Clemens Behrend

Hydrocarbon Reforming

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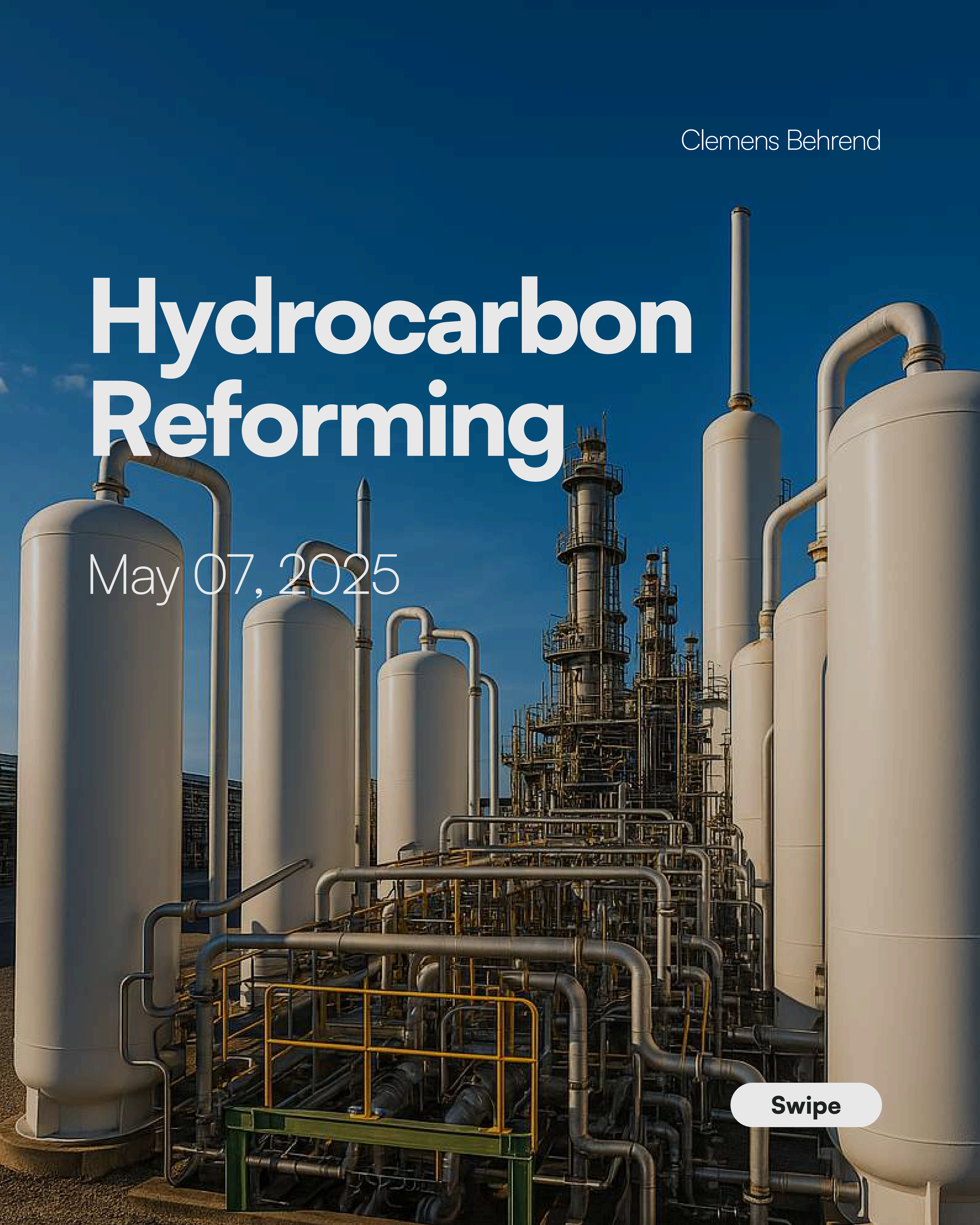

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Overview (I)

- The core process in this respect is hydrocarbon reforming, where the production of Hydrogen from sources such as oil, natural gas, and coal is carried out through some chemical reactions.

- Industrial Backbone: Established practice responsible for more than 95% of feedstock in the global hydrogen supply, especially in refining and chemical applications.

Source: (Chen et al., 2022)

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Overview (II)

- High Carbon Footprint: Typically associated with significant CO_2 emissions, making carbon capture and storage (CCS) combination significant for sustainability.

Source: (Chen et al., 2022)

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Definition

- Steam Reforming: This process involves high-temperature steam that acts on the hydrocarbon feedstock, usually methane, yielding Hydrogen and carbon monoxide.

- Partial Oxidation: Hydrocarbons with limited oxygen are used in the reaction to form mainly Hydrogen and syngas.

- Auto-thermal reforming combines steam reforming with partial oxidation to improve efficiency and energy balance.

Source: (Fowles & Carlsson, 2021)

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Cost Structure (I)

- Feedstock Costs: Hydrocarbons are the most critical feedstock, and natural gas is used extensively; thus, they account for 50-70% of the cost of production.

- Operational Costs: This includes energy for high-temperature processes and periodic maintenance of reforming units.

Source: (Zhang et al., 2020)

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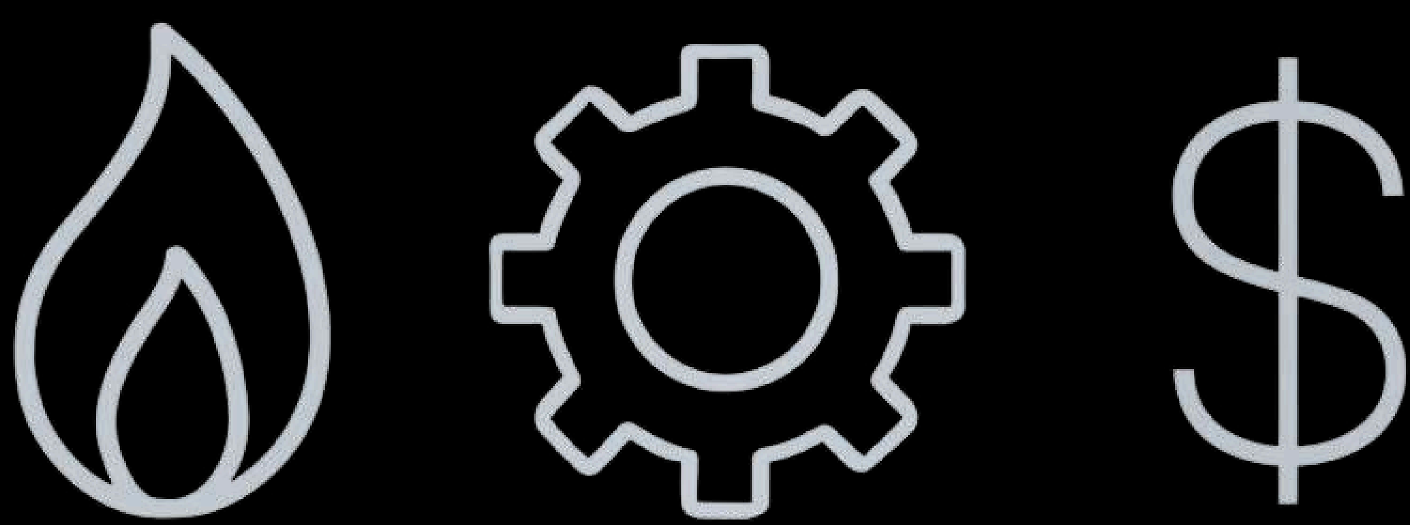
Cost Structure (II)

- Carbon management: While adding CCS increases cost by 20-30%, it is considered indispensable in emission reduction and an essential means of compliance with regulatory requirements.



Source: (Zhang et al., 2020)

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Technology Readiness Level (TRL)

- TRL 9: Completely mature and widely used by the industry for many years.
- Decarbonization Focus: Research aims to integrate better CCS and develop low-carbon reforming processes.
- Emerging Variants: Commercializing better processes, such as methane pyrolysis, is also underway; these will have a much lower carbon footprint.

Source: (Greer, 2021)

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Companies

- Air Products: A leading company in hydrogen production, Air Products operates a large reforming plant integrated with CCS.

- Shell: Develop technologies related to autothermal reforming and integrate them into blue hydrogen production.

- Linde stands out for its inventive drive to ensure more efficiency and lower emissions in reforming and gas processing.

Source: (Afzal et al., 2023) (Friedlingstein et al., 2020) (Chidozie Eluwah et al., 2023)

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Public Studies and Research

- Efficiency Gains: This is supported by studies showing that reforming coupled with CCS will capture about 90% of CO_2 emissions.

- Lifecycle Emissions: Several studies have indicated that, with reforming plus CCS, blue Hydrogen far outstrips grey Hydrogen with a carbon footprint of 60-70% less.

- Future Innovations: Methane pyrolysis is under investigation, which seems like a low-carbon option since it would yield solid carbon instead of CO_2.

Source: (Zhang, Pan, et al., 2020) (Kennedy-Karpat, 2021)

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Process Steps

- Feedstock Pre-treatment: Hydrocarbons are first purified to remove sulfur or other impurities that can poison catalysts.

- Reformation reactions refer to the high-temperature chemical processes whereby hydrocarbons and steam are transformed into Hydrogen and carbon monoxide.

- Gas Processing: The resulting syngas are treated in a water-gas shift reaction, and then Hydrogen is purified.

Source: (S. Nirmal Kumar et al., 2021)

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Benefits

- High Efficiency: Hydrogen produces an energy efficiency of 65-75%, higher than most other methods.
- Analogous and conventional infrastructure, such as pipelines and reforming facilities, already supports widespread adoption and scalability.
- Potential for Decarbonization: Adding CCS would present a bridge to low-carbon hydrogen.

Source: (Aziz et al., 2021)

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Challenges

- High Emission: The process emits quite a significant amount of CO_2 without CCS, which adds to global warming.
- Feedstock dependence: Very dependent upon fossil feedstocks, vulnerable to price spikes and geopolitical supply disruptions.
- Energy Intensity: It requires considerable energy inputs due to its high-temperature operation and lower overall sustainability.

Source: (Bertolini & Conti, 2021)

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Example Applications

- Oil Refining: Hydrogen feeds into refineries during the hydrocracking and desulfurization processes.
- Ammonia Production: As its primary feedstock, it is a building block in manufacturing fertilizers and industrial chemicals.
- Synthetic Fuels produce Hydrogen, which is used to create synthetic fuels by Fischer-Tropsch synthesis.

Source: (Zhu et al., 2019)

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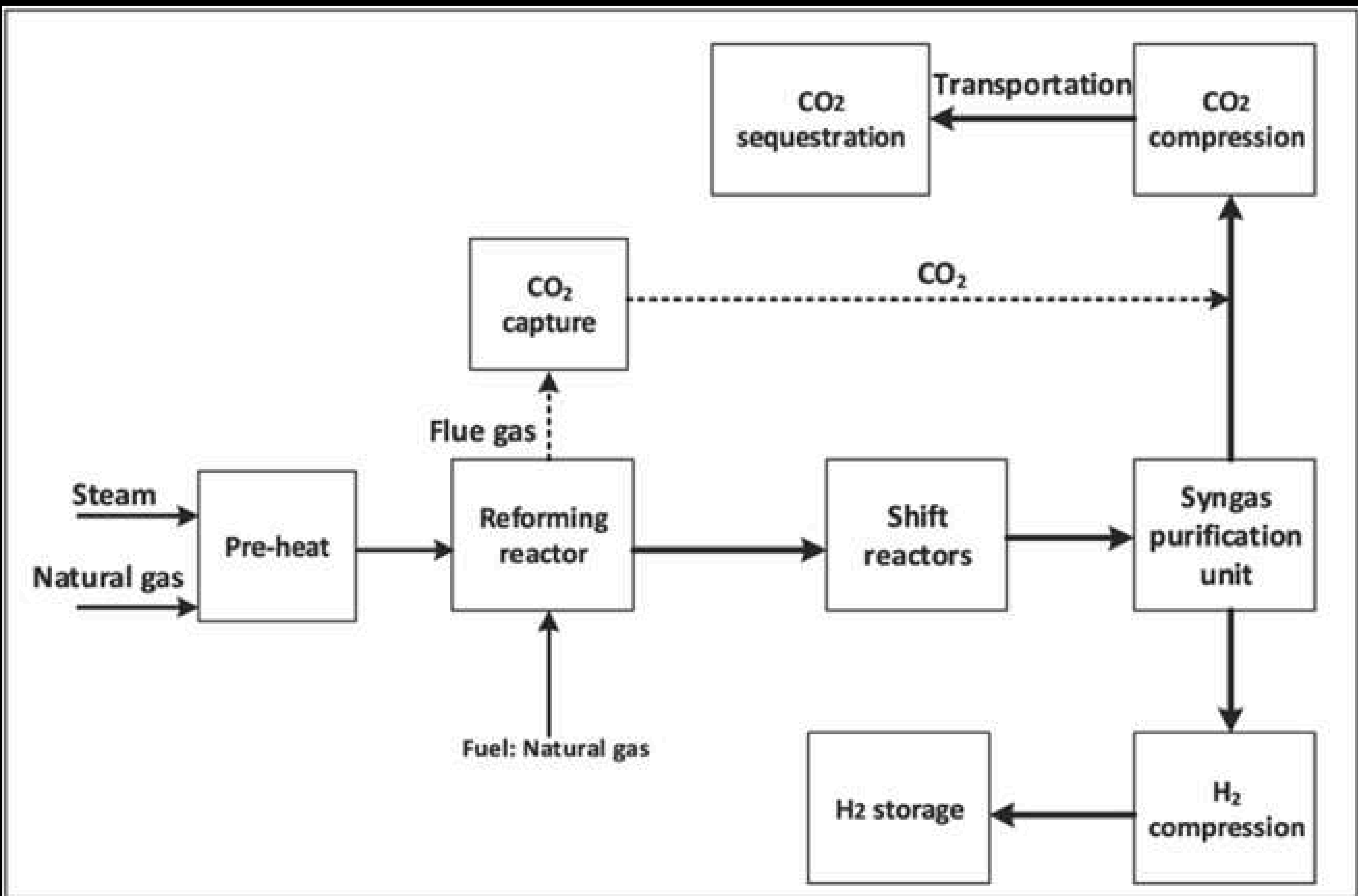
Images (I)

- Flow diagram of integrated steam methane reforming with CCS.



Source: (Zhu et al., 2019)

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Images (II)

- Comparative CO_2 emissions of production routes for grey, blue, and green Hydrogen.
- Industrial-scale reformer unit with CCS infrastructure.

Source: (Suryanto et al., 2021)

Summary and Outlook

- Proven Technology: Hydrocarbon reforming remains one of the major bases for industrial hydrogen production.

- Decarbonized Potential: CCS can be the bridge that facilitates this low-carbon hydrogen economy.

- Future Developments: Innovations in reforming and emergent low-carbon variants, such as pyrolysis, may change their role within the energy transition.