A COMPARATIVE TECHNO-ECONOMIC ANALYSIS OF SUSTAINABLE METHANOL SYNTHESIS PATHWAYS FROM BIOMASS AND CO_2 (Paper No. 421)

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Contents

Background: Methanol

Methanol spans multiple sectors including both fuels and chemicals

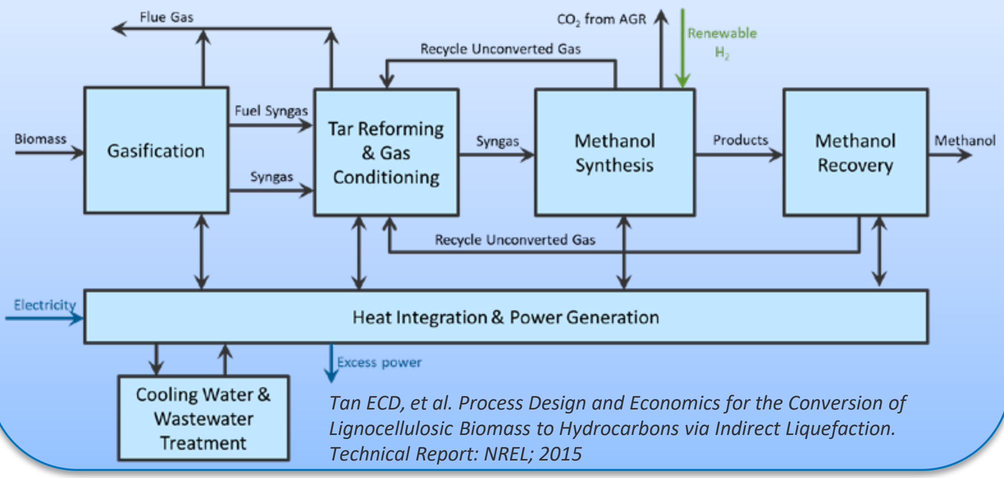
Current methanol global demand is ~90 Million Tonnes annually and is projected to increase

Conventional synthesis routes include natural gas reforming and coal gasification

Numerous pathways exist in literature for fossil vs. non-fossil carbon sources

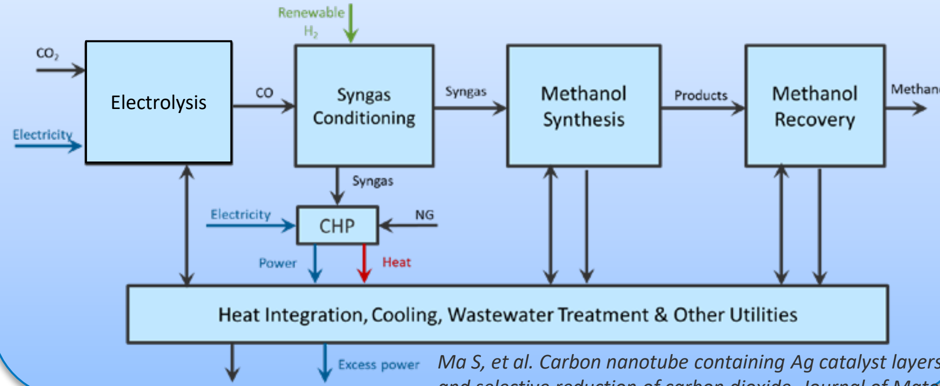
Alvarado M. Methanol Industry Overview. 35th World Methanol Conference. Berlin, Germany: IHS; 2017

Biomass Gasification to Syngas and Methanol Synthesis



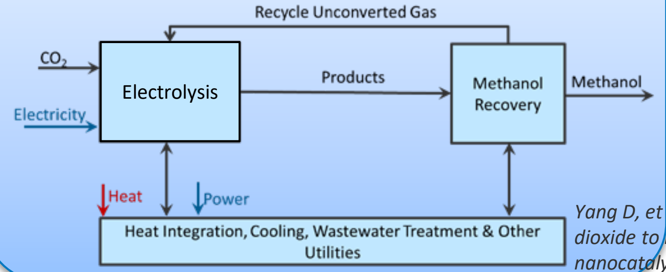
Tan ECD, et al. Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons via Indirect Liquefaction. Technical Report: NREL; 2015

Indirect CO_2 and H_2 to Syngas and Methanol Synthesis



Ma S, et al. Carbon nanotube containing Ag catalyst layers for efficient and selective reduction of carbon dioxide. Journal of Materials Chemistry A. 2016;4:8573-8.

Direct CO_2-to-Methanol Synthesis



Yang D, et al. Selective electroreduction of carbon dioxide to methanol on copper selenide nanocatalysts. Nat Commun. 2019;10:677.

Approach: Techno-Economic Analysis (TEA)

aspentech

Process models developed in Aspen Plus

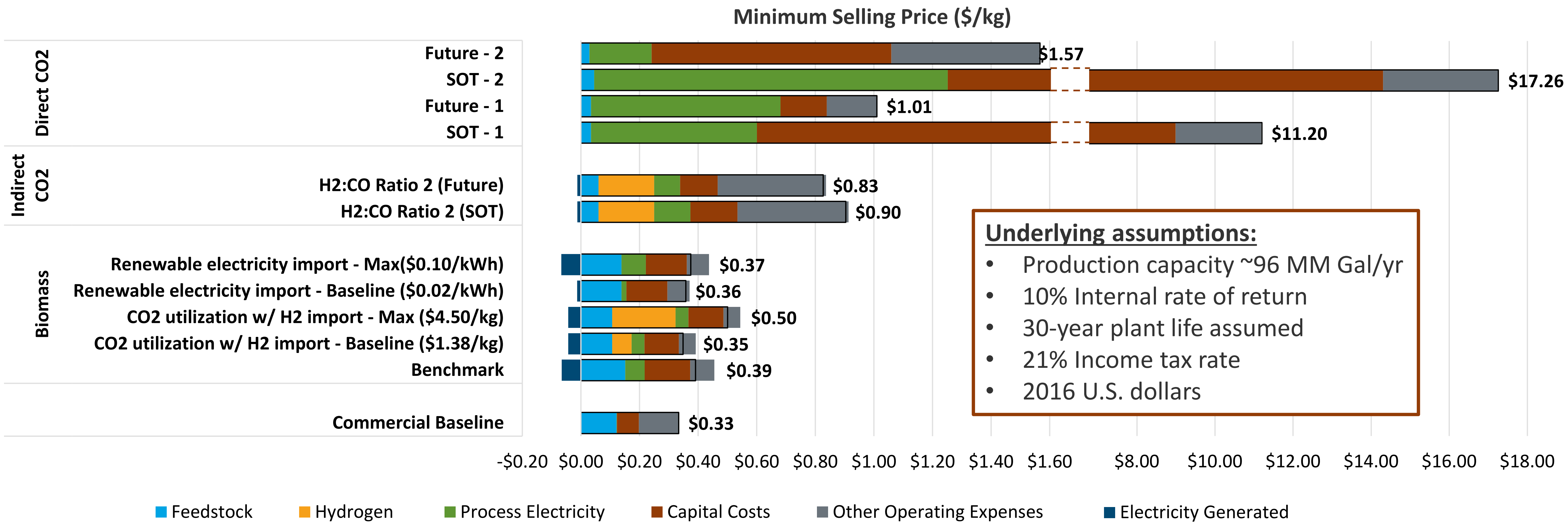
Discounted cash-flow rate of return (DCFROR) analysis and sustainability assessment conducted

Key metrics identified and leveraged to generate comparative analysis

Metric	Definition	Unit
Cost	Minimum methanol selling price	\$/kg
Carbon efficiency	$\frac{Carbon\ in\ product\ (methanol)}{Total\ carbon\ in\ (biomass\ \frac{and}{or}\ CO2)}$	%
Energy efficiency	$\frac{Product\ LHV\,(methanol)}{Total\ energy\ in\ (biomass, H_2, process\ electricity\ and\ heat)}$	%
Technology Readiness Level (TRL)	U.S. Department of Energy (DOE) TRL Guide 2011	Scale 1-9

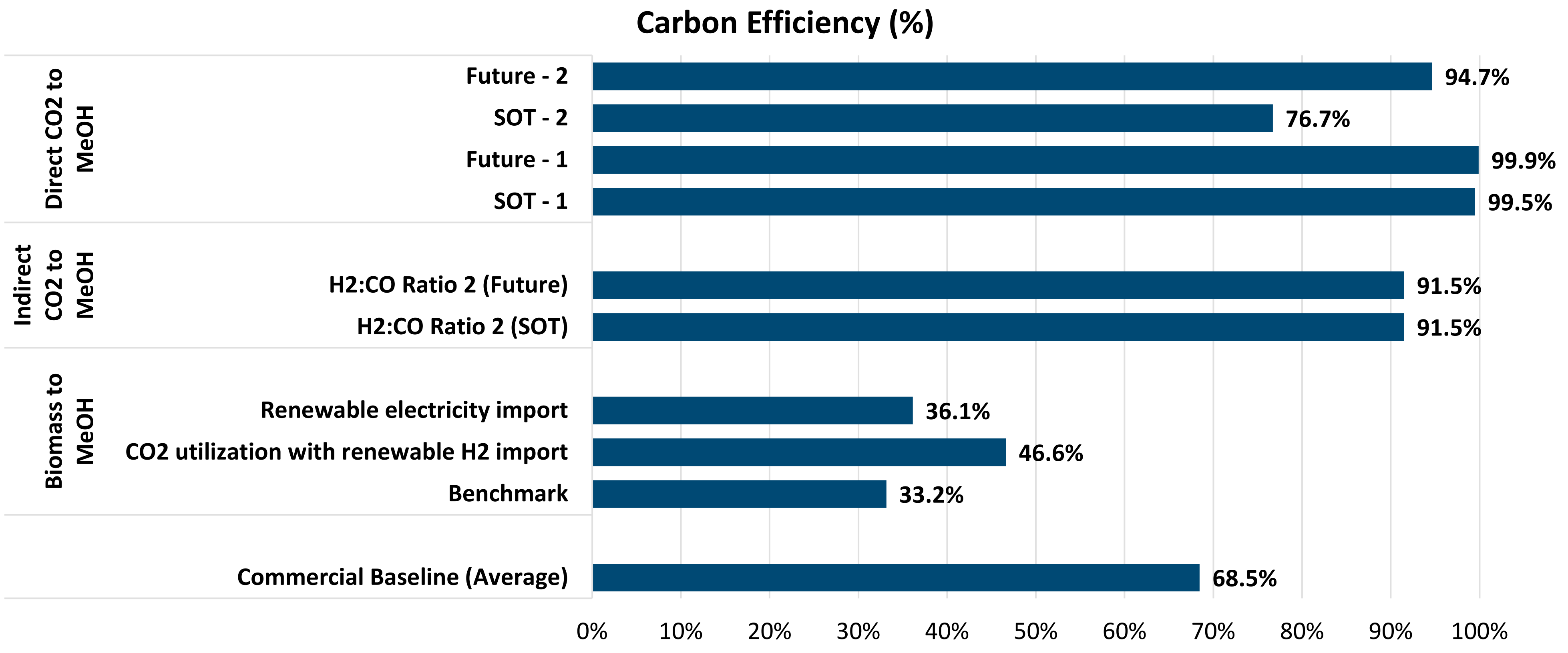
Key Metrics

- Derived from TEA to produce cross-comparison
- Selected to harmonize economic and environmental factors
- Considers “time-to-deployment” as a key indicator



$ Cost (Minimum Methanol Selling Price)

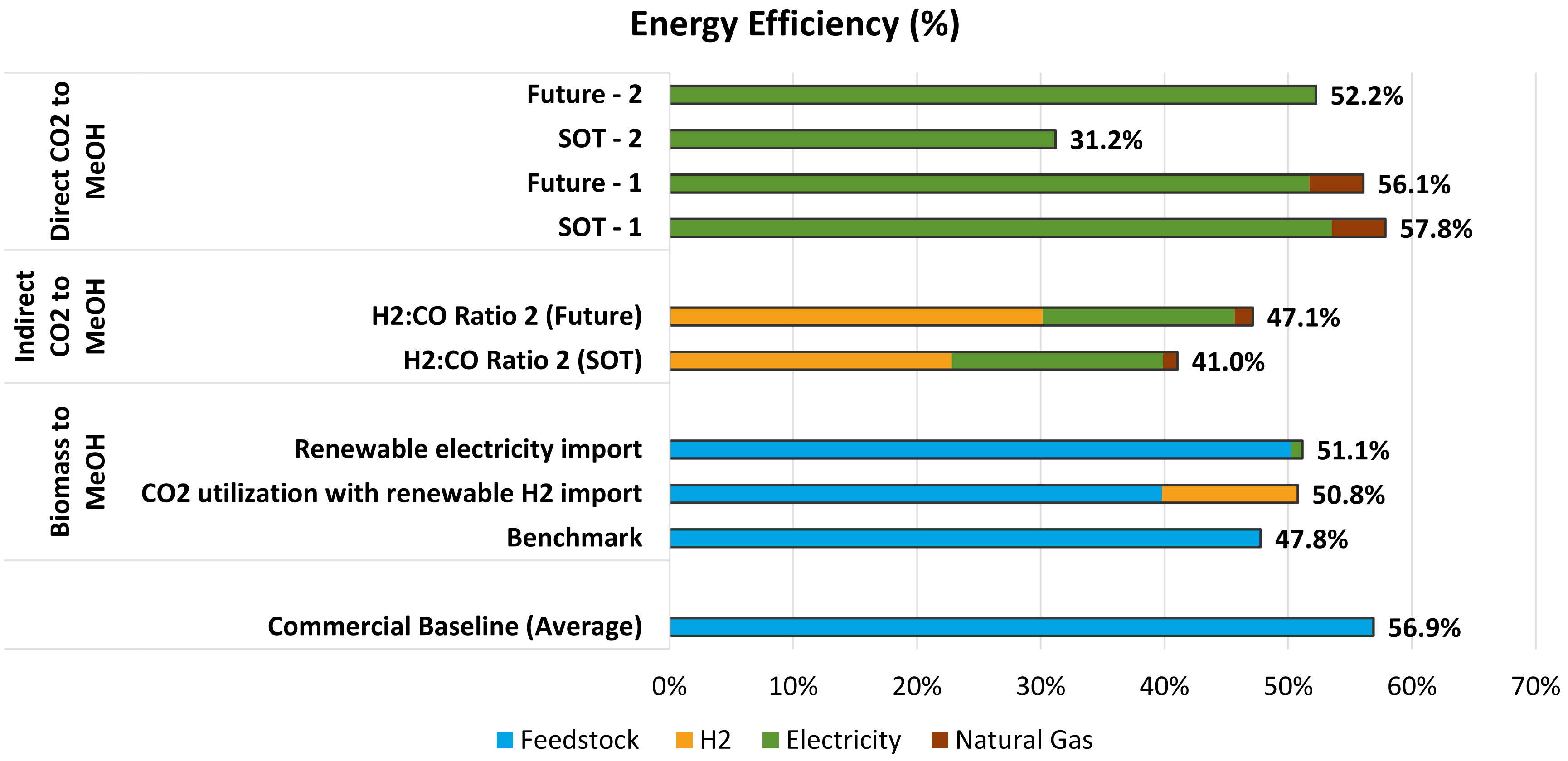
- Biomass to MeOH is on-par with commercial baseline
- Indirect CO_2-to-MeOH benefits from high faradaic efficiency (FE, 98%) and current density (CD, 350 mA/cm^2) relative to direct case (78% FE, 41.5 mA/cm^2 CD)
- Key cost drivers for direct CO_2-to-MeOH are electricity and electrolyzer capital expenses



Direct CO_2-to-Methanol Case 2 exhibits lower selectivity towards methanol in the SOT case than Case 1

Carbon Efficiency

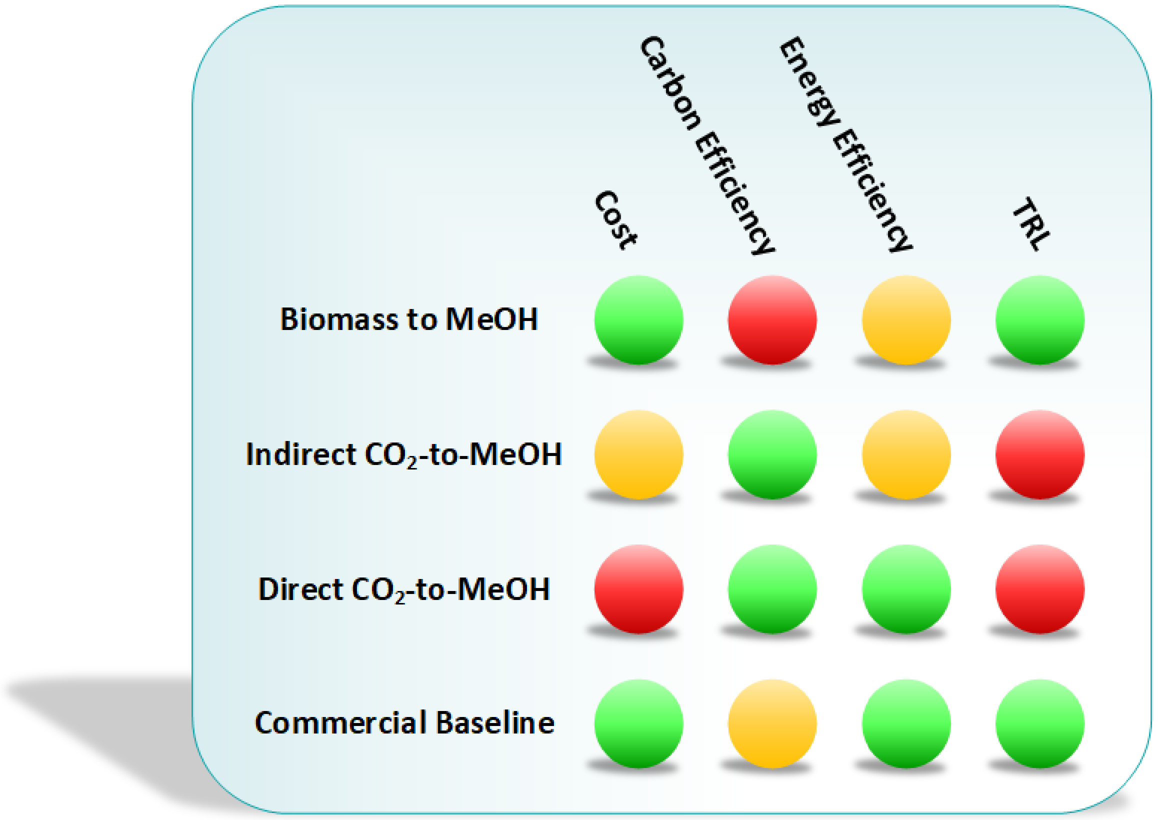
- Direct CO_2-to-MeOH potentially has the best carbon efficiencies when considering carbon recycling. Note that the demonstrated single pass CO_2 conversion is less than 10%
- Indirect CO_2-to-MeOH exhibits high selectivity towards desired product
- Carbon efficiency for biomass pathway can be improved to near 50% with CO_2 utilization



Energy Efficiency

- Biomass pathways rely on biomass as a source for carbon, heat, and power
- Utilizing renewable energy sources can help to offset environmental impacts of each pathway

Identifying Pathway Limitations



Favorable Moderate Unfavorable

	Favorable	Moderate	Unfavorable
Cost ($/kg)	< $0.45	$0.45-$1.00	> $1.00
Carbon Efficiency (%)	> 80%	80%-60%	< 60%
Energy Efficiency (%)	> 55%	55%-40%	< 40%
TRL (1-9)	> 6	6-4	< 4

Near-term drivers:

- Cost
- TRL
- **Favors biomass to MeOH and commercial baseline**

Long-term drivers:

- Carbon Efficiency
- Energy Efficiency
- **Favors direct and indirect CO_2-to-MeOH pathways and commercial baseline**

Comparative Analysis

Key Takeaways

- Biomass gasification to methanol pathway is capable of meeting market competitive costs and displays a high TRL, and of the studied pathways is the most promising technology for the near-term. However, sustainability metrics are key elements for impactful change in the ongoing global decarbonization efforts.

- The direct CO_2 pathway is comparatively much lower in TRL and requires the most substantial R&D efforts pushing commercialization feasibility the farthest into the long-term, while the indirect CO_2 pathway may be achievable in less R&D time if electrolysis costs can be reduced.

- Long-term solutions will require both improved carbon and energy efficiencies over the commercial baseline which may be possible through the indirect and direct electrolysis pathways. Future analyses should consider process designs that are optimized across a variety of economic and environmental metrics rather than solely economic drivers.

Thank you

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