ENVIRONMENTAL SCIENCE ARCHIVES
ISSN: 2583-5092
Volume V, Conference Special Issue, 2026
Received: 15-Feb-26 **Accepted:** 06-Apr-26 **Published:** 17-Apr-26
DOI: 10.5281/zenodo.19625110

REVIEW **OPEN ACCESS**

Valorization of Biogenic Carbon dioxide from Indian Distilleries

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Abstract

Distilleries are as diverse as the spirits they produce, yet their environmental challenges remain universally pressing. Alcohol production, particularly in distilleries, generates significant volumes of carbon dioxide during fermentation. This CO2, if left unmanaged, contributes to greenhouse gas emissions and environmental degradation. CO2 recovery offers an innovative solution, turning a byproduct of the distillation process into a valuable resource. By capturing, purifying, and repurposing CO2, distilleries can enhance their environmental credentials while improving operational efficiency. This paper reviews the recovery of carbon dioxide, its numerous applications and use in various industrial sectors. Based on studies in respect of techno commercial analysis for carbon dioxide recovery from 60 KLPD distillery capacity, the project is technically feasible and commercially viable.

Keywords: Valorization; Biogenic; Carbon dioxide; Indian Distilleries

Introduction

India is the largest producer of sugarcane as well as sugar in the world. The Indian sugar industry (534 operational sugar units in 2024-25) occupies a pride of place in rural economy. Most of the sugar industries are located in rural area providing employment to rural masses. Molasses (C heavy and B-heavy) and syrup are considered feedstocks for alcohol production. The molasses/syrup and grains are used mainly for production of ethyl alcohol. There were 499 distilleries in the country with annual installed capacity about 18.22 billion liters of alcohol in the year 2024-25. Carbon dioxide is one of the important co-products of alcohol industry.

Theoretical yields of ethyl alcohol / carbon dioxide

During fermentation, yeast strain belonging to the species, *Saccharomyces cerevisiae*, a liking microorganism belonging to the class fungi converts sugar present in the molasses to alcohol. Chemically this transformation for sucrose to alcohol as per Gay Lussac equation can be:

Following theoretical yield is unattainable due to various reasons. In practice carbon dioxide is formed about 16 kg per 100 kg of molasses, out of which 11-12 kg/100kg of molasses may be recovered. Thus from 30 KLPD distillery, about 12 tonnes of carbon dioxide can be recovered.

$$\underset{\text{Cane Sugar}}{C_{12}H_{22}\ O_{11}H_2O} \xrightarrow{\text{Invertage}} \underset{\text{Glucose and Fructose}}{2\ C_6H_{12}O_6}$$

$$\underset{(180)}{C_6H_{12}\ O_6} \xrightarrow{\text{Yeast}} \underset{2\ (46) + 2\ (44)}{2C_2H_5OH + 2CO_2}$$

Carbon dioxide

Carbon dioxide (CO_2) is considered neither an environmental, nor a human toxin. Because it is non-inflammable and does not explode. CO_2 has a National Fire Protection Assn. (NFPA, Quincy, Mass) hazard rating of Zero, or negligible, for both fire and reactivity. As a health risk, CO_2 is rated as a slight hazard or 1. Essentially non-toxic in solid, liquid and gaseous form, CO_2 is extremely stable, and is neither carcinogenic nor corrosive to human tissues. The major hazard that CO_2presents is the risk of asphyxiation, by excluding oxygen from the lungs. Skin contact with solid or liquid carbon dioxide presents a freezing hazard. Besides the potential for causing frostbite, co_2 has no known long term health effects. The tolerance limit to CO_2 is set by OSHA at 10,000 ppm per 8 hour work shift. This limit is easily achieved with adequate monitoring and ventilation.

No special containment equipment or procedures are required for the safe storage of the material, other than pressurized and refrigerated tanks for liquid CO_2 and cylinders for compressed CO_2 gas. There is no need to construct cement dams, walls or secondary containment lagoons, and no decontamination facilities are needed to handle worker exposure. When released to atmosphere, liquid carbon dioxide solidifies and then sublimes, leaving no residue to contaminate either the environment and / or personnel.

Some Physical Constants for carbon dioxide

Carbon dioxide is a compound of carbon and oxygen in proportions by weight of about 27.3 % carbon to 72.7% oxygen. A gas, at normal atmospheric temperatures and pressures, it is colourless, odourless and about 1.5 times as heavy as air. A slightly acid gas, it is felt by some persons to have a slight pungent odour and bitter taste. It is relatively non-reactive and non-toxic. It will not burn and it will not support combustion and/ or life. When dissolved in water, Carbonic acid (H_2CO_2) is formed. The pH of carbonic acid varies from 3.7 at atmospheric pressure to 3.2 at 23.4 atm. It may exist simultaneously as a solid, liquid and gas at a temperature of 69.9°F (-56.6°C) and a pressure of 60.4 psig (416kPa), its triple point. Figure 1 is the phase diagram for carbon dioxide. At temperatures and pressures below the triple point, carbon dioxide may be either a solid (dry ice) or a gas, depending upon temperature conditions. Solid carbon dioxide at a temperature of -109°F (-78.5°C) and atmospheric pressure transforms directly to a gas (sublimes without passing through the liquid phase). Lower temperatures will result if solid carbon dioxide sublimes at pressure less than atmospheric. At temperatures and pressures above the triple point and below 87.9°F (31.1°C), carbon dioxide liquid and gas will be in equilibrium in a container. Within this temperature range, the vapour pressure in a closed container holding carbon dioxide liquid and gas in equilibrium bears a definite relationship to the temperature. Above the critical temperature, which is 87.9°F (31.1°C), carbon dioxide cannot exist as a liquid regardless of the pressure.

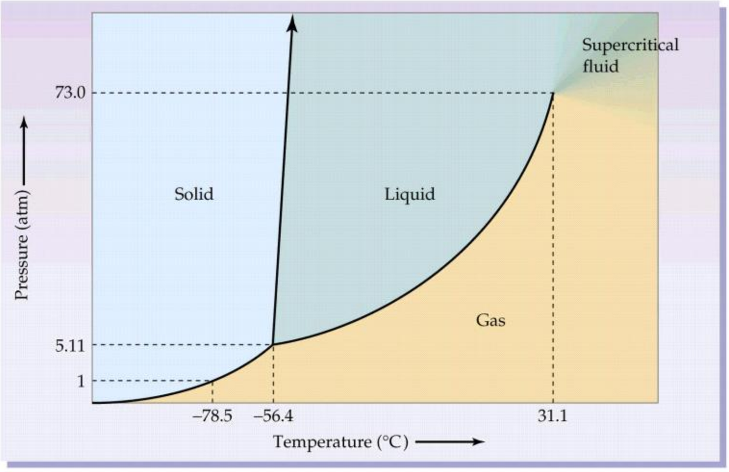

Fig. 1. Phase Diagram for Carbon Dioxide

Uses

The applications of solid carbon dioxide would be refrigerating dairy products, meat products, frozen foods and other perishable foods while in transit. It has application as a cooling agent in many industrial processes such as grinding heat sensitive materials, rubber tumbling, cold treating metals, shrink fitting of machinery parts, vacuum cold traps and so on. The use of gaseous carbon dioxide will be to carbonate soft drinks, for pH control in waste water treatment, in chemical processing, as a food preservative, as an inert 'blanket' in chemical and food processing and metal welding, as a growth stimulant for plant life, for hardening moulds and cores in foundries and in pneumatic devices. The uses of liquid carbon dioxide would be as an expendable refrigerant for freezing and chilling food products, for low temperature testing of aviation, missile and electronic components, for stimulation of oil and gas wells, for rubber tumbling and for controlling chemical reactions. It can be used as a fire extinguishing agent in portable and built in extinguishing systems.

Some Prominent Applications of CO_2

Precursor to chemicals

In the chemical industry, carbon dioxide is mainly used as an ingredient in the production of urea and methanol. Metal carbonates and bicarbonates, as well as some carboxylic acids derivatives (e.g., sodium salicylate) are made from CO_2.

Foods

Carbon dioxide serves various roles in the food sector as an additive, propellant, and acidity adjuster. Regulatory bodies in the EU, USA, Australia, and New Zealand have approved its use. Pop Rocks candy gets its fizz from carbon dioxide pressurized to around 40 bar (580 psi). In the mouth, the candy dissolves like typical hard sweets, freeing gas bubbles that create a distinctive popping sound. Leavening agents help dough expand by generating carbon dioxide. Baker's yeast ferments sugars in the dough to produce the gas, whereas chemical options like baking powder and soda release it upon heating or contact with acids.

Beverages

Carbon dioxide carbonates soft drinks and soda water. In beer and sparkling wine, carbonation historically arose from natural fermentation, though producers now often capture and reuse the gas from that process.

Wine making

Winemakers use dry ice (solid carbon dioxide) to rapidly chill freshly harvested grapes, deterring unwanted fermentation by wild yeasts. Unlike water ice, dry ice avoids diluting the grapes' sugar content, which preserves higher alcohol levels in the final product. During cold soaking, dry ice maintains low temperatures. Its sublimation produces carbon dioxide gas, denser than air, which pools at the tank bottom to form an oxygen-poor zone that inhibits bacterial growth on grapes until controlled yeast fermentation begins. Carbon dioxide also enables carbonic maceration, a technique for specific wine styles, by establishing a low-oxygen setting.

Inert gas

Carbon dioxide ranks among the top choices for compressed gas in pneumatic tools. In welding, it creates a shielding atmosphere, especially in automotive applications where its lower cost beats inert alternatives like argon or helium. For MIG welding, CO_2-based methods are known as MAG (Metal Active Gas) welding since the gas reacts at elevated temperatures. This generates a hotter weld pool with better flow, potentially from reactions at the site—though it can make the weld more brittle, which matters less for everyday mild steel work prioritizing strength over flexibility. Its affordability, nonflammability, and ability to liquefy at room temperature under about 60 bar (870 psi, 59 atm) make carbon dioxide ideal for consumer products needing pressurized gas, packing more into containers than gas alone would allow. Life vests use CO_2 canisters for instant inflation. Small aluminum CO_2 cartridges power airguns, paintball guns, bike tire pumps, and home carbonation devices. In coal mining, quick vaporization of liquid CO_2 blasts rock. High CO_2 levels control pests, while supercritical liquid CO_2 aids in drying foods and materials, preparing electron microscopy samples, and decaffeinating coffee.

Fire extinguisher

Carbon dioxide smothers fires, filling some extinguishers—particularly for electrical hazards—with pressurized liquid CO_2. These excel against small fuel or electrical blazes but falter on ordinary combustibles: they displace oxygen without much cooling, so reignition risks remain once the gas dissipates. CO_2 also features in stationary systems for targeted hazard suppression or full-space flooding, including IMO-approved setups for ship cargo holds and engine rooms. At fire-suppressing levels (around 40%), it cannot sustain human life, leading to fatalities in some cases, yet it poses no direct toxicity.

Agricultural and biological applications

Photosynthesis in plants relies on carbon dioxide. Large greenhouses supplement CO_2 to boost and sustain growth; even a halving of levels can halt plant development or cause death. At extremes (over 100 times ambient levels), it harms animals, so short exposures at 10,000 ppm (1%) or more eradicate greenhouse pests like whiteflies and spider mites. CO_2 also feeds Spirulina algae cultivation in greenhouses. Researchers suggest infusing ponds with CO_2 to cultivate algae for biodiesel production.

Oil recovery

In enhanced oil recovery, supercritical carbon dioxide injects near production wells in aging fields, potentially boosting yields by 7–23% beyond initial extraction. It pressurizes reservoirs and, when mixed with crude, slashes oil viscosity for easier flow to extraction points. Extensive pipelines deliver CO_2 to injection sites.

Refrigerant

In food logistics, liquid and solid CO_2 preserve items like ice cream during shipping and storage. Known as dry ice, the solid form suits small-scale transport without bulky refrigeration gear, staying at or below -78.5 °C under normal pressure. Liquid CO_2 (R744) served as a refrigerant before R-12 and could resurgence as R-134a faces climate scrutiny. Its superior cooling volume suits refrigeration and heating, though systems must handle up to 130 bar (1880 psi). In cars north of 50° latitude, R744 outperforms R-134a in over 90% of conditions. With no ozone harm, toxicity, or flammability, it eyes replacement of HFCs in vehicles, stores, and heat pumps. Coca-Cola deploys CO_2 coolers, and the US military explores it for cooling/heating. The auto sector anticipates choosing next-gen AC refrigerants, with CO_2 a strong contender.

In- Transit Refrigeration

Refrigerated trucks and vans haul massive frozen/chilled food loads. CO_2 increasingly replaces mechanical systems, which demand heavy maintenance and use climate-damaging CFCs/HCFCs, plus diesel emissions and noise. CO_2 systems avoid these issues, needing minimal upkeep, hitting temperatures faster, costing less to run, and lasting twice as long. In the US, railcars for frozen foods draw liquid CO2 from a food warehouse receiver tank via pipeline to a loading station, then a hose to the car. After sealing the insulated car with product, CO2 injects at 300 psig into an overhead bunker, expanding into gas and "snow" (fine solid particles). This sublimes over 7–20 days for steady cooling. For 2–5 day deliveries, compact 4x4x6 ft fiberglass containers use four ceiling-mounted CO2 bottles. An internal thermostat releases CO2 as needed, holding temperatures within 2°F for up to five days.

CO_2 Conversion into Methanol (CO_2-to-MeOH Technology)

Conversion of carbon dioxide (CO_2) into methanol is a key carbon capture and utilization (CCU) pathway. It helps reduce greenhouse gas emissions while producing a valuable fuel and chemical feedstock.

Overall Reaction

$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$ ($\Delta H = -49.5$ kJ/mol)

Industrial & Fuel Applications

- Fuel blending (M15–M100)
- Marine fuel (IMO-compliant)
- Hydrogen carrier
- Feedstock for chemicals

Carbon and Environmental Impact

Parameter	Methane	Hydrogen	Methanol
Carbon content	Yes	No	Yes (low)
Tailpipe CO_2	Yes	Zero	Low
Lifecycle CO_2*	Low (synthetic)	Very low (green)	Very low (green)
Methane slip	Possible	Not applicable	Not applicable

*Depends on production route.

CO_2 for Clarification / Carbonatation

Carbonatation is a sugar juice purification step where CO_2 gas is bubbled through limed sugar juice (Ca $(OH)_2$-treated juice) to remove impurities. It is an alternative to sulphitation and is widely used in beet sugar and increasingly in cane sugar refineries.

Basic Chemistry

First, milk of lime is added:

Ca $(OH)_2$ + Impurities → Flocs (adsorb colour, proteins, gums)

Then CO_2 is passed through the limed juice:

Ca $(OH)_2 + CO_2 \rightarrow CaCO_3 \downarrow$ (solid precipitate)

- The **calcium carbonate crystals trap impurities**
- The solids settle or are filtered out
- Clear juice remains → sent for evaporation & crystallization

Comparison: Carbonatation vs Sulphitation

Aspect	Carbonatation (CO_2)	Sulphitation (SO_2)
Chemical used	Lime + CO_2	Lime + Sulphur
Colour removal	High	Moderate
Sugar type	Refined / plantation white	Plantation / raw
Residual chemical	$CaCO_3$	Sulphites
Health/environment	Safer	SO_2 concerns

Environmental Impact

Factor	Carbonatation	Sulphitation
Gas emissions	Utilizes CO_2	Emits SO_2
Worker health	Safer	Risk
Public perception	Positive	Negative

If CO_2 comes from distillery fermentation, you gain carbon-recycling advantage.

CO_2 for Algae Production

CO2 is essential for algae production as it's the carbon source for photosynthesis, fueling growth and biomass formation, with algae consuming significant amounts (around 1.83 kg CO2 per 1 kg biomass) and converting it into valuable organic compounds. Supplying CO2, often from industrial flue gases or purified sources such as from distillery or biogas unit, enhances productivity, helps control pH in bioreactors, and can be optimized for specific species like *Chlorella* or *Scenedesmus* for maximum yield, potentially even remediating wastewater.

How CO2 is used

- **Photosynthesis:** Algae use sunlight to convert CO2 and water into oxygen and sugars (organic carbon) for energy and building biomass.
- **Carbon Fixation:** The carbon from CO2 becomes part of lipids, proteins, carbohydrates, and other valuable molecules.

Coal bed methane recovery

In enhanced coal bed methane recovery, carbon dioxide is pumped into the coal seam to displace methane.

Fumigation

Carbon dioxide can replace many chemical pesticides traditionally used for fumigation. Registered with the U.S. Environmental Protection Agency (EPA, Washington, D.C.) as a non-restricted use pesticide, carbon dioxide kills insects via desiccation caused by hyperventilation.
Carbon dioxide offers considerable benefits over such commonly used pesticides as phosphine or methyl, bromide. Insects cannot develop a resistance to it, and, since the gas leaves no toxic residues, it requires no special aeration or handling procedures. To carry out fumigation, carbon dioxide is stored as a liquid at 0°F, and is converted into a gas through a vaporizer, as needed. As it is passed through a filter and a pressure valve, the gas pressure is reduced to about 10 PSIG- sufficient to force the gas to injection points at the top of a grain storage bin / silo, without the help of pumps. Once injected into the silo, the CO_2 migrates down ward by gravity, ultimately displacing the existing atmosphere and creating atmosphere that is lethal to insects. As a gas, the small diameter CO_2 molecules readily permeate all parts of the silo. Even, if the silo is not airtight, an atmosphere of 60% CO_2 is sufficient to kill 100 % of all insect life in a silo within 4 days. Typical CO_2 usage for the full four-day treatment is about 0.15 to 0.20 lb CO_2 per bushel of grain.

pH control

Carbon dioxide can be widely used to control the pH of highly alkaline effluent streams. It effectively brings pH down from 12 or 13 to a range of 6-9. When mixed with water, CO_2 produces carbonic acid, bicarbonate and carbonate. The free hydrogen ions react with hydroxides present in an alkaline solution, reducing the pH. The bicarbonate acts as a natural buffer in the solution, and creates equilibrium in the system that makes it virtually impossible to produce a highly acidic or corrosive mixture. Carbon dioxide has edge over traditional pH control chemicals. Among the advantages of this is the avoidance of handling (more hazardous) acids such as sulphuric acid (H_2SO_4). It is safer and less expensive to use than the acid. To neutralize a solution with a pH greater than 12, -CO_2 can substitute for H_2SO_4. The savings come from both the favourable cost differential associated with CO_2 and by avoiding the costs associated with handling, storing and disposing of H_2SO_4 and maintaining the safety equipment required to handle the acid. CO_2 can be used to control pH levels in paper mill and textile effluent, to control river and stream pH, and to condition water in effluent pipelines, so as to prevent scale formation. Carbon dioxide can be used as a means of controlling the pH of swimming pools, by continuously adding gas to the water, thus keeping the pH level from rising. Similarly, it is also used in the maintaining reef aquaria, is commonly used in calcium reactors to temporarily lower the pH of water being passed over calcium carbonate in order to allow the calcium carbonate to dissolve into the water more freely where it is used by some corals to build their skeleton.

Supercritical Co_2 For Cleaning & Extraction

For many cleaning and extraction operations, CO_2 can replace chlorinated fluorocarbons (CFCs) and many volatile organic chemicals (VOCs). Both CFCs and VOCs have deleterious effects when released to the environment. CFCs are a major contributor to the deterioration of the earth's stratospheric ozone layer, as such, they have been banned internationally and will no longer be legal. Worldwide, many VOCs are regulated as hazardous materials under a variety of environmental laws, and require multiple safeguards for workers and environment.

At 90°F and about 1100 psi, carbon dioxide reaches its super critical state, in which it becomes a dense gas with the solvent properties of a liquid. Supercritical fluids have a lower viscosity and density, and a higher diffusivity than many traditionally used chemical solvents and supercritical CO_2 produce no toxic emissions. A versatile solvent, supercritical CO_2 is ideal for extracting chemicals and contaminants from another process stream under pressure. To clean an equipment component using supercritical CO_2 the item is placed in a sealed vessel, which is then flooded with supercritical CO_2 at 1100 psi or greater. After just seconds, a valve is operated, the pressure is lowered and the contaminants drop out, leaving a clean component. Supercritical CO_2 is also used for solvent extraction in the foods and fragrances industries, for such processes as stripping caffeine from coffee or removing fat from milk. Typically, the mixture of chemicals or foodstuff to be separated is fed into the top of an extraction vessel either in batches or continuously CO_2 gas is fed into the bottom. As the CO_2 contacts the stream, the chemicals dissolve into the CO_2 gas. As it exist the vessel, it passes through a pressure-reducing valve to induce separation. The extract is collected for reuse or disposal and the CO_2 is purified or vented.Carbon dioxide has applications in the pharmaceutical and chemical industries as a less toxic alternative to more traditional solvents such as organo-chlorides. It is used by some dry cleaners for this reason.It can also be used for cleaning gyroscope and filling hardware; optical components; instrument bearings; computer disk drive components; medical devices; and fabrics, cloths, and rags.

Cost- Economics of CO2 Recovery from 60 KLPD distillery

The Project cost and the details of economics are based on the following assumptions:

- The distillery capacity- 60 KLPD
- The CO2 recovery - 24 TPD
- The distillery working days as 270 days/annum with 70%, 80% and 90% capacity utilization in 1st, 2nd, 3rd year respectively & 100 % capacity utilization from 6th year onward.
- The proportion of industrial, food grade CO2 and dry ice on percent basis: 70: 20: 5
- The purchase price of raw CO2 from distillery- Rs 500 per MT
- The average selling price of Co2 for industrial grade, food grade and dry ice as Rs4500/MT, Rs 7500/MT and Rs 20000/MT respectively.
- The power requirement and its price- 180 units/MT of CO2 @ Rs 6 per unit of power.
- The steam requirement & its price- 50 Kg/MT of CO2 @ Rs2000/MT steam.
- The makeup water & its price- 18 Cu.meter/day @ Rs 50/Cu.meter.
- The chemicals & its price- Mainly potassium permanganate @ two Kg/day, price@ Rs 200 per Kg.
- Estimated Project cost as Rs 305.08 Lacs, Term loan as 70 Percent of project cost, to be paid in 1+ 7 years duration, rate of interest as 13 percent per annum.

The project cost and means of finance is shown in Table 1. The production and sales analysis have been given in Table 2. The projected profitability statement is shown in Table 3. Based on the financial analysis, the financial indicators for the project are as follows:

Table 1. ESTIMATED COST OF THE PROJECT

(Rs.In Lakhs)

SN	PARTICULARS	AMOUNT
1	Land Development, Fencing etc.	7.30
2	Building	9.75
3	Plant and Machinery	225.00
4	Misc. Fixed Assets	25.00
5	Preoperative & Preliminary Expenses	19.30
6	Contingency Provision	13.60
7	Margin Money for Working Capital	5.13
	TOTAL	305.08

MEANS OF FINANCE

(Rs.In Lakhs)

SN	PARTICULARS	SHARE	AMOUNT
1	Own equity	30%	91.53
2	Term Loan from F.I.	70%	213.56
	TOTAL	100%	305.08

Financial Indicators (24 TPD CO2 Recovery)

Break Even Point (BEP):	21.88%
Internal Rate of Return (IRR):	38.76 %
Pay Back Period (PBP):	2Yr and 6 months
Debt Service Coverage Ratio (DSCR):	
Average DSCR:	4.47
Maximum DSCR:	5.39
Minimum DSCR:	2.94

Table 2. Production And Sales (Input Output Analysis)

Sr. No.	PARTICULARS		OPERATING YEARS									
			I	II	III	IV	V	VI	VII	VIII	IX	X
A	Installed Capacity of CO2 per day	MT/Day	24	24	24	24	24	24	24	24	24	24
B	Number of Shifts per day		3	3	3	3	3	3	3	3	3	3
C	Number of Working Days		270	270	270	270	270	270	270	270	270	270
D	Installed Capacity per annum	MT	6480	6480	6480	6480	6480	6480	6480	6480	6480	6480
E	Capacity Utilization %		70	80	90	90	90	100	100	100	100	100
F	CO2 processed per annum (MT)		4536	5184	5832	5832	5832	6480	6480	6480	6480	6480
G	**Effective Production (MT) 70, 25 & 5 % of total Co2 used for industrial grade, food grade and dry ice production respectively**											
1	Industrial grade Co2 per annum, MT/A	70%	3175	3629	4082	4082	4082	4536	4536	4536	4536	4536
2	Food grade Liquid Co2 /annum, MT/A	25%	1134	1814	2041	2041	2041	2268	2268	2268	2268	2268
3	Dry ice per annum, MT/A	5%	227	259	292	292	292	324	324	324	324	324
H	**Sale value (wholesale rate), Rs Lakhs**	Rate, Rs / MT										
1	Food grade Co2	4,500	142.88	163.30	183.71	183.71	183.71	204.12	204.12	204.12	204.12	204.12
2	Liquid Co2	7,500	85.05	136.08	153.09	153.09	153.09	170.10	170.10	170.10	170.10	170.10
3	Dry ice	20,000	45.36	51.84	58.32	58.32	58.32	64.80	64.80	64.80	64.80	64.80
I	**Total Sale**		**273.29**	**351.22**	**395.12**	**395.12**	**395.12**	**439.02**	**439.02**	**439.02**	**439.02**	**439.02**

Table 3. Projected Profitability Statement

PARTICULARS	**Operating years**									
	I	II	III	IV	V	VI	VII	VIII	IX	X
1) No. of working days per annum	270	270	270	270	270	270	270	270	270	270
2) Capacity Utilization (%)	70%	80%	90%	90%	90%	100%	100%	100%	100%	100%
3) Sales Realization per annum	273.29	351.22	395.12	395.12	395.12	439.02	439.02	439.02	439.02	439.02
4) Production Cost per annum										
a) Raw Material	22.68	25.92	29.16	29.16	29.16	32.40	32.40	32.40	32.40	32.40
b) Wages & Salaries	8.08	9.11	9.77	9.77	9.77	9.77	9.77	9.77	9.77	9.77
c) Consumables & Packaging	0.91	1.04	1.17	1.17	1.17	1.30	1.30	1.30	1.30	1.30
d) Utilities	58.84	67.24	75.65	75.65	75.65	84.06	84.06	83.40	84.06	84.06
e) Repairs and maintenance	0.00	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79	7.79
f) Other manufacturing expenses	9.14	11.71	12.42	12.42	12.42	13.13	13.53	13.53	13.53	13.53
TOTAL	99.64	122.82	135.95	135.96	135.96	148.45	148.85	148.19	148.85	148.85
5) Gross Profit (EBIDT)	173.65	228.40	259.16	259.16	259.16	290.57	290.17	290.83	290.17	290.17
g) Interest on Working Capital	2.16	2.67	2.99	2.99	2.99	3.32	3.32	3.31	3.32	3.32
h) Instalment	0.00	30.51	30.51	30.51	30.51	30.51	30.51	27.64	0.00	0.00
i) Interest on Term Loan	27.76	23.80	19.83	15.86	11.90	7.93	3.97	0.00	0.00	0.00
6) Income Before Depreciation	143.73	171.43	205.83	209.79	213.75	248.82	252.38	259.89	286.86	286.86
j) Depreciation (SLM)	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03
7). Operating profit (PBT)	113.70	141.40	175.80	179.76	183.73	218.79	222.36	229.86	256.83	256.83
8) Tax @ 30%	21.98	35.49	49.72	53.85	57.25	69.44	71.76	74.96	83.76	84.30
9) Net Profit (PAT)	91.72	105.91	126.08	125.91	126.47	149.35	150.59	154.90	173.07	172.53

Conclusion

From the fore-going discussion, carbon dioxide from distillery is observed as a precious co-product. It is to be recovered and can be used for the variety of applications. CO_2 recovery is more than a technical solution; it represents a strategic evolution for the distillery industry. Based on the techno-commercial analysis, the recovery of carbon dioxide from the distillery is commercially viable and attractive proposition. Distilleries may consider for putting up of carbon dioxide plant, which consists of manufacturing facilities for production of CO2 as industrial grade, food grade and dry ice. By capturing emissions and repurposing resources, distilleries can achieve cost efficiency, meet regulatory demands, and solidify their reputation as sustainability champions. Paired with innovative by-product utilization strategies, CO_2 recovery for distilleries offers a roadmap to a greener, more profitable future. As the industry continues to embrace these transformative technologies, the vision of a climate-neutral distillery is no longer a distant dream but a tangible reality.

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Author Contributions

BBG conceived the concept, wrote and approved the manuscript.

Acknowledgements

Not applicable.

Funding

Not applicable.

Availability of data and materials

Not applicable.

Competing interest

The author declares no competing interests.

Ethics approval

Not applicable.

Citation: Gunjal BB (2026) Valorization of Biogenic Carbon dioxide from Indian Distilleries. Environmental Science Archives 5 (Conference Special Issue): 119-126.