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Techno-Economics Analysis to Reshape Global Clean and Green Energy

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Abstract**—***Renewable methanol is produced from biomass or synthesized from green hydrogen and carbon dioxide CO_2. These are essential components that are consumed as chemical feedstock and fuel. E-methanol is also vital in the petroleum/ petrochemical industry and transport sectors toward net carbon-neutral goals. In the current operational scenario, renewable methanol production costs are high, and production volumes are low. We need to establish the right policies to address the challenges of producing e-methanol cost-effectively to deliver clean, green energy and fuel in the competitive market.*

Keywords—Green hydrogen, Electro Fuel, PV, Renewable, E-methanol

Words	Definition
E- Methanol	Electro Methanol
ICE	Internal Combustion Engines
DMFC	Direct Methanol Fuel cells
LCM	Low carbon Methanol
MSW	Municipal Solid waste
CAPEX	Capital expenditure
SGAB	Subgroup on Advanced Biofuels
TEA	Techno-Economic Analysis
DOE	Department of Energy

I. INTRODUCTION

Green hydrogen production mainly depends on renewable power generation and electrolysis and gains in efficiency and durability. Pure Hydrogen is essential for various industrial processes, mostly petroleum refining and ammonia synthesis[1]. However, the central part of Hydrogen is produced from fossil fuels (known as gray and brown Hydrogen), and only a minimal amount of almost 4% is delivered through an electrolysis process using renewable energy to complete the chemical process, known as green Hydrogen[2]. A liquid product is easily obtainable from CO2 and green Hydrogen through a one-step catalytic process through electrolysis. This paper discusses four essential topics: firstly, production and application of E-Methanol, Technologies, performance, sustainability, and operational challenges and opportunities[3].

II. PRODUCTION AND APPLICATION OF E- METHANOL

A. E-Methnol raw material (Heading 2)

In the 1920s, wood was the only source of methanol production. Industrial methanol was first produced from coal and natural gas in 1940[4]. This approach reshapes the fossil resources for an intense increase in methanol production and enhances its capacity. Drastically changed its production in 2019/2020 and reached 100 Mt methanol per year, equal to 125 billion L[5]. Over 60% was used to synthesize chemical formaldehyde, acetic, etc. Fig. 1 indicates Methanol derivatives and market.

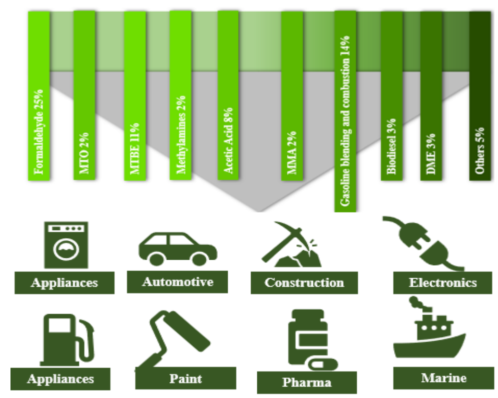

Fig. 1. *Methanol derivatives and market*

Methanol has many other uses likewise, paint, pharma, Marine and construction etc., Fig 2 indicates <1% for biomass and renewable, 35% coal and 65% from fossil, including as a solvent, antifreeze, windscreen washer fluid and for denitrification at wastewater treatment plants[5], [6]. Fig.2

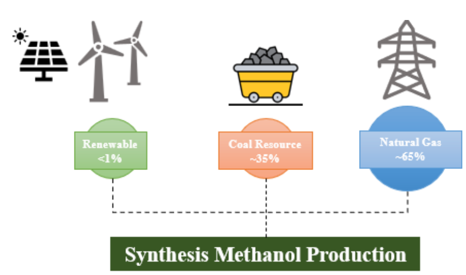

Fig. 2. *Feedstock and application of Methanol*

B. *Methanol as an E-Fuel*

As witnessed, E-methanol is directly used as a fuel by replacing heavy diesel (fuel) engines and producing electricity, drastically growing from 1% in 2000, the share of methanol consumption for that purpose has now increased to more than 14%. As per refinery specs, it carries a high-octane rating to enhance combustion engine performance[7],[8]. This fuel type can be used as an additive or substitute for gasoline in internal combustion engines (ICEs). E-methanol has half the volumetric energy density of conventional fuel likewise gasoline (Hi-octane) and diesel[9],[10].

DMFC-Direct methanol fuel cells can also convert direct chemical energy into electrical energy at ambient temperature. E-methanol is also used as an electro-fuel to produce electric power, heat, and steam in industrial boilers. Fig.3 indicates the methanol demand in the world based on extensive source data MMSA-2020[11],[12].

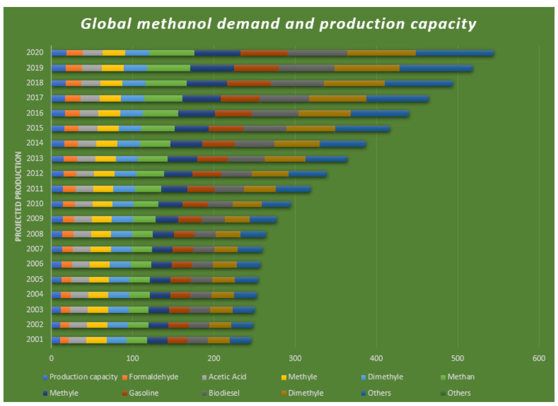

Fig. 3. *Global methanol demand and production capacity*

C. *Storage, transport and distribution of Methanol*

In most applications, a liquid energy storage medium such as methanol would be preferable to a gaseous one. The application of e-methanol preferred liquid form to store and easily transport at different locations through a pipeline or marine shipment. This fuel type is a global commodity with extensive consumption, distribution, and storage capacity in place[13]. Refueling stations have been commissioned to dispense methanol for cars, buses, and trucks. Methanol pump stations can be placed alongside existing gasoline or diesel dispensing pumps[14].

III. METHANOL PRODUCTION & TECHNOLOGIES

Statistically, e-methanol consumption reached 98.3 Mt in 2019 and is projected to reach more than 120 Mt by 2025 and may reach 500 Mt in 2050 in the World. The current statistic indicates that the World's most significant methanol production and consumption, China, reached 55 Mt in 2018, a quarter of which was utilized in fuel application and followed by the rest of the World, Europe, North America, and South America [15].

Majorly, the Carbon sources use natural gas, biomass, and product stream carbon dioxide- CO2 from various sources, including industrial flue gases or direct air capture (DAC) after the chemical process will produce e-methanol [16]. A simplified synopsis of the steps involved in E-methanol production is given in Fig.5. Mostly based on techno-economic analysis the E-methanol is still made from fossil fuels. Statistically, it shows that almost 65% of methanol is produced using natural gas and 35% from coal gasification. Only about 0.22% comes from renewable sources (green methanol)[16].

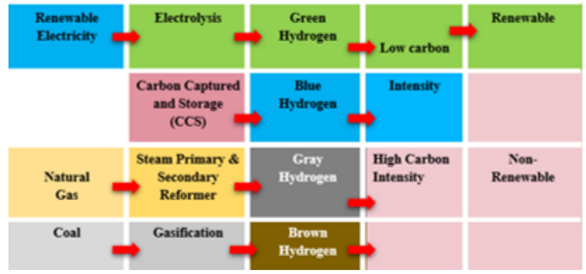

Fig. 4. *Simplified step involved in Green Hydrogen production*

A. *Low carbon methnol*

Many companies are working to produce low-carbon methanol (LCM) to reduce the carbon intensity and make this process environmentally friendly. Several methods have been studied to reduce CO2 emissions while using fossil resources. The first possibility is to inject CO2 into the synthesis loop to produce e-methanol [17]. A further possibility is to decarbonize the first possibility of producing methanol from natural gas; this is also known as the reforming step to syngas [18].

B. *Renewable methanol*

Mounting apprehension about international environmental change due to anthropogenetic GHG (Green House Gases) emissions has prompted governments, policymakers, industry, and scientists to look for ways to "green" their activities actively[19]. In this circumstance, renewable methanol generated sustainably and reliably can ultimately be part of the pathway to decarbonize the chemical and transport sectors[20].

Ultra-low-carbon or net carbon-neutral renewable methanol can be generated from various resources. Renewable methanol manufactured from biomasses such as forestry and agricultural waste and byproducts, municipal solid waste (MSW), biogas, sewage, and liquor from the pulp and paper industry is generally known as bio-methanol—e-methanol obtained from carbon dioxide and green hydrogen to produced renewable electricity[21].

C. *Bio-methanol from MSW and Biomass*

The technologies used in producing methanol from biomass and MSW-municipal solid waste are relatively well-known since they are similar to or the same as technologies used in the commercial gasification-based industry, where feedstocks are usually coal, heavy residual oil, and natural gas[22].

Biomass and MSW- municipal solid waste resources are used to produce methanol through well-known technologies. These are commercially used in the gasification-based industry using coal, heavy residual oil, and natural gas as feedstock[23].

Conversely, the gasification appearance contrasts with feedstock preparation [24].

IV. PERFORMANCE AND SUSTAINABILITY

A. Performance & Efficiency

The world's most significant methanol production is executed from natural gas as feedstock instead of coal, producing brown hydrogen with an intense carbon footprint. Methanol production from coal is overwhelmingly encouraged in China, leading to a high carbon footprint. Energy conversion is 70% from natural gas-based plants and 50-60% produced from coal-based technologies being used worldwide [25]. Table 1 also indicates the Energy conversion efficiencies for specific process units [26].

Table No.1 Energy Conversion efficiencies

Process operation	Energy efficiency	Comment
Gasification of feedstock	0.7-0.8(+)	The wide range depends on feedstock characteristics such as level of inerts and moisture, and overall gasifier temperature
WGS	0.95-0.97	The higher the H_2/CO ratio is in the feed gas, the less water-gas shifting is required, thus the lower the energy losses
Methanol synthesis	0.79-0.8	With a stoichiometric syngas and limited amount of inert gases
Overall	0.53-0.62	

Renewable methanol production plants' performance depends on the amount of methanol manufactured in a given period, e.g., a year. Secondly, this is contingent on numerous factors, on plant operations set-up the throughput, co-products, technology) and local operating conditions (e.g., brownfield known as unmanned or greenfield site seamless operations, availability of feedstock, or to produce renewable electricity to achieve set production target.

Determining the real-life performance of the plant operations and feedstock availability is complicated, whereas limited commercial plants are in operation Globally, as indicated in **Table 2.**

Different operational models have been developed and simulated on various assumptions to investigate different plant operational configurations to set production targets and product quality in specific locations. This approach leads to estimating plant production operational efficiency and environmental impact, which is often difficult to compare[9]**.**

Table 2. Gasification technologies and their application

Gasification technology Name/owner	Heating principle	Type	Feedstock	Project, reference	Project phase	Product	Plant capacity (unit varies) kt/year
SES Gasification Technology (U-Gas)	DO_2	BB	Biomass/ MSW	Trans World Energy, Florida (US) (Trans World Energy, 2020)	FEED done, start-up Q2 2023	Methanol	875 kt/y
NextChem Technology	DO_2	UO_2	MSW	ENI Refinery, Livorno, Italian (IT) (NextChem, 2020b)	Basic engineering ready Q3 2020	Methanol	115 kt/y
MSW/ waste wood	LowLand Methanol (NL) (LowLands Methanol, 2020)	Start-up early 2023	Methanol	120 kt/y			
PDQ/ Thyssenkrupp	DO_2	EF	Biomass (torrefied)	BioTfueL Demo Project (FR) (BioTfuel, 2020)	Operational	FT products (slipstream based)	15 MWt of biomass
HTW/ Thyssenkrupp	DO_2	BB	Biomass	Värmlands- metanol (SE) (Värmlandsmetanol, 2017)	Planning	Methanol	100 kt/y
TRI	IH	BB	MSW	Fulcrum (US) (TRI, 2020)	Start-up Q4 2020	FT products	40000m_3/y

B. Renewable methanol Vs Alterantives

Methanol has several recompences equated to some other projected renewable energy carriers, including hydrogen, encompassed ammonia, CNG/LNG, & large Battery-Banks. Hydrogen-H2 gas production has projected as an energy storage energy medium and makes, furthermore drive, only water when conflagrated to complete electrolysis process.

In operational, because of its low volumetric density, it required compression from 350-700 bar pressure to turn into a liquid form or other way to liquefaction by drop temperature up to -253 deg C; this required a tremendous amount of energy to compress and propane cold box to drop the temperature, storage challenging and energy intensive. This Gas is highly explosive and combustible and can verbose and prolix easily through many generally used metals and materials. Massive infrastructure indispensable to the carriage, stock, and safe distribution of hydrogen would, therefore, be costly.

Table 3. Comparison of various fuel properties

Fuel type	LHV (MJ/kg)	Volumetric energy density (GJ/m₃)	Storage pressure (bar)	Storage temperature (°C)
Methanol	19.9	15.8	1	20
DME	28.9	19.2	5	20
LNG	48.6	20.8	1	-162
CNG	48.6	9	250	20
Liquid ammonia	18.6	11.5	1–10	-34 (at 1 bar)–20 (at 10 bar)
Liquid hydrogen	120	8.5	1	-253
Compressed hydrogen	120	4.7	700	20
Gasoline	43.4	32	1	20
Marine gas oil	42.8	36.6	1	20
Lithium ion battery	0.4-1	0.9-2.4	1	20

C. Emission & sustainability

The primary aim is to produce Methanol based on biomass and CO_2, which reduces CO_2 GHG (greenhouse gas) emissions. Based on the cradle-to-grave analysis, this is essential to complete life-cycle analysis (LCA), which compresses all steps of methanol manufacture, distribution, and consumption by taking into account, focusing the environmental impacts of each step, including GHG emission and other components (NOx, CO, particulates, SOx) of emission and H2O use. This process depends on numerous parameters comprising feedstocks, by-product production, methods applied, and how the methanol product is consumed. This approach builds the fortitude of an actual set of operations to equate with the inclusive environmental influence of other fuels and feedstock stimulating. However, such examines will be progressively indispensable to measure the ecological impact of various fuels/materials and processes. The first step toward the anthropogenic carbon cycle is to capture CO2 from flue gases to produce various industries and Hydrogen from Biomass to produce Methanol. This type of methanol production could be painstaking a low-carbon fuel. The second type of methanol production from natural gas and coal are non-renewable resources, formerly economical from a cost assessment with gasoline and diesel fuel, as shown in Fig.5.

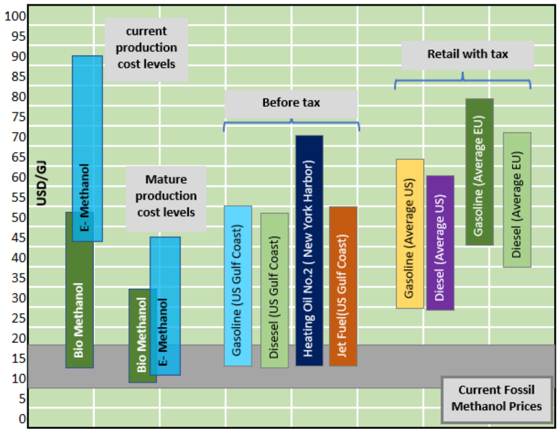

Fig. 5. Capital cost for bio-methanol plants [1]

V. Current Cost and Cost of Projection

A. Methanol production from biomass and MSW via gasification

For bio-methanol fuel production, the procedure applied in this paper to establish the cost of manufacture is comparable to that expended and putative by many operational stakeholders. In this approach, various issues were discussed and confirmed while accumulating and positioning evidence expended as the basis for the "**Cost of Biofuels**," as concluded by SGAB, a group under the Sustainable Transport Forum. The cited outcomes expended as a source for a project presented in this research work named "**Advanced Biofuels – Potential for Cost Reduction**." The evidence on projects exploiting thermal conversion of biomass in these two research reports has been updated and adjusted to estimate production costs for various biofuels applied. Fig.6. indicates the capital cost for bio–methanol plants.

S.No	Project/ study	Status	Capacity (t/y)	Investment (million USD)	Investment (USD/t/y)	Investment (USD/kW)	Source
1	Trans World Energy (TWE), Florida (US)	FEED done, start-up Q2 2023	875 000	430	490	710	TWE
2	ENI Refinery, Livorno (IT)	Basic engineering ready Q3 2020	115 000	330	2900	4 280	NextChem
3	LowLand Methanol (NL)	Start-up early 2023	120 000	130	1 110	1 620	LowLand Methanol
4	Södra (SE)	Operational	5 000	11	2 220	3 230	Södra
5	Enerkem, Rotterdam (NL)	Engineering	215 000	580	2 690	3 840	Enerkem

Fig. 6. Capital cost for bio-methanol plants [1]

B. Capital cost element of total production cost

The Assigned company transformed the CAPEX (Capital expenditure) into a venture intensity, articulated as a middling value with an interval of +/- 20%, and was conveyed as USD/kW of product capacity to allow appraisal of CAPEX for several schemes with dissimilar products and services. The capital cost range was then compared and adjusted in a conventional way with other studies such as Brown. The range of investment cost for a biomass-fed plant is assumed to be 1,560-2,220 USD/t/y and for MSW-based projects to be 2,000-2,780 USD/t/y. The relative investment for MSW-based projects was higher. Still, these plants are typically at a smaller scale, in the range of 100,000 t/y of methanol compared to 200,000-250,000 t/y for biomass-based projects, explaining why a higher relative investment should be expected.

C. Feedstock cost element of total production

The Assigned company transformed the Capital expenditure of the Hydrogen and CO2 production plant projects into a venture strength, uttered as an average value with an interval of +/- 20%, and was articulated as USD/kW of product capacity to allow comparison of CAPEX for various projects with different products. The energy conversion efficiency for biomass to methanol is 60-70% (based on the feedstock LHV at the plant gate). The conversion efficiency is mostly lower, around 50-60% for MSW-Municipal solid waste projects. This type of feedstock Cost varies considerably depending on the facility's location. Fig.7 shows the supply curve for primary biomass globally.

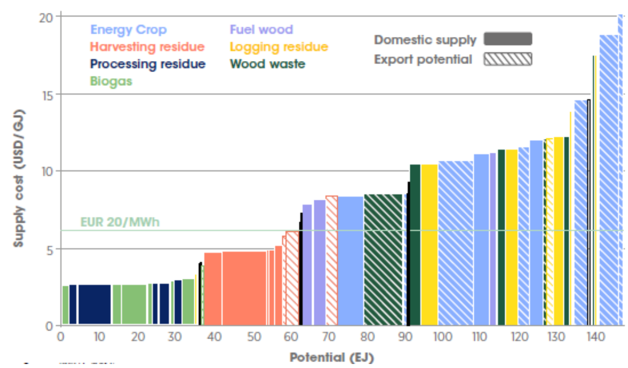

Figure 7 Global supply curve for primary biomass

VI. Opporunities and Challenges

A. Demand

Methanol production from fossil fuels or renewable sources, has the same chemical structure: CH_3OH, and the renewable methanol will replace in any of its current uses. This is feedstock and consumption of various chemical, material, plastics, and products, as electro fuel for transport, shipping, and renewable electricity production. Renewable green methanol playing vital role to replace fossil fuel-based hydrocarbons and petrochemicals, which is carbon neutral to protect the environment.

Secondly, through methanol derivatives for a potential market possibly billions of tons of methanol per year will be manufactured and consumed. Evidently the methanol production is projected to grow drastically from 100 Mt in 2019 and to more than 120Mt by 2025, and 500 Mt by 2050.

B. Sustainable feedstock

As per DOE, 2016 research report shows that United States acquired natural resources around 300 Mt/y of unused(dry) biomass is available and potentially 750-1 000 Mt/y will last up to 2040, whereas two-thirds of energy crops that are not cultivated yet. This report also shows that in Europe, projected 1050-1370 Mt/y maintainable (dry) biomass this will last by 2030, of which 525-850 Mt/y would be obtainable after meeting other stresses [9].

C. *Impact of renewable methanol*

The increasing de-fossilization of the energy drives in the chemical industries sector and their concurrent electrification through manipulating renewable energy sources will have extreme consequences. Variable renewable energy sources and intermittence in electricity generation determine its fluctuation from hourly, daily, and monthly, which must be dealt with to maintain a stable and reliable operational grid for seamless power delivery.

To address environmental issues, electro-fuel, and electrochemical can be vital in stabilizing grid operations by integrating renewable power when supply demand is higher during peak hours. The E-Methanol dynamically constitutes "follow the load" as a spinning reserve in the electric grid and adjusts its methanol production accordingly, which is explicitly exploited for that objective.

D. *Drivers and*

The principal driver for e-methanol (renewable) production is the ability to dissociate society from its dependency on fossil fuel consumption, leading to a high carbon intensity of GHG emissions and correlated environmental concerns.

Viable and enduring solutions based on renewable energy resources are essential to deliver the required results. Effectively, in the energy transition, renewable E-methanol (Renewable) can act as an innovative energy carrier to neutralize and eventually eliminate the carbon footprint of the chemical/petrochemical and energy sectors.

The key benefits & drivers of E-methanol (Renewable) Electro fuel include:

1. Versatile index to produce numerous chemicals and materials
2. Low GHG emission & carbon intensity
3. Become sustainable feedstocks such as biomass, MSW or CO_2 and H_2
4. Liquid forms easily to transport, store, and dispense
5. Consistent with existing sharing infrastructure and can partly be amalgamated with established fuels to enhance octane rating.
6. Reduction in other harmful emissions (SOx, PM, NOx, etc.)
7. Source of Liquid hydrogen carrier

E. *Challenges*

- The principal obstacle to accepting renewable methanol is the same as for some other renewable substitution feedstocks and fuels, known as the cost-of-production.
- Policies are needed to accelerate and continue the production and exercise of renewable e-methanol (renewable) on a large scale.
- Realistically, the cost of bio-methanol is lower than that of e-methanol (renewable). In other instances, it remains higher than the gray and brown hydrogen produced from natural gas and coal. The cost factors and environmental issues are ultimately the situations for all fuel and chemical commodities that could replace their fossil equivalents.

VII. Conculsion & Discussion

This paper briefly introduces E-Methanol and its significance in the context of renewable energy and sustainable practices. It highlights E-Methanol production, application, technologies, performance, sustainability, and operational challenges and opportunities. The paper emphasized using Techno-Economic Analysis as a pivotal tool for reshaping the global clean and green energy landscape. It provided an in-depth overview of major clean and green energy technologies. The advancements and innovations in hydro, bioenergy, and emerging technologies like hydrogen and advanced energy storage are also discussed. The methodologies involved in Techno-Economic analysis and the importance of cost-benefit analysis, life-cycle analysis, and sensitivity analysis were discussed. In the work, we identified and analyzed barriers and challenges hindering the global adoption of clean energy technologies and discussed how TEA can provide insights into mitigating these challenges. Finally, the paper discussed potential improvements in TEA methodologies and how they adapt to evolving technologies.

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