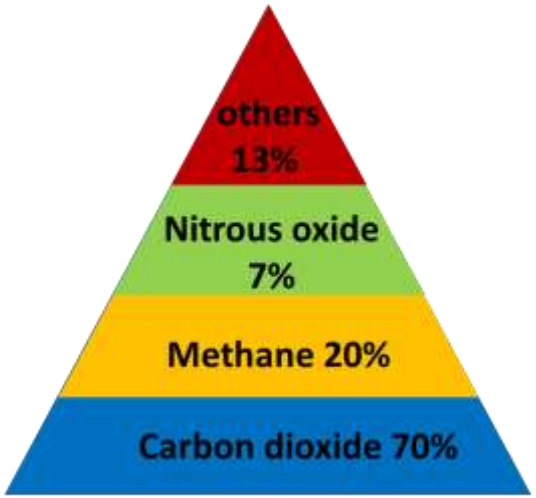
Direct Air capture

Biogas Enrichment

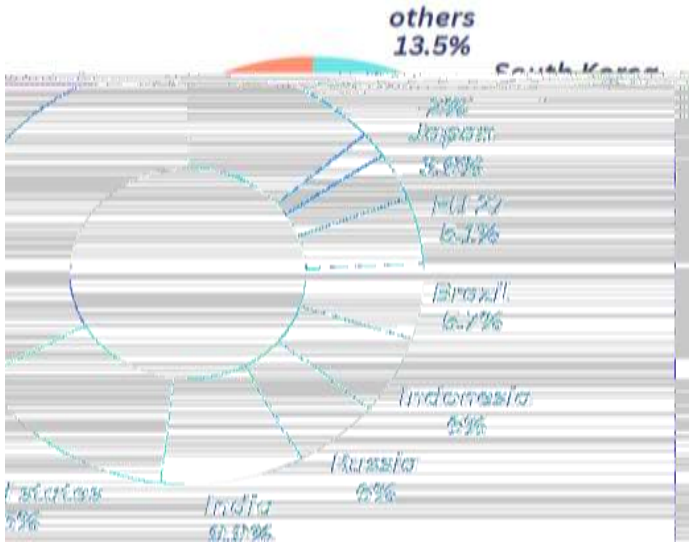
CO_2 mineralization

CCUS ACTIVITIES @ CSIR CECRI

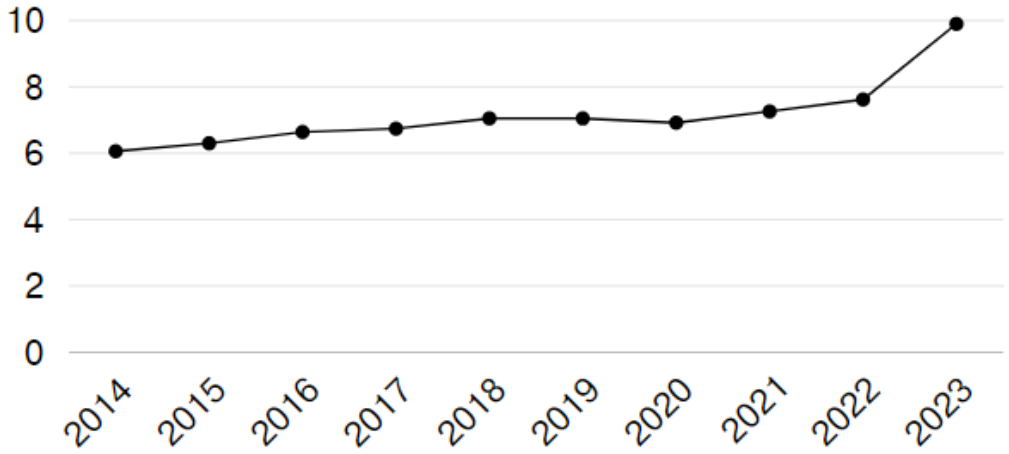
Need for carbon capture



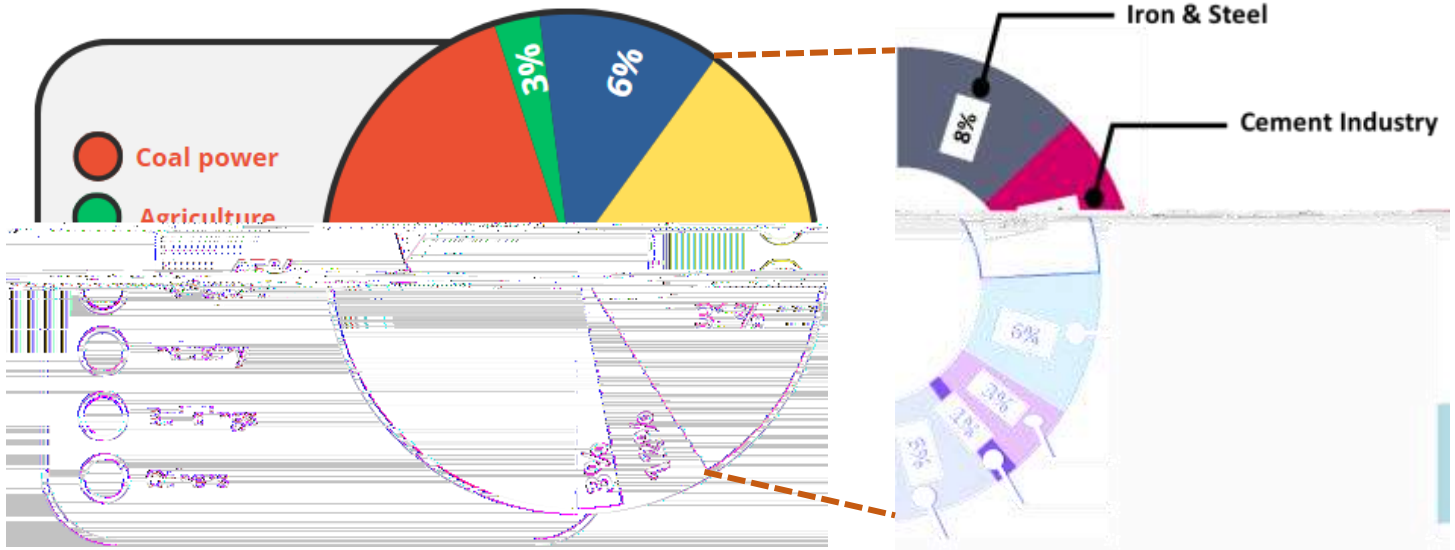
Contribution of GHGs towards global warming



Global contributors towards CO_2 emissions



Contribution of India towards CO_2 emissions (%)



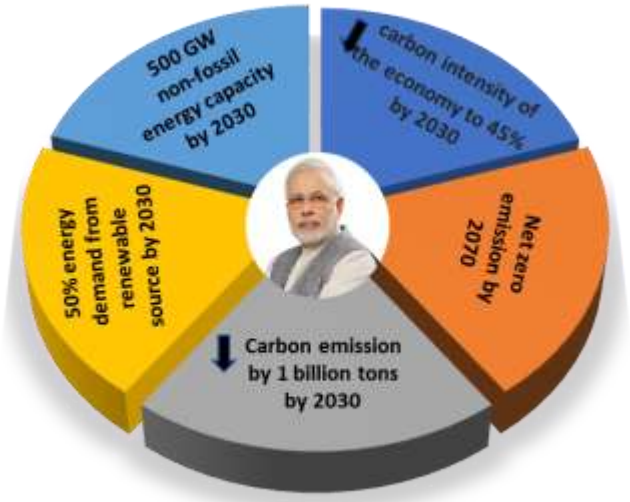
CO_2 emissions in India by sectors

Source: Niti Aayog

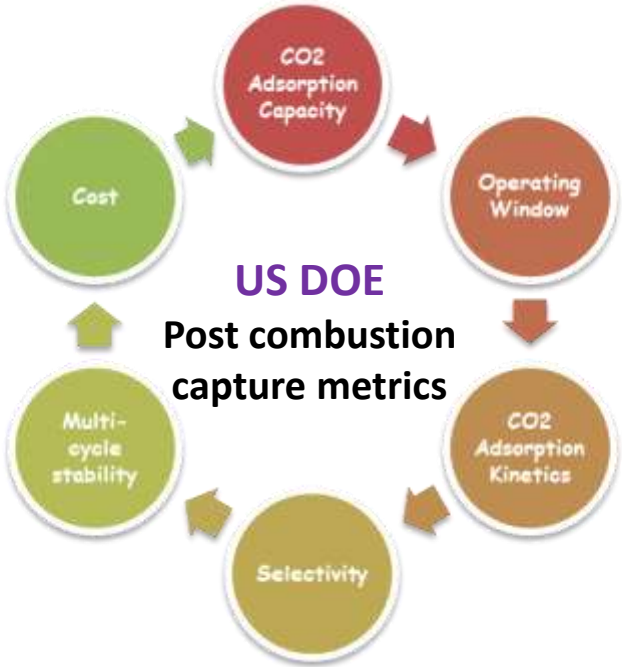
Per capita CO_2 emissions in India have soared in recent decades, climbing from 0.39 metric tons in 1970 to a high of 1.91 metric tons in 2022.

CO_2 ADSORPTION FROM INDUSTRIAL FLUE GAS

CHALLENGES FOR CARBON CAPTURE FROM POINT SOURCES



India's "PANCHAMRIT TATVA" at COP-26



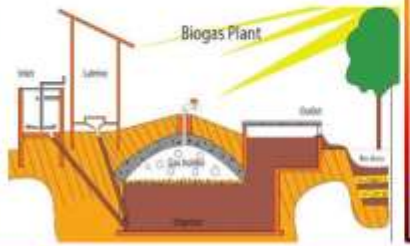
US DOE
Post combustion capture metrics

Typical CO_2 Emissions from Various Industrial Point Sources

THERMAL POWER

- Temperature (45-75 °C)
- Total pressure (1 bar)
- Mean composition
  - 75-80% N_2
  - 10-20% CO_2
  - 4-6% O_2
  - 100-150 ppm SO_2, NO_X
  - 10-12% H_2O

BIO GAS



- Temperature (45-55 °C)
- Total pressure (1 bar)
- Mean composition
  - 55-65% CH_4
  - 35-45% CO_2
  - 0-1% H_2S
  - 0-1% N_2
  - 0-2% H_2
  - 0-3% CO
  - 0-2% O_2

BLAST FURNACE

- Temperature (100 °C)
- Total pressure (1 bar)
- Mean composition
  - 25% CO
  - 20% CO_2
  - 3% H_2
  - 49% N_2
  - Trace of H_2S, PM, Pb, ZN, Mn

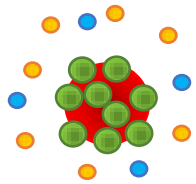
CEMENT

- Temperature (100-200 °C)
- Total pressure (1 bar)
- Mean composition
  - 60-70% N_2
  - 15-20% CO_2
  - 6-10% O_2
  - 5-10% H_2O
  - 10-100 ppm-SO_x, NO_X, NH_3

Common challenges

High Temperature

Ambient pressure



Selective removal of CO_2

High energy demand

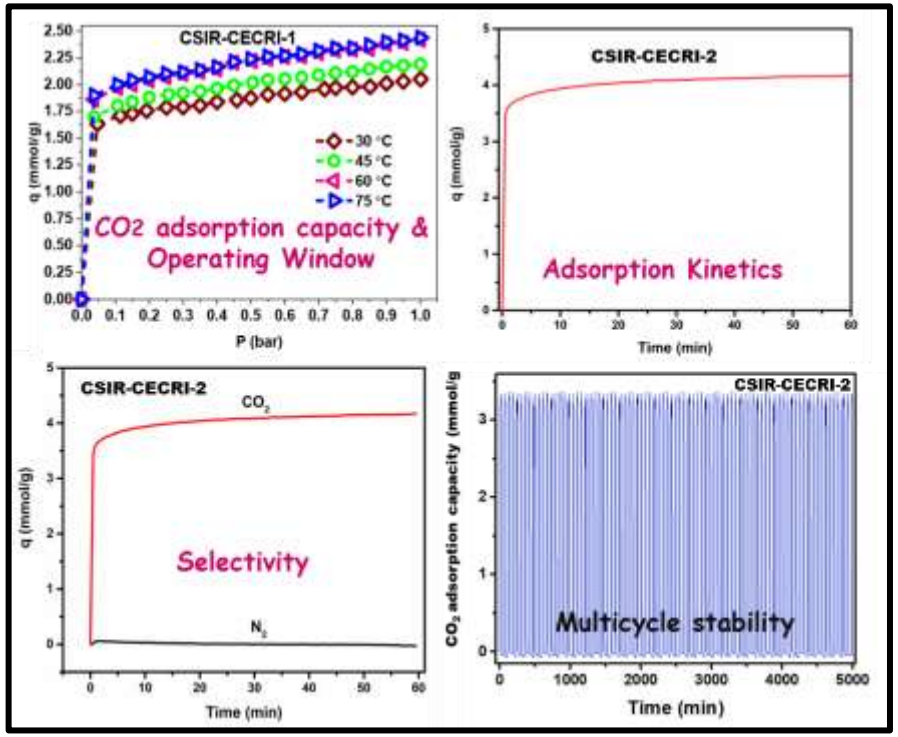
Energy requirement for maintaining the ΔT/ΔP for carbon capture and regeneration adds on **60-70%** of total operating costs

Technological solution should be aimed at solving the challenges

CSIR Activities in Carbon Capture Under Flue Gas Conditions

(Thermal Power Stations, Cement and Steel Industries)

Indigenous CO_2 sorbent demonstrating benchmark characteristics



10 kg/day- CO_2 adsorption pilot plant

Merits

- Highest carbon capture capacity under flue gas conditions
- Flexible operating window
- Faster adsorption and desorption kinetics
- Selectivity towards only CO_2 in flue gas mixture
- Multi-cycle stability
- Scalable and cost effective sorbent

Technology transfer to
SUMMITS HYGRONICS PVT. LTD.,
Coimbatore, Tamil Nadu
on 17-06-2022

Market Potential

- CO_2 capture from flue gas (power plants, cement and automobile sectors)
- Syngas purification in steel industries
- Direct-air capture
- Biogas enrichment
- CO_2 capture from space-shuttle and submarines

CSIR-CECRI GAS SEPARATION TECHNOLOGY FROM MIXTURE OF GASES

Merits

- Highest carbon capture capacity under flue gas conditions
- Flexible Operating Window
- Faster adsorption and desorption kinetics
- Selectivity towards only CO_2 in flue gas mixture
- Multi-cycle stability
- Scalable and cost effective sorbent

Market Potential

- CO_2 capture from flue gas (power plants, cement and automobile sectors)
- Syngas purification in steel industries

CSIR-CECRI GAS SEPARATION TECHNOLOGY FROM MIXTURE OF GASES

Technology transferred to Summits Hygronics Private Limited, Coimbatore

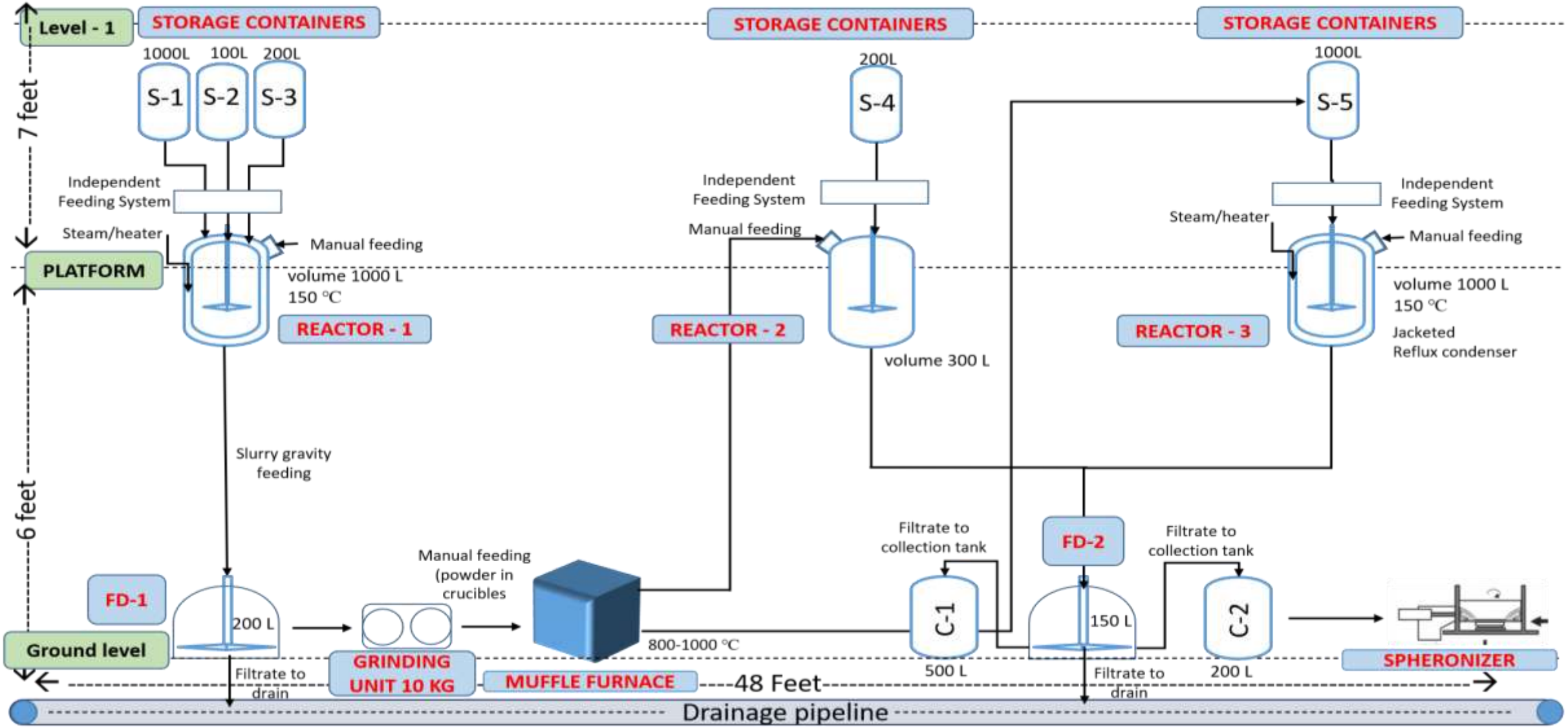
CSIR-CECRI gas separation technology from mixture of gases

Industrial level testing at Summits Hygronics private limited, Coimbatore

Bulk scale production of adsorbent (5kg/batch) at CECRI

Establishment of Pilot Scale Facility (10kg/batch) for Production of Indigenous Sorbent

PILOT PLANT DESIGN FOR PRODUCTION OF ADSORBENT



Establishment of Pilot Scale Facility (20kg/batch) for Production of Indigenous Sorbent

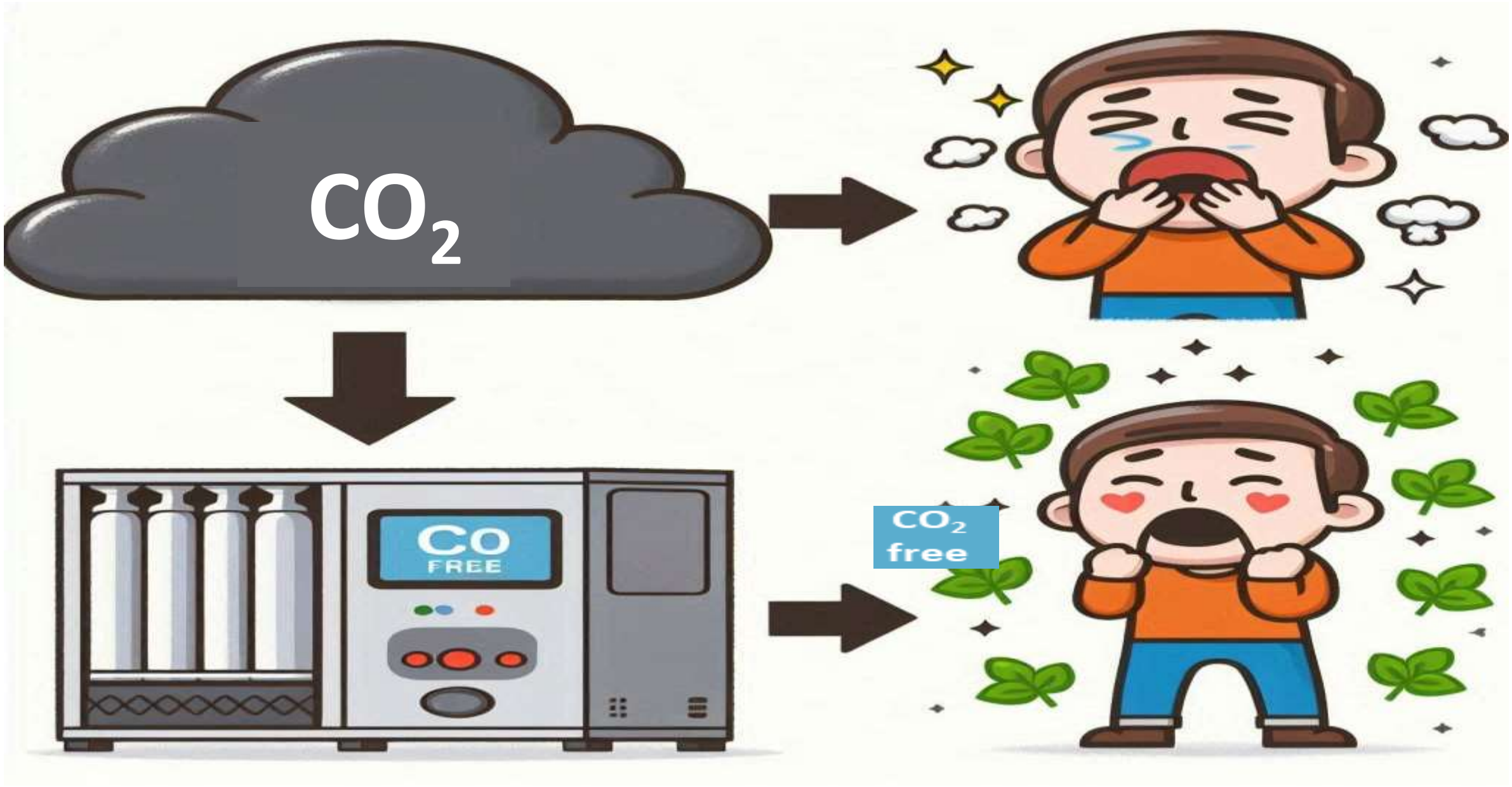

C-03

CO_2 SEPARATION FACILITIES AVAILABLE AT CECRI

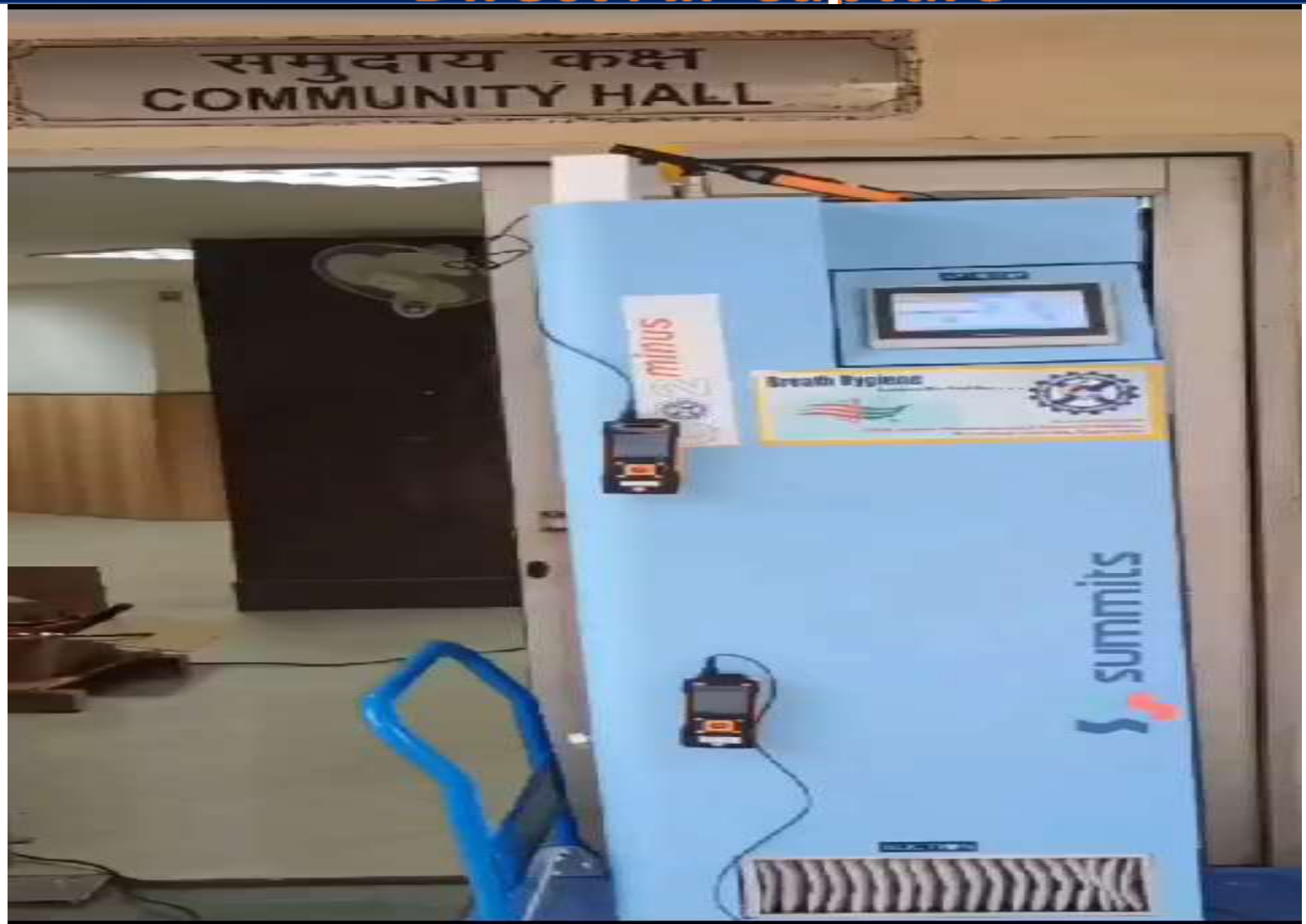
Fabricated gas adsorption units (50g, 1 kg, 25 kg)

10 kg/day- CO_2 adsorption unit

CO_2 ADSORPTION FROM DIRECT AIR



Direct Air Capture



CSIR Activities in Direct Air Capture

Alarming effect of PM 2.5 and CO_2 on air quality

Press Trust of India
New Delhi, UPDATED: Mar 19, 2024 07:24 IST
Posted By: Sudeep Lavania

(PM2.5) Shortens An Average Indian's Life Expectancy By 5.3 Years

- Delhi's PM2.5 levels worsened to 92.7 micrograms per cubic metre in 2023
- 1.36 billion Indians exposed to PM2.5 concentrations exceeding WHO guidelines

The levels of CO_2 in the air and potential health problems are:

- **400 ppm: average outdoor air level**
- **400–1,000 ppm: good air exchange**
- **1,000–2,000 ppm: drowsiness and poor air**
- **2,000–5,000 ppm: headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea**
- **5,000 ppm: Toxicity or oxygen deprivation could occur. This is the permissible exposure limit for daily workplace exposures.**
- **40,000 ppm: Immediately harmful due to oxygen deprivation.**

Challenges

- **Immediate solution for purified air in open atmosphere is challenging in terms of short-term goal, as it depends on controlling the industrial emissions, automobile emissions etc.**

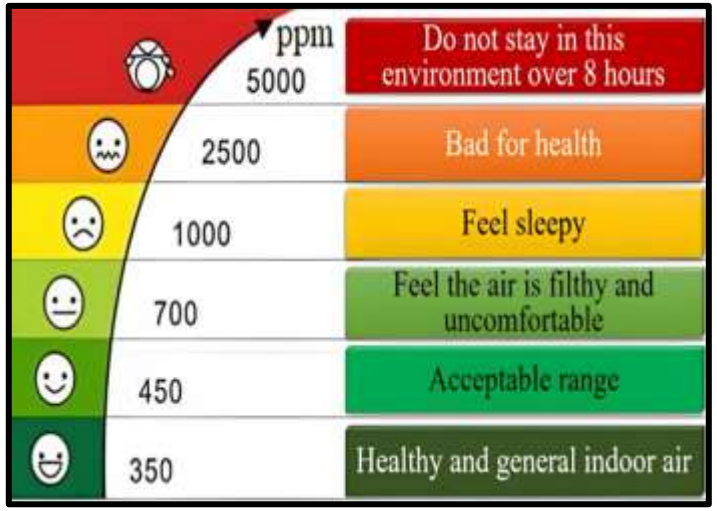
Immediate option for improving air quality

Motivation behind CSIR's initiation towards abating indoor air pollution (IAP)

- WHO designated IAP as one of the foremost critical global environmental problems in developing countries.
- This contributes ~28% (i.e. 2 million) of all deaths.
- ~80-90% of our total times are spent in indoor.
- However, a far less attention has been paid to the IAP, though an equally important issue.
- However, sensing the importance of IAP studies in India, *an effort has been made by CSIR to map the indoor air quality in different indoor environments as well as heavy foot-fall areas in the city of Delhi*, which is on the top of the list of 20 most air polluted cities across the globe.

Development and Demonstration of Ambient Fine Particulate Matter (PM) and Carbon-di-oxide (CO2) Mitigation System

The levels of CO_2 in the air and potential health problems



- 400 ppm: average outdoor air level.
- 400–1,000 ppm: typical level found in INDOOR with good air exchange.
- 1,000–2,000 ppm: level associated with complaints of drowsiness and poor air.
- 2,000–5,000 ppm: level associated with headaches, sleepiness, and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea may also be present.
- 5,000 ppm: this indicates unusual air conditions where high levels of other gases could also be present. Toxicity or oxygen deprivation could occur. This is the permissible exposure limit for daily workplace exposures.
- 40,000 ppm: this level is immediately harmful due to oxygen deprivation.
- >100,000PPM: oxygen deprivation in seconds: convulsions, coma and death

Source: Wisconsin Department of Health Services

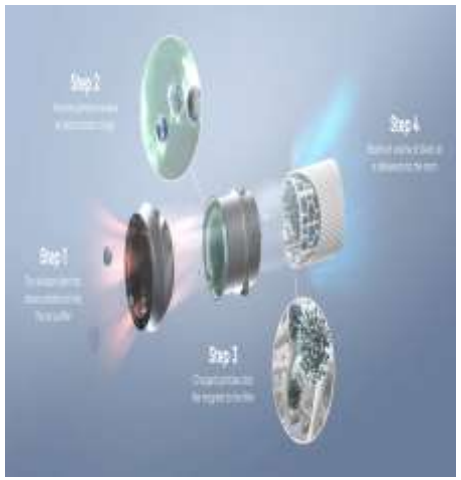
Activated carbon from coconut shell

Impregnated activated carbon

IQ air

COWAY

BLUE AIR

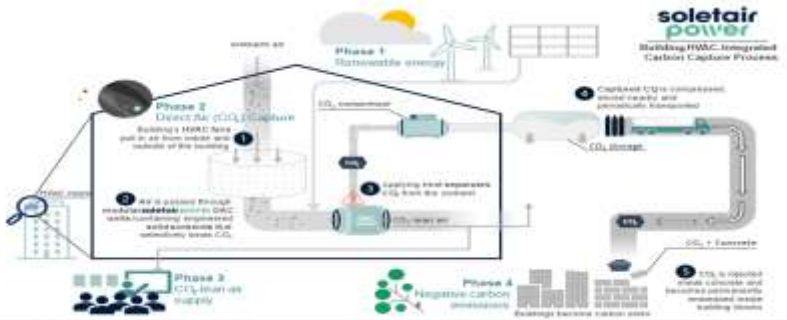


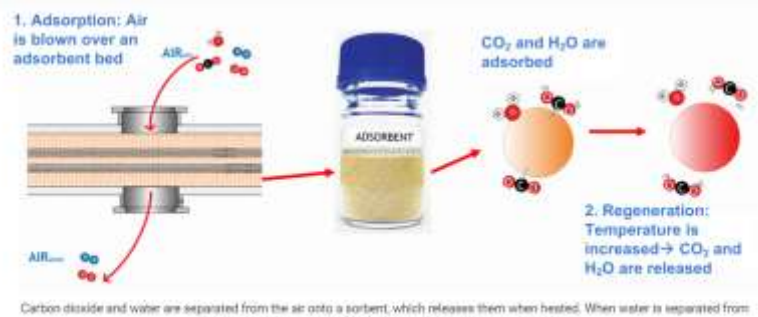
AVAILABLE TECHNOLOGIES FOR INDOOR

Development and Demonstration of Ambient Fine Particulate Matter (PM) and Carbon-di-oxide (CO2) Mitigation System

AVAILABLE TECHNOLOGIES INCLUDING CO2 CAPTURE

SOLETAIR POWER



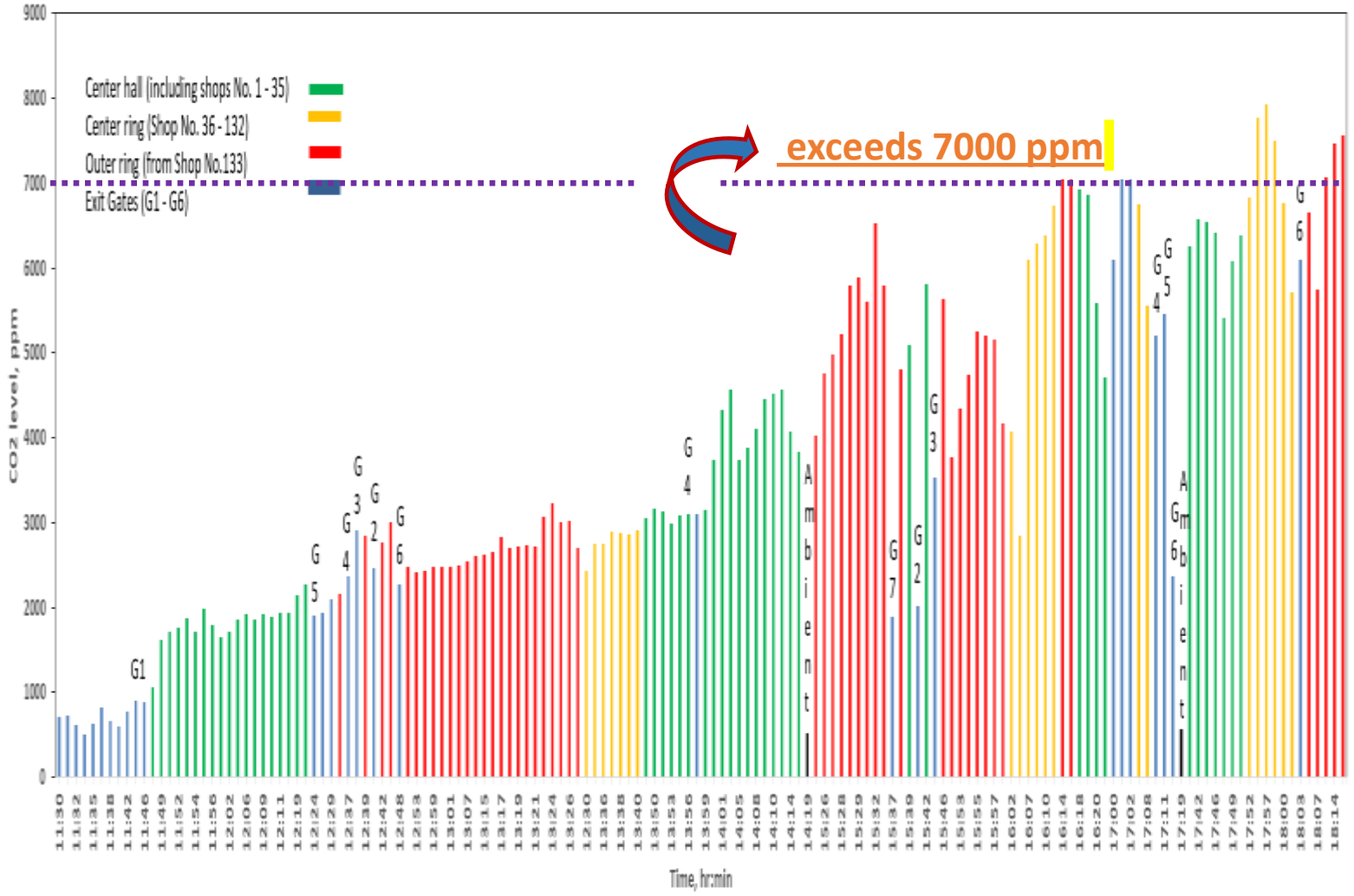


Carbon dioxide and water are separated from the air onto a sorbent, which releases them when heated. When water is separated from

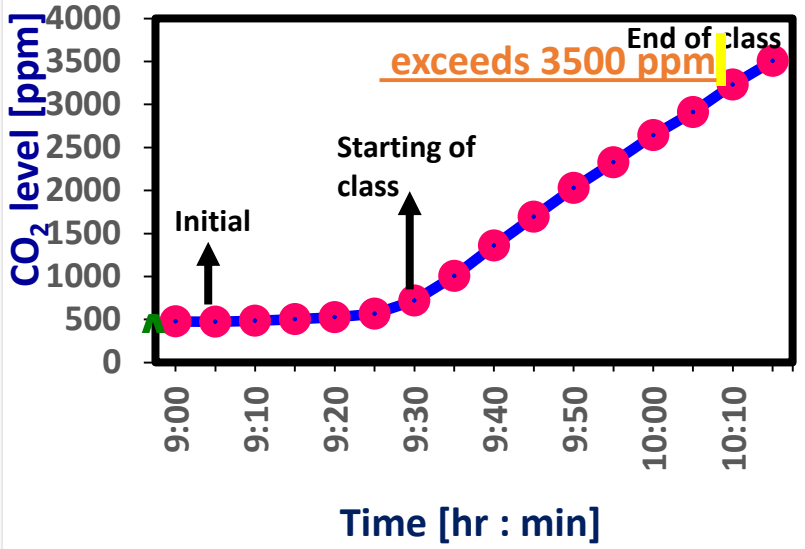
Building Integrated Carbon Capture Unit

CSIR Activities in Direct Air Capture

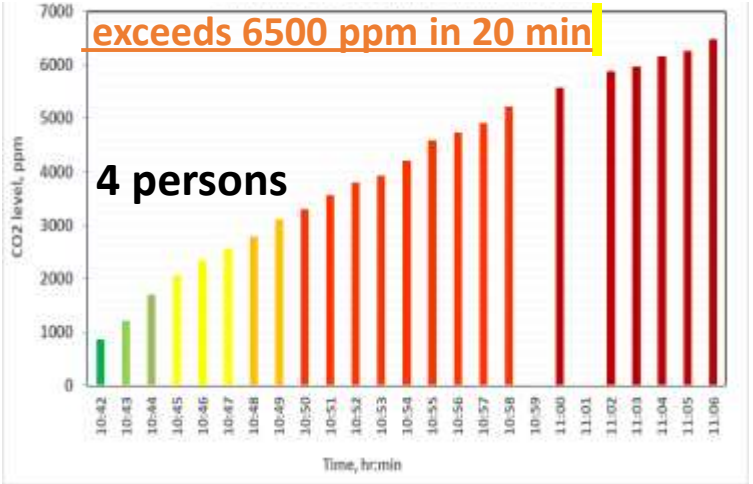
CO_2 Level Monitoring in Palika Bazaar, New Delhi, 04.11.2023



CO_2 Level Monitoring in AC classroom

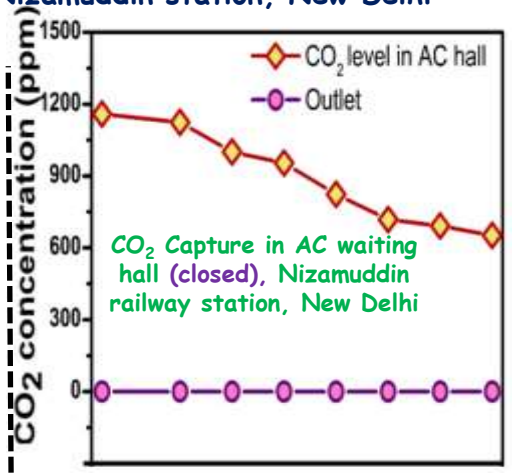


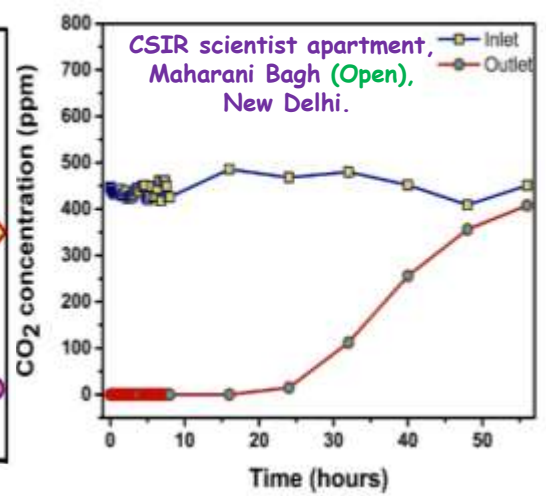
CO_2 Level Monitoring in AC Car



CSIR Activities in Direct Air Capture

PM & CO_2 mitigation study in AC waiting hall, Nizamuddin station, New Delhi





Particulate matter concentration in AC waiting hall, Hazrat Nizamuddin railway station, New Delhi.

PM	WHO limit µg/m³	Inlet µg/m³	Outlet µg/m³	Removal efficiency (%)
PM-2.5	15 (0.015 mg/m³)	114 (0.114mg/m³)	5 (0.005mg/m³)	95.6%
PM-10	45 (0.045 mg/m³)	269 (0.269 mg/m³)	6 (0.006mg/m³)	97.7%

"Development and demonstration of ambient air particulate matter (PM) and carbon dioxide (CO_2) mitigation system"

Activity start date: 31.07.2023

Activity end date: 31.03.2024

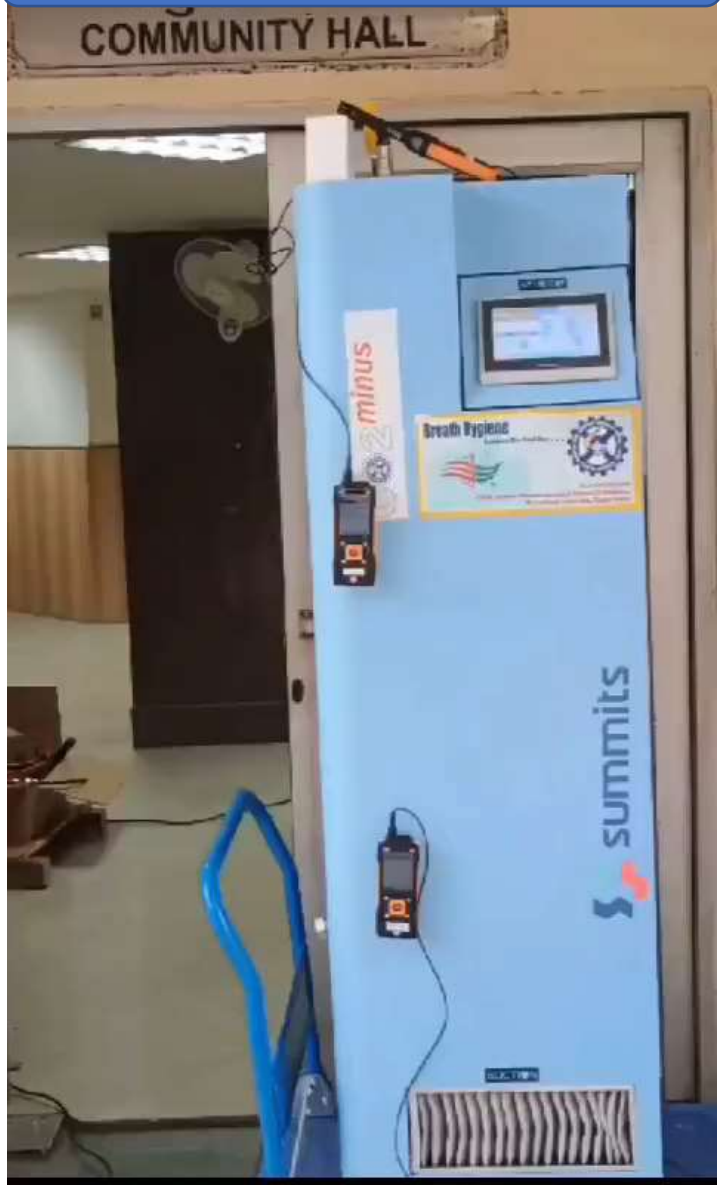
Current status: To be launched in market

Outcome of the project

Developed CO_2 mitigation unit that can purify air in closed, semi-open and open heavy footfall areas

Product has been certified as per OSHA & ASHRAE, United States of America

DIRECT AIR CAPTURE VIDEO



DIRECT AIR CAPTURE


summits

INDOOR AIR QUALITY MONITORING REPORT FOR THE CARBON DIOXIDE CONTENT IN THE CLOSED ROOM ATMOSPHERE

Date: 09-Oct-2024

Product Name : RELAXAIR CARBON DIOXIDE CAPTURING SYSTEM
Model : RELAXAIR 600 (Sr. No. : 2425RA1001) & RELAXAIR 250 (Sr. No.: 2425RA1002)
Testing Area : 600 sq. ft.
Number of persons in the testing area : 25 persons

Table - 1

S. No	Time	CO_2 PPM (Before switch ON Relaxair)	Time	CO_2 PPM (While Relaxair running after 2 hours)
1.	12.30 PM	1285 PPM	04.30 PM	1154 PPM
2.	01.30 PM	2301 PPM	05.30 PM	1035 PPM
3.	01.45 PM	1383 PPM	05.30 PM	511 PPM
4.	02.30 PM	1450 PPM	05. 52 PM	727 PPM


summits

The above readings in Table – 1 were verified physically with CO2 sensor is adhering with the Appendix of OHSAS, NIOSH & ASHRAE standards for the indoor acceptable limits of Carbon Dioxide.

Prepared By | Reviewed By | Witnessed By


summits AIR QUALITY CERTIFICATE

Product Name: RELAXAIR (600 Sq. Ft)
Sample location: ACT Outlet

As per OSHA requirements

S. No	Parameter	Unit	Actual	Requirement	RESULT
1.	Carbon dioxide, CO_2	ppm	211	5000 max	OK
2.	Methane, CH_4	ppm	1.80	5 max	OK
3.	Nitrogen, N_2	%(v/v)	78.8	78	OK
4.	Oxygen, O_2	%(v/v)	21.1	19.5-23.5	OK
5.	Carbon monoxide, CO	ppm	BLQ of 0.2	10	OK
6.	Ammonia NH_3	ppm	0.03	100	OK
7.	Sulphur dioxide SO_2	ppm	0.043	5	OK
8.	Nitrogen dioxide NO_2	ppm	BLQ of 0.005	5	OK
9.	Chloroform (VOC)	$\mu g/m^3$	0.0507	0.75	OK
10.	1,2 Dichloroethane (VOC)	$\mu g/m^3$	0.0141	0.75	OK

*Other BLQ's are BLQ 0.0010 $\mu g/m^3$, **BLQ - Below Limit of Quantification

The above results are based on the test results provided in the enclosed reports "SS2406080801452 dated 13-06-2024, 852405270067291 dated 31-05-2024, 852405270067271 dated 31-05-2024 and ATL/2024/0851 dated 10.05.2024" are verified against the OSHA standard and found within the stated requirements.


summits AIR QUALITY CERTIFICATE

Product Name: RELAXAIR (600 Sq. Ft)
Sample location: ACT Outlet

As per ASRAE requirements

S. No	Parameter	Unit	Actual	Requirement	RESULT
1.	Carbon dioxide, CO_2	ppm	211	1000 max	OK
2.	Methane, CH_4	ppm	1.80		OK
3.	Nitrogen, N_2	%(v/v)	78.8	78	OK
4.	Oxygen, O_2	%(v/v)	21.1	19.5-23.5	OK
5.	Carbon monoxide, CO	ppm	BLQ of 0.2	9 max	OK
6.	Ammonia NH_3	ppm	0.03	0.72	OK
7.	Nitrogen dioxide NO_2	ppm	BLQ of 0.005	0.450	OK
8.	Chloroform (VOC)	$\mu g/m^3$	0.0507	0.75	OK
9.	1,2 Dichloroethane (VOC)	$\mu g/m^3$	0.0141	0.75	OK

*Other BLQ's are BLQ 0.0010 $\mu g/m^3$, **BLQ - Below Limit of Quantification

The above results are based on the test results provided in the enclosed reports "SS2406080801452 dated 13-06-2024, 852405270067291 dated 31-05-2024, 852405270067271 dated 31-05-2024 and ATL/2024/0851 dated 10.05.2024" are verified against the OSHA standard and found within the stated requirements.


AIR QUALITY CERTIFICATE

Product Name: RELAXAIR (600 Sq. Ft)
Sample location: ACT Outlet

As per NIOSH requirements

S. No	Parameter	Unit	Actual	Requirement	RESULT
1.	Carbon dioxide, CO_2	ppm	211	5000 max	OK
2.	Methane, CH_4	ppm	1.80	100	OK
3.	Nitrogen, N_2	%(v/v)	78.8	78	OK
4.	Oxygen, O_2	%(v/v)	21.1	19.5-23.5	OK
5.	Carbon monoxide, CO	ppm	BLQ of 0.2	35	OK
6.	Ammonia NH_3	ppm	0.03	35	OK
7.	Nitrogen dioxide NO_2	ppm	BLQ of 0.005	1	OK
8.	Chloroform (VOC)	$\mu g/m^3$	0.0507	0.75	OK
9.	1,2 Dichloroethane (VOC)	$\mu g/m^3$	0.0141	0.75	OK

*Other BLQ's are BLQ 0.0010 $\mu g/m^3$, **BLQ - Below Limit of Quantification

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SHIVA
SHIVA ANALYTICALS (INDIA) PRIVATE LIMITED


SHIVA
SHIVA ANALYTICALS (INDIA) PRIVATE LIMITED


SHIVA
SHIVA ANALYTICALS (INDIA) PRIVATE LIMITED


ATL
Analytical Technology Laboratory


ATL
Analytical Technology Laboratory

Certified as per OSHA, ASRAE & NIOSH

Certification for indoor and semi-indoor air purification system (CO_2 capture)

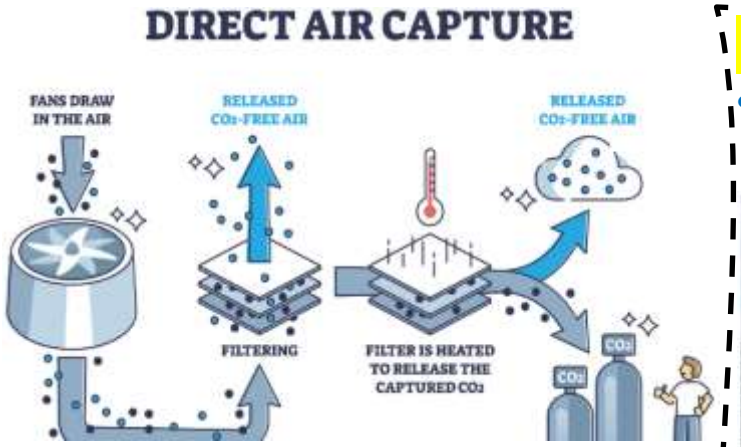
DIRECT AIR CAPTURE

Commercialization of standstill Indoor and semi-indoor air purification system (CO_2 capture)

Indoor and semi-indoor air purification system will be available in the market from next month


CO_2 ADSORPTION PILOT PLANT

CO_2 CAPTURE RAIL

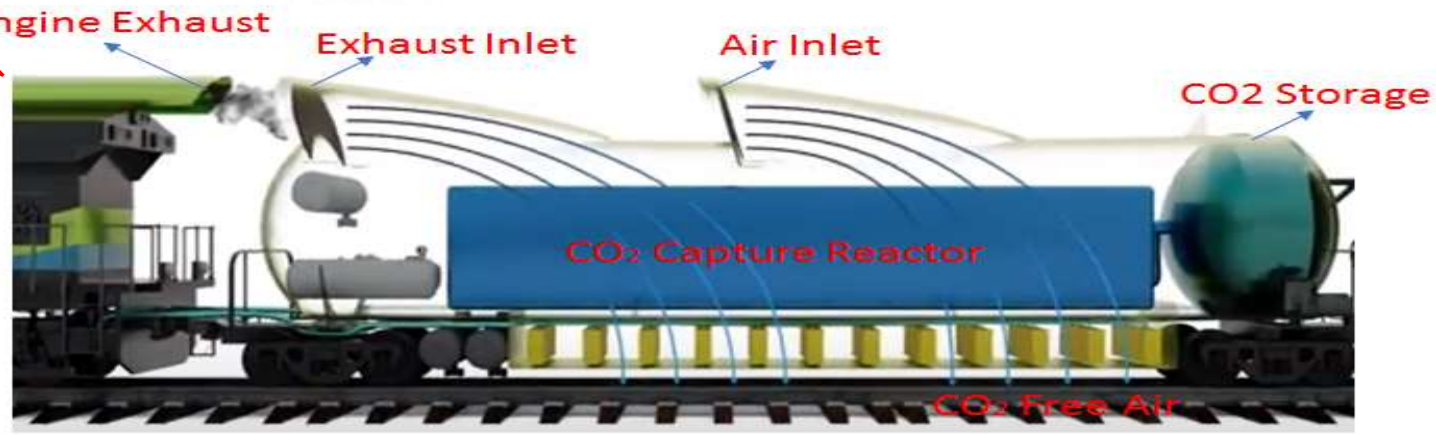


Advantage of DAC

- Offers flexibility in sitting the plant in any location as compared to CO_2 capture from point-sources

Challenges in adopting DAC

- High energy penalty for drawing air to DAC units through compressor/blower and hence cost of DAC systems ranges from $250/Ton to $600/Ton of CO_2 capture depending on the technology used, energy choice, and scale.

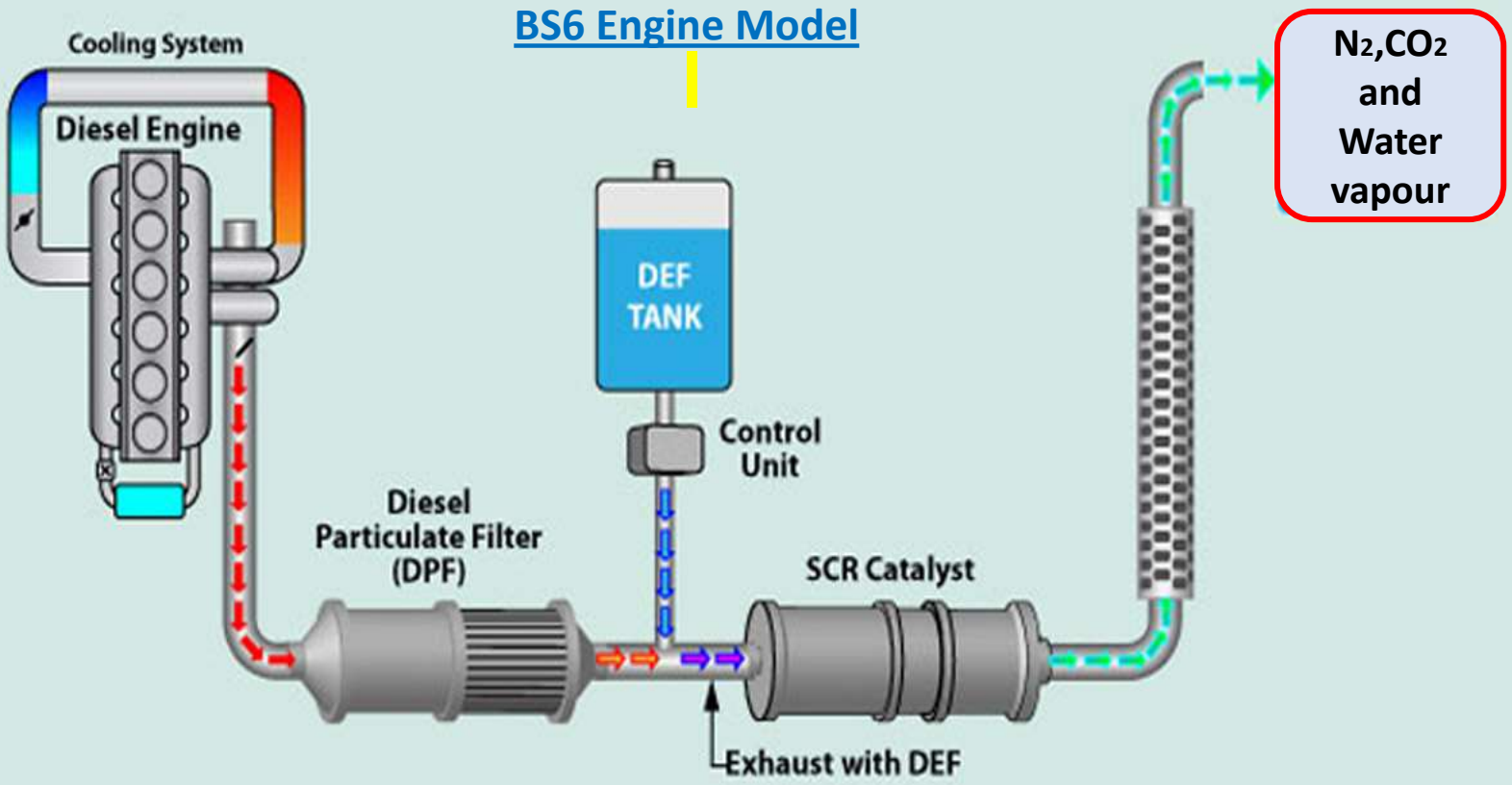


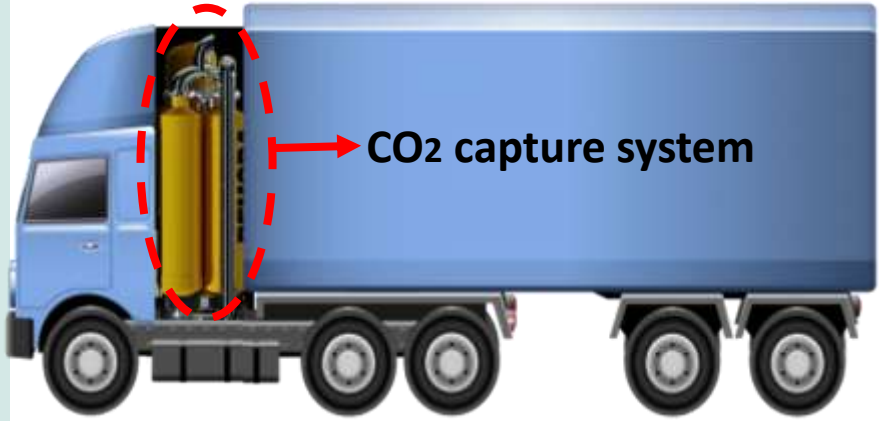
Merits of CO_2 Capture RAIL

- Overcomes the necessity for drawing air via blower and hence major energy penalty could be avoided
- Avoids land requirement and CO_2 transportation cost
- >20,000 trains (including passenger and freight) running in India per day. If ~0.5 ton of CO_2/day is captured per train, ~4 million tons of CO_2 can be abated per year using carbon capture rail system

CO_2 CAPTURE FROM HEAVY TRUCKS

BS6 Engine Model





Advantages of CO_2 capture on trucks

- Implementation can be feasible with simple infrastructure
- CO_2 storage tank can be unloaded and delivered at collecting points
- Transportation cost for delivering CO_2 to end users like industries could be avoided

Benefit of CO_2 capture on trucks

Cost of diesel/litre	= Rs. 90
CO_2 produced/ liter of diesel	= 2.64 kg
Average running time of truck	= 450 km/day
Diesel required/ day	= 150 liter
CO_2 produced/day	= 150*2.64
	= 396 kg
CO_2 price/kg	= Rs 20
CO_2 selling price/day	= Rs 7920
CO_2 selling price/year (300 days)	= 300*7920
	= Rs 23,76,000
Cost of diesel per year	= 45000*90
	= Rs 40,50,000

SYNTHESIS AND SCREENING OF BENCHMARK ADSORBENT FOR CO_2 CAPTURE UNDER FLUE GAS CONDITIONS

Data Sheet of CECRI Adsorbent

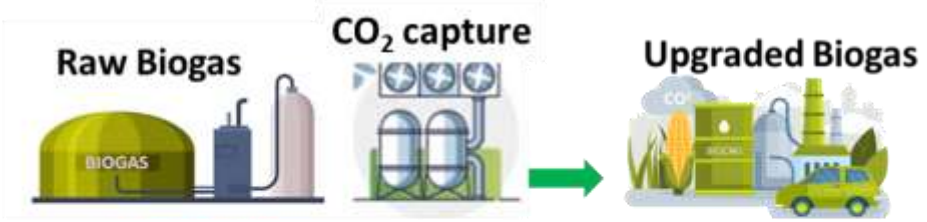
	CECRI	Honey well	Clime works	Global thermostat	BASF	Svante
Surface area m^2/g	1200	1500	-	SBA-858, Aziridine-SBA-75	150-200	550
Pore size (nm)	2-50	-	10 µm Diameter 250 µm length	-	12-20	-
Pore Volume (cc/g)	2.78	-	-	SBA-0.80 Aziridine-SBA-0.11	0.8-1.2	-
CO2 capacity	3.3-4, 1.8 mmol/g	9.8 lbs CO_2/ft^3	1-2.5 mmol/g	5.55, 1.72 mmol/g	0.86 mmol/g	1.3 mmol/g
Composition	20%, 400 ppm	-	400 ppm CO_2, 60% RH	10% CO2, 400 ppm	-	100%
Ads temp (℃)	75 , 30	-	30 ℃	25	20	90
Des temp (℃)	105	-	90 ℃	110	45-65	-
Ads Pressure	1 bar	20-50 bar	1 bar	1 bar	1 bar	-
Des pressure	1 bar	5 bar	1 bar	1 bar	1 bar	-

SYNTHESIS AND SCREENING OF BENCHMARK ADSORBENT FOR CO_2 CAPTURE UNDER FLUE GAS CONDITIONS

	CECRI	Honey well	Clime works	Global thermostat	BASF	Svante
Limitations	Limitations associated with large scale capture plant is yet to be studied	Adsorption process occurs at high pressure conditions	Tested only under direct air capture conditions. Capture under flue gas conditions have not been tested	Energy intensive raw material storage (0 ℃), Tedious and multi step synthesis procedure	Low CO2 adsorption capacity and maximum working temperature is 65 ℃	Low CO2 adsorption capacity at high temperature conditions
Plant size	-	15 million tons/year (absorption & membrane)	**Orca-** 1900 tons/year	1 kiloton/year	70,000 tons/year (400 plants)	**URSA 1000-** 500 tons/year
Reference	Patent Submitted	Patent No- WO2007/11173 A3	Patent No- EP3319998B1	Patent No- US 8.491,705 B2	Patent No- US 11,229,897 B2	https://doi.org/10.1038/s41467-024-48136-0

BIOGAS ENRICHMENT TO BIO-FUEL

CSIR Activities in Enrichment of Biogas



Composition

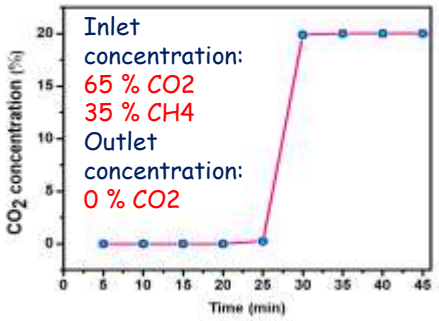
- Methane (CH_4): 55-65%
- CO_2: 35-40%
- Calorific value: 20-25 MJ/m³

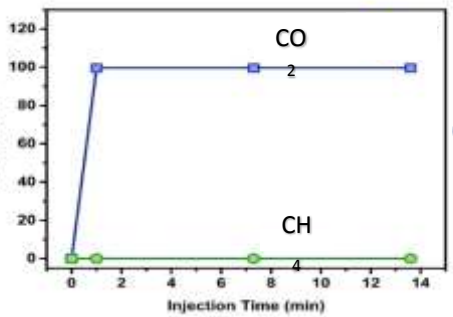
Composition

- Methane (CH_4): 99%
- Other gases 1%
- Calorific value: 40-45 MJ/m³

Industrial problem statement

- In existing bio gas enrichment plants **20-30 % methane loss** occurs during raw biogas purification process due to lack of technology towards selective CO_2 capture

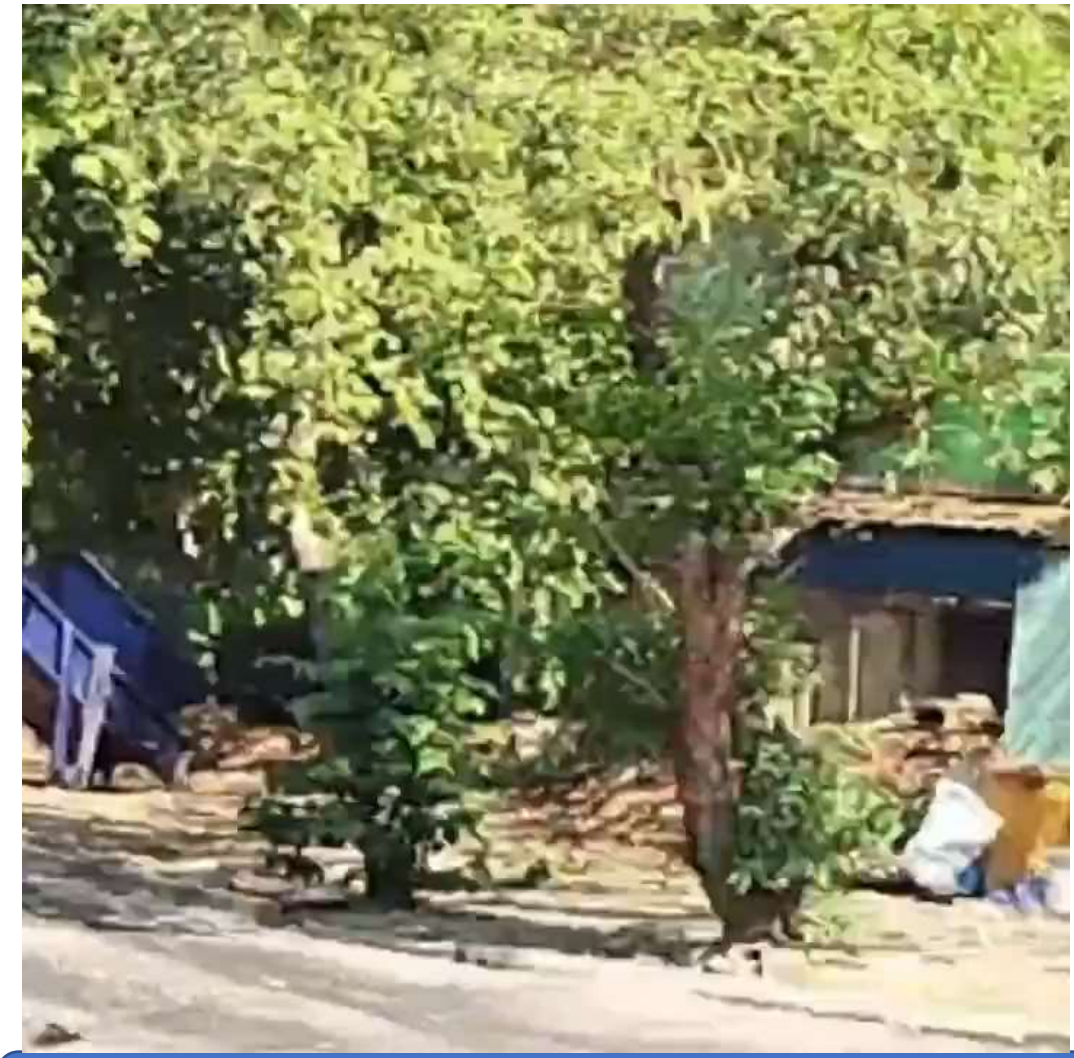




Indigenous sorbent arrests methane loss

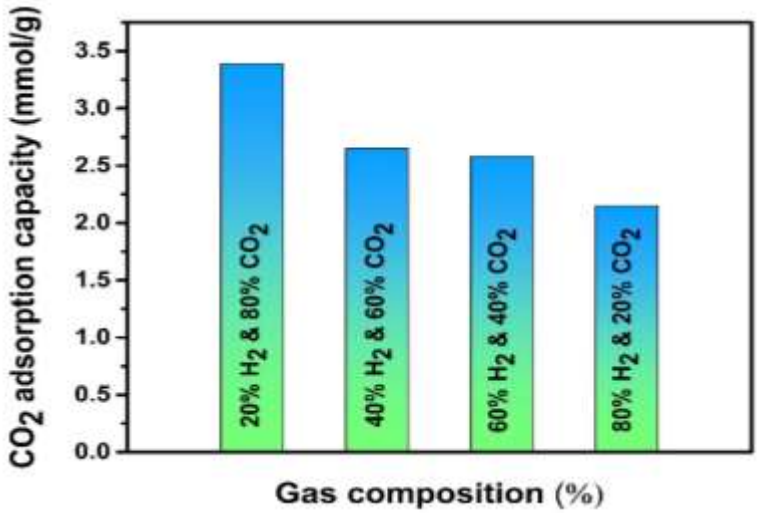
Outcome of field trials

SWMS Bio-CNG plant, Chennai

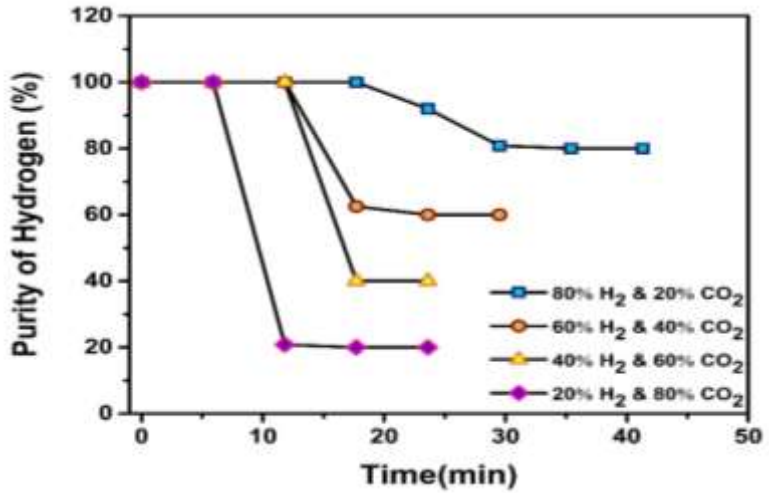


BIO-GAS ENRICHMENT VIDEO

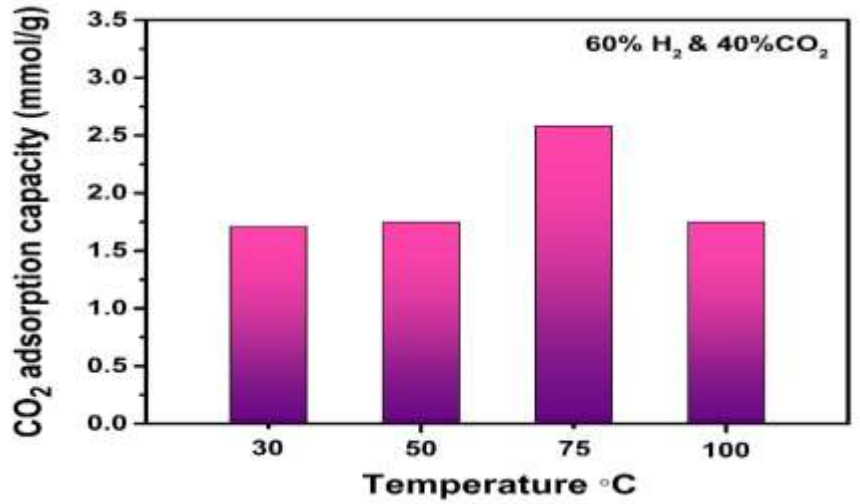
CSIR Activities in Enrichment of Bio-H_2



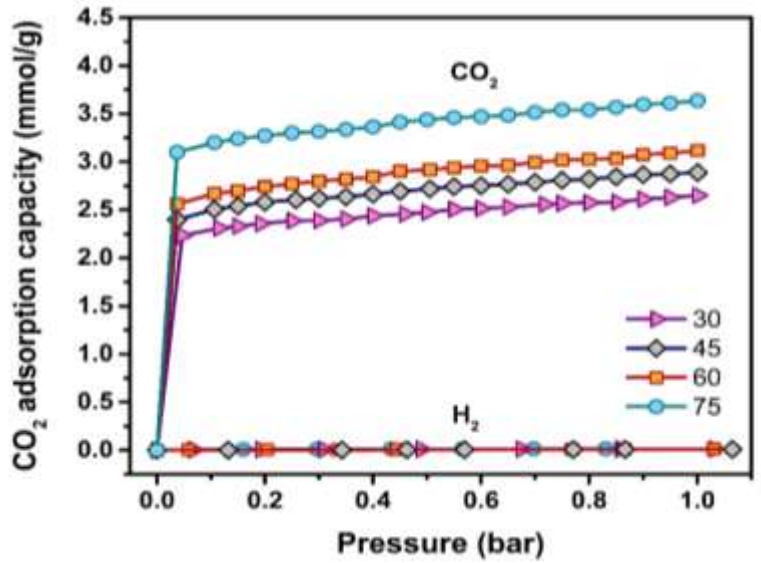
CO_2 adsorption capacity at different composition



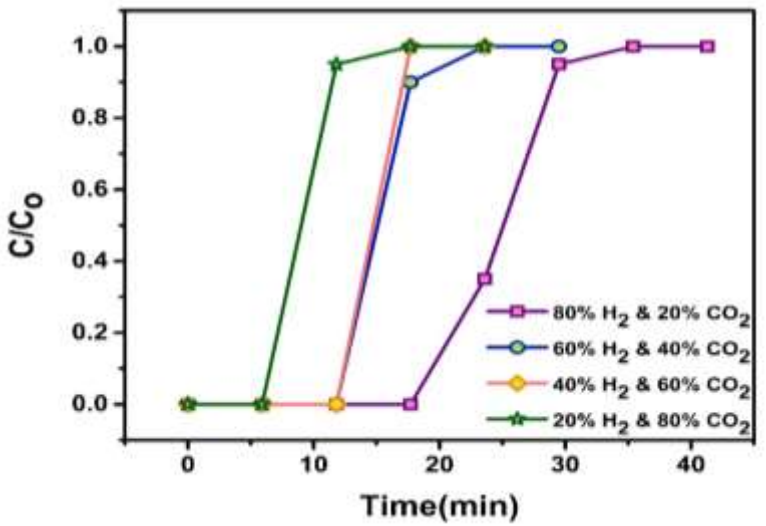
Purity of hydrogen in outlet



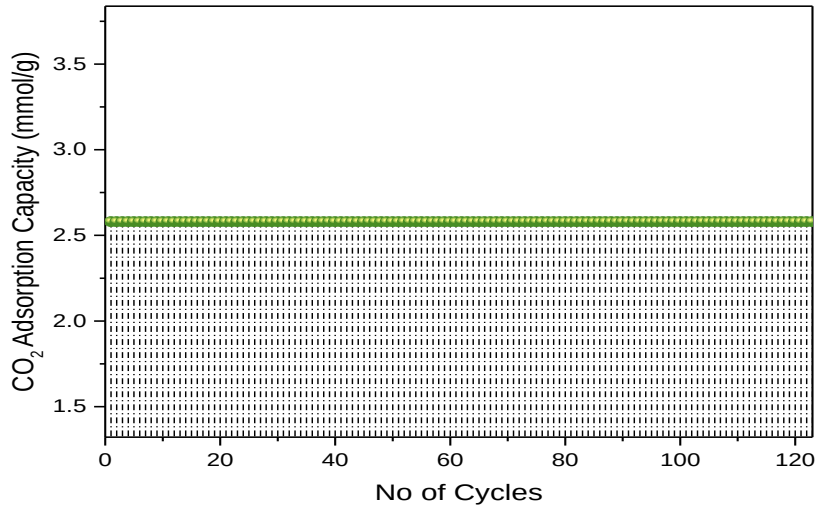
CO_2 adsorption capacity at different T



Selectivity

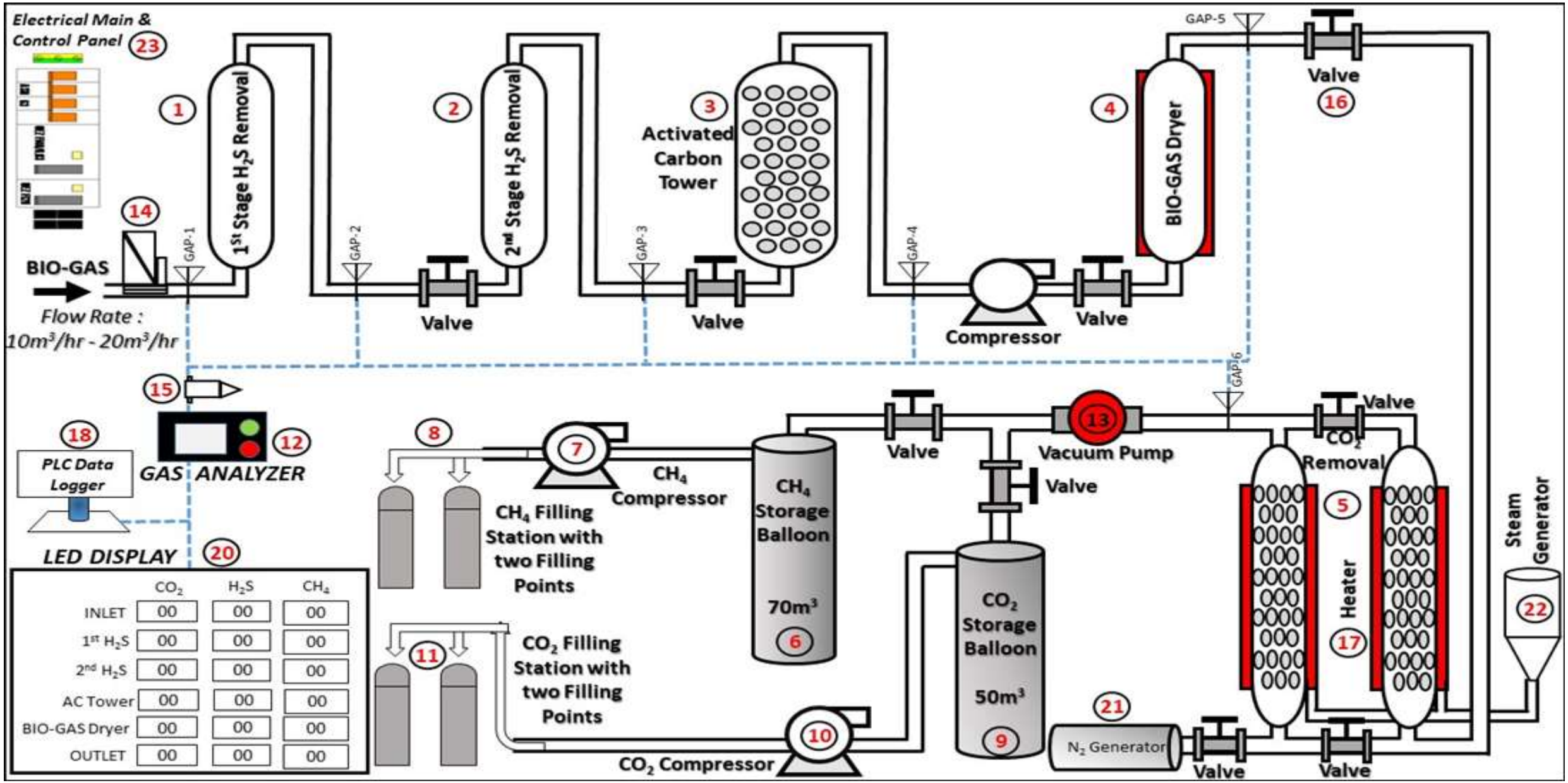


Breakthrough curve



Multicycle stability

PILOT PLANT DESIGN FOR PURIFICATION OF BIOGAS PRODUCED FROM 1 TON OF BIOMASS



AA Mineralization Process (AAM)

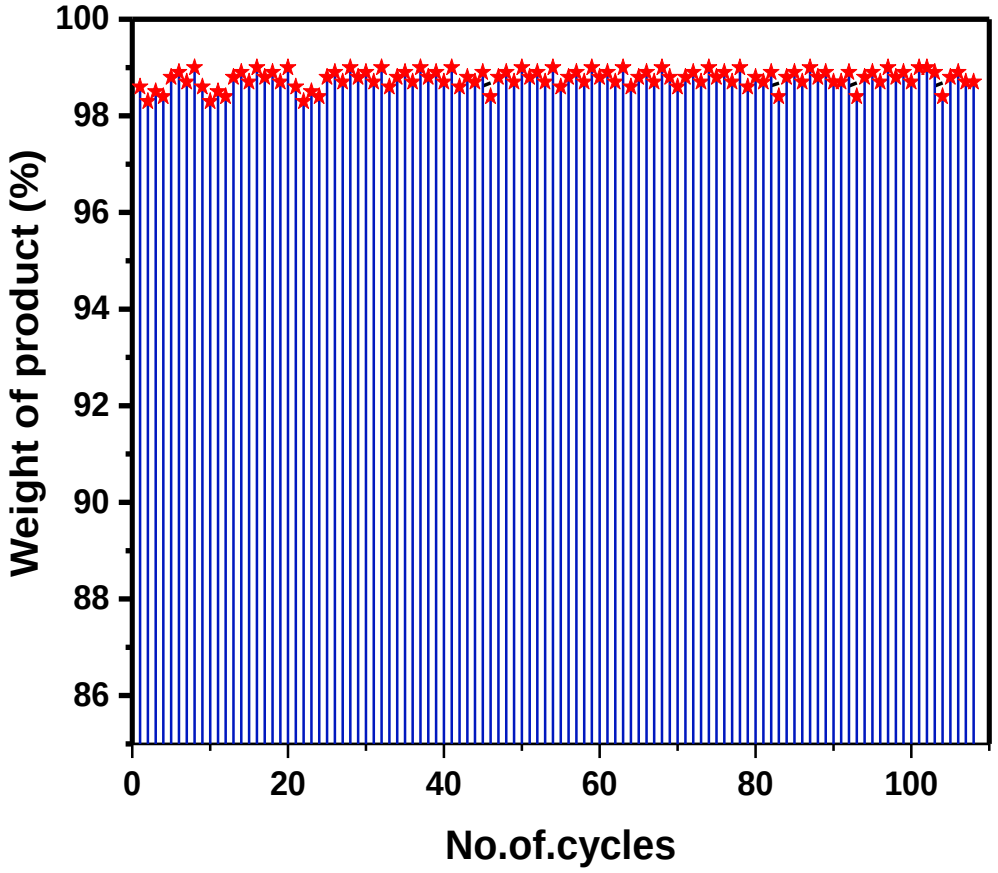
AAM introduces several advantages over conventional process.

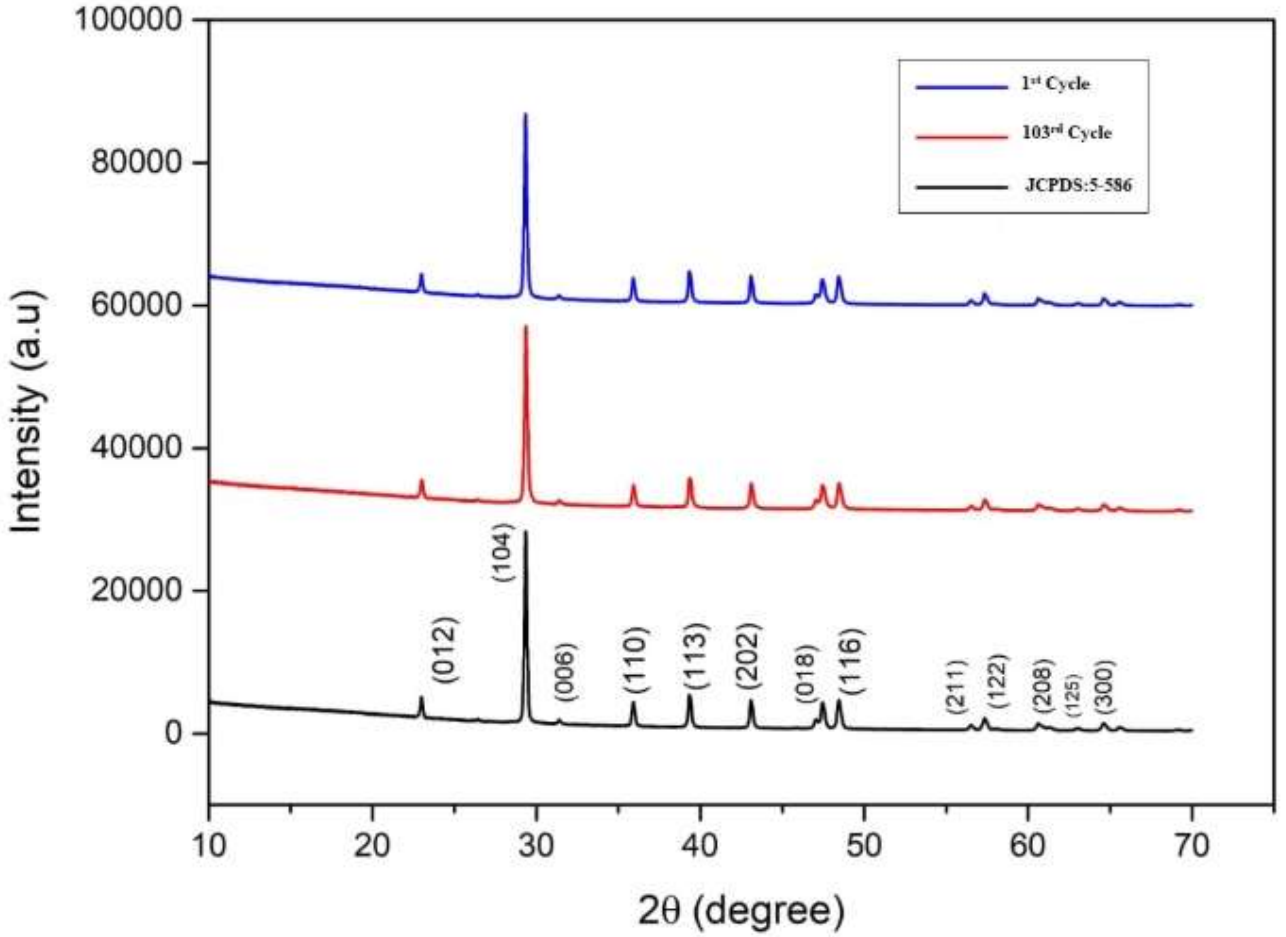
Advantages of AAM

1. Integration with Carbon Capture and utilization (CCU): AAM often part of CCU strategies, directly converting captured CO2 into valuable products.
2. Enhanced reaction kinetics: Increasing the solubility of CO2 with increasing the rate of carbonation
3. Reduced CO_2 loss : Due to more solubility of CO2 it will decreses the CO2 loss
4. Lower Energy Requirments: AAM system can operate efficiently under ambient conditions
5. Improved Control Over Particle Morphology
6. High purity
7. Reduced CO_2 loss

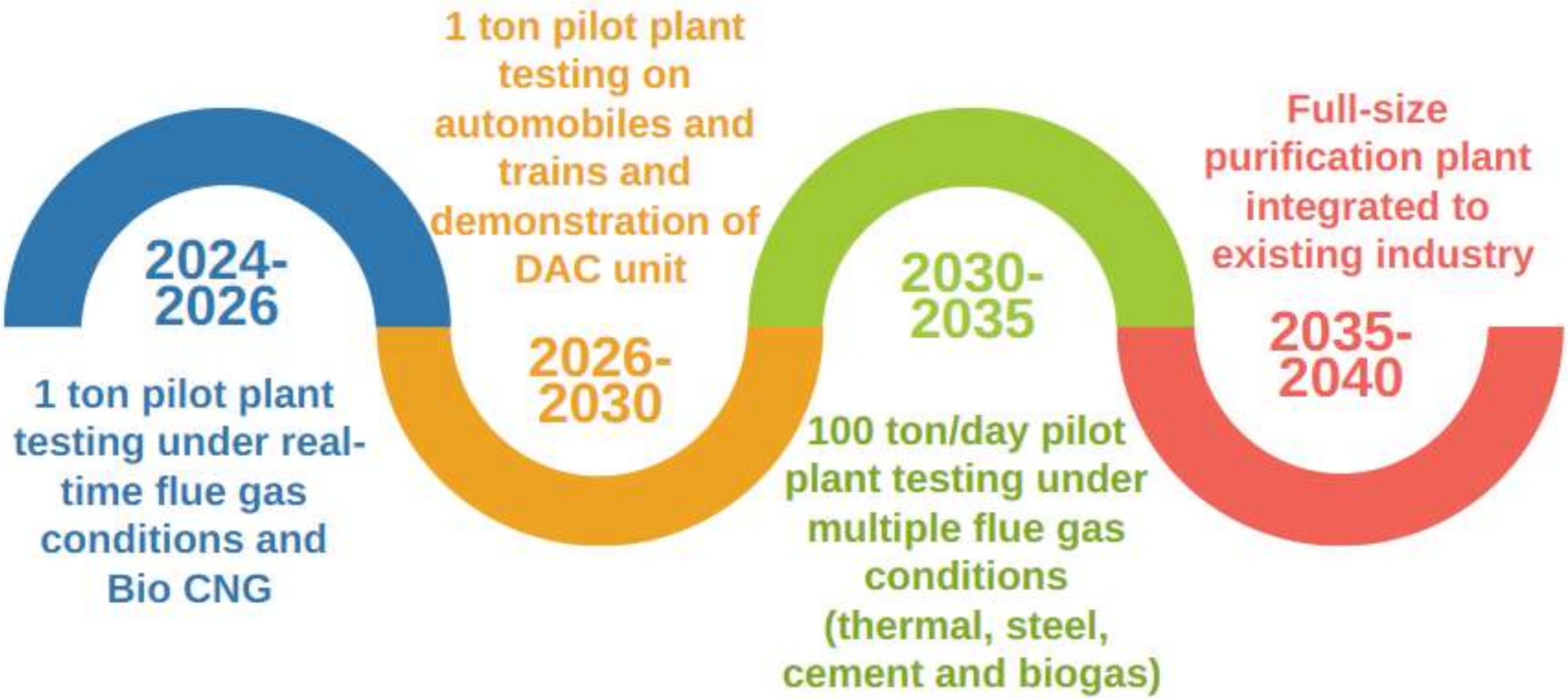
Features	AA Mineralization	Normal Mineralization
CO_2 Solubility	High	Low
Reaction Kinetics	Faster	Slower
Energy Requirements	Lower	Higher (for Pressurization)
Control Over Morphology	High	Limited
Purity of Minerals	High	Moderate
CO_2 Utilization Efficiency	High	Moderate
Industrial Integration	Easy (with CCU system)	Standalone process

AA Mineralization Process (AAM)





CSIR CCUS Strategy Road Map



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