

ZERO EMISSION TECHNOLOGY TO PRODUCE POWER IN THERMAL PLANTS AND DIMETHYL ETHER FROM CAPTURED CARBON DIOXIDE

FIELD OF INVENTION

5 The present invention relates to zero-emission technology for producing power in thermal plants using natural gas (NG) or liquefied natural gas (LNG) and converting captured carbon dioxide into Dimethyl Ether (DME). This invention outlines two pathways: the production of green methane (green NG) for power generation in a gas-based power plant, and the capture and conversion of carbon dioxide into DME in a single process. The technology is
10 implemented in an Integrated Poly-generation Gasification Combined Cycle (IGCC) power plant.

This advanced energy production process not only generates electricity with zero emissions but also actively captures and recycles carbon dioxide (CO₂) to produce a useful and low-emission e-fuel, dimethyl ether (CH₃OCH₃ or (CH₃)₂O), achieving a 94% reduction in
15 greenhouse gases (GHG). DME serves as a carbon-neutral drop-in fuel, usable in compression ignition (CI) engines, as a substitute for diesel, in fuel cells, or in other applications requiring a clean-burning fuel. This integrated approach demonstrates a sustainable method to generate power from natural gas while recycling captured carbon dioxide into DME, potentially replacing petroleum-based fuels.

BACKGROUND OF THE INVENTION

Global energy-related greenhouse gas (GHG) CO₂ emissions grew by 0.9% in 2023, or 321 million tons, reaching a new high of more than 37.4 billion tons (Gt CO₂), according to the IPCC report. This increase has led to a record-high mean atmospheric carbon dioxide (CO₂) concentration of 427 parts per million (ppm) in April 2024, representing a 20% increase
25 compared to April 1990 levels. In 2023, the global average annual CO₂ concentration reached 421 ppm.

Total electricity generation worldwide in 2020 was 26,823.2 TWh, with 358 TWh produced from renewable energy (RE) sources. To achieve Net Zero Emissions (NZE), the entire 26,823.2 TWh must be sourced from RE sources, or thermal power must be produced using
30 zero-emission technology by 2050. India has committed to cutting GHG emissions by 45% by 2030 and achieving NZE by 2070, as stated at COP 27.

"Zero Emission Technology Power" refers to power generation technologies that produce

- little to no GHG emissions during operation. These technologies aim to minimize or eliminate the release of CO₂ and other harmful pollutants associated with traditional power generation methods. Our objective is to achieve carbon neutrality, balancing the net emissions of CO₂ from the system by capturing and recycling the CO₂ produced. This approach significantly advances sustainable energy production and CO₂ utilization by reducing emissions and recycling CO₂ into valuable fuel, thereby contributing to a circular carbon economy. This process aligns with global efforts to combat climate change and transition to a sustainable, low-carbon energy system by recycling CO₂ into carbon-neutral Dimethyl Ether (DME).
- 10 Since 2015, there has been a marked increase in focus and ambition on achieving NZE. At the Paris Convention in 2016, no major country had formally committed to NZE. However, emissions have increased from less than \$30 billion in 2015 to over \$330 billion in 2020, an 11-fold increase in just five years. The climate emergency has driven the world toward NZE. In 2023, global GHG emissions were 37.4 billion tons, up from 34.9 Gt CO₂ in 2021. At COP
- 15 27 in 2021, countries agreed to cut emissions by 50% by 2030 and achieve NZE by 2050.
- The energy efficiency of this process is 93.04%. It uses 44 kg of CO₂ for abatement and produces 94% energy equivalent of clean liquid fuel from LNG input, resulting in 44.8% direct CO₂ abatement and producing carbon-neutral fuel. This will help reduce oil imports and support the global goal of achieving NZE.
- 20 The invention addresses the issue of grid stability, as relying on more than 50% renewable energy can destabilize the grid, potentially leading to blackouts, as historically occurred in the USA. This invention provides a method to produce thermal power while achieving NZE in the shortest possible time.
- CO₂ emissions must be drastically reduced to net-zero or even net-negative in the second half
- 25 of the 21st century to limit human-induced global warming. The IPCC's sixth assessment report concluded that global warming of 1.5°C could be exceeded in the early 2030s unless deep reductions in CO₂ occur in the coming decades. It is crucial to recycle CO₂ produced by power plants and other industries, which account for 65% of global GHG emissions, with forestry contributing an additional 11%.
- 30 The global pledge for NZE by 2050 has increased the urgency to find ways to reduce CO₂ emissions, lower the carbon intensity of power projects, and decarbonize the transportation sector. Most CO₂ emissions are from burning fossil fuels in power and transportation sectors.

Despite not being the most potent GHG, CO₂ has the greatest volume impact, currently accounting for 65% of climate change effects. The world emitted around 40.53 billion tons of CO₂ in 2021, with atmospheric concentrations continuing to rise. The energy sector is responsible for 75.6% of global GHG emissions.

- 5 Two major products from captured CO₂ are methanol and DME. These can produce various renewable liquid or gaseous transport fuels of non-biological origin (RFNBO) and clean e-fuels for applications like trucks and marine transport. They can be modified to produce methanol-to-olefins (MTO), which can be used as clean aviation fuel (ATF) from recycled CO₂, termed e-ATF. The recycling of CO₂ (CCU-R or Carbon Capture, Utilization, and
- 10 Recycling.) opens new opportunities to produce clean fuels using the sorption-enhanced DME synthesis (SEDMES) process, including methanol and DME, for various RFNBO applications.

PRIOR ART DOCUMENTS

- A prior art search had been carried out relating to zero-emission technology for producing
- 15 power in thermal plants using natural gas (NG) or liquefied natural gas (LNG) and converting captured carbon dioxide into Dimethyl Ether (DME). A list of prior art documents are listed below by way of reference. Here is an analysis of how the present invention differs from the prior art and what makes it unique.

- WO2004109206A1** discloses a liquefied natural gas regasification configuration and method thereof. Describes a method of degasifying LNG and utilizing the refrigeration content to
- 20 increase power generation efficiency in a combined cycle power plant. Here the primary focus is on the regasification of LNG and improving power plant efficiency, not on capturing CO₂ and converting it to DME.

- US9643906B2** discloses a systems and methods for manufacture of dimethyl ether (DME) from natural gas and flare gas feedstock. Describes a mobile system for reforming natural gas
- 25 or flare gas to directly produce DME using an air-methane mixture. Main difference is that this patent focuses on mobile systems and the use of flare gas, without integrating power generation and CO₂ capture for DME production.

- US11492315B2** relates to a process for the production of methanol from gaseous
- 30 hydrocarbons. Describes a multi-stage process for producing methanol from gaseous hydrocarbons, including electrolysis of water to produce hydrogen. Main difference is that it

focuses on methanol production with stages like desulfurization and partial oxidation, without addressing DME production from captured CO₂.

5 **US9856197B2** discloses a method for producing dimethyl ether (DME) from flare gas or other raw natural gas sources. Details a method for producing DME directly from natural gas using air without steam. It concentrates on producing DME directly from natural gas, not integrating power generation and CO₂ capture for DME production.

10 **US7906559B2** relates to a method of converting carbon dioxide to methanol and/or dimethyl ether using methane sources. This Patent describes the BI-REFORMING process for converting CO₂ to methanol and DME using a combination of steam and dry reforming. Here focus is on BI-REFORMING process without integrating power generation, and the recycling of water into the process differs from the proposed method according to the present invention.

15 **US9803142B1** discloses catalysts and processes for converting DME and/or methanol to liquid fuels with high selectivity and yield. Main difference with the instant invention is that this Patent focuses on converting DME/methanol to liquid fuels rather than the initial production from CO₂ in a power generation context.

20 **US7378561B2** teaches a method for producing methanol and dimethyl ether using air as the sole source of materials. Here the applicant describes a method for producing methanol and DME from atmospheric air using hydrogen produced by electrolysis. This Patent uses air as the source and focuses on electrolysis, differing from the integrated power generation and CO₂ capture approach.

25 **US7846978B2** discloses a method of producing methanol from a methane source. Here the focus is on producing methanol from methane by oxidation followed by treatment steps to convert formaldehyde to methanol. But the instant invention concentrates on methanol production from methane, without the integration of CO₂ capture and DME production.

30 **US8198338B2** relates to a process for producing high octane fuel from carbon dioxide and water. Describes a process for producing high octane fuel from CO₂ and water, including methanol and DME as intermediates. Main difference is it primarily focuses on producing high octane fuels, not specifically on integrating power generation with DME production from captured CO₂.

US7605293B2 discloses an environmentally beneficial method of producing methanol from carbon dioxide sources. Details a method for converting CO₂ from various sources to

methanol via electrochemical reduction. Main difference with the instant invention is that it focuses on electrochemical reduction to methanol, differing from the thermal power and CO₂ capture to DME approach.

5 US9090543B2 discloses a process for production of dimethyl ether from methane or natural gas. Describes a dry-reforming process for producing DME from methane or natural gas. Main difference is that it concentrates on dry-reforming for DME production, not integrating power generation and CO₂ capture.

The present invention differentiates itself from prior art by integrating power generation with CO₂ capture and conversion to DME, focusing on a zero-emission technology. This
10 comprehensive approach, utilizing NG/LNG and optimizing the conversion process, offers a novel solution distinct from the cited prior art.

Hence our effort is to design an Integrated Poly-generation power plant using advanced technology for electricity generation and at the same time produce Dimethyl Ether (DME) from the CO₂ emissions, this aims to improve efficiency and reduce environmental
15 impacts compared to traditional power plants using coal or LNG that leads to zero emission technology in a thermal Power Plant.

The first step involves using advanced power generation technologies like CCUS (Carbon Capture, Utilization, and Storage) systems that ensure minimal to zero emissions when burning natural gas which are highly efficient and can achieve lower emissions up to 94%
20 than normal Greenhouse Gas (GHG) Emissions that refer to gases in the Earth's atmosphere that trap heat, contributing to the greenhouse effect and global warming. Here carbon capture technologies are implemented to capture carbon dioxide (CO₂) emissions produced from the combustion of natural gas. This prevents the CO₂ from being released into the atmosphere, effectively reducing the carbon footprint of the power generation process. The
25 captured CO₂ is then redirected to a conversion process, where it is used as a feedstock to produce Dimethyl Ether (DME). Here Dimethyl Ether (DME) is synthesized from the captured CO₂ and hydrogen (H₂).

Thus, this process leverages the synergy of a 24x7 thermal power plant by utilizing its CO₂ emissions and the steam produced, integrating them into the Steam Methane Reforming
30 process without wasting the steam generated within the power plant. The process then proceeds to produce a clean e-fuel, Dimethyl Ether (DME), which achieves a 94% greenhouse gas (GHG) abatement and an exceptional energy efficiency of 93% in DME

production. Therefore, the present invention demonstrates significant novelty and inventiveness in the domain of zero-emission technology for power generation and carbon capture utilization. Unlike conventional methods, this invention uniquely integrates the direct conversion of captured CO₂ into DME within the continuous operation of a thermal power plant, making a crucial contribution to global net-zero targets.

SUMMARY OF THE INVENTION

The present invention relates to a zero-emission technology for producing power in a thermal plant using natural gas (NG) or liquefied natural gas (LNG), followed by capturing carbon dioxide (CO₂) and converting it into green Dimethyl Ether (DME). This technology is applied in an Integrated Poly-generation Gasification Combined Cycle (IGCC) power plant. The process produces the cleanest fuel known from CO₂, directly abating CO₂ emissions from the thermal power plant and generating a carbon-neutral fuel, Green Dimethyl Ether, which helps achieve net-zero emissions while producing bulk thermal power.

Natural gas, primarily composed of methane (CH₄), is combusted in the presence of oxygen (O₂) from the air within the combustion chamber. This exothermic reaction generates carbon dioxide (CO₂), water (H₂O), and a substantial amount of heat. The balanced chemical equation for this combustion reaction is: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

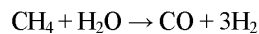
The heat is used to generate electricity in a gas turbine, while the waste heat is further utilized in a Heat Recovery Steam Generator (HRSG) to produce steam for a steam turbine, maximizing energy extraction. The CO₂ produced during combustion is captured using advanced CO₂ capture technologies, reducing greenhouse gas emissions. The integration of these processes results in an efficient and environmentally friendly power generation system.

Thermal power plants producing bulk power emit CO₂, and capturing these emissions requires a two-stage carbon capture process. The first stage involves Pressure Swing Adsorption (PSA), widely used for separating gases in industrial processes, followed by the purification of the CO₂ using a Monoethanolamine (MEA) solution. The captured CO₂ is then used in the following processes to achieve Net Zero Emissions (NZE).

Post-Capture Process Steps

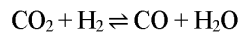
1. Hydrogen Generation via Steam Methane Reforming (SMR) (Figure 3)

The process begins with hydrogen generation through Steam Methane Reforming (SMR) of natural gas in the presence of a catalyst:



2. Reverse Water Gas Shift (RWGS) Reaction (Figure 2)

In the RWGS reaction furnace, waste CO_2 and renewable H_2 are introduced through their respective inlets. The CO_2 reacts with H_2 at high temperatures (above 900°C) in the presence of an oxy-hydrogen flame, producing CO and H_2O as per the following equation:



The reaction is facilitated by the specific design of the furnace, that incorporates thermal insulation to retain heat and a heat exchanger to enhance energy efficiency by using the excess heat of this reaction for steam methane reforming. The non-catalytic, thermally isolated environment allows for rapid CO_2 conversion, with up to 75% efficiency achieved in less than 0.03 seconds. The resulting syngas, composed of CO and H_2O , is then collected through the outlet for further processing in steam Methane reforming.

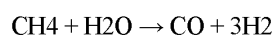
The generated hydrogen is then used in the Reverse Water Gas Shift (RWGS) reaction to reduce CO_2 to CO at high temperatures ($>900^\circ\text{C}$) using an oxy-hydrogen flame:

Managing the hydrogen consumption required to sustain the oxy-hydrogen flame is crucial for operating costs. However, it has been shown that hydrogen usage can be minimized to as low as 1 mol H_2 /mol CO_2 at a CO_2 conversion range of 48–60%. Higher CO_2 conversion with minimal hydrogen consumption is expected in an insulated industrial reactor with integrated heat recovery.

3. Steam Methane Reforming (SMR) Reactor (Figure 3)

Methane and steam, along with about 25% residual CO_2 and the shifted gases (CO and H_2), are passed through a Steam Methane Reformer (SMR) at an inlet temperature of 525°C and 25 ATA pressure over metal catalysts including base metals (Ni , Co , Fe) and noble metals (Pt , Ir , Rh , Ru). The outlet temperature reaches 700°C before the gases are taken to the Auto-Thermal Reforming Reactor (ATR).

The SMR reaction conditions include desulfurization with ActiSorb G1M ZnO catalyst, followed by the steam reforming reaction:



A portion of the hydrogen is recycled (approximately 4 mol%) and separated using Pressure Swing Adsorption (PSA), a technology that separates gas species under pressure according to

molecular characteristics.

4. Auto-Thermal Reforming Reactor (ATR)

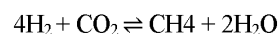
The gases from the SMR are further processed in an Auto-Thermal Reforming Reactor (ATR), a chemical reactor used to produce synthesis gas (syngas), which is a mixture of hydrogen (H₂) and carbon monoxide (CO). The reaction conditions are as follows:

- **Inlet Temperature:** 700°C
 - **Outlet Temperature:** 975°C
 - **Air Inlet Temperature:** 230°C
 - **Air Flow:** 14 mol/hr
- 10 • The outlet gas composition in mol% is as follows:
- CH₄: 0.4, CO: 17.879, CO₂: 10.436, H₂: 71.108, N₂: 0.177
 - The total dry gas flow is 134.829 kmol/hr with a steam flow of 91.336 kmol/hr. The catalyst volumes are 0.5 m³, consisting of nickel-based catalyst, Refor-Max 420 (0.115 m³) at the top and another nickel-based catalyst, Refor-Max 330 (0.385 m³) at the bottom.
- 15 As a result, CO₂ is reduced from 47.82% to 10.436%, and H₂ increases to 71.108%. A mole equivalent of 2.173% H₂ is removed by PSA to be used in the first RWGS reaction furnace, and the remaining 68.935% H₂ is carried forward to the second RWGS reaction.

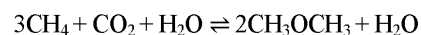
5. DME Synthesis

The balance of 68.461% H₂ and 24.52% CO is sent to the DME Reactor. The invention involves two pathways:

1. Production of Green Methane (CH₄):



2. Conversion of Captured CO₂ into DME:



25 The DME synthesis reaction represents a novel and innovative approach in green energy and sustainable chemistry, converting CO₂ directly into a clean fuel, DME. The reaction is best performed at 25–40 ATA and 250°C–300°C in the presence of a suitable catalyst.

For an input heat value of 48 kg LNG (622,944 Kcal), the output is 92 kg DME (579,600 Kcal),

resulting in an Energy Efficiency Factor (EEF) of 93.04%.

The catalyst used includes a cocktail of one-third M-OP Molybdenum Catalyst on a silica base, two-thirds CuZnAl₂O₃ on a silica base, and one-third ZMS-5 dehydration catalyst. The inlet temperature is 525°C, and the outlet temperature can reach up to 900°C, as the reaction is exothermic.

Process Overview and Reactions (Figure 3)

1. Desulfurization of feedstock and RWGS reaction at 900°C
2. Steam Reforming of Methane-SRM- at 900°C
3. The outlet of SRM taken to Auto-Thermal Reactor to produce syngas
4. Second Reverse Water Gas Shift reaction to convert residual CO₂ to CO
5. DME Reactor-1: Regulated syngas temperature to 250°C and regulated pressure to 30 bar
6. DME Reactor-2: Complete conversion of the remaining syngas to DME under the above conditions
7. Distillation Column No.1: Separation of DME, methanol, and water
8. Distillation Column No.2: Separation of methanol and water

The process reactions involved are as follows:

1. **Reverse Water Gas Shift Reaction:**

$$\text{H}_2 + \text{CO}_2 = \text{CO} + \text{H}_2\text{O}$$
2. **Methane Steam Reforming:**

$$3\text{CH}_4 + \text{H}_2\text{O} + \text{CO}_2 = 2\text{CH}_4 + \text{CO} + 3\text{H}_2$$
3. **Methanol Synthesis:**

$$2\text{H}_2 + \text{CO} = \text{CH}_3\text{OH}$$
4. **DME Synthesis:**

$$2\text{CH}_3\text{OH} = \text{CH}_3\text{OCH}_3 + \text{H}_2\text{O}$$
5. **Overall Reaction:**

$$3\text{CH}_4 + \text{CO}_2 + 3\text{H}_2\text{O} = 2\text{CH}_3\text{OCH}_3 + 3\text{H}_2\text{O}$$

The gases are then cooled in a heat recovery system to reduce the temperature to 240°C and 30

bar pressure. The reaction temperature and pressure (240°C and 30 bar) are ideally suited to achieve the highest yield of DME. Increasing the H₂/CO molar ratio in the feedstock increases CO₂ conversion by the RWGS reaction, and a H₂/CO ratio higher than 0.8 mol H₂/mol CO at 240°C and 30 bar should be adopted to obtain a selectivity for DME higher than that for methanol or CO and achieve Net Zero Emission in a thermal power plant.

Figure 4 depicts a graph for H₂/CO conversion to Dimethyl Ether (DME), showing the percentage of syngas (CO and H₂) conversion to DME at the optimal pressure range of 30-40 ATA and a reaction temperature of 200°C-250°C. The graph demonstrates an optimum conversion rate of 80%-85% under these conditions.

Figure 5 is a Pie Chart Showing Global Greenhouse Gas Emissions by Gas. This chart provides a visual representation of the global distribution of greenhouse gas emissions by gas type, emphasizing the significance of CO₂ emissions and the impact of the proposed technology on reducing these emissions.

The instant invention discloses a method for producing power in a thermal plant and synthesizing Dimethyl Ether (DME) from captured carbon dioxide (CO₂), comprising the steps of:

- a) combusting natural gas (NG) (101) or liquefied natural gas (LNG) in a gas combustor (103) to generate electricity and produce flue gases containing CO₂, wherein the natural gas comprises primarily methane (CH₄);
- b) capturing the CO₂ from the flue gases using a two-stage carbon capture process, consisting of a Pressure Swing Adsorption (PSA) system (106), followed by purification using a Monoethanolamine (MEA) solution to achieve a purity of captured CO₂ of at least 95%;
- c) converting the captured CO₂ into carbon monoxide (CO) through a Reverse Water Gas Shift (RWGS) reaction, in a RWGS Reaction Furnace (306), wherein, the reaction is performed in a non-catalytic furnace with an oxy-hydrogen flame at a temperature above 900°C, with gas residence time is less than 0.03 seconds, and achieving a CO₂ conversion efficiency of up to 75%.
- d) reforming methane (CH₄) (304) with steam (H₂O)(305) in a first Steam Methane Reforming (SMR) reactor (308a), which is incorporated within the RWGS reaction furnace to efficiently utilize the excess heat generated, with provisions for precise temperature control and optimal heat transfer for SMR operation and the Methane is then

further reformed in a second SMR reactor (308), wherein the inlet temperature is in the range of 525°C to 900°C, pressure is in the range of 24-25 kg/cm² (ATA), and catalyst composition is Nickel (Ni) on an alumina support, optionally doped with Cobalt (Co) or Iron (Fe).

- 5 e) further reforming the syngas in an Auto-Thermal Reforming (ATR) reactor (309), wherein inlet temperature is 700°C, outlet temperature is 975°C, air inlet temperature is 230°C, and air flow is 14 mol/hr, so that said ATR process optimizes the CO and H₂ content in the syngas, reducing methane content and enhancing the overall composition for subsequent DME synthesis.
- 10 f) synthesizing DME from the syngas mixture in DME synthesis reactors (312, 313) using Cu/ZnO/Al₂O₃ catalysts, wherein, the synthesis is carried out at a pressure of 25-40 ATA and a temperature of 250-300°C, and the reactor system includes a secondary reactor for complete conversion to DME, thereby maximizing the selectivity and conversion rate to achieve efficient DME production.
- 15 g) distilling the synthesized DME (316) to separate it from methanol and water, involving a first distillation column(314) to achieve an initial separation and a second distillation column (315) for further purification, ensuring that the final product is high-purity DME while methanol and water are recovered for reuse or safe disposal.

- According to an aspect of the invention, the RWGS reaction achieves a CO₂ conversion efficiency between 48% and 60% with a hydrogen consumption minimized to 1 mol H₂ per mol CO₂, facilitated by integrated heat recovery in an insulated industrial reactor.
- 20

According to an aspect of the invention, wherein the PSA system optimizes the H₂/CO ratio to approximately 2:1 for DME synthesis, ensuring minimal excess hydrogen.

- According to an aspect of the invention, wherein the second SMR reactor operates at an inlet temperature 525°C, an outlet temperature of 900°C, and a pressure of 25 ATA over a metal catalyst selected from the group consisting of Ni, Co, Fe, Pt, Ir, Rh, and Ru. Here at the outlet of the SMR reactor the gas composition is : CH₄: 15.399%, CO: 8.105%, CO₂: 11.242%, H₂: 65.040%, and N₂: 0.213%.
- 25

- The ATR reactor produces a syngas mixture with the following outlet composition: CH₄: 0.4%, CO: 17.879%, CO₂: 10.436%, H₂: 71.108%, N₂: 0.177%, with a total dry gas flow of 134.829 kmol/hr and a steam flow of 91.336 kmol/hr.
- 30

Said DME synthesis reactors achieve a conversion efficiency of up to 85% in a single pass, with a final yield of 92 kg DME per 48 kg LNG input, and an energy efficiency factor (EEF) of 93.04%.

- 5 According to another aspect of the invention, the CO₂ captured from the flue gases is processed in the RWGS reaction with a heat input sufficient to maintain the reaction temperature above 900°C, supplied by the combustion of 2 moles of hydrogen per mole of CO₂.

The first distillation column provided therein separates DME from methanol and water at a pressure of 30 bar, and the second distillation column further purifies methanol and water.

- 10 The instant process achieves an overall energy efficiency of 90% or higher, and the CO₂ reduction footprint is -63 grams CO₂ e/MJ of DME produced, achieving a 94% abatement of greenhouse gases. The overall process involves the conversion of 44 kg of CO₂ and 48 kg of LNG to produce 92 kg of DME, with a heat recovery system that reduces the syngas temperature from 900°C to 250°C before entering the DME reactors.
- 15 Present process further comprises monitoring and optimizing the conversion efficiency of H₂ and CO to DME using a control system based on real-time data from the DME synthesis reactors.

- According to an aspect of the invention, the captured CO₂ is derived from a gas-based combined cycle power plant, and the waste heat from the power generation process is utilized
- 20 in the steam methane reforming step.

According to one aspect of the invention, the process parameters are continuously monitored using a control system to optimize the H₂/CO conversion rate, ensuring maximum efficiency in DME production.

- According to another aspect of the invention, the environmental impact of the process is
- 25 assessed using a global greenhouse gas emissions model, as shown in Figure 5, to evaluate the reduction in CO₂ emissions and the effectiveness of the DME production in mitigating climate change.

- The overall energy efficiency of the DME production process is above 90%, with an energy efficiency factor of 93.04%. The process captures 67 grams of CO₂ per MJ of DME
- 30 produced, resulting in an overall CO₂ reduction footprint of -63 grams CO₂ e/MJ, achieving a 94% abatement of greenhouse gases.

This innovative process provides a sustainable solution for power generation and CO₂ utilization, addressing global environmental challenges by converting captured CO₂ into a valuable fuel, DME.

Unique aspects of the present Invention are that it integrates a thermal power plant with a CO₂ capture system and a conversion process to produce DME. This holistic approach is unique compared to prior art that often addresses these components separately. Further the present invention aims to achieve zero emissions by capturing CO₂ from power generation and converting it to a useful fuel, DME. This dual approach of energy production and environmental sustainability is a key differentiator. The use of natural gas (NG) or liquefied natural gas (LNG) as the primary feedstock for both power generation and subsequent DME production from captured CO₂ sets this invention apart. The process details specific conditions and catalysts that optimize the conversion of CO₂ to DME, ensuring high efficiency and selectivity.

BRIEF DESCRIPTION OF FIGURES AND DRAWINGS:

These and other features, aspects and advantages of the present invention will become better understood, when the detailed description is read with reference to the accompanying drawing.

Figure 1 is a flow sheet of a gas-based power plant with CO₂ Capture, wherein. 101-Natural Gas Inlet; 102- Air Inlet; 103- Combustion Chamber; 104- Heat Recovery Steam Generator (HRSG); 105- Gas Turbine; 106- CO₂ Capture Unit; 107- CO₂ product; 108- Exhaust Stack; 109- Steam Turbine; and 110- Condenser.

Figure 2 shows the Reverse Water Gas Shift (RWGS) reaction furnace to convert waste CO₂ and renewable H₂ to CO and H₂O, wherein 201- O₂/CO₂ Inlet; 202- H₂ Inlet; 203- Reaction Furnace; 204- Oxy-Hydrogen Flame; 205- CO and H₂O Outlet; and 206- Insulation.

Figure 3 is a flow sheet of the process of producing DME from CO₂, given in two parts wherein 301-CO₂ Inlet ; 302- H₂ Inlet; 303- Compressor; 304- Methane; 305- Steam; 306- Reverse Water Gas Shift (RWGS) Reaction Furnace; 307- De-sulphuration; 308a- First Steam Methane Reforming (SMR) Reactor inside the Reverse Water Gas Shift (RWGS) Reaction Furnace; 308a- Second Steam Methane Reforming (SMR) Reactor ; 309- Auto-Thermal Reforming (ATR) Reactor); 310- Secondary RWGS Reaction; 311- Pressure Swing Adsorption (PSA) System; 312 and 313 -DME Synthesis Reactors; 314 and 315- Distillation Columns; and 316- DME.

Figure 4 shows the Graph for H₂,CO conversion to DME. and

Figure 5 is a pie chart showing Global Greenhouse Gas Emissions by Gas.

DETAILED DESCRIPTION OF THE INVENTION

This invention relates to a zero-emission technology for producing power in thermal plants using natural gas (NG) or liquefied natural gas (LNG) and converting captured carbon dioxide (CO₂) into Dimethyl Ether (DME). The invention outlines two pathways: the production of green methane (green NG) for power generation in a gas-based power plant and the capture and conversion of CO₂ into DME in a single process. This technology is implemented in an Integrated Poly-generation Gasification Combined Cycle (IGCC) power plant. The advanced energy production process not only generates electricity with zero emissions but also actively captures and recycles CO₂ to produce a useful and low-emission e-fuel, DME (CH₃OCH₃ or (CH₃)₂O), achieving a 94% reduction in greenhouse gases (GHG). DME serves as a carbon-neutral drop-in fuel usable in compression ignition (CI) engines as a substitute for diesel, in fuel cells, or in other applications requiring a clean-burning fuel. This integrated approach demonstrates a sustainable method to generate power from natural gas while recycling captured CO₂ into DME, potentially replacing petroleum-based fuels. Given the global nature of climate change, achieving net zero emissions (NZE) often requires international cooperation and agreements to ensure global emissions reductions. The push for NZE reflects a commitment to combat climate change and limit global warming. Capturing CO₂ from flue gases and converting it into DME results in using 67 grams of CO₂ to produce each megajoule (MJ) of DME, leading to an overall capture footprint of -63 grams CO₂ e/MJ DME and achieving a 94% reduction in CO₂ as a greenhouse gas while producing DME.

Now we will explain with more details with reference to Figure 1, which is a flow sheet of a gas-based combined cycle power plant with CO₂ capture. Here's a description of the important parts and their roles in the combustion of natural gas, primarily methane (CH₄), in the presence of oxygen (O₂):

Natural Gas Inlet (101): This is where the natural gas, primarily composed of methane (CH₄), enters the system. The natural gas serves as the primary fuel for the combustion process, supplying the necessary hydrocarbons for energy production.

Air Inlet (102): Air is introduced into the combustion chamber through this inlet. The oxygen (O₂) in the air is crucial for the combustion process, as it reacts with methane to produce carbon dioxide (CO₂) and water (H₂O), releasing energy in the form of heat.

5 **Combustion Chamber/ Combustor (103):** The core of the energy conversion process, where methane (CH₄) combusts in the presence of oxygen (O₂) from the air. The exothermic reaction produces CO₂, H₂O, and a significant amount of heat. The balanced chemical reaction is: $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{Heat}$

10 **Heat Recovery Steam Generator (HRSG) (104):** This component captures the waste heat from the combustion process and uses it to convert water into steam. The steam generated is then utilized in a steam turbine to produce additional electricity, enhancing the overall efficiency of the power plant.

Gas Turbine (105): The high-temperature gases generated in the combustion chamber are expanded through the gas turbine. This expansion drives the turbine blades, converting thermal energy into mechanical energy, which is then converted into electrical energy.

15 **CO₂ Capture Unit / CO₂ Absorbers (106):** The flue gases, which contain CO₂, are processed through this unit. The CO₂ is separated from other gases using technologies such as Pressure Swing Adsorption (PSA) and chemical absorption (using a Monoethanolamine (MEA) solution). The captured CO₂ (107) can be stored or utilized, reducing the overall carbon emissions of the plant.

20 **Exhaust Stack (108):** After the CO₂ is captured, the remaining gases, mainly nitrogen and any residual oxygen, are released into the atmosphere through the exhaust stack. This minimizes the environmental impact by reducing the amount of CO₂ emitted.

25 **Steam Turbine (109):** The steam produced in the HRSG is routed to both High-Pressure (HP) and Low-Pressure (LP) turbines, where it drives the turbines to generate additional electricity. This process effectively utilizes the thermal energy from the combustion process, improving the plant's efficiency.

Condenser: (110): After the steam passes through the steam turbine, it is condensed back into water in the condenser. This water is then recycled back to the HRSG, ensuring continuous and efficient use of water in the steam cycle.

30 In a Gas Based Combined Cycle Power Plant which produces power, the Gas Turbine is run by a direct feeding of Natural Gas and Air into the Combustor of the Gas Turbine which

drives the Alternator to produce power and the Waste heat recovery boiler then again generate steam to again generated power and this is called the Combined cycle gas-based power plant. As we've seen above, combined cycle power plants are known for their high thermal efficiency, typically reaching over 50% and sometimes above 60%. In other words, they're able to produce more electric energy compared to the fuel used. In India a baseline of 2270 Kcal/Kwh has been announced by Bureau of Energy Efficacy for the Combined Cycle Gas Based Power Plants and an energy efficiency of 37.88%. The Line diagram also shows a recovery and capture of CO₂ from flue gasses and the same has been explained below. This captured CO₂ is then unlisted in the downstream DME manufacturing process to abate CO₂.

10 Efficiency Challenges

Significant Heat Loss: The condensation process during the Rankine cycle results in substantial heat loss.

Low Energy Return: Only 35 units of energy are returned for every 100 units consumed.

Operational Complexities: Managing heat loss and improving efficiency require complex and costly solutions.

High Emissions

CO₂ Emissions: Coal-based power plants emit approximately 0.915 kilograms of CO₂ e per unit of power generated and these emissions are 0.416/kg CO₂e per kWh in a Gas based Combined Cycle Power Plant. .

20 Environmental Impact: High emissions contribute to significant environmental concerns.

Our innovative process addresses the efficiency and emissions challenges of the Rankine cycle by re-pressurizing steam and utilizing it for CO₂ capture/ recovery. This approach significantly reduces energy loss and enhances environmental sustainability.

Efficiency Improvement

25 Steam Re-Pressurization: We re-pressurize the steam, saving approximately 444 kcal per kilogram by reducing the energy loss from the initial 544 kcal to just 100 kcal.

Energy Conservation: This method retains more energy within the system, improving overall efficiency.

CO₂ Recovery Process

30 MEA Solution Preparation: We use a 20% Monoethanolamine (MEA) solution mixed with

80% water to create a 2M solution.

CO₂ Capture: The re-pressurized steam is utilized in conjunction with the MEA solution to effectively capture and regenerate CO₂.

Environmental Impact

- 5 Our innovative process addresses the efficiency and emissions challenges of the Rankine cycle by re-pressurizing steam and utilizing it for CO₂ recovery. This approach significantly reduces energy loss and enhances environmental sustainability.

We have devised an advanced process that enhances the Rankine cycle's efficiency and reduces emissions. By re-pressurizing steam and integrating a CO₂ recovery system using an
10 MEA solution, we achieve significant energy savings and environmental benefits. This innovative approach represents a substantial improvement over traditional methods, making power generation more efficient and sustainable. Our process would make the Thermal Power Plants which produce bulk of 24x7 power into Zero emission Power Plant and produce DME from the captured CO₂.

- 15 Source: Levelized Cost of Energy Comparison – Version 17.0, Lazard Levelized Cost of Energy+ June 2024 - Storage Costs increase renewables lifecycle cost: Coal based power would be US 17 Cents per Kwh, Gas Based power would be US 12 Cents per Kwh, Wind onshore and Battery Power would be US 13 Cents per Kwh, Solar PV Grid plus Storage Power would be US 22 Cents per Kwh, Solar PV Utility Cost without storage would be US 8
20 cents per Kwh. These are the Lifecycle Costs on delivery of Power to the Power Grid.

To inform the world to design of emission-limiting pathways, IPCC has quantified the remaining carbon space available as the “carbon budget.” As per their estimates, from the beginning of 2020, the world has approximately 500 GtCO₂ left for a target of 1.5°C and 1150 GtCO₂ for a target of 2°C (with a likelihood of 50% and 67%, respectively). With each
25 passing year, the budget gets smaller, and the time available to act slips away. Nations are then expected to commit to “accelerated and equitable mitigation pathways” while walking the tightrope of developmental demands. The alarmism sounds quite dreadful, with the IPCC stating, “there is a rapidly closing window of opportunity to secure a livable and sustainable future for all”. Such forebodings notwithstanding, the purported climate solution has some
30 fundamental issues of equality.

Figure 2, which depicts the Reverse Water Gas Shift (RWGS) reaction furnace for converting waste CO₂ and renewable H₂ into CO and H₂O, here's a description of the

important parts and their roles:

CO₂ Inlet (201): The CO₂ inlet introduces the captured carbon dioxide (waste CO₂) into the RWGS reaction furnace. This CO₂ is the primary feedstock for the reaction and is typically sourced from the CO₂ capture unit of the power plant.

- 5 **H₂ Inlet (202):** The H₂ inlet introduces renewable hydrogen (H₂) into the reaction furnace. This hydrogen is essential for the RWGS reaction, as it reacts with CO₂ to produce carbon monoxide (CO) and water (H₂O).

- 10 **Reaction Furnace (203):** The reaction furnace is the core of the RWGS process, where the chemical reaction takes place. CO₂ reacts with H₂ at high temperatures (typically above 900°C) facilitated by an oxy-hydrogen flame. The reaction occurs in a non-catalytic, thermally isolated furnace, achieving up to 75% CO₂ conversion with a gas residence time of less than 0.03 seconds. This step is crucial for producing syngas, a mixture of CO and H₂O, which is suitable for downstream applications such as fuel synthesis or further chemical processing.

- 15 **Oxy-Hydrogen Flame (204):** The oxy-hydrogen flame supplies the necessary heat to maintain the high temperatures essential for the RWGS reaction. This flame is produced by combusting a mixture of hydrogen and oxygen, allowing the reaction furnace to reach and sustain the desired temperature for optimal CO₂ conversion and steam methane reforming.

- 20 **Heat Exchanger** (not shown in the figure): The heat exchanger recovers heat from the hot reaction products (CO and H₂O) as they exit the furnace. This recovered heat can be used to preheat the incoming CO₂ and H₂, improving the overall energy efficiency of the process.

- 25 **CO and H₂O Outlet (205):** This outlet allows the reaction products, carbon monoxide (CO) and water (H₂O), to exit the furnace. The CO produced is an important component of syngas and can be used in various downstream applications, while the water can be condensed and removed from the system.

Temperature Control System (not shown in the figure): This system monitors and regulates the temperature within the reaction furnace. Maintaining the correct temperature is critical for the RWGS reaction, as it directly impacts the conversion efficiency and the equilibrium between CO₂, H₂, CO, and H₂O.

- 30 **Insulation (206):** The reaction furnace is insulated to minimize heat loss, ensuring that the high temperatures required for the RWGS reaction are maintained with minimal energy input.

This also helps in achieving a higher conversion efficiency and maintaining the integrity of the reaction process.

Now we will explain with more details on how said Reverse Water Gas Shift (RWGS) reaction furnace converts waste carbon dioxide (CO₂) and renewable hydrogen (H₂) into carbon monoxide (CO) and water (H₂O). This conversion forms part of the overall process of producing syngas suitable for downstream applications.

The RWGS reaction is similar to the Boudouard reaction in its kinetics, occurring at temperatures above 900°C. This temperature is achieved using an oxyhydrogen flame, which reaches a maximum temperature of around 2800°C. The flame is much hotter than a standard hydrogen flame in air, providing the necessary conditions for the reaction.

Chemical Equation: $\text{CO}_2 + \text{H}_2 \rightarrow \text{CO} + \text{H}_2\text{O}$

Kinetics of RWGS Reaction:

CO₂ Conversion:

The conversion of CO₂ is calculated using the formula:

$$\text{CONV.CO}_2 = 100 \cdot \frac{R}{1 + R} \quad (\text{molar percentage})$$

R is the molar ratio of $\frac{n_{\text{CO}}}{n_{\text{CO}_2}}$ at the exit of the reactor.

Syngas Quality Ratio S:

The ratio S is defined to characterize syngas quality:

$$S = \frac{x_{\text{H}_2} - x_{\text{CO}_2}}{x_{\text{CO}} + x_{\text{CO}_2}}$$

Where x represents the molar or volumetric concentrations of each species.

Apparent Equilibrium Constant K' :

An apparent equilibrium constant K' is calculated as follows:

$$K' = \frac{x_{\text{CO}} \cdot x_{\text{H}_2\text{O}}}{x_{\text{CO}_2} \cdot x_{\text{H}_2}}$$

This parameter equals the RWGS reaction's equilibrium constant if thermodynamic equilibrium is reached inside the reactor. An apparent equilibrium temperature T_{app} is

calculated for each K' value.

Process of RWGS Reaction

Innovative Non-Catalytic Conversion:

The RWGS reaction employs a non-catalytic approach, achieving up to 75% CO_2 conversion in a single pass. The gas residence time within the reactor is less than 0.03 seconds, optimized through the use of a hydrogen-oxy flame at the core of the process, ensuring rapid and efficient thermal conversion.

Reactor Design and Operating Range:

The reactor is designed in such that the velocities V_A and V_B do not exceed 75 m/s, with V_B being greater than or equal to V_A . An excess of hydrogen beyond stoichiometric needs ensures a syngas H_2/CO ratio close to 2.0.

Assuming 100% conversion, 3 moles of H_2 per mole of CO_2 are required to produce syngas with the desired ratio. Additionally, a minimum of 0.8 moles of H_2 is needed to heat CO_2 and H_2 to 1200°C and to support the RWGS reaction. Excess heat generated in the furnace is subsequently utilized in the Steam Methane Reforming reaction.

Techno-Economic Efficiency Factor (E):

The CO_2 conversion efficiency factor (E) is defined as:

$$E = \frac{\text{CONV.CO}_2/100}{\text{H}_2 \text{ b-ratio}}$$

This factor should be optimized to maximize CO_2 conversion at a minimal hydrogen cost, considering syngas quality requirements for downstream applications like methanol production.

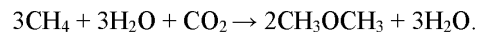
Hydrogen Excess Handling:

The excess hydrogen does not affect downstream reactions. The output is fed directly into the Steam Methane Reforming (SMR) section, where high temperatures help convert methane into syngas with an H_2/CO ratio suitable for further conversion into Dimethyl Ether (DME).

Figure 3 depicts the process of producing Dimethyl Ether (DME) from CO_2 . This figure outlines the steps involved in converting captured CO_2 into DME. The process includes several key stages: RWGS reaction, steam methane reforming (SMR), auto-thermal

reforming (ATR), secondary RWGS, DME synthesis, and distillation.

Now we will explain with more details on the Post-Capture Process of Producing Dimethyl Ether (DME) from CO₂ with reference to figure 3. The innovative process begins with the following balanced equation for the direct conversion of CO₂ into Dimethyl Ether (DME) as per the equation:



This process equation represents the conversion of CO₂ into 2 moles of DME, with steam recovered back into the process. For every 48 kg of methane (3 moles of CH₄, where 1 mole CH₄ = 16 kg) having a heat value of 12,978 kcal/kg, the input heat value is calculated as follows:

- **Methane:** 48 kg with a heat value of 12,978 kcal/kg equals 622,944 kcal.
- **Steam:** 54 kg with a heat value of 29,160 kcal.

These react with 1 mole of CO₂ (44 kg) to produce 92 kg of DME (46 kg/mole x 2 moles) with a heat value of 92 kg x 6,903 kcal/kg = 635,076 kcal.

Considering a 10% process loss, the output heat value is: 635,076 kcal – 63,480 kcal = 571,596 kcal

This results in a net heat recovery efficiency of 91.55%.

To achieve this reaction, the captured CO₂ from flue gases begins the post-capture process.

CO₂ Inlet (301): This inlet introduces the captured carbon dioxide (CO₂) into the DME synthesis process. The CO₂ serves as the primary feedstock for the production of DME.

H₂ Inlet (302): The hydrogen (H₂) inlet introduces renewable hydrogen into the system. This hydrogen is essential for converting CO₂ into syngas (a mixture of CO and H₂), which is then further processed to produce DME.

Reverse Water Gas Shift (RWGS) Reaction Furnace (306): The RWGS reaction furnace is the first key reaction step where CO₂ is reduced to carbon monoxide (CO) by reacting with H₂ at high temperatures (>900°C) as per the equation: CO₂ + H₂ ⇌ CO + H₂O. This process is facilitated by a stoichiometric oxy-hydrogen flame in a thermally isolated furnace. The RWGS reaction achieves up to 75% CO₂ conversion with a gas residence time of less than 0.03 seconds, producing syngas suitable for downstream applications.

To efficiently utilize excess heat generated in the furnace, a Steam Methane Reforming (SMR) Reactor (308a) is incorporated within the furnace, with provisions to ensure appropriate temperature control and heat transfer for optimal SMR operation.

- 5 **Second Steam Methane Reforming (SMR) Reactor (308):** The second SMR reactor processes the CO and H₂O produced from the RWGS reaction, in addition to desulfurized methane (304) and supplemental steam (305) as per the following equation. $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$. In this reactor, methane undergoes reforming with steam over metal catalysts at temperatures ranging 525°C to 900°C and pressure of 25 ATA, producing a mixture of CO, H₂, and residual gases. This setup is designed to maximize the production of
10 syngas, enhancing overall process efficiency and facilitating downstream reactions.

Auto-Thermal Reforming (ATR) Reactor (309): The ATR reactor further reforms the gases from the SMR reactor to increase the CO and H₂ content. The gases are reformed at an inlet temperature of 700°C and an outlet temperature of 975°C, resulting in a higher concentration of CO and H₂ and reduced methane content.

- 15 **Secondary RWGS Reaction (310):** In this step, any remaining CO₂ is converted to CO using hydrogen and a Cu-based catalyst as per the equation: $\text{CO}_2 + \text{H}_2 \rightleftharpoons \text{CO} + \text{H}_2\text{O}$.

This reaction further increases the CO content in the syngas, maximizing the conversion of CO₂ before the DME synthesis. To facilitate this synthesis, the temperature of the resulting gases is reduced to a range of 250 to 300°C.

- 20 **Pressure Swing Adsorption (PSA) System (311):** The PSA system is used to remove excess hydrogen, optimizing the H₂/CO ratio for the subsequent DME synthesis. This ensures that the syngas has the correct composition for efficient DME production.

- DME Synthesis Reactors (312 and 313):** The purified syngas is converted into DME in the DME synthesis reactors using Cu/ZnO/Al₂O₃ catalysts. The reaction occurs at 25-40 ATA
25 pressure and 250-300°C, with a conversion efficiency of up to 85% in a single pass as per the equation: $2\text{CH}_3\text{OH} \rightarrow \text{CH}_3\text{OCH}_3 + \text{H}_2\text{O}$. A twin reactor system is provided for complete conversion, ensuring that the maximum amount of syngas is converted to DME.

- Distillation Columns (314 and 315):** The distillation columns separate DME from other liquids, such as methanol and water. The separation process occurs in two stages of
30 distillation, resulting in purified DME (316), with methanol and water separated for further processing or recycling.

Reference is made to Figure 4 which depicts a graph for H₂CO Conversion to DME. The graph demonstrates the efficiency of converting H₂ and CO to DME, providing insights into the optimal operating conditions for maximizing DME yield.

5 Reference is made to Figure 5, a pie chart highlights the global distribution of greenhouse gas emissions by gas, with CO₂ being the predominant contributor. This underscores the importance of technologies aimed at capturing and converting CO₂ to mitigate climate change.

By refining the claims to emphasize the novel aspects of the process and ensuring that these aspects are not covered by prior art, the inventor can strengthen the case for patentability.

10 This process has the potential to implement zero emission technology to produce large scale power in a thermal power plant by carbon recycling technology to produce a clean alternative fuel to petroleum fuels producing green Dimethyl Ether and achieve net zero emissions by 2050. It will also provide a solution to 65% of world emissions from thermal power plants and achieve near net zero emissions or 94% GHG abatement by this cycle and
15 help achieve NZE by 2050.

Total electricity generation in the world in 2020 was 26823.2 TWh, of this 358 TWh was the power produced from renewable energy resources. To achieve net zero emissions to produce the entire 26823.2 TWh, it has to be sourced from RE sources or the world has to produce the thermal power by using the zero-emission technology to achieve National
20 Emission Standards for Hazardous Air Pollutants by 2050, aligning with global efforts to limit global warming to well below 2 degrees Celsius above pre-industrial levels. Hence the only alternative is to find alternate mode of thermal power generation is through advancements in technology by making use of the zero-emission technology. Given the global nature of climate change, achieving net zero emissions in short, the direct conversion
25 of CO₂ into Dimethyl Ether disclosed according to our invention will be highly promising in the quest for sustainable and green energy technologies and thereby achieving net zero emission target set by 2050.

This process has the potential to implement zero emission technology to produce large scale power in a thermal power plant by carbon recycling technology to produce a clean
30 alternative fuel to petroleum fuels producing green dimethyl ether and achieve net zero emissions by 2050.

Providing a solution to 65% of world emissions from thermal power plants and achieve net zero emissions by 2050.

Total electricity generation in the world in 2020 was 26823.2 TWh of this 358 TWh was the power produced from renewable energy resources. To achieve net zero emissions to
5 produce the entire 26823.2 TWh, it has to be sourced from renewable energy sources or the world has to produce the thermal power by using the zero-emission technology to achieve Net Zero Emissions by 2050 which is the world climate goal.

What makes DME especially interesting is that it can be produced from captured CO₂ using Power-to-X technologies, making it a renewable liquid or gaseous transport fuel of non-
10 biological origin (here abbreviated to RFNBO) according to the EU Renewable Energy Directive (RED II). Such fuels are characterized by their embodied energy being derived from renewable energy, usually electricity, hence their alternative name of e-fuels. Considering the difficulty experienced in electrifying heavy goods vehicles, DME could have a promising future as a sustainable diesel fuel replacement.

15 **Salient Features of the Instant Invention in a Nutshell:**

1. **Direct Conversion Efficiency:** The process captures 67 grams of CO₂ per megajoule (MJ) of DME produced, resulting in an overall capture footprint of -63 g CO₂ e/MJ, achieving a 94% greenhouse gas (GHG) abatement through the ‘SEDMES’ (Solvent Enhanced DME Synthesis) process. This level of efficiency in CO₂ utilization and DME
20 production is unprecedented, marking a significant advancement over existing technologies that typically require multiple steps involving methanol as an intermediate.
2. **Integrated Power and Fuel Production:** This invention uniquely integrates power generation with the production of a clean, blendable fuel—Dimethyl Ether (DME)—by capturing and utilizing steam and CO₂ emissions from the thermal power plant. This
25 approach maximizes energy efficiency while directly addressing the 76% of global greenhouse gas (GHG) emissions attributed to power generation and petroleum-based fuel consumption.
3. **Synergistic Process Integration:** The process leverages the synergy between the thermal power plant’s waste heat and steam methane reforming (SMR) reactions, enhancing
30 overall system efficiency to 93%. The seamless integration of CO₂ capture and conversion within the power plant’s operational cycle provides a unique solution to the dual challenges of energy production and GHG mitigation.

4. **Exceptional Energy Efficiency:** The process achieves an exceptional energy efficiency factor of 93.04% in the production of DME, far surpassing conventional methods. This is made possible by the optimized use of hydrogen in the Reverse Water Gas Shift (RWGS) reaction and the strategic management of process conditions, ensuring minimal energy loss and maximum yield.
5. **Validation through Simulation Study:** A simulation study conducted by the inventors confirms the high CO₂ conversion efficiency, energy recovery, and the seamless integration of CO₂ capture and DME production. This empirical evidence further solidifies the practical feasibility of the invention.
- 10 6. **Contribution to Global and National Net-Zero Goals:** a) Crucial Role in Achieving Net-Zero Targets: The invention contributes significantly to global net-zero targets, particularly in the context of India's goal of achieving net-zero emissions by 2070. The Government of India is actively promoting carbon capture, utilization, and storage (CCUS) technologies through initiatives such as viability gap funding (VGF), carbon pricing, and subsidies. This invention aligns with these national priorities by offering a scalable and efficient solution to reduce the carbon footprint of power generation and fuel production. b) Momentum in India: The deployment of CCUS technologies is gaining momentum in India, with significant storage potential identified across the country. By integrating CCUS with power generation and DME production, this invention not only supports India's net-zero ambitions but also positions the country as a leader in sustainable energy innovation.
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We have brought out the novel features of the invention by explaining some of the preferred embodiments under the invention, enabling those skilled in the art to understand and visualize the present invention. This invention achieves unprecedented efficiency in CO₂ utilization and DME production, capturing 67 grams of CO₂ per megajoule (MJ) of DME produced, resulting in a net CO₂ capture footprint of -63 g CO₂ e/MJ and a 94% greenhouse gas (GHG) abatement through the 'SEDMES' process. By integrating power generation with DME production using the thermal power plant's steam and CO₂ emissions, the process directly addresses 76% of global GHG emissions from power and fuel consumption. Leveraging waste heat recovery and steam methane reforming (SMR), the process achieves a remarkable energy efficiency of 93.04%, far surpassing conventional methods. The optimized use of hydrogen in the Reverse Water Gas Shift (RWGS) reaction ensures minimal energy loss and maximum yield. A simulation study further validates the high CO₂ conversion efficiency and

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energy recovery, confirming the practical feasibility of the invention. Contributing significantly to global and national net-zero targets, especially in India's goal of achieving net-zero by 2070, this invention offers a scalable solution to reduce the carbon footprint. While the invention has been detailed with reference to preferred embodiments, it is not

5 limited to these specifics, and modifications can be made within the scope defined by the appended claims.

We Claim:

1. A method for producing power in a thermal plant and synthesizing Dimethyl Ether (DME) from captured carbon dioxide (CO₂), comprising the steps of:
 - a) combusting natural gas (NG) (101) or liquefied natural gas (LNG) in a gas combustor (103) to generate electricity and produce flue gases containing CO₂, wherein the natural gas comprises primarily methane (CH₄);
 - b) capturing the CO₂ from the flue gases using a two-stage carbon capture process, consisting of a Pressure Swing Adsorption (PSA) system (106), followed by purification using a Monoethanolamine (MEA) solution to achieve a purity of captured CO₂ of at least 95%;
 - c) converting the captured CO₂ into carbon monoxide (CO) through a Reverse Water Gas Shift (RWGS) reaction, in a RWGS Reaction Furnace (306), wherein, the reaction is performed in a non-catalytic furnace with an oxy-hydrogen flame at a temperature above 900°C, with gas residence time is less than 0.03 seconds, and achieving a CO₂ conversion efficiency of up to 75%;
 - d) reforming methane (CH₄) (304) with steam (H₂O)(305) in a first Steam Methane Reforming (SMR) reactor (308a), which is incorporated within the RWGS reaction furnace to efficiently utilize the excess heat generated, with provisions for precise temperature control and optimal heat transfer for SMR operation and the Methane is then further reformed in a second SMR reactor (308), wherein the inlet temperature is in the range of 525°C to 900°C, pressure is in the range of 24-25 kg/cm² (ATA), and catalyst composition is Nickel (Ni) on an alumina support, optionally doped with Cobalt (Co) or Iron (Fe);
 - e) further reforming the syngas in an Auto-Thermal Reforming (ATR) reactor (309), wherein inlet temperature is 700°C, outlet temperature is 975°C, air inlet temperature is 230°C, and air flow is 14 mol/hr, so that said ATR process optimizes the CO and H₂ content in the syngas, reducing methane content and enhancing the overall composition for subsequent DME synthesis;
 - f) synthesizing DME from the syngas mixture in DME synthesis reactors (312, 313) using Cu/ZnO/Al₂O₃ catalysts, wherein, the synthesis is carried out at a pressure of 25-40 ATA and a temperature of 250-300°C, and the reactor system includes a

secondary reactor for complete conversion to DME, thereby maximizing the selectivity and conversion rate to achieve efficient DME production and.

5 g) distilling the synthesized DME (316) to separate it from methanol and water, involving a first distillation column(314) to achieve an initial separation and a second distillation column (315) for further purification, ensuring that the final product is high-purity DME while methanol and water are recovered for reuse or safe disposal.

2. The method as claimed in claim 1, wherein the RWGS reaction achieves a CO₂ conversion efficiency between 48% and 60%, with hydrogen consumption minimized to 1 mol H₂ per mol CO₂, facilitated by integrated heat recovery within an insulated industrial reactor.

3. The method as claimed in claim 1, wherein the Pressure Swing Adsorption (PSA) system (311) optimizes the H₂/CO ratio to approximately 2:1 for DME synthesis, thereby minimizing excess hydrogen and enhancing process efficiency.

15 4. The method as claimed in claim 1, wherein the second SMR reactor(308) operates at an inlet temperature 525°C, an outlet temperature of 900°C, and a pressure of 25 ATA over a metal catalyst selected from the group consisting of Ni, Co, Fe, Pt, Ir, Rh, and Ru.

20 5. The method as claimed in claim 4, wherein the gas composition at the outlet of the second SMR reactor (308) is approximately as follows: CH₄: 15.399%, CO: 8.105%, CO₂: 11.242%, H₂: 65.040%, and N₂: 0.213%.

25 6. The method as claimed in claim 1, wherein the Auto-Thermal Reforming (ATR) reactor (309) produces a syngas mixture with the following outlet composition: CH₄: 0.4%, CO: 17.879%, CO₂: 10.436%, H₂: 71.108%, N₂: 0.177%, with a total dry gas flow of 134.829 kmol/hr and a steam flow of 91.336 kmol/hr.

7. The method as claimed in claim 1, wherein the DME synthesis reactors achieve a conversion efficiency of up to 85% in a single pass, with a final yield of 92 kg DME per 48 kg LNG input, and an energy efficiency factor (EEF) of 93.04%.

30 8. The method as claimed in claim 1, wherein the CO₂ captured from the flue gases is processed in the RWGS reaction with a heat input sufficient to maintain the reaction temperature above 900°C, supplied by the combustion of 2 moles of hydrogen per

mole of CO₂, ensuring the optimal temperature for efficient conversion.

9. The method as claimed in claim 1, wherein the first distillation column separates DME from methanol and water at a pressure of 30 bar, and the second distillation column further purifies methanol and water.
- 5 10. The method as claimed in claim 1, wherein the process achieves an overall energy efficiency of 90% or higher, with a CO₂ reduction footprint is -63 grams CO₂e per MJ of DME produced, achieving greenhouse gas abatement rate of 94%.
- 10 11. The method as claimed in claim 1, wherein the overall process involves the conversion of 44 kg of CO₂ and 48 kg of LNG to produce 92 kg of DME, with a heat recovery system that reduces the syngas temperature from 900°C to 250°C before entering the DME reactors.
12. The method as claimed in claim 1, wherein the process further includes monitoring and optimizing the conversion efficiency of H₂ and CO to DME through a control system that utilizes real-time data from the DME synthesis reactors.
- 15 13. The method as claimed in claim 1, wherein the captured CO₂ is sourced from a gas-based combined cycle power plant, and the waste heat from the power generation process is utilized in the steam methane reforming step.
14. The method as claimed in claim 1, wherein the process parameters are continuously monitored using a control system to optimize the H₂/CO conversion rate, ensuring maximum efficiency in DME production.
- 20 15. The method as claimed in claim 1, wherein the environmental impact of the process is assessed using a global greenhouse gas emissions model, as shown in Figure 5, to evaluate CO₂ emissions reduction and the effectiveness of the DME production in mitigating climate change.