Recent advancements in CO_2 capture technologies

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Carbon di oxide

- CO_2 is colourless , odourless gas and is integral part of earth's carbon cycle.
- Humans and animals exhale CO_2 whereas plants absorb it during a process called photosynthesis in order to grow.
- CO_2 is called a greenhouse gas (GHG) because as part of Earth's atmosphere
- CO_2 traps the energy from the sun and keeps the world at a desirable temperature.
- When put under pressure or in very cold conditions, it can transform into a liquid or solid
- At temperatures below minus 78.5°C, carbon dioxide becomes a solid (also known as "dry ice").
- CO_2 is non flammable hence it is used in fire extinguishers.

Introduction

- Rapid economic growth has contributed to today's ever increasing demand for energy.
- An obvious consequence of this is an increase in the use of fuels, particularly conventional fossil fuels (i.e. coal, oil and Natural gas) that have become key energy source since the industrial revolution.
- According to the Emission Database for Global Atmospheric Research , global emission of CO_2 was 33.4 billion tonnes in 2011, which is 48% more than that of two decades ago.

CONT...

- Over the past century, atmospheric CO_2 level has increased more than 39%, from 280 ppm during pre-industrial time to the record high level of 410 ppm in 2017 with a corresponding increase in global surface temperature of about 0.81ºC
- Global warming and climate change concerns have triggered global efforts to reduce the concentration of atmospheric carbon dioxide (CO_2).
- Carbon dioxide capture and storage (CCS) is considered a crucial strategy for meeting CO_2 emission reduction targets.

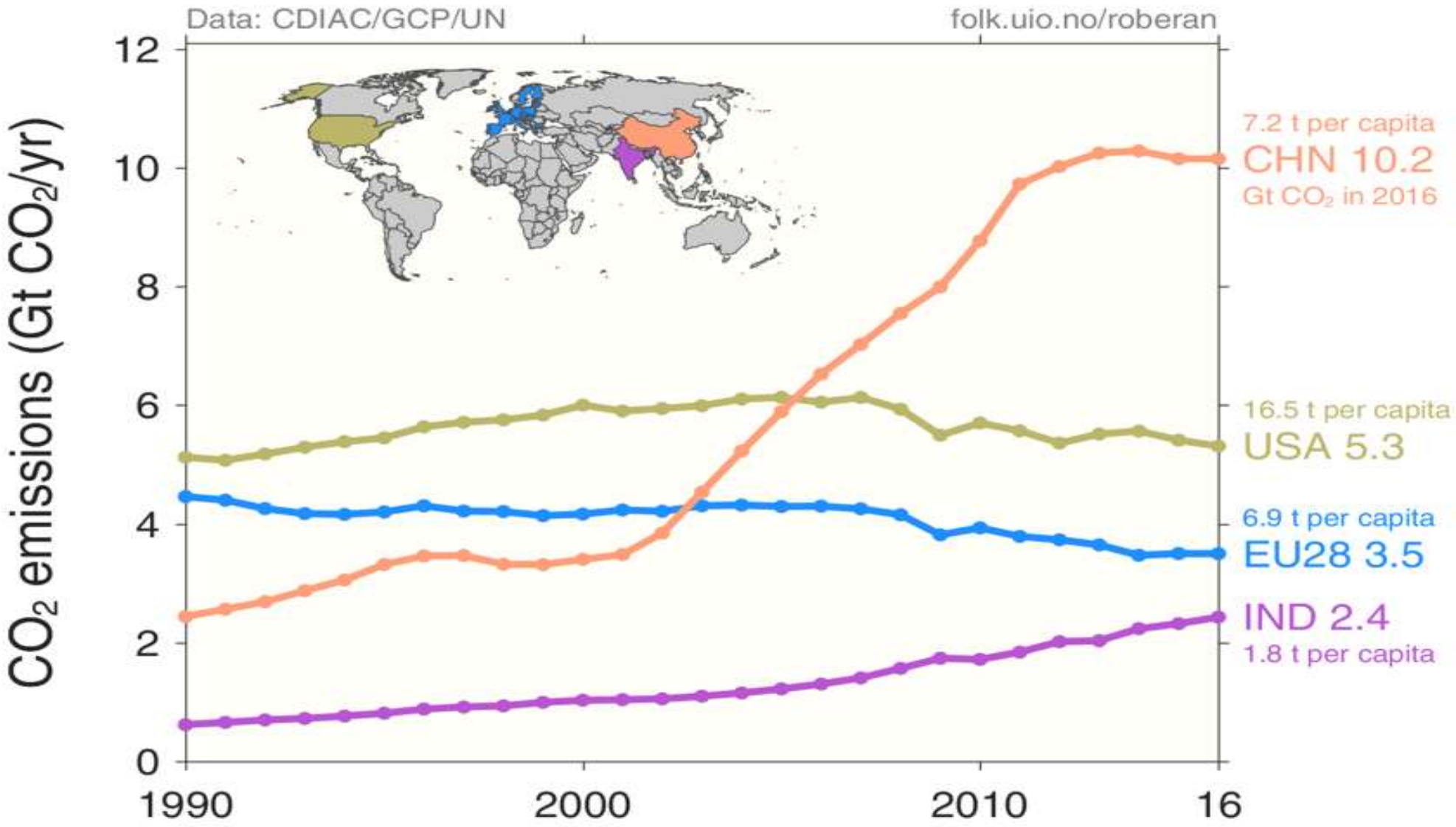
Indian Scenario with CO_2 emissions

- India's pledge under the Paris Agreement is to reduce the carbon intensity of its economy by 33-35% by 2030, compared to 2005 levels.
- India has the world's fourth highest CO_2 emissions, but its emissions per person are very low. World-average per capita emissions were 4.2 tonnes in 2016. Source: CDIAC, Global Carbon Project, and UN.
- The total vehicle population in 2001 and 2015 was 55 and 210 million respectively.

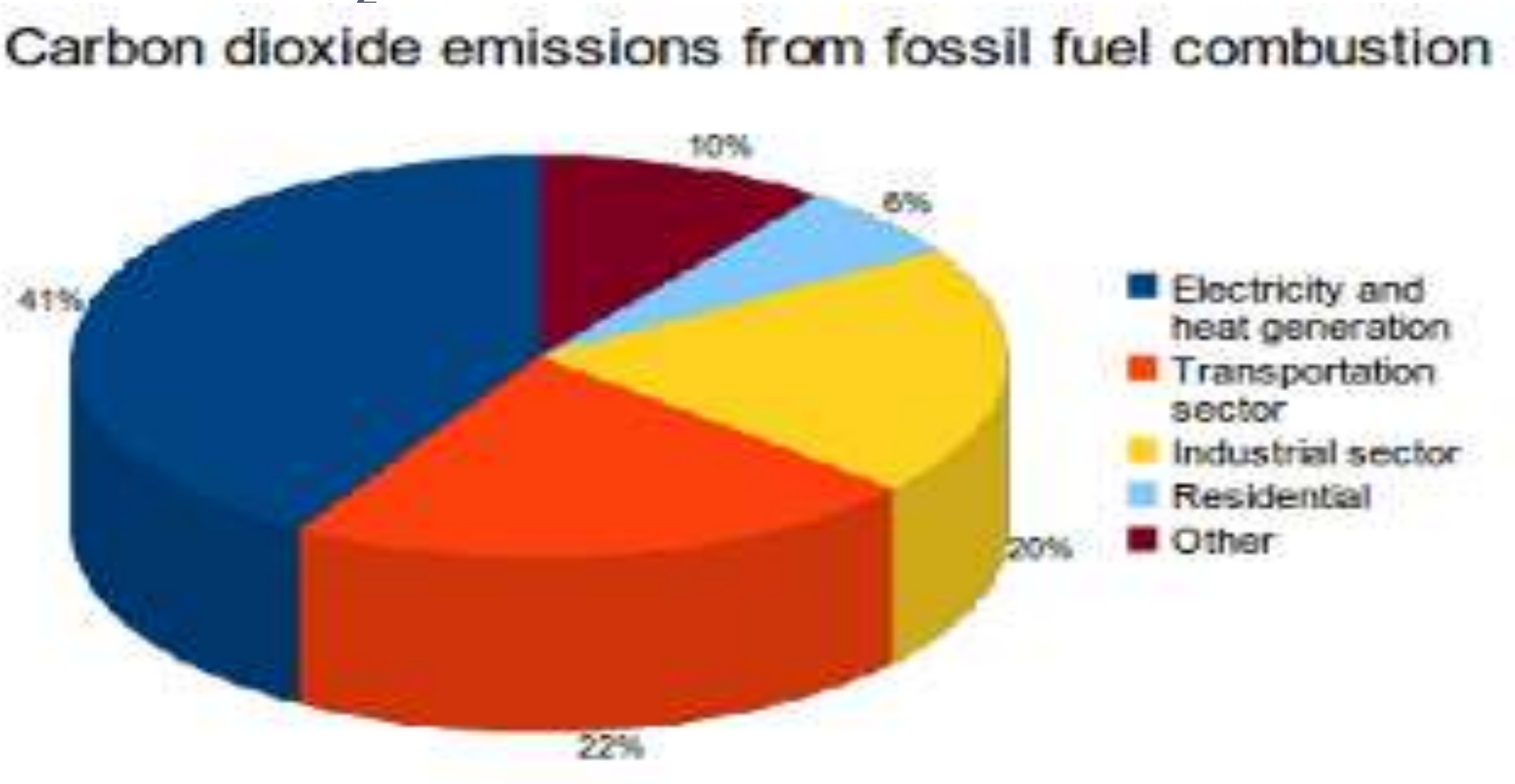
CONT…

- As compared to the year 2001, the share of two wheelers changed by 3.40%, the share of cars, jeeps and taxis changed by 0.80%, the share of buses changed by -0.2%, the share of goods vehicle changed by -1% and the share of other vehicles changed by -3%.

- The revenue received by the government of India during 2012-13 financial year was around 1,33,840 Crores. With the above statistics, it is essential to take necessary steps to control CO_2 emissions from the automobile vehicles.


Data: CDIAC/GCP/UN
folk.uio.no/roberan
CO_2 emissions (Gt CO_2/yr)
12
10
8
6
4
2
0
1990
2000
2010
16
7.2 t per capita
CHN 10.2
Gt CO_2 in 2016
16.5 t per capita
USA 5.3
6.9 t per capita
EU28 3.5
IND 2.4
1.8 t per capita

SOURCES OF CO_2 EMISSIONS

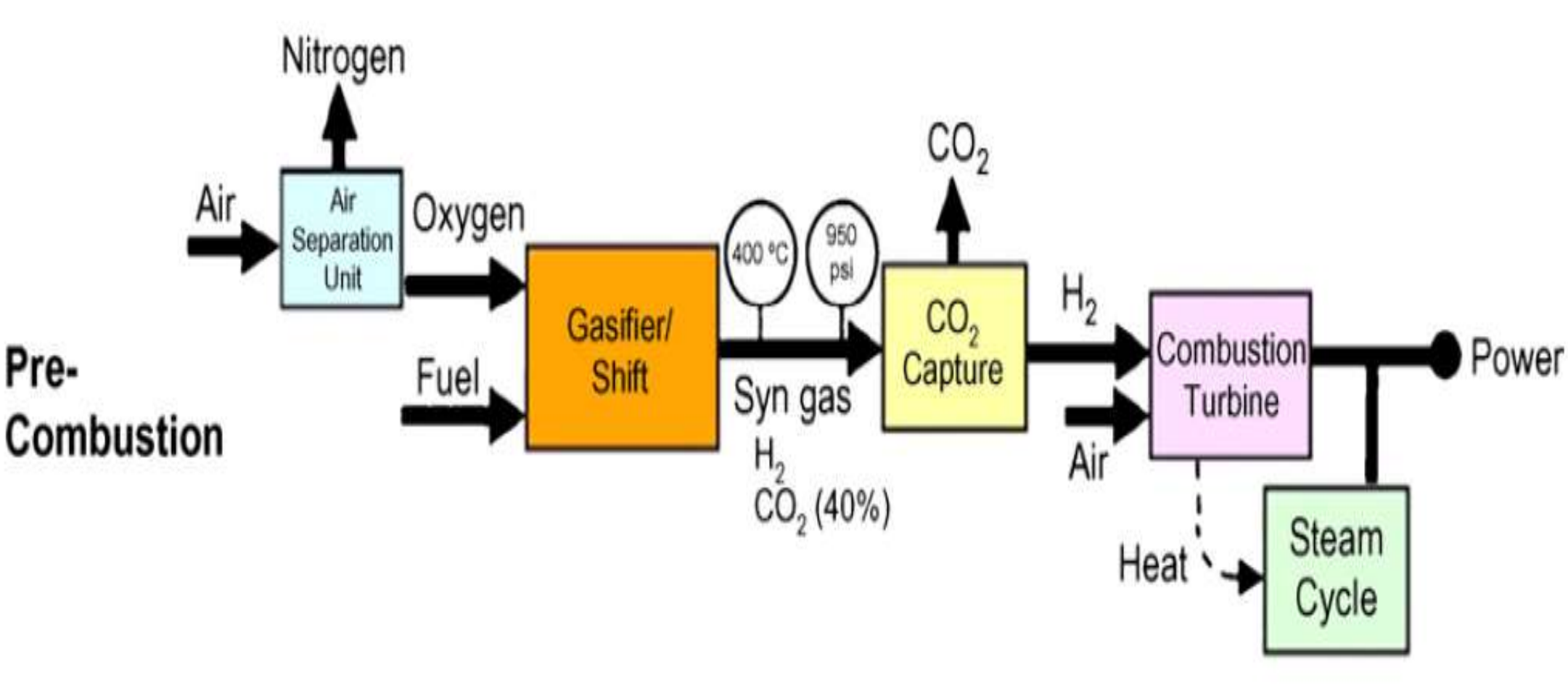


Approaches to mitigate global climate change

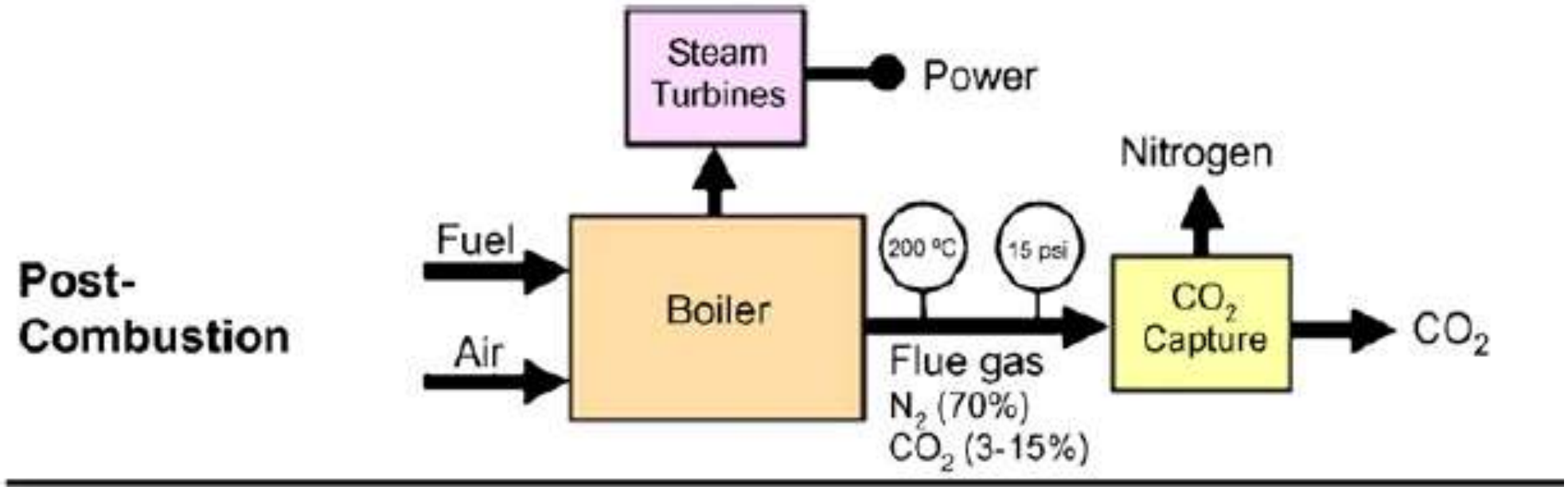
Different approaches are considered and adopted by various countries to reduce their CO_2 emissions, including

- Improve energy efficiency and promote energy conservation
- Increase usage of low carbon fuels, including natural gas, hydrogen or nuclear power;
- Deploy renewable energy, such as solar, wind, hydropower and bioenergy;
- Apply geoengineering approaches, e.g. afforestation and reforestation;
- CO_2 capture and storage (CCS)

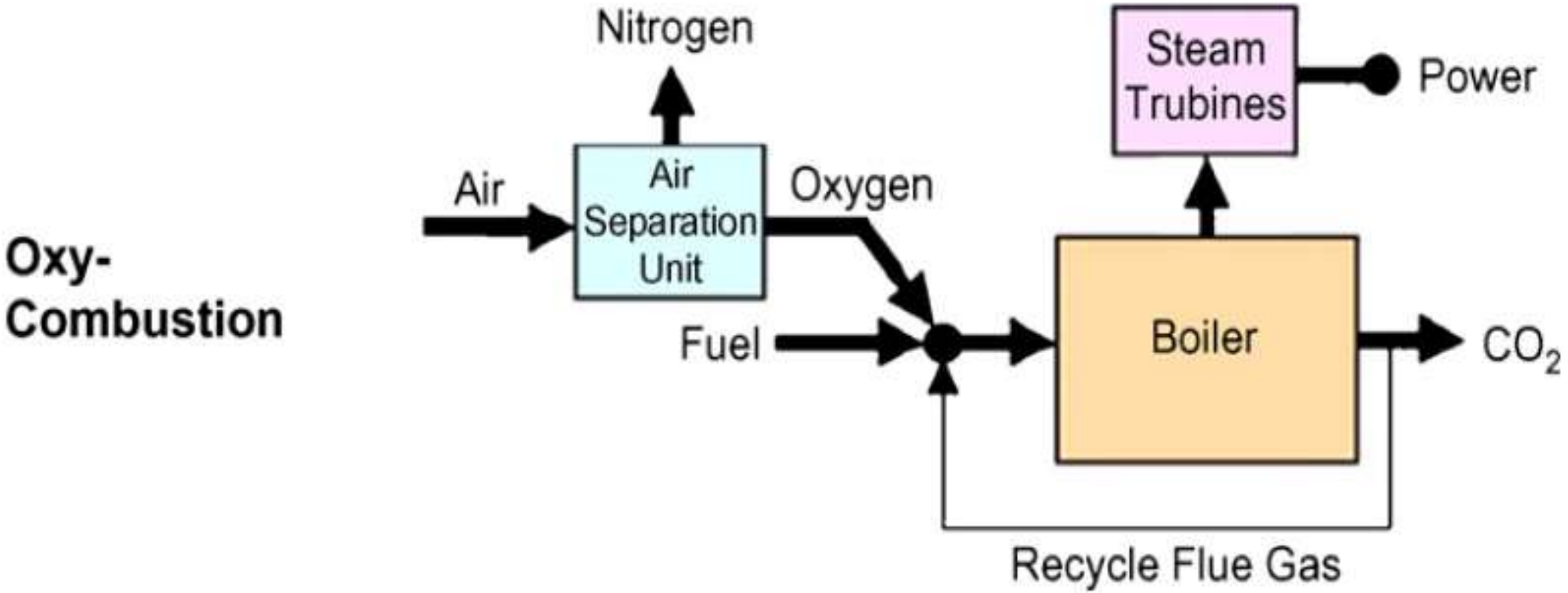
Pre combustion



Post combustion



OXY-COMBUSTION



NORMS

2015 target

- The law requires that the new cars registered in the EU do not emit more than an average of **130 grams of CO_2 per kilometre** (g CO_2/km) by 2015.
- In 2016, the Indian government announced that the country would skip the BS V norms altogether and adopt BS VI norms by 2020

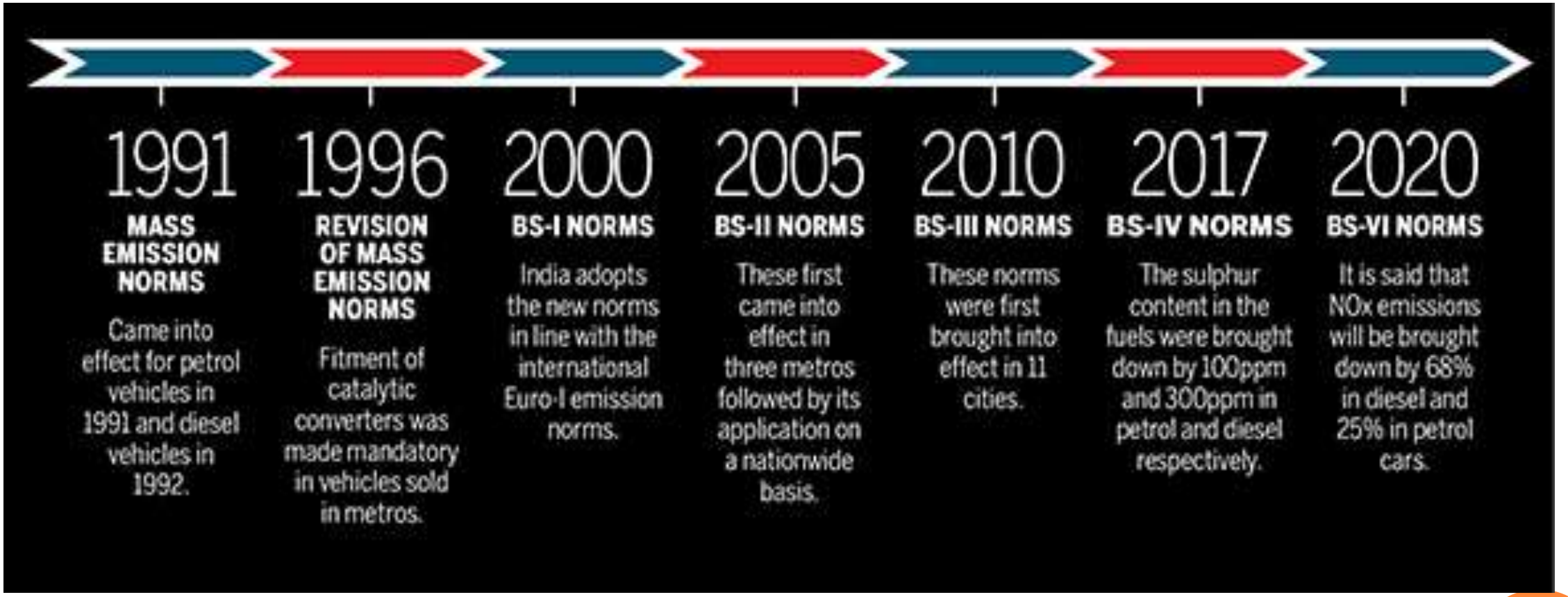
2021 target

- By 2021, phased in from 2020, the fleet average to be achieved by all new cars is **95 grams of CO_2 per kilometre**.

Scenario of Indian emission standards

- Bharat stage emission standards (BSES) are emission standards instituted by the Government of India to regulate the output of air pollutants from internal combustion engines and Spark-ignition engines equipment, including motor vehicles.
- The standards and the timeline for implementation are set by the Central Pollution Control Board under the Ministry of Environment & Forests and climate change
- But the government's "unanimous decision to leap-frog to BS-VI directly from 01/04/2020", as Road Transport & Highways Minister Nitin Gadkari announced, skipped the BS-V stage all together

Timeline of BS6 norms



BS NORMS FOR LIGHT DUTY DIESEL VEHICLES

Year	Reference	CO	HC	HC+NO_x	NOx	PM	PN
		g/km					#/km
Compression Ignition							
1992	–	17.3-32.6	2.7-3.7	–	–	–	–
1996	–	5.0-9.0	–	2.0-4.0	–	–	–
2000	India Stage I	2.72-6.90	–	0.97-1.70	–	0.14-0.25	–
2005†	Bharat Stage II	1.0-1.5	–	0.7-1.2	–	0.08-0.17	–
2010†	Bharat Stage III	0.64 0.80 0.95	–	0.56 0.72 0.86	0.50 0.65 0.78	0.05 0.07 0.10	–
2010‡	Bharat Stage IV	0.50 0.63 0.74	–	0.30 0.39 0.46	0.25 0.33 0.39	0.025 0.04 0.06	–
2020	Bharat Stage VI*	0.50 0.63 0.74	–	0.17 0.195 0.215	0.08 0.105 0.125	0.0045 0.0045 0.0045	$6x10^{11}$ $6x10^{11}$ $6x10^{11}$

What needs to be done to upgrade from BS-IV

BS-V requires a key fitment in the engine; BS-VI needs one more, but each comes with its set of problems

FOR BS V: DIESEL PARTICULATE FILTER

WHAT: DPF is a cylinder mounted vertically inside the engine compartment. Its function is to remove particulate matter, or soot, from the diesel exhaust. It needs temperatures of 600°C — difficult in Indian conditions

WHY A PROBLEM: Small cars (popular in India) with limited bonnet space would need major re-design to accommodate DPF. Making bonnet bigger may lead to car breaching the sub-4m mark, losing excise benefits

FOR BS VI: SELECTIVE CATALYTIC REDUCTION TECHNOLOGY

WHAT: SCR, or selective catalytic reduction module reduces oxides of nitrogen by injecting an aqueous solution (AUS 32) into the system. AUS 32 contains ammonia, for which a separate container needs to be put

WHY A PROBLEM: An anti-defect mechanism is needed to put the vehicle into limp mode if AUS 32 is not re-filled. Separately, infrastructure is needed for countrywide supply of AUS 32

PARTICULATE CUTS

Diesel Cars

BS-III → IV: 50%

BS-V ⇩ VI

BS-IV → V: 80%

NO CHANGE

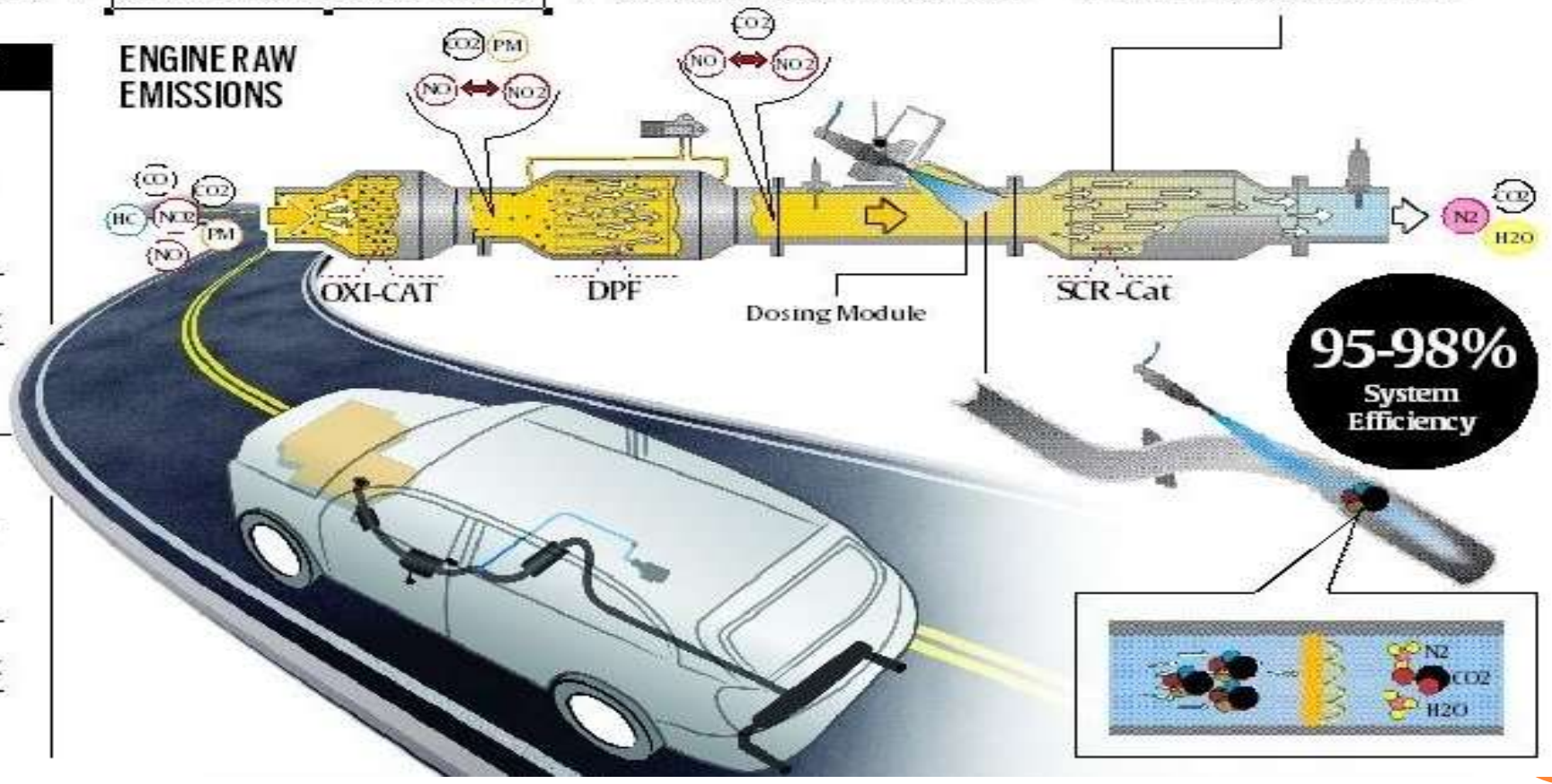
Heavy Trucks

BS-III → IV: 80%

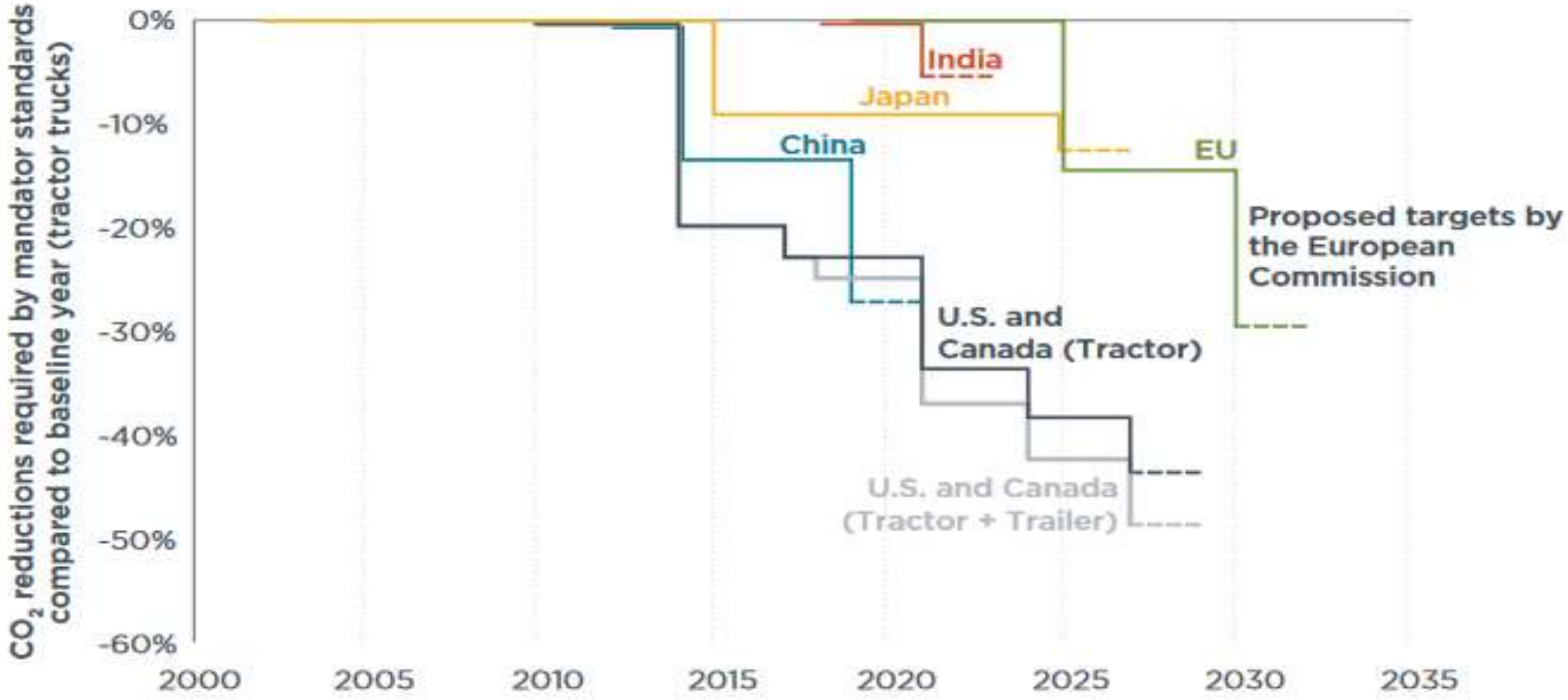
BS-IV ⇩ V

BS-V → VI: 50%

NO CHANGE



Tractor-truck standards around the world relative to the baseline in the first phase of the standards



CO_2 Emissions from Automobiles

- A typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year.
- This number can vary based on a vehicle's fuel, fuel economy, and the number of miles driven per year

1. CO_2 Emissions from a gallon of gasoline: 8,887 grams CO_2/ gallon
2. CO_2 Emissions from a gallon of diesel: 10,180 grams CO_2/ gallon

Challenges in implementing CO_2 reduction systems in Automobile

- Even though there are emission norms around the world to restrict the amount of pollutants (HC ,CO ,NO_x , PM) which are released from an automobile. There are no current standards at Europe and India set to restrict the CO_2 emission released form the vehicle
- On May 17, 2018, the European Commission released a regulatory proposal 1 for setting the first ever carbon dioxide (CO_2) emission standards for new heavy-duty vehicles (HDVs) sold in the European Union (EU). The proposed targets aim to reduce the average CO_2 emissions from new HDVs by 15% in 2025 and by 30% in 2030, both relative to a 2019 baseline

ENERGY SOURCES

- Gasoline - 73 gCO_2/MJ
- Propane - 65 gCO_2/MJ
- CNG - 56 gCO_2/MJ
- Ethanol - 71 gCO_2/MJ
- Hydrogen - No Direct CO_2
- Bio-diesel - 75 gCO_2/MJ

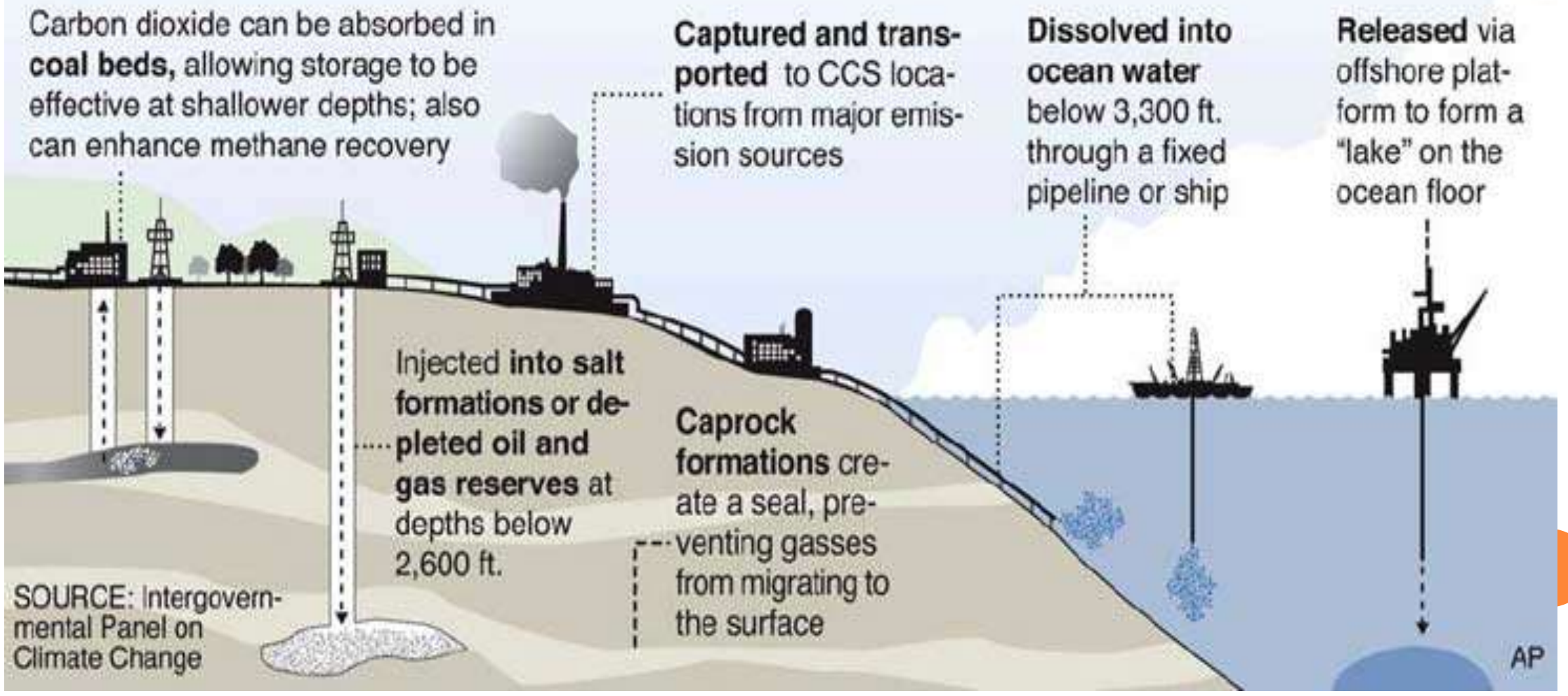
CCS SYSTEM IMPLEMENTATION IN VEHICLES

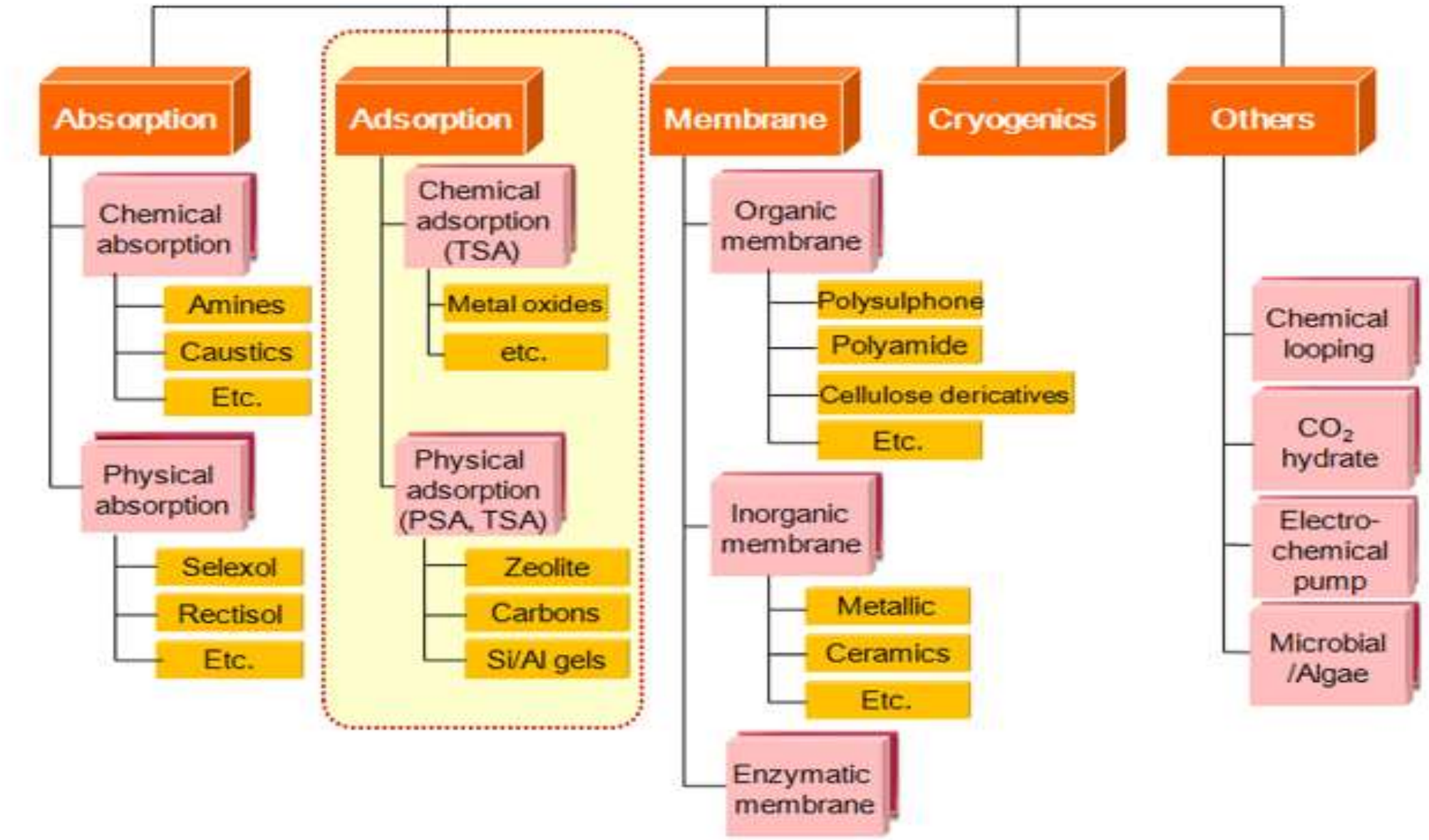
- Increase vehicle weight wrt.. Distance travel
- Space for storage
- Compressed CO_2(73 bar) requires three times as the gasoline fuel tank
- Collection facilities
- Discharge Time
- Infrastructure facilities(Piping)
- Investment cost for Vehicles
- Maintenance Cost
- Location to fix CCS system

Capturing carbon

Governments are urged to step up research of a process called carbon capture and sequestration (CCS) – capturing carbon dioxide and storing it underground or underwater.

Technology and theory

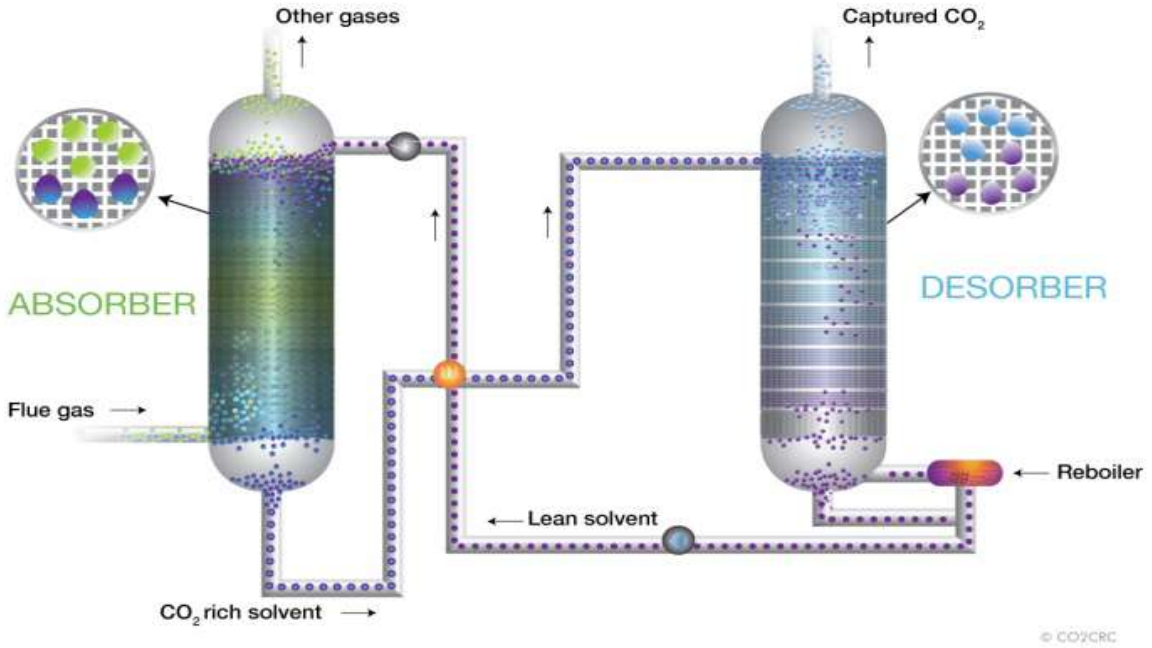



Absorption
Chemical absorption
Amines
Caustics
Etc.
Physical absorption
Selexol
Rectisol
Etc.
Adsorption
Chemical adsorption (TSA)
Metal oxides
etc.
Physical adsorption (PSA, TSA)
Zeolite
Carbons
Si/Al gels
Membrane
Organic membrane
Polysulphone
Polyamide
Cellulose dericatives
Etc.
Inorganic membrane
Metallic
Ceramics
Etc.
Enzymatic membrane
Cryogenics
Others
Chemical looping
CO_2 hydrate
Electro-chemical pump
Microbial /Algae

METHODS TO CAPTURE CO_2

ABSORPTION

- In this method, exhaust gases are first passed through a liquid medium into which the carbon dioxide selectively dissolves.
- A second step is required to remove the carbon dioxide from the solution.

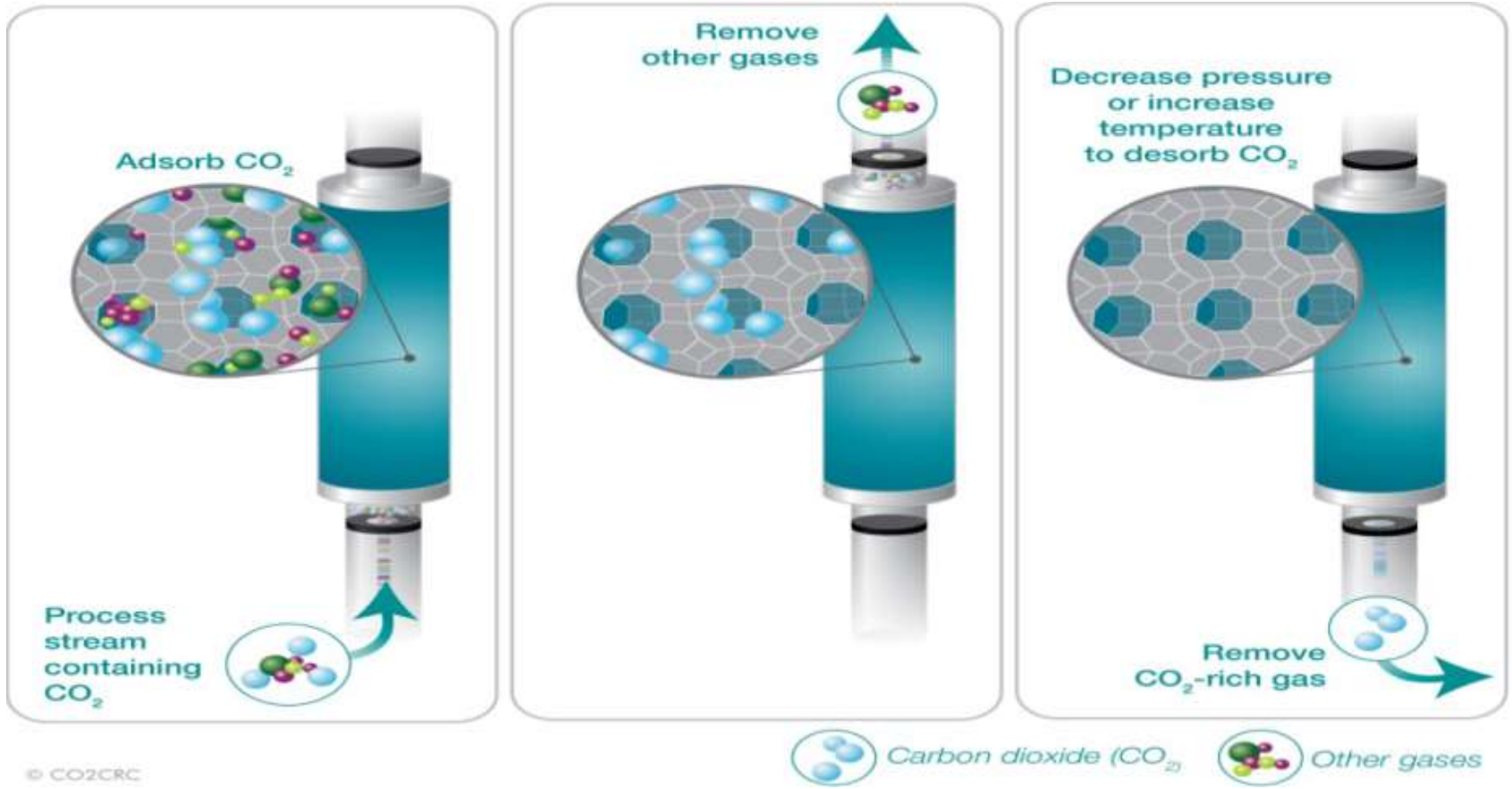


Absorption :

- In this method, exhaust gases are first passed through a liquid medium into which the carbon dioxide selectively dissolves. A second step is required to remove the carbon dioxide from the solution.
- This is generally done by heating the solution to remove the carbon dioxide for capture and storage.
- This method is commonly used for carbon capture on a small scale and is being adapted for use in large-scale coal-burning electrical-power operations

ADSORPTION

- In this process, CO_2 first selectively adheres to the surface of a material without forming a chemical bond while other gases pass through.

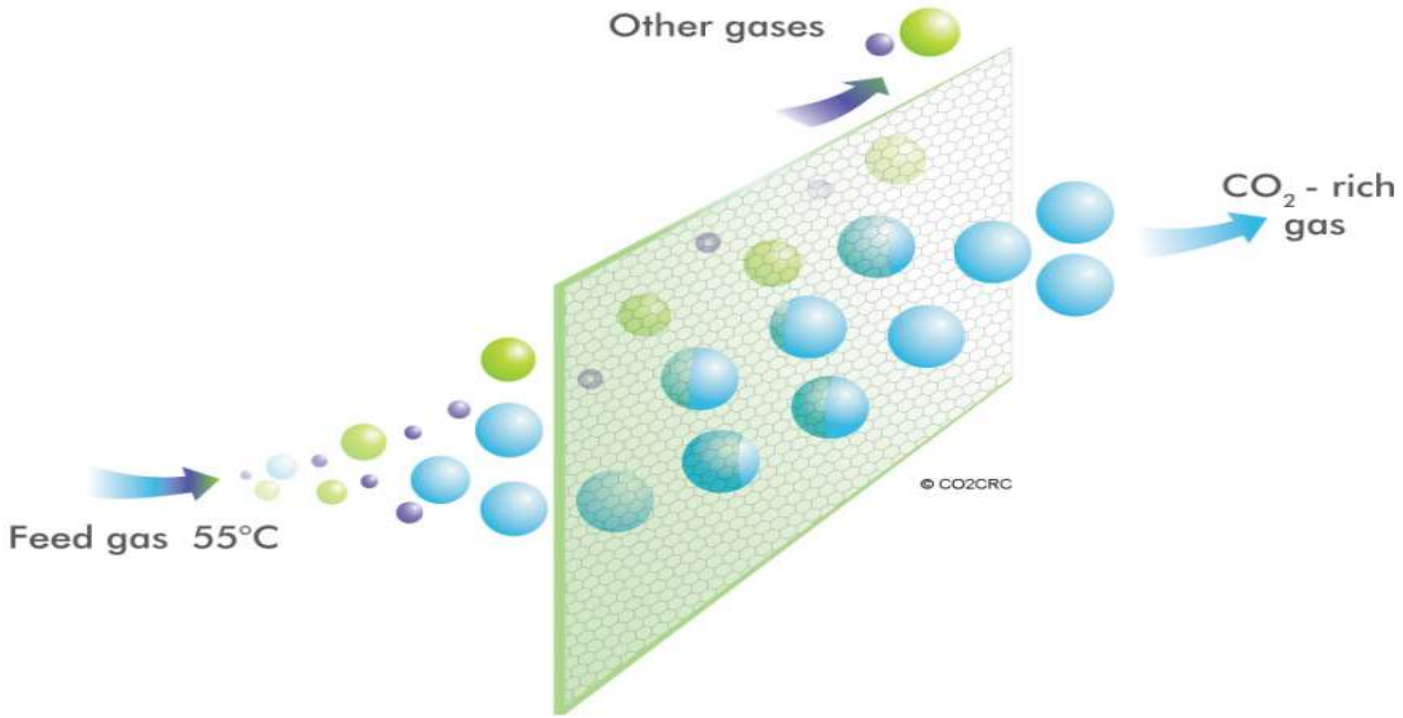


ADSORPTION

- In this process, CO_2 first selectively adheres to the surface of a material without forming a chemical bond while other gases pass through. This is done under either increased pressure or decreased temperature.

- In a second phase, the CO_2 is separated by reducing the pressure and/or increasing the temperature, allowing the CO_2 to be drawn off.

Membrane separation



Cont...

- In this process, CO_2 is separated from the other exhaust gases using a semipermeable membrane that allows CO_2 to pass through more easily than other gases in the exhaust stream.
- The separated CO_2 is then captured for later storage. This process requires high pressure to drive the separation
- Membranes, which generally consist of thin polymeric films, owe their selectivities to the relative rates at which chemical species permeate.
- Because permeation rates vary inversely with membrane thickness, membranes are made to be as thin as possible without compromising mechanical strength.

MATERIALS FOR CO_2 ADSORPTION

PHYSICAL ADSORBENTS	CHEMICAL ADSORBENTS
ZEOLITE	Titanium dioxide(TiO_2)
CARBON NANO TUBES	Amines
ACTIVATED CARBON, SOLID AMINES	Photo-catalytic reductions

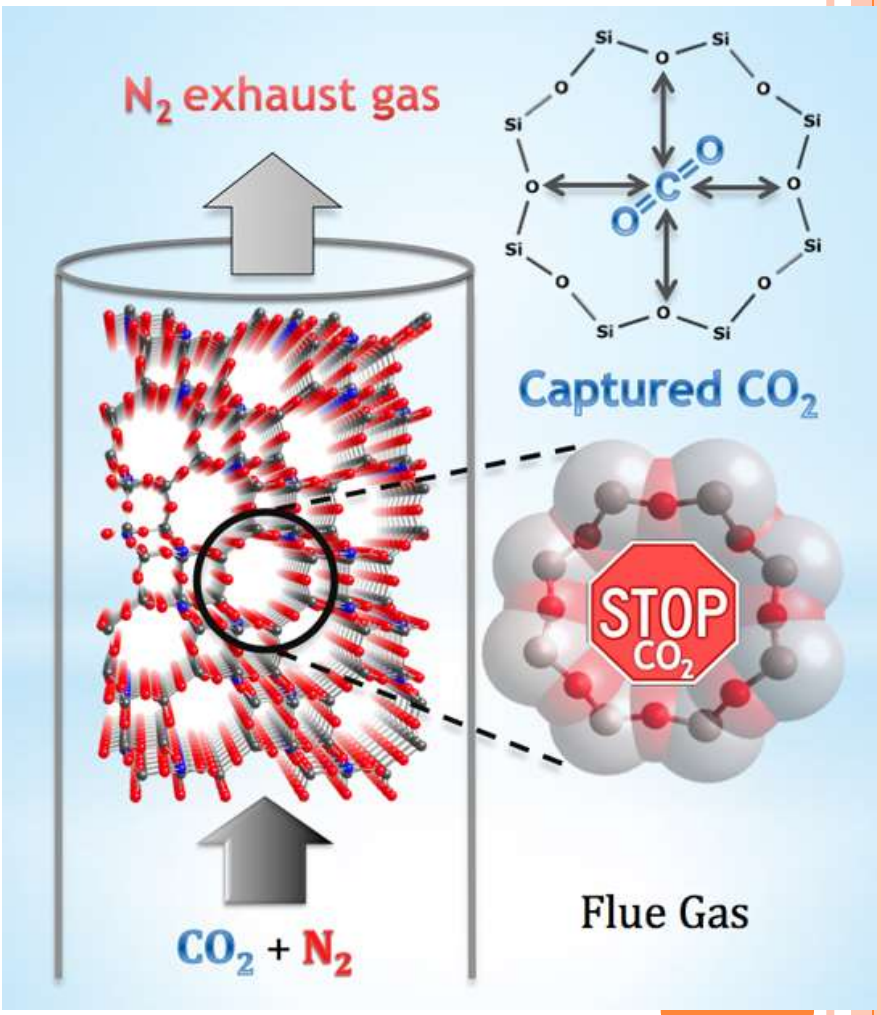
ACTIVATED CARBON

- Activated carbon also called activated charcoal.
- low-volume pores that increase the surface area available for adsorption.
- Activated carbon has a surface area in excess of 3000 m^2

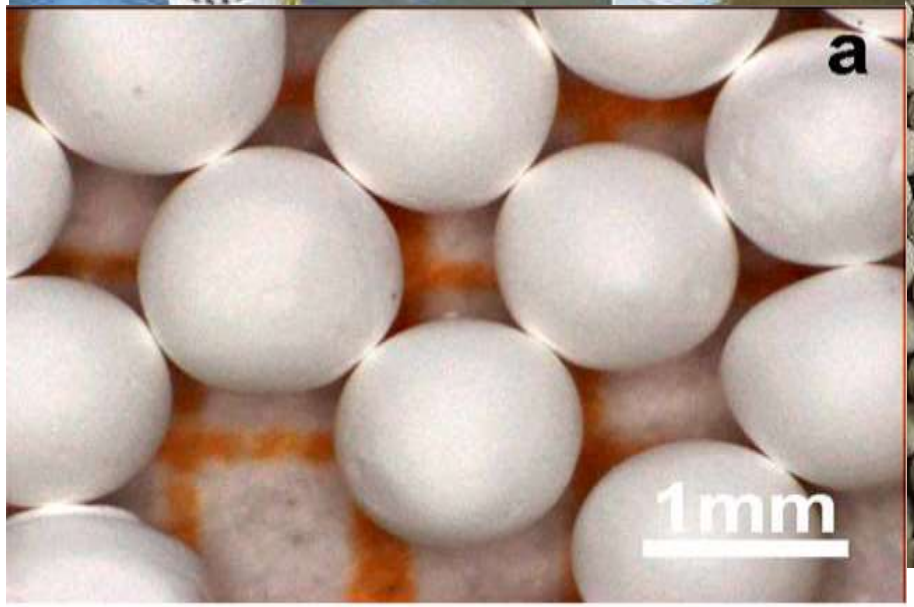
ZEOLITE

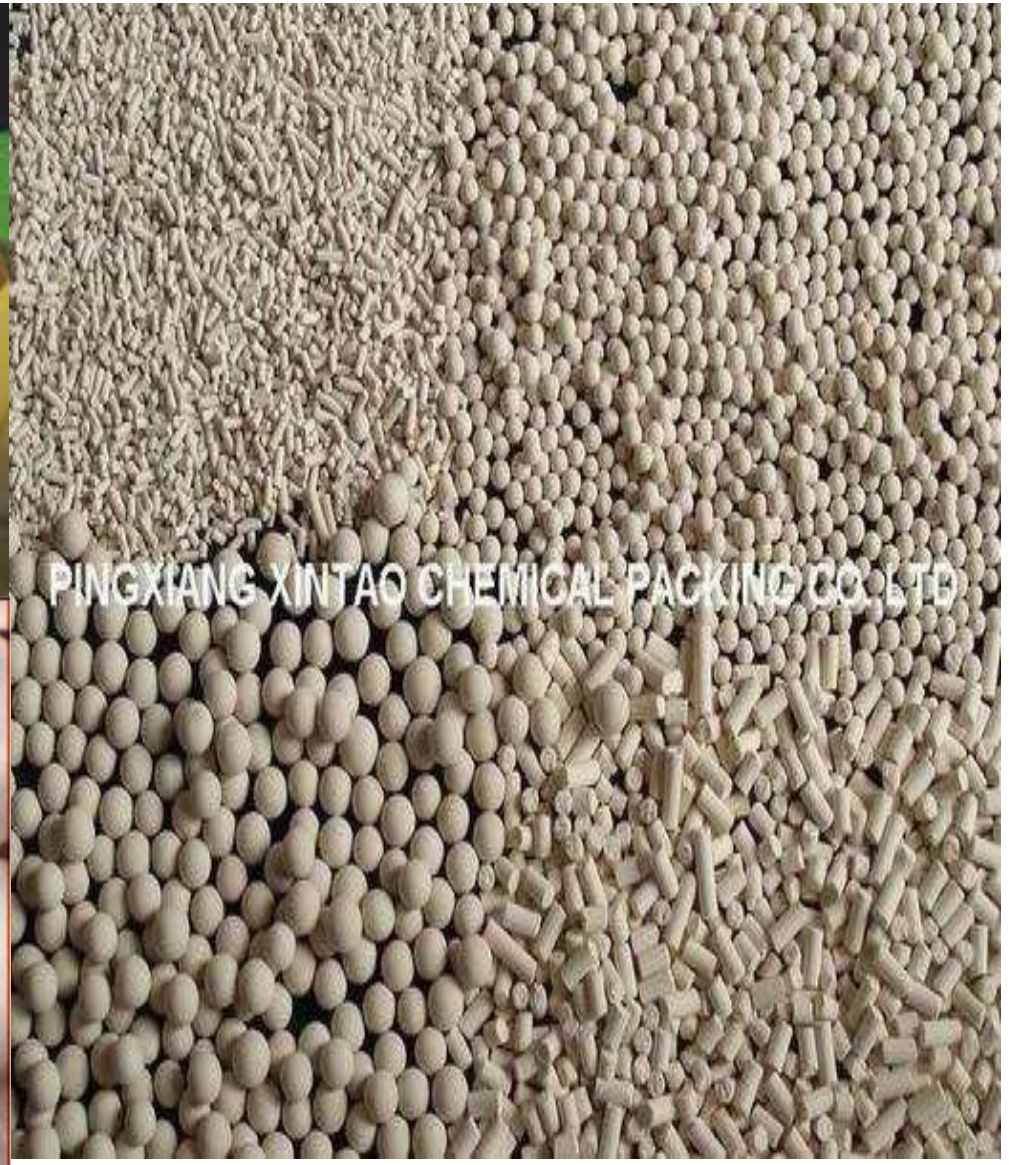
- Zeolite are micro porous crystalline solids with well-defined structure.
- Generally they contain silicon, aluminium, oxygen in their framework and other molecules.
- Zeolite pellets have a **surface area of 1000 m^2**
- **Diameters** of pellet is from **0.5 to 6.0 mm**

- Zeolites while they occur in nature, they can be manufactured as well.
- Their toughness, high surface area and ability to be reused hundreds of times makes them ideal candidates for filtering gas mixtures.
- If an unwanted molecule in the gas mixture is found to stick to a zeolite, passing the mixture through it can scrub the gas of many impurities, so zeolites are widely used in industrial chemistry as catalysts and filters.



ZEOLITE PRODUCTS





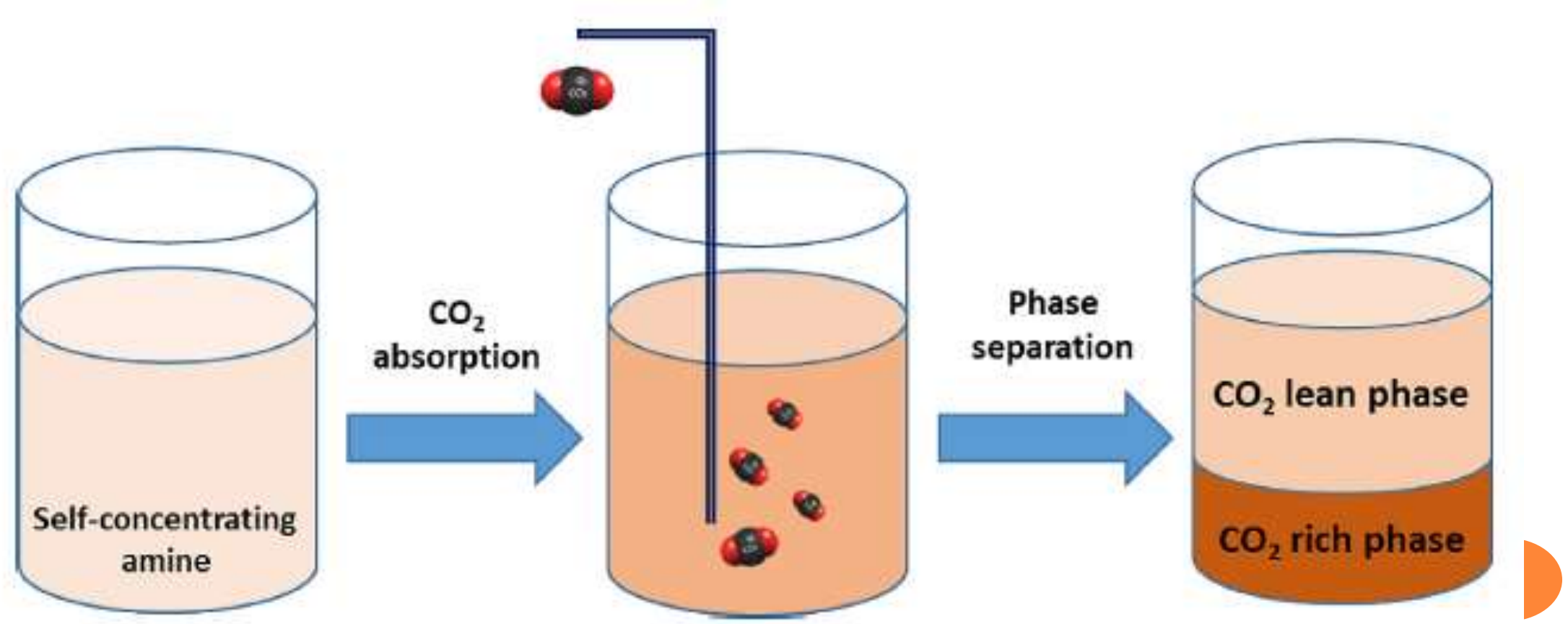
phase-change solvents

- A new class of solvents, phase-change solvents, has emerged and been developed into one of the most promising technologies for CO_2 capture.
- Such phase change technology removes CO_2 from power-plant flue gases using a solvent that, when it reacts with CO_2, rapidly forms two distinct phases:

1. a CO_2-rich phase
2. a CO_2-lean phase.

- Only the CO_2-rich phase will then undergo regeneration to remove the CO_2 and recycle the solvent.

Phase change in ammine liquids with CO_2 absorption



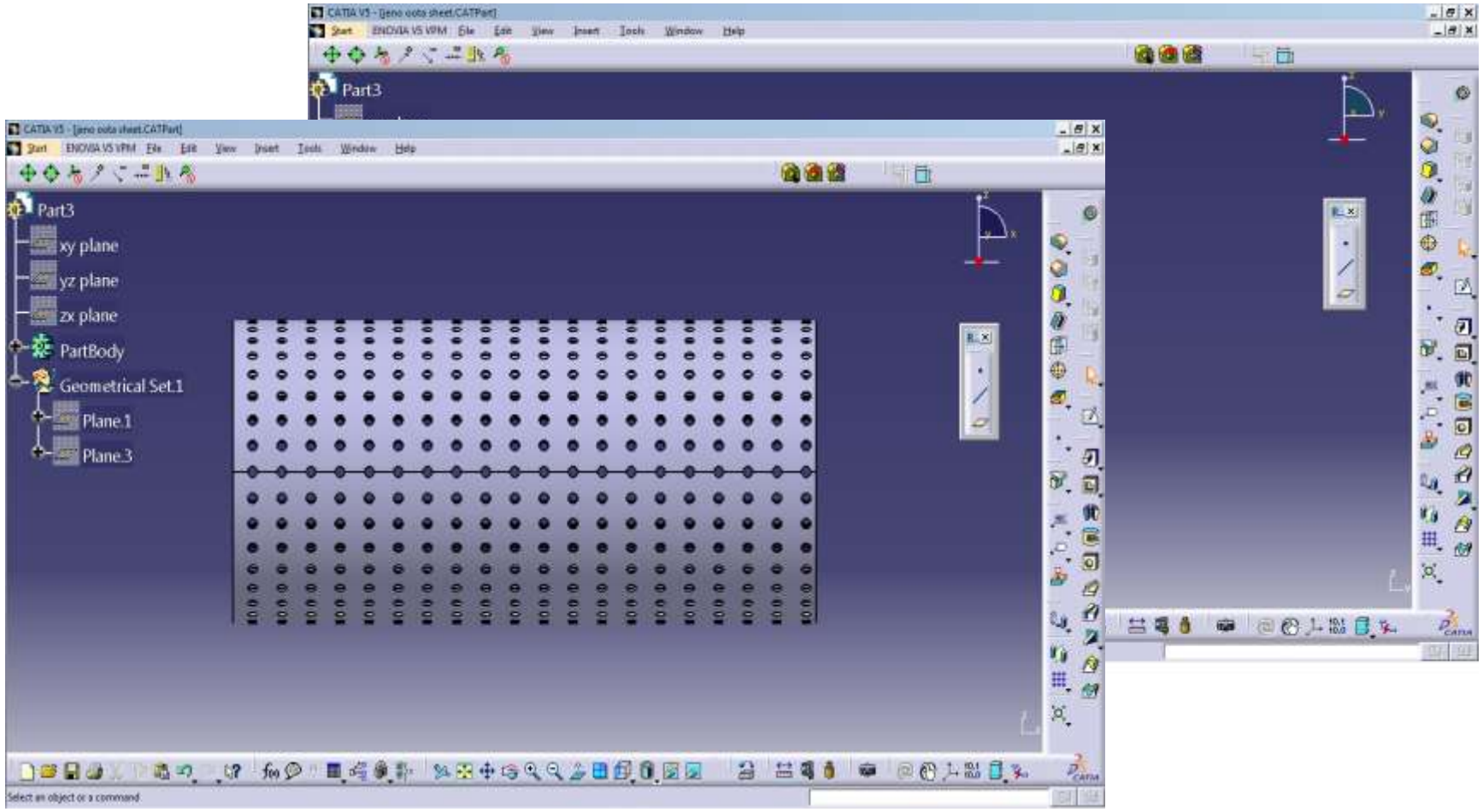
EXPERIMENTAL WORK

Experimentation carried out with CCS

1. Reduction of CO_2 emissions by adsorption in an Internal combustion engine using Zeolite Pellets

2. CO_2 capture from diesel engine using absorption technique on phase changing amino acids

Zeolite Sieve designed to hold Zeolite pellets




ZEOLITE
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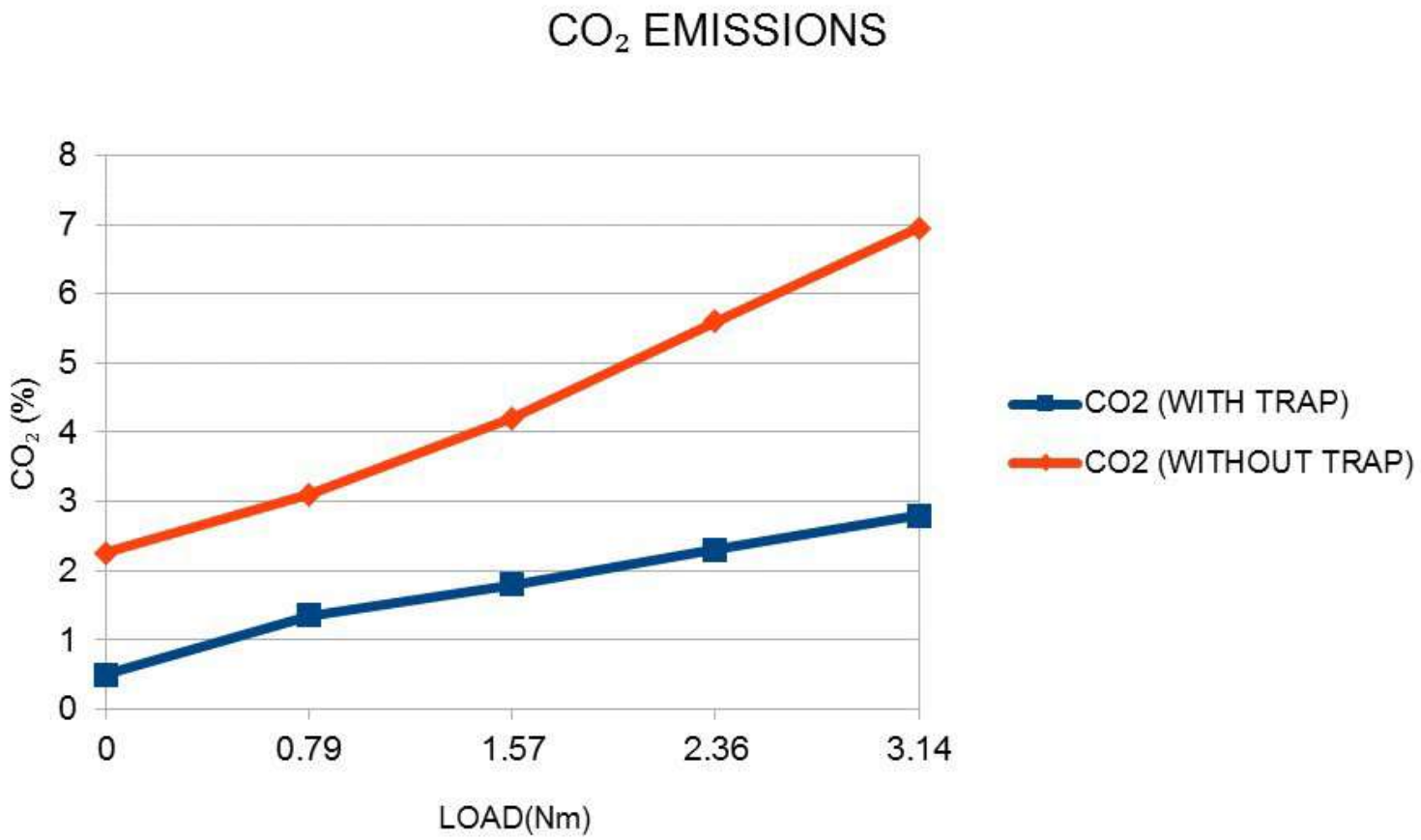
CO_2 EMISSIONS



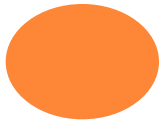
Results

- Zeolites balls have been chosen as an adsorbent. The porosity nature of the material provides the better adhering with CO_2 molecules.
- The Trap filled with One kg of Zeolites shows the positives results on CO_2 adsorption upto 60% in the single cylinder diesel engine.

Reduction of CO_2 emissions through Absorption using Ammine solutions

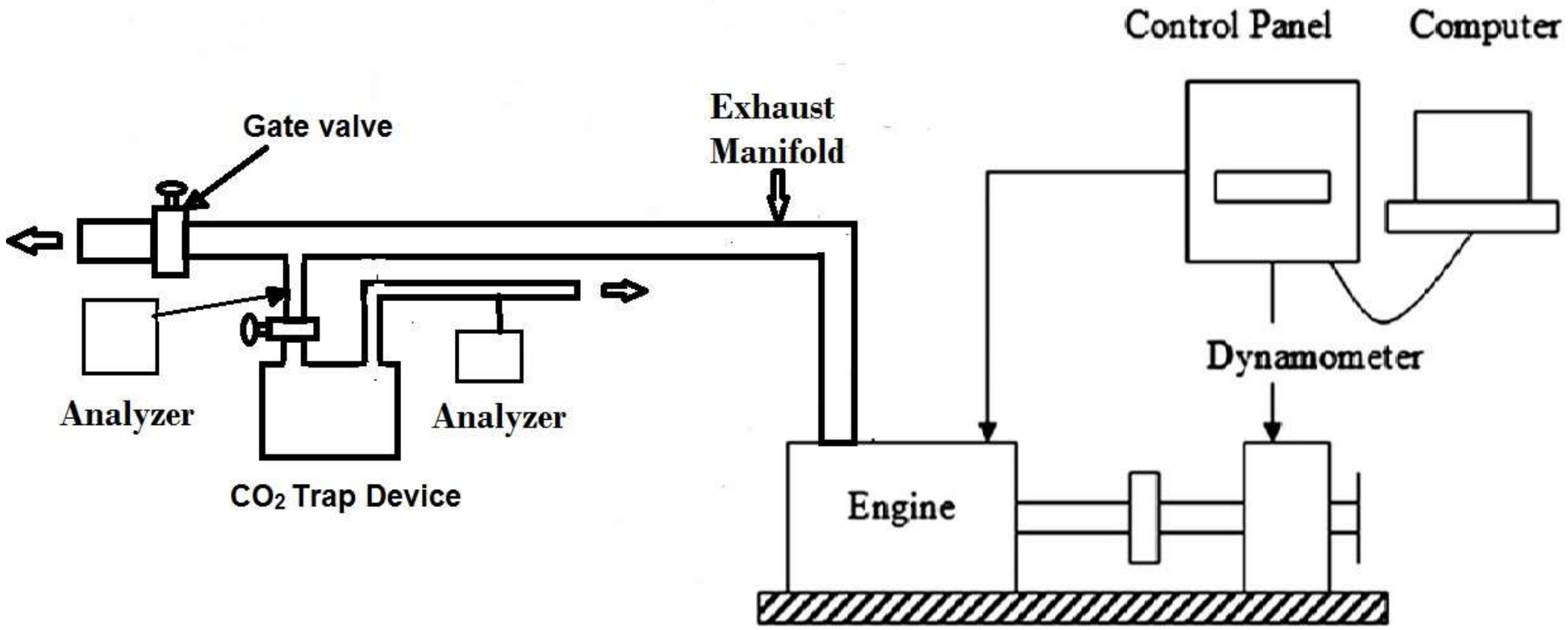
- Various amino acids were used to capture the carbon dioxide emission from the single cylinder four stroke diesel engine
- The acids employed are

1. L Alanine
2. L Arginine
3. L Serine
4. L Lysine
5. L Aspartic acid



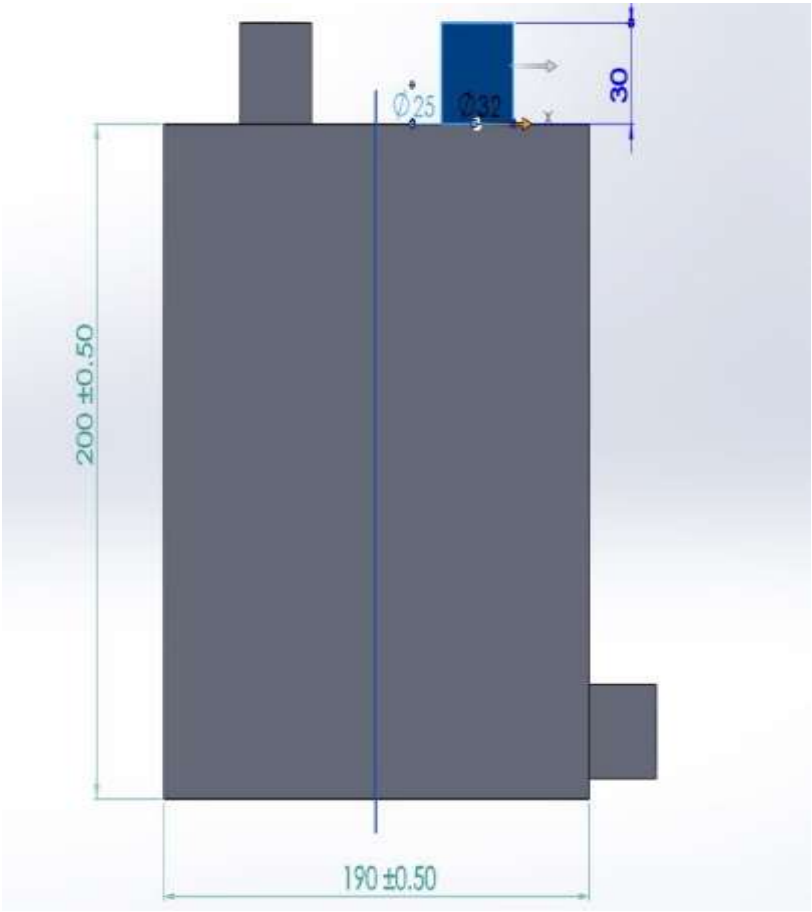
Properties	L-Alanine	L-Arginine	L-Aspartic acid	L-Serine	L-Lysine Mono hydrochloride	Sodium Hydroxide
Molecular Formula	$C_3H_7NO_2$	$C_6H_{14}N_4O_2$	$C_4H_7NO_4$	$C_3H_7NO_3$	$C_6H_{14}N_2O_2$	NaOH
Molecular Weight (g/mol)	89.09	174.2	133.1	105.09	182.65	40.00
Appearance	crystalline	powder	powder	powder	powder	powder
Colour	white	colorless	white	white	white	white
pH at 25 °C	5.5 - 7	11.25	2.8	5.68	5.0 - 6	13 - 14
pKa	2.35	2.18	1.88	2.21	2.2	13.8
Melting point (°C)	314.5	235	270	246	263	318
Boiling point (°C)	189	368	324		224.5	139
Density (g/cm³)	1.424	1.660	1.660	1.603	1.522	2.13
Acidity	9.69 (Amino)	-	1.88, 3.65, 9.60	2.21 (carboxy) 9.15 (amino)	-	-
Water solubility	89.1 g/l at 20 °C	50 mg/ml	-	-	Freely soluble	-
Specific Rotation	-	26.9 (16.5 mg/ml, 6.0 N HCl, 20 °C)	-	-	-	-
Vapour pressure	-	-	-	-	-	< 24,00 hPa at 20°C 4,00 hPa at 37 °C

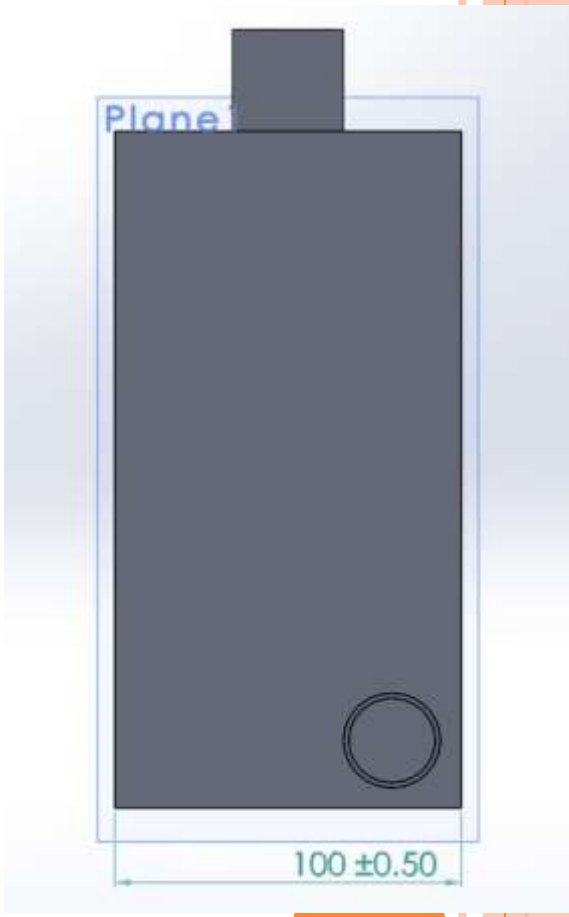
EXPERIMENTAL SETUP



Absorption chamber design

Fabricated Container

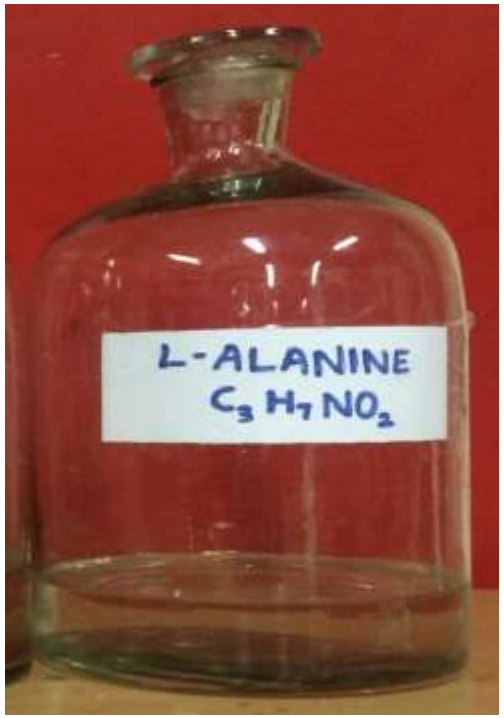




ENGINE SPECIFICATION

PARAMETERS	DETAILS
MAKE	KIRLOSKAR ENGINE
MODEL	AV1
TYPE	UNDER SQUARE
NO OF CYLINDER	1
BORE	87mm
STROKE LENGTH	110mm
SPEED	1500 rpm
MAXIMUM POWER	8hp
SWEPT VOLUME	$780cm^3$
COMPRESSION RATIO	16.5:1
LUBRICATING OIL	SAE30/SAE40
COOLING SYSTEM	WATER
INJECTION TIMING	27^OBTDC
INJECTOR TYPE	MECHANICAL INJECTOR

L-ALANINE



BEFORE ABSORPTION

AFTER ABSORPTION

L ALANINE + L ARGININE

AFTER ABSORPTION

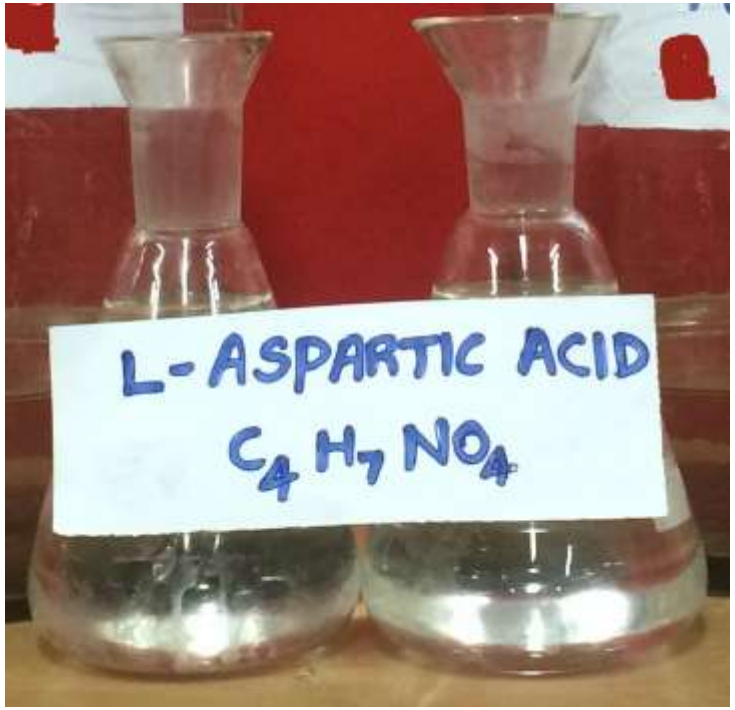
L-ARGININE

L ARGININE BEFORE ABSORPTION

L ARGININE AFTER ABSORPTION

L LYSINE + L ARGININE AFTER ABSORPTION

L-ASPARTIC ACID



L ASPARTIC ACID BEFORE ABSORPTION

L ASPARTIC ACID AFTER ABSORPTION

L ASPARTIC ACID + L ALANINE

AFTER ABSORPTION

L-LYSINE MONOHYDROCHLORIDE

L LYSINE BEFORE ABSORPTION

L LYSINE AFTER ABSORPTION

L LYSINE + L SERINE AFTER ABSORPTION

L SERINE

L SERINE

BEFORE ABSORPTION

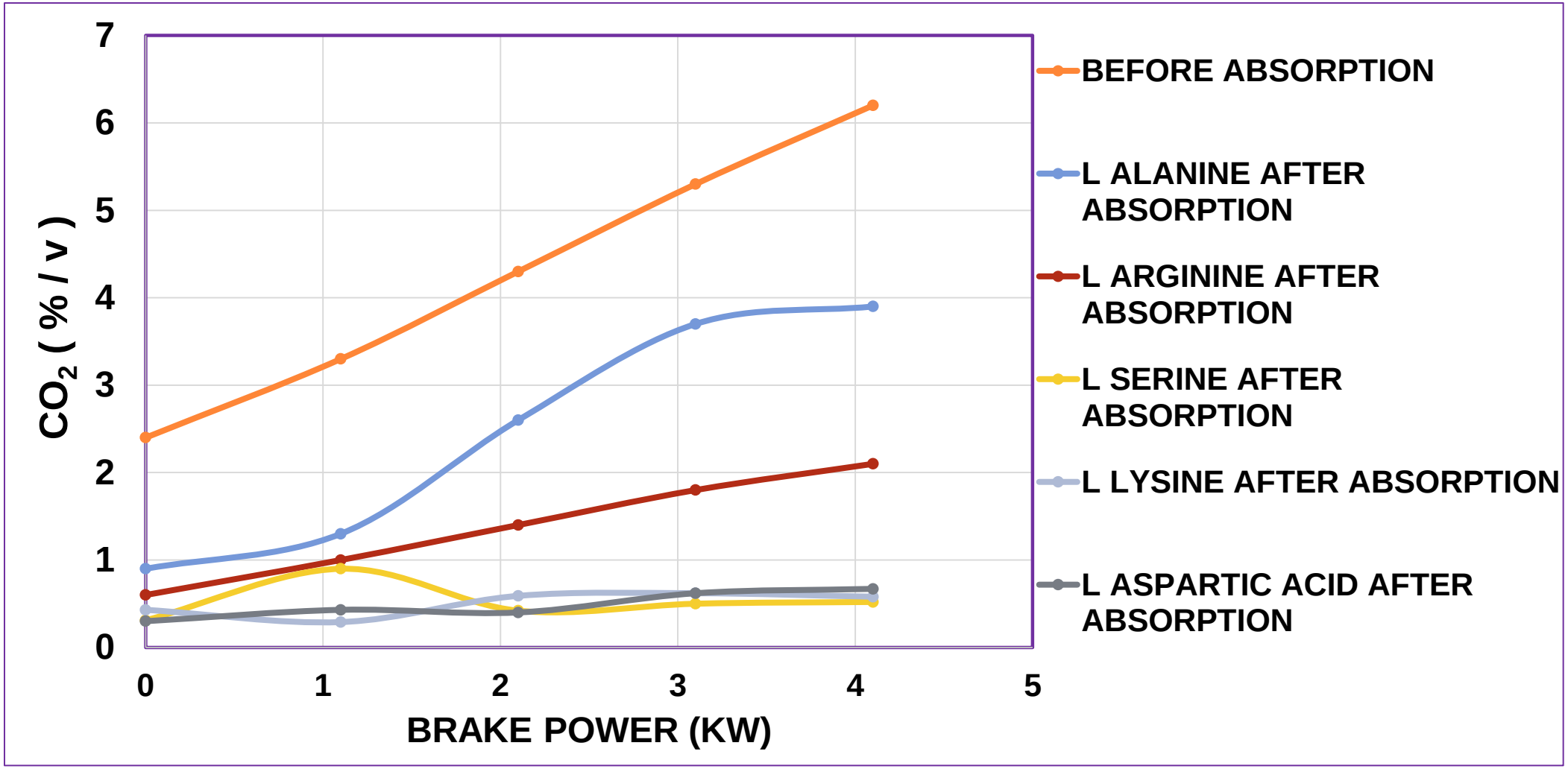
L SERINE

AFTER ABSORPTION

L ASPARTIC ACID + L SERINE

AFTER ABSORPTION

CARBON DIOXIDE EMISSION



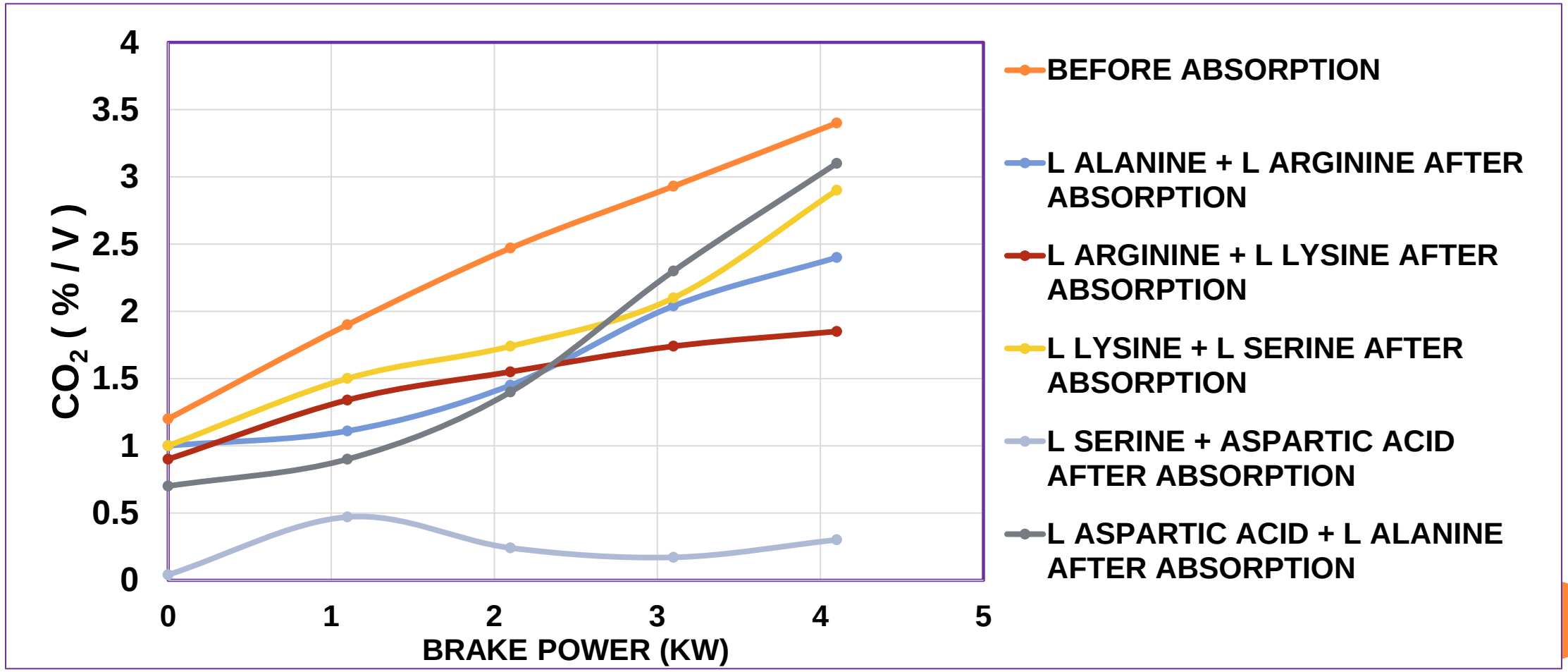
Results for Adsorbent mixtures

The mixtures were prepared in four different combinations

- L Serine + L Aspartic acid.
- L Alanine + L Arginine.
- L Lysine+ L Serine.
- L Lysine + L Arginine.
- L Aspartic acid + L Alanine.

And then the emission characteristics were tested.

CARBON DIOXIDE EMISSION



Results

- The **L Aspartic acid** is very good absorbent and at low and high load condition 90% of CO_2 emission are reduced.

- The **L Serine + L Aspartic acid** is very sensitive absorbents it is absorbs 90% of CO_2 emissions from the exhaust at low load conditions due to the amino acids are basic material it is absorbs the acidic gases.

Conclusion

- The potential impact from climate change brought about by increasing atmospheric concentrations of greenhouse gases is a global problem that requires urgent global action.

- Carbon capture and storage (CCS) will need to play an important role within the portfolio of approaches required to achieve a material reduction in CO_2 emissions for two reasons

1. The continued importance of fossil fuels to future energy supply;
2. The scale of CO_2 emissions from industries where there are limited other abatement options.

- The integration of capture, transport and storage in full-scale projects is needed to gain the knowledge and experience required for a more widespread deployment of CCS technologies.
- R&D is also needed to improve knowledge of emerging concepts and enabling technologies for CO_2 capture that have the potential to significantly reduce the costs of capture for new and existing facilities
- Among the capture mechanisms reviewed, post-combustion technologies were given focus because these mechanisms are most likely to be readily adaptable to operate with existing internal-combustion engines. Three separation processes were described: absorption, membrane separation, and adsorption.

- Research has been carried out with Adsorption materials and phase change absorption materials to know the potential of CO_2 capture in Internal combustion engines and also the regeneration.
- Even though there are current norms for Carbon di oxide in Automobiles , future norms are proposed by 2020-25 for heavy vehicles and tractors
- Considerations about operational costs from the point of view of the consumer have to be taken into account, including storage management of captured CO2, additional energy costs to support separation and storage, discharge procedures, and additional maintenance costs.
- Proper Education, Motivation is required to the public.
- All the above considerations have to be taken account to make CCS a viable after treatment system in Automobiles in the forthcoming years


The key to a greener planet is in our hands

Thank you