Biotechnological Interventions for CO_2 Capture and Utilization

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Outline

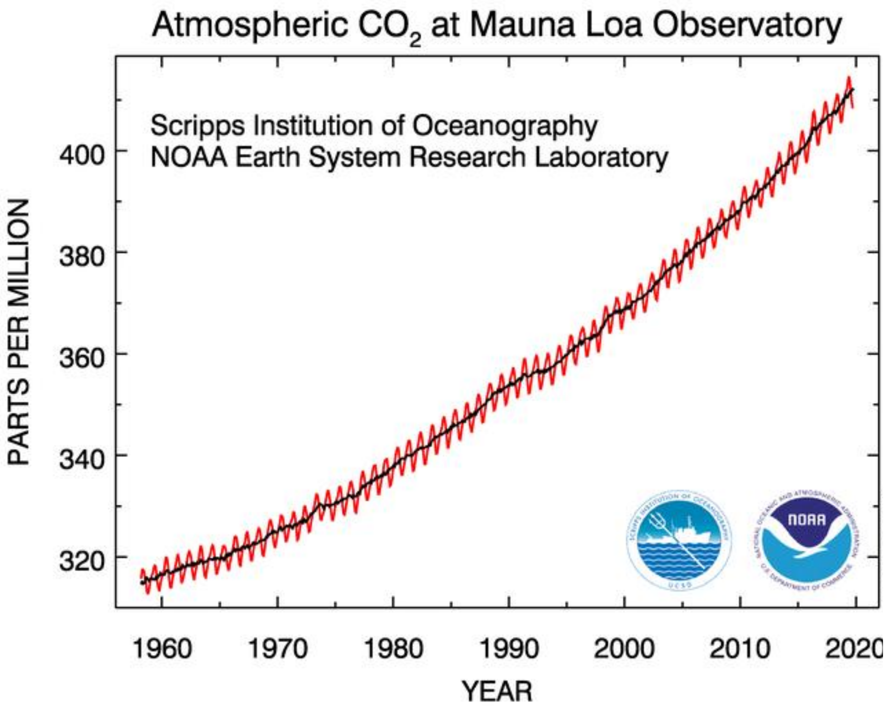
- Background
- CO2 capture and Utilization
- Enzyme assisted CO_2 capture
- CO_2 utilization thru Bio-technological interventions
  - Heterotrophic Microalgae based conversion
  - Electrobiocatalytic Conversion
- Conclusions

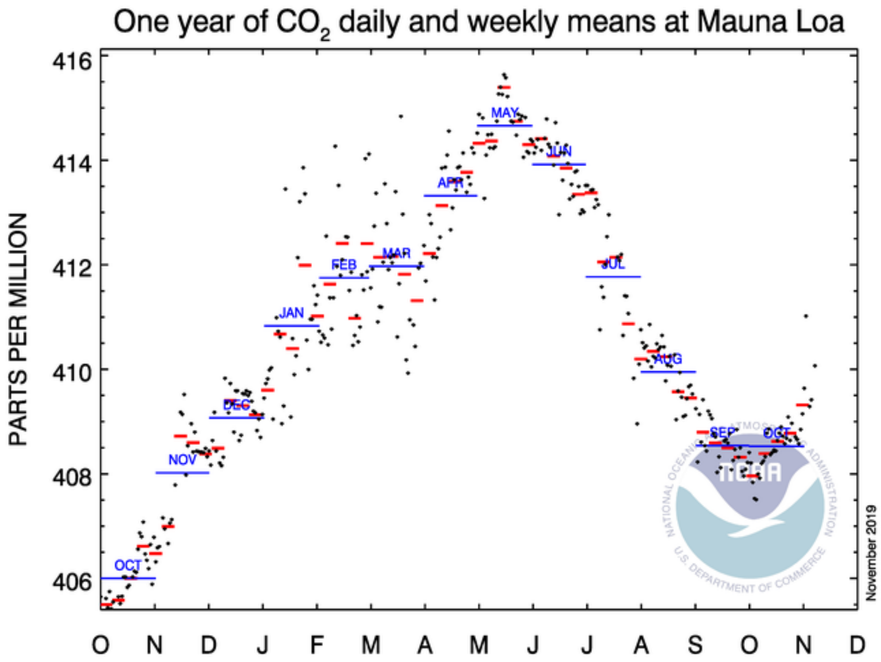
Background

Week beginning on October 27, 2019: 409.32 ppm

Weekly value from 1 year ago: 406.43 ppm

Weekly value from 10 years ago: 385.06 ppm





Global CO_2 concentration Status

Global greenhouse gas emission levels

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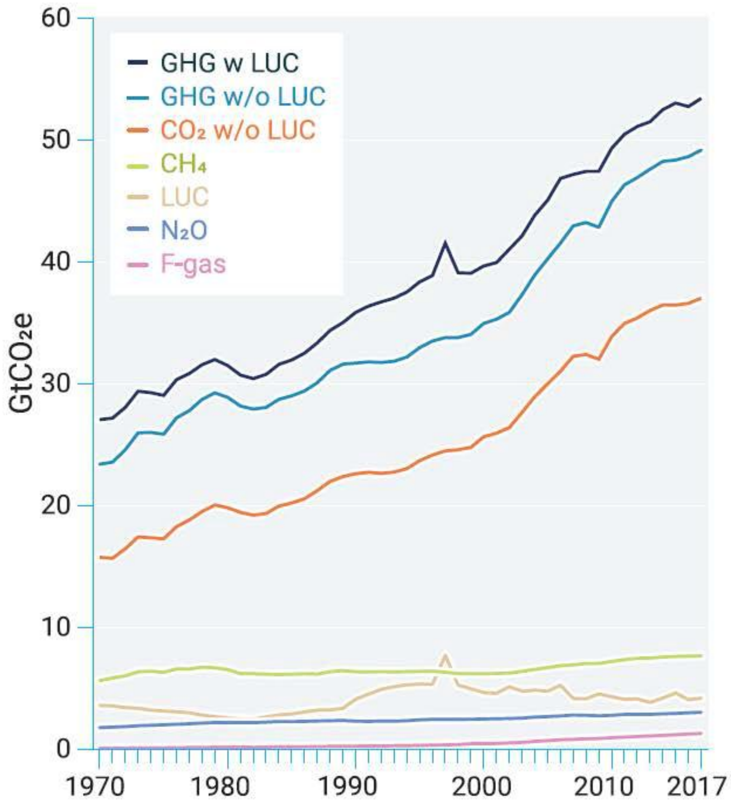
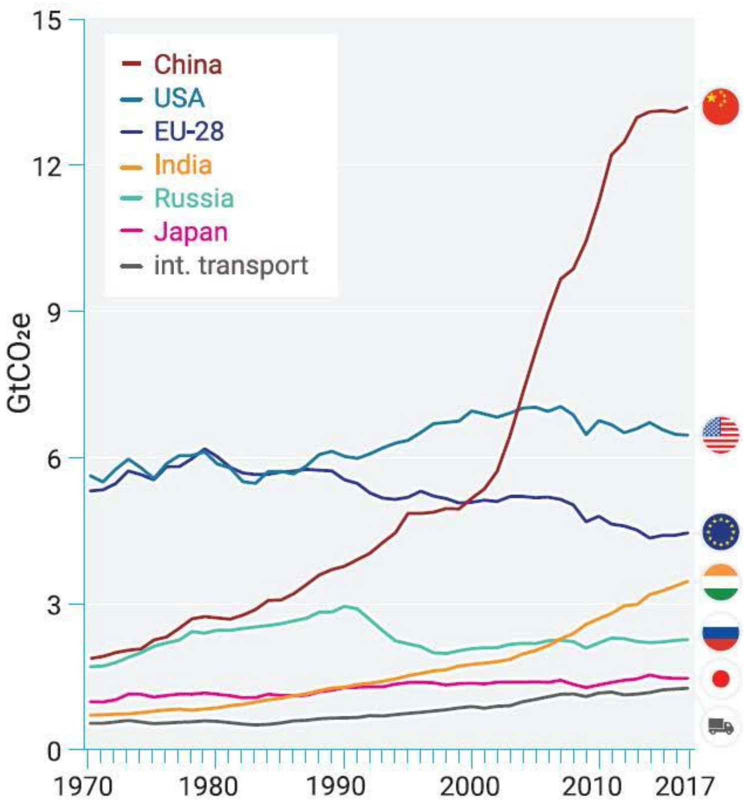
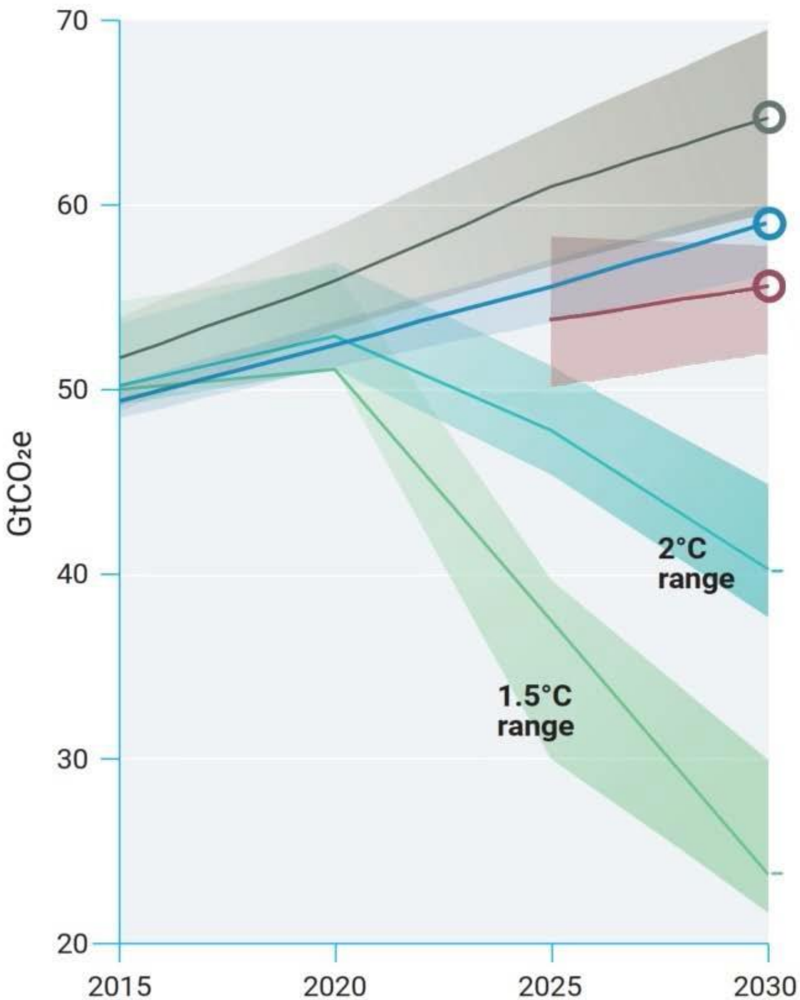




Indian contributing about 3 GtCO2 e GHG Emissions

NDC contributions and the emissions gap



No policy baseline
Global total emissions **60 -70GtCO2e**

Current policy scenario
Global total emissions **56-60 GtCO2e**

Unconditional NDC scenario
Global total emissions **52-58 GtCO2e**

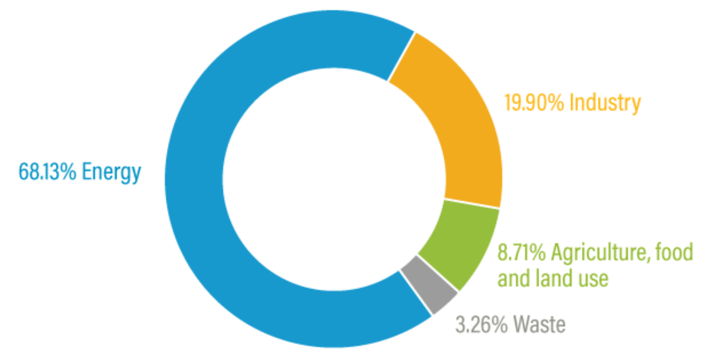
2°C pathways
Global total emissions **40 GtCO2e**

1.5°C pathways
Global total emissions **24 GtCO2e**

Source: Nationally Determined Contribution (NDC) targets for 2030 :UN Emission Gap Report 2018

Background

Most of India's Emissions Come from the Energy Sector



Source: GHG Platform India.

India 4th Highest Carbon Dioxide Emitter, Emissions May Grow by 6.3 %

In India, emissions are expected to grow by a solid 6.3 per cent in 2018, pushed by strong economic growth of around 8 per cent per year.

- Massive CO_2 accumulation result in climate change
- India promises a 33-35% reduction in emissions intensity by 2030, compared to 2005 levels*.

*https://www.telegraphindia.com/india/india-pledges-33-35-cut-in-carbon-intensity-by-2030/cid/1433584

Technological Opportunities

CO_2 CAPTURE & UTILIZATION

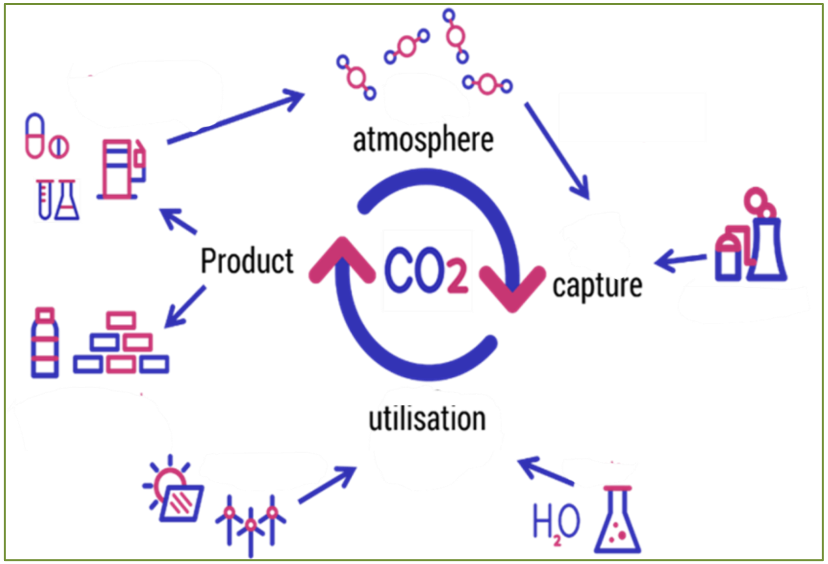
CO_2 Capture & Utilization

CO_2 Capture

- Involves process of separation of CO_2 from industrial and energy related sources

CO_2 Utilization

- It is the industrial process aimed to accelerate the utilization of CO_2 akin to process of producing various substances in nature from CO_2 that are consumed by humans and animals



CO_2 capture

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Common industrial practices

- Amine scrubbing is commonly used process for CO_2 capture.
- Amine based carbon capture have many challenges:
  - High cost due to High energy requirement for solvent Regeneration
  - Low stability
  - Corrosive
- **To overcome such limitations enzymatic CO_2 capture is a viable solution**
- **Enzyme (Carbonic anhydrase, CA) is used as a catalyst to enhance the CO_2 absorption in amine/carbonate solution and for low temperature CO_2 desorption**

Enzymatic CO_2 capture

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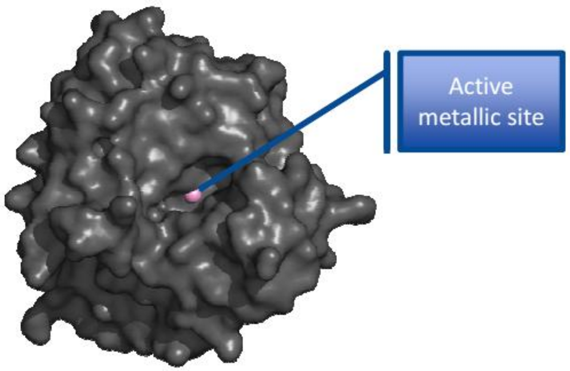
- Carbonic Anhydrase (CA) enzyme: Fastest natural enzyme
- Accelerator for CO_2 capture (TON = 10^6/second)
- CA obtained from thermostable microbes: Stable in industrial Extreme conditions (P, T, Salinity)



Catalyses CO_2 hydration reactions

$$CO_2 + H_2O \overset{CA}{\leftrightarrow} HCO_3^- + H^+$$

CO_2 Capture of CA is 4000 times higher than that of MEA with energy consumption 7 times less*

*Source: Journal of Membrane Science, 2015, 494, 196-204
CO2 Solution

Active metallic site can be synthetically mimicked

Mechanism of CO_2 capture by CA

- In amine-based chemical CO_2 gas scrubbing processes bicarbonate formation is the rate determining step of the reactive absorption of CO_2 for amines and alkali carbonates, which leads to slower reaction and low CO_2 uptake.

$$R_3N + H_2O + CO2 \leftrightarrow R_3NH^+ + HCO_3^-$$

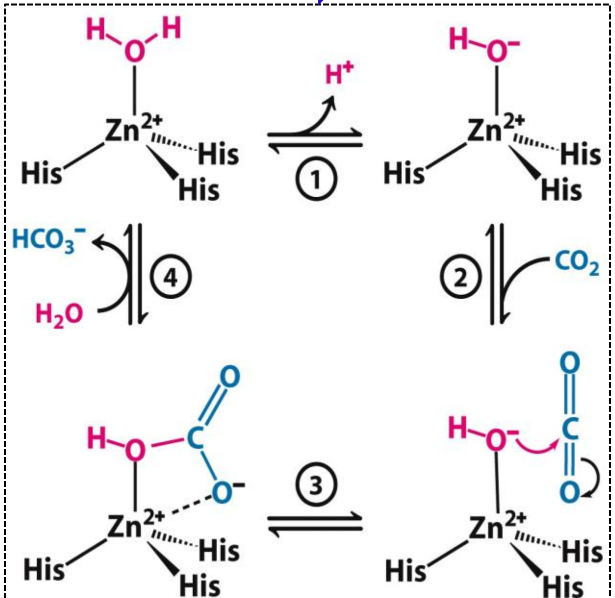
(Slowest)

Catalyzed
By CA

$$R_3N + H_2O + CO2 \leftrightarrow R_3NH^+ + HCO_3^-$$

(Fastest)

- CA accelerates the rate of reaction of solubilising CO_2 to proton (H^+) and carbonate (HCO_3^-) and make the process faster resulting higher CO2 uptake..



Enzymatic CO_2 capture

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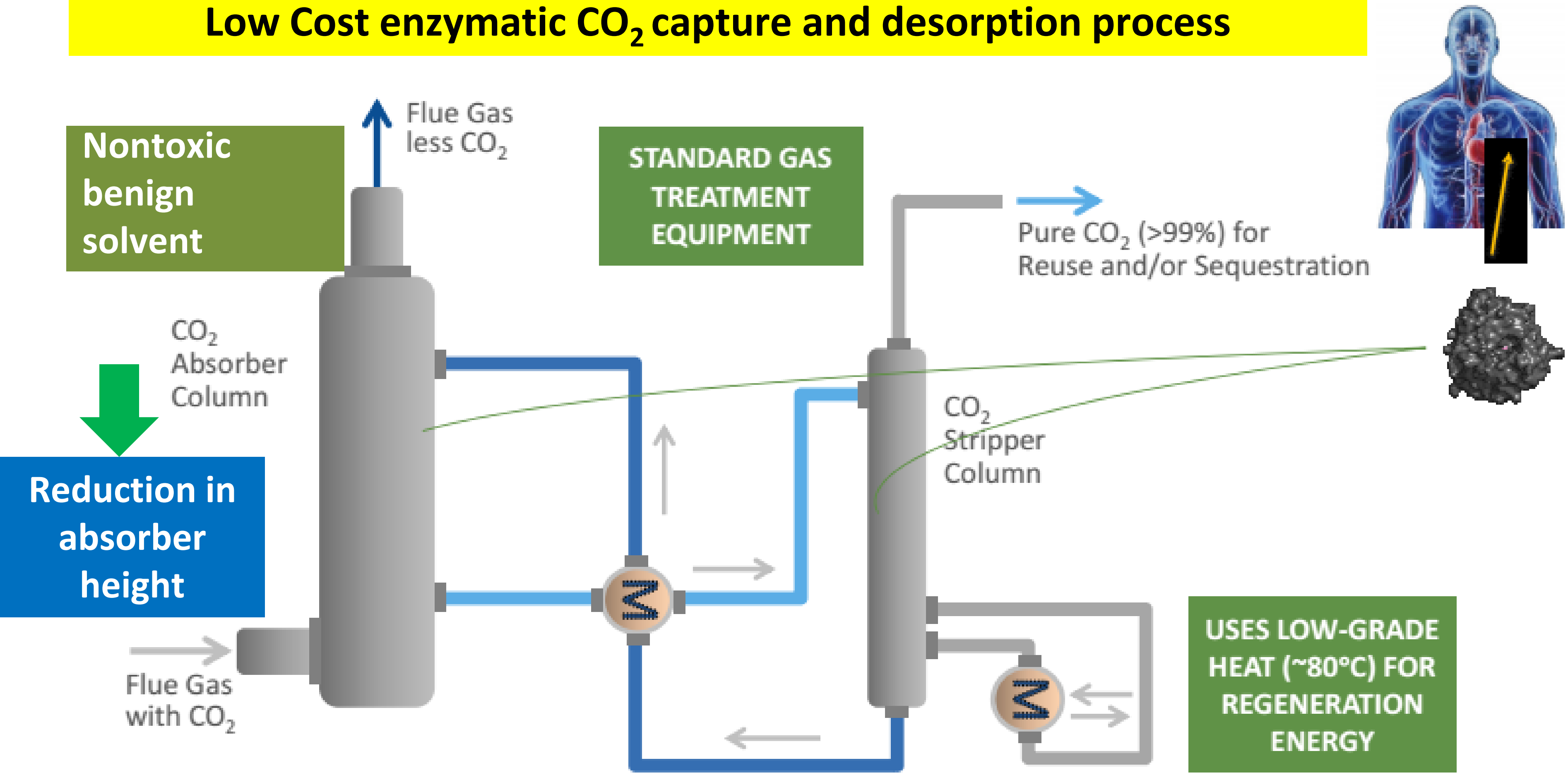
Low Cost enzymatic CO_2 capture and desorption process



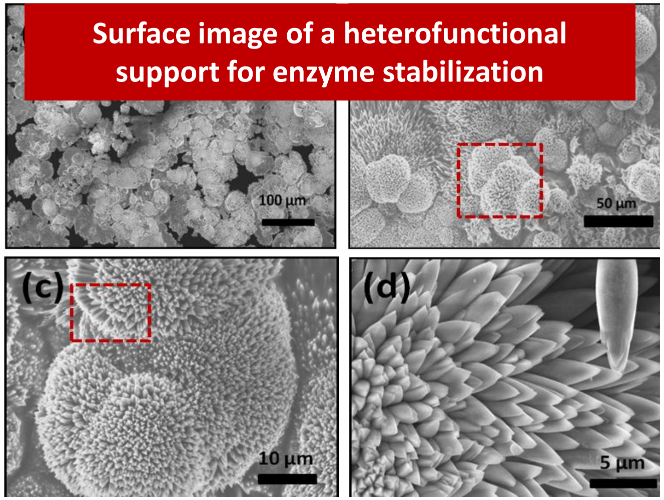
Enzyme catalyses CO_2 capture with low levels of energy, in a benign absorbing solution

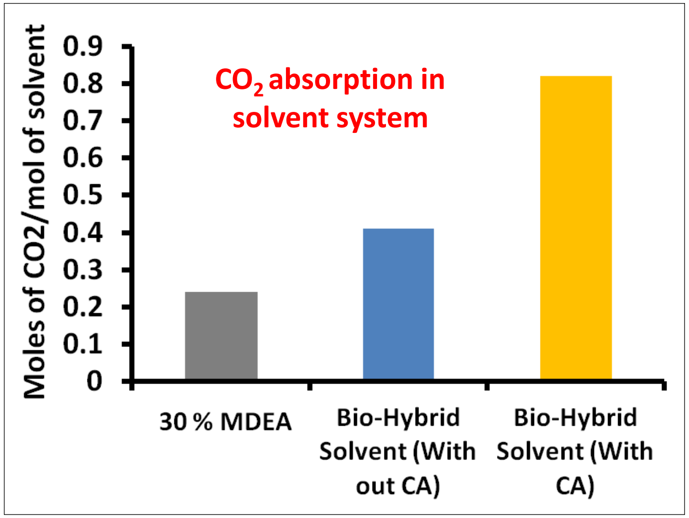
*Source: CO_2 Solution

Advantages

- Enzyme thermostable up to 110 °C with broad pH tolerance developed.
- Functionalized and reusable matrix systems were developed for immobilization of enzyme.
- ~2.1 times enhancement in CO_2 absorption
- Desorption at 90 °C in comparison to 120-140 °C in amine based system.
- Requires significantly less heat to release CO_2 than conventional amines
- High desorption efficiency
- Comparatively less corrosive (low temp) and low volatile
- Reduction in CO_2 absorber column size

Solvent System	Net Capacity (mol/L)
MEA (30%) @25% CO_2	1.2 mol/l
Commercial @25% CO_2	2.25 mol/l
Bio-Hybrid@25% CO_2	4.54 mol/l





Opportunities : CO_2 Utilization or Sequestration

CO_2 Utilization : Three pathways :Chemical, Biotechnology & as such use

CO_2 capture, utilization or sequestration

CO_2

Capture

Utilization as O and C

Bioprocessing or photo conversion

Sequestration

Industrial emission

Carbonates and derivatives

Methanol or formic acid

Fuels or chemicals

Underground storage

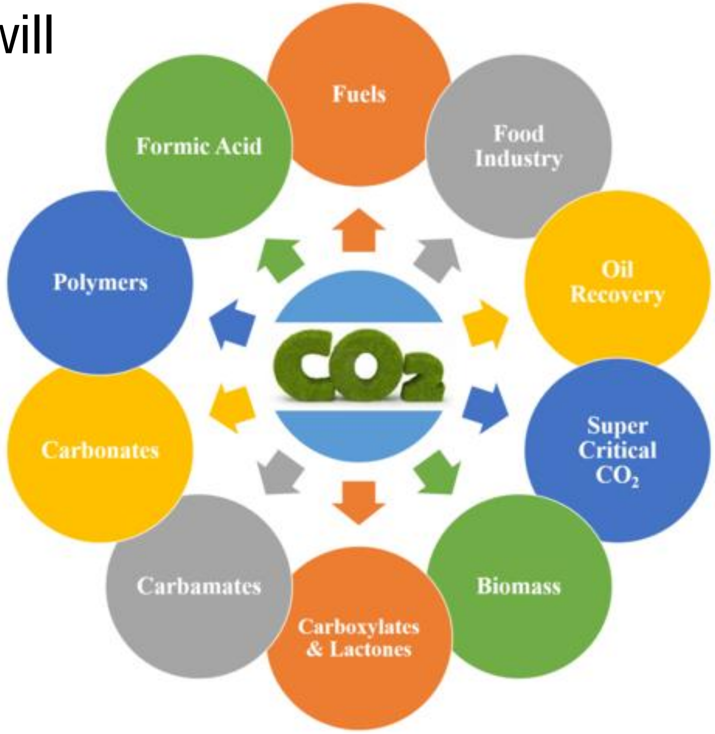
With declining fossil fuel reserves, CO_2 may become the best source of carbon

Aim : CO_2 utilization to produce value added products

CO_2 Utilization

- It opens a window of possibility of recycling carbon through CO2 conversion
- Any marketable product obtained from CO_2 will have added value: the correct conversion of CO2 will generate a profit in a frame of availability of large volumes of CO_2
- The major pathways are:
  – Utilization of CO_2 as feedstock for chemicals/fuels:

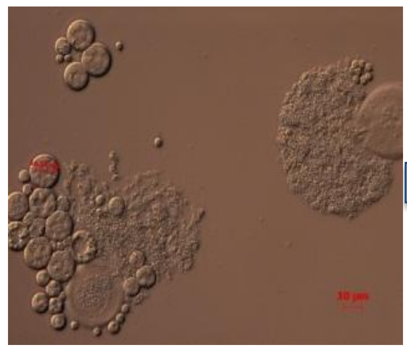
    The utilization of CO_2 (conversion into chemicals and other chemical applications) ranges around 200 Mt/y (Source: TCGR, Catalyst Group, 2012)



ElMekawy et.al. *Bioresource technology* 215 (2016): 357-370.

CO_2 Utilization

CO_2 to High value lipids & Bio-fuels through Biotechnological Interventions



LanzaTech

DBT-IOC
BIO-ENERGY RESEARCH CENTRE

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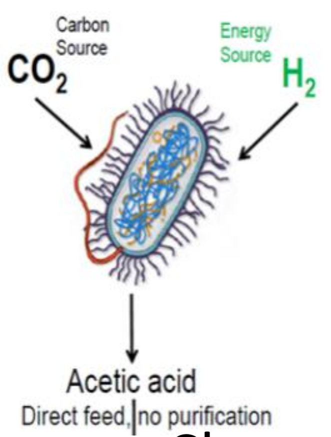
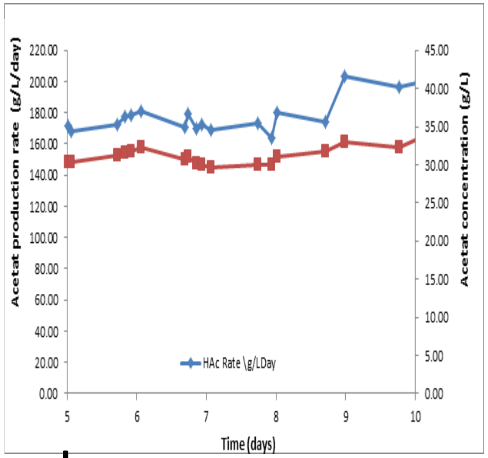
Integrated process for CO_2 to value added products

LanzaTech Process

- Selectively produces Acetic acid (3-4%) from CO_2
- Proprietary anaerobe
- Extraction Uneconomical

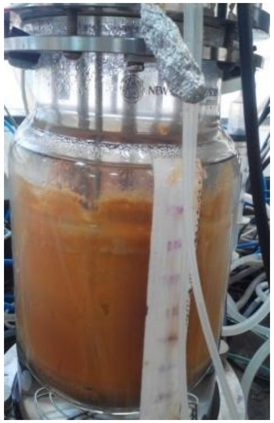


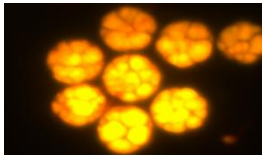


Cheap carbon source as acetate available

DBT-IOC Process

- Microalgae (Thraustochytrids)
- Fast growing
- Biomass (70 gm/l/day)
- Acetate consumption ~135 gm/l/day
- 40-50 % of total oil suitable for biodiesel
- Omega-3 fatty acids (40-60 % of total oil)
- Easy harvesting





Requires carbon source

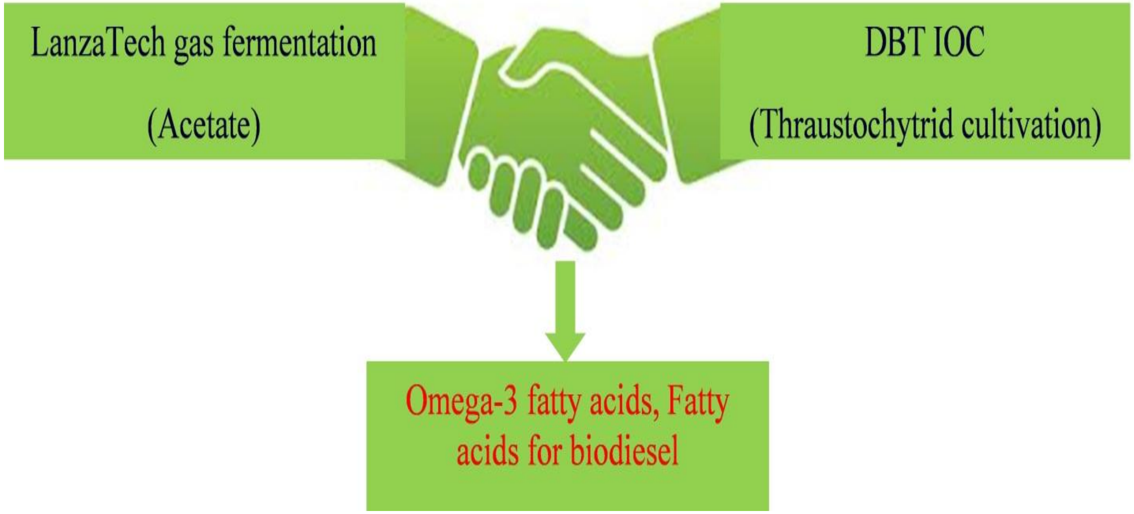
Heterotrophic Microalgae-
The Potential of Thraustochytrids

- Several Oleaginous microbes belonging to yeasts, microalgae and fungi can be exploited for heterotrophic lipid production.
- **Thraustochytrids** are marine heterotrophic microalgae which have several advantages
  - Fast growing (up to 14.2 g $l^{-1}d^{-1}$ CDW)
  - High oil content (up to 60-80 % of CDW, 10 g $l^{-1}d^{-1}$ oil production)
  - **40-50 % of total oil suitable for biodiesel production (<C18)**
- **The most distinguishing feature is significant co- production of high value co-products (Omega-3 fatty acids, 40-50 % of total oil, carotenoids 63 mg $l^{-1}d^{-1}$)**
- ***Several strains of thraustochytrids isolated and developed at DBT IOC Centre***

Heterotrophic production of lipids using Microalgae

- Advantages of Heterotrophic mode
  - Light independence
  - Relatively easy scale up for industrial use
  - High degrees of growth control
  - Reduced harvesting costs due to higher cell density.
- Challenge- Availability of commercially sustainable supply of carbon source for the fermentation which is major cost element
- Integration with synergistic waste streams rich in organic carbon could provide solution

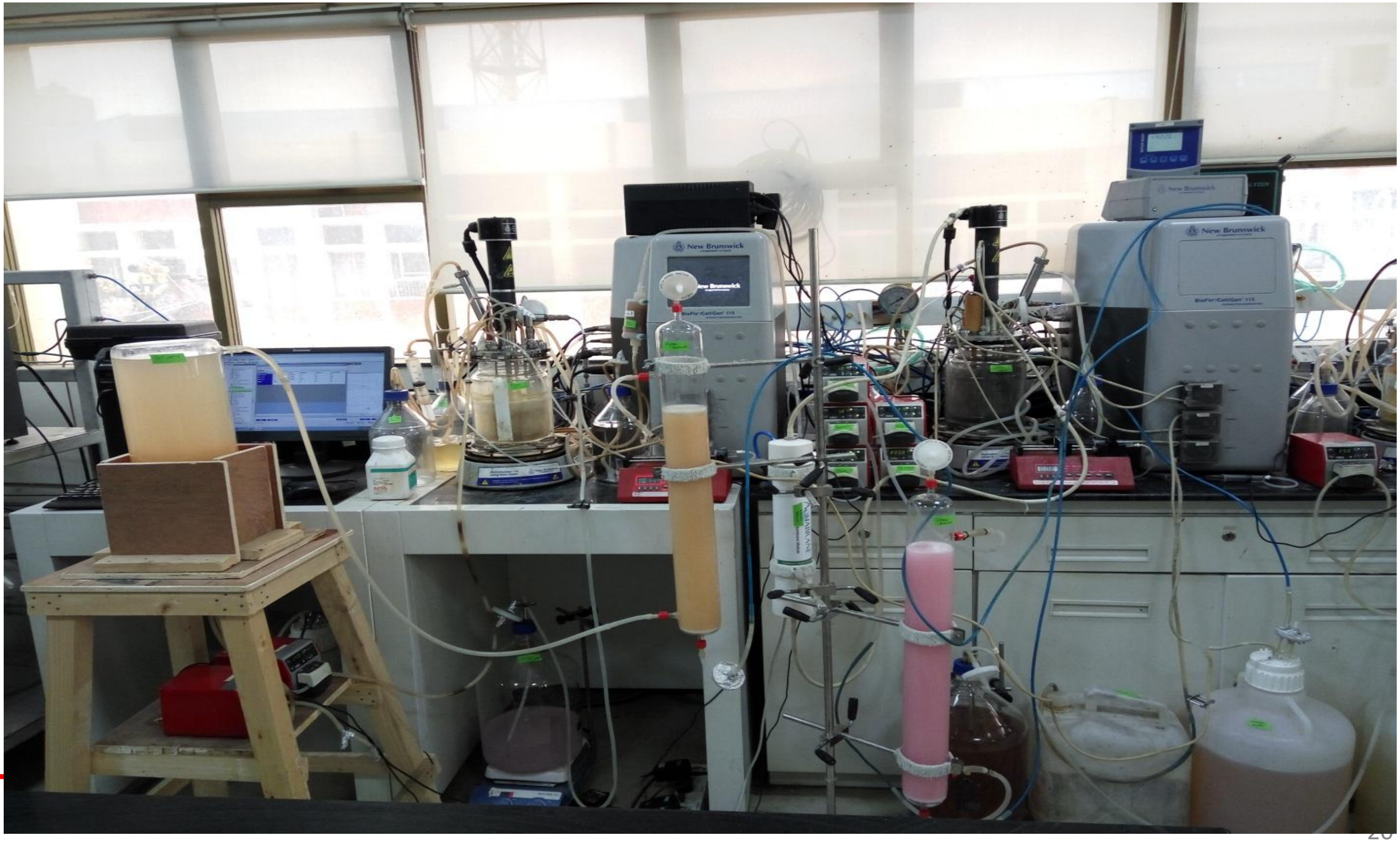
Integrated process for CO_2 to value added products



Significance of the integrated process

- Solution for utilization of green-house gases (e.g. CO_2) to food and fuels .
- Cheap and enough carbon source.
- Long term sustainability of the process- minimized use of acid & base
- Lipid for biodiesel production
- High value co products as nutraceuticals /pharmaceuticals

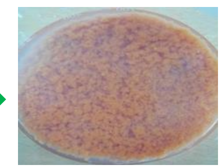
Lab set up of the integrated process



10 kg/day CO2 to Lipids Integrated Pilot plant –World's First

- Three reactor-30L, 60L, 100L
  - 30L- Woodii growth reactor
  - 60L- Algae growth reactor
  - 100L- Lipid production reactor
- Three 200L tanks, one 100L tank

CO_2 Sequestration Potential



0.07 MT/ Day DHA

0.14 MT/Day Lipids

1 MT CO_2/Day sequestration + 0.09 MT Hydrogen

0.42 MT Acetate/Day production

0.28 MT biomass/Day production

0.07 MT/Day Biodiesel

Commercialization/ Benefits

- Carbon recycling and commoditizing CO_2
- Economically feasible process due to production of valuable Omega fatty acids along with lipids (Oil)
- Commercialization of process shall provide energy access (competetive Bio-diesel) and affordable nutrition (DHA) for all.
- **Shall lead to reduced carbon emissions, which in turn shall provide carbon credits**

The Technology once proven at pilot scale has a potential to be a game changer technology for IOC & LanzaTech

Bio-electrochemical Synthesis

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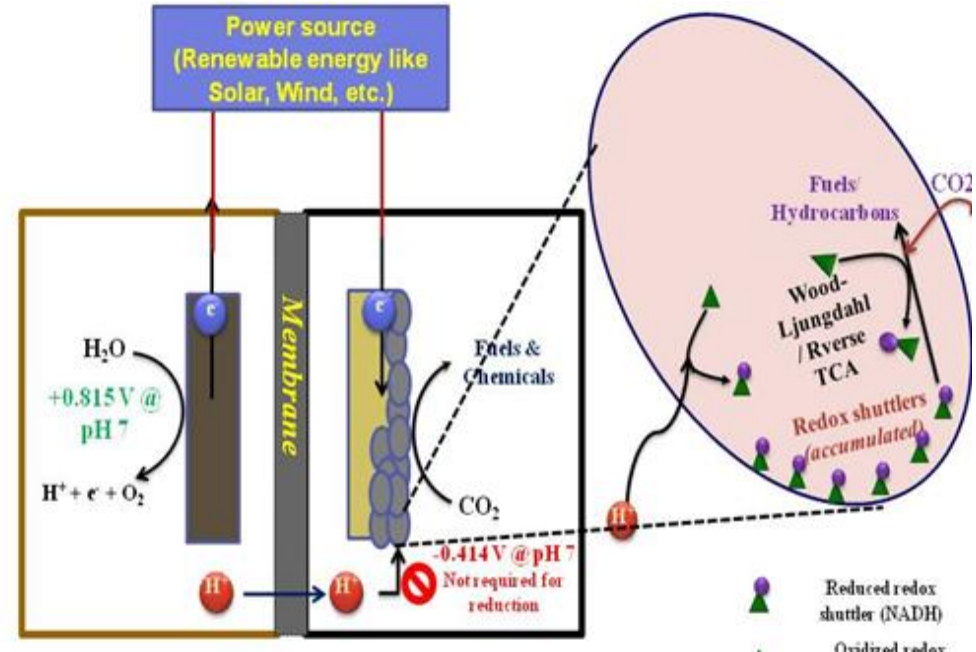
Concept

Bio-electrochemical system (BES) comprising of biofilm of specific microbes anchored at customized cathode surface i.e., biocathode , transforms CO_2 using minimum energy that can be supplied from renewable sources like solar

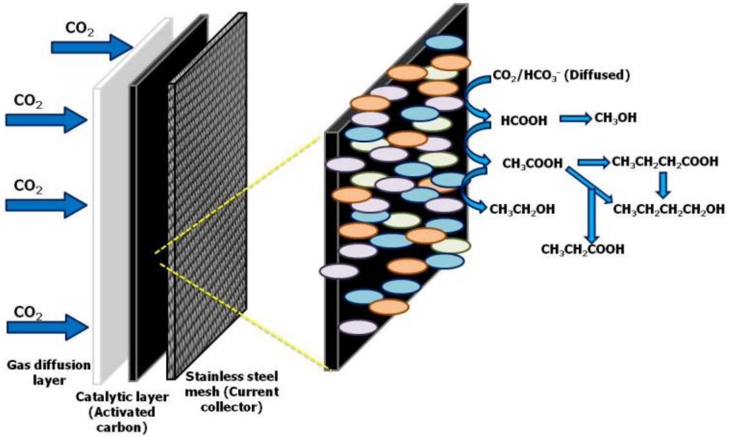


This process needs +0.815 V unlike +1.23 V of total cell potential in conventional electrolysis. This also can be further reduced by modifying the anode.

Electro-biocatalyzed Conversion of CO_2 to Bio-fuels

Advantages

- Sustainable process
- Carbon foot print reduced
- High conversion efficiency
  - Electricity to chemical commodities efficiency of electrobiocatalytic process is 80-90%.
  - Powering electrobiocatalytic system with electricity from solar cells could be more potent strategy
- Carbon losses avoided



Ethanol and Butanol production at IOC R&D Centre set up

Ongoing IOC-VITO research collaboration for conversion of CO_2 to alcohols

Electro-biocatalyzed Conversion of CO_2 to Fuels

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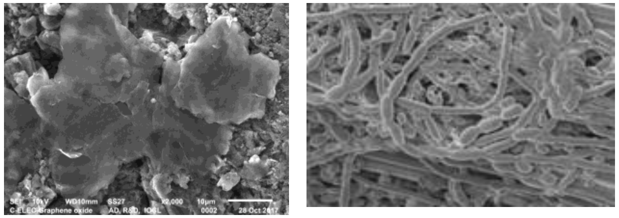
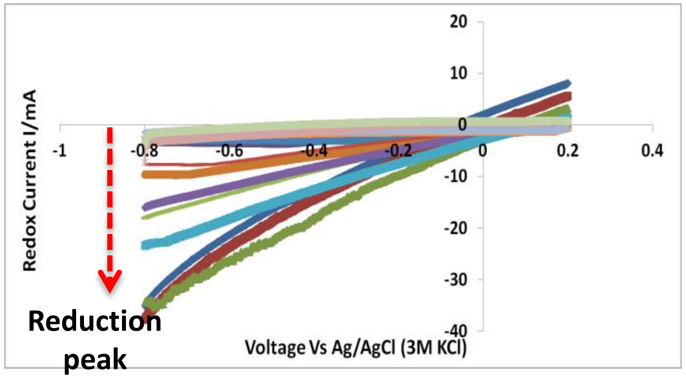
- Rapid screening assay developed for isolating potential electro-active microbes
- Strain improvement through rigorous mutagenesis and genome shuffling
- Novel microbial blend for selective CO_2 transformation to alcohols developed
- Process established at 5L scale stack operation
  - 7.34 g/l/day product with C - conversion efficiency @75%
  - Columbic efficiency @ >95%
  - Ethanol as dominant product (70% of total products)



SEM images of biofilm on electrode

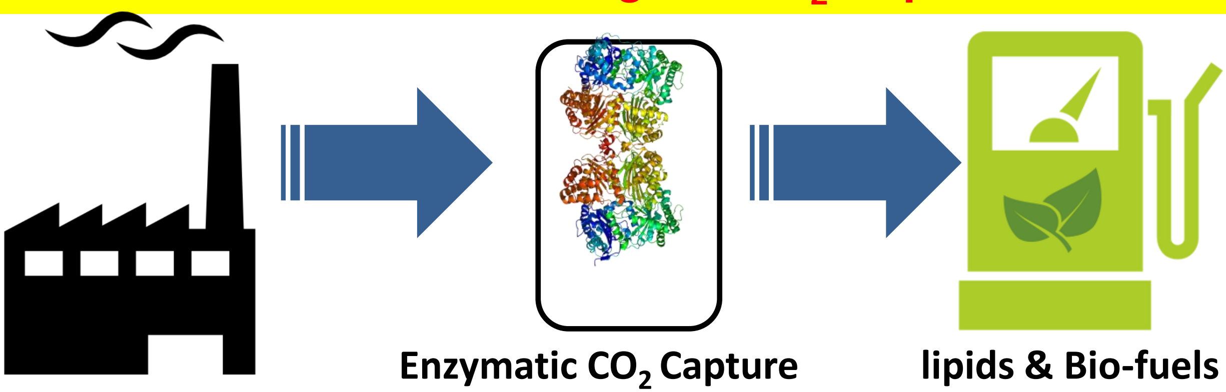


Electrochemical data of CO2 reduction using different mutants

Conclusions

- GHG emissions issue : require clean technologies
- Enzyme assisted CO_2 capture may improve the existing amine based CO_2 capture process
- CCU is an attractive option for CO_2 transformation to value-added chemicals
- Bio-technological process can play important role

The Whole Value Chain for Biological CO_2 Capture and Utilization



Thank You