Kalama Methanol Plant - Review of Greenhouse Gas Impact Assessments

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This **Low Carbon Prosperity Institute** analysis examines various scenarios of life-cycle GHG emissions attributable to the proposed Kalama Methanol Manufacturing and Marine Export Facility, and the range of net global GHG changes likely from other methanol or end-use product displacement.

Executive Summary

The Kalama Methanol Manufacturing and Marine Export Facility (KMMEF) would produce and export up to 3.6 million tonnes of methanol annually from Cowlitz County, adding to the consumption of natural gas and electricity in Washington state. The project would generate additional greenhouse gas (GHG) emissions, including upstream methane leakage. The parent company of KMMEF, Northwest Innovation Works (NWIW), proposes to voluntarily mitigate an expected one million tonnes of carbon dioxide equivalents ($MtCO_2e$) per year occurring within Washington State, totalling around half of the annual life-cycle emissions from methanol production and export.

Methanol produced at KMMEF has the potential to influence global markets in several ways - from displacing much higher emissions intensity methanol from coal, to replacing similar or slightly lower emissions intensity petroleum-derived plastics precursors (olefins), and increasing demand for fossil fuels. This Low Carbon Prosperity Institute analysis examines various scenarios of life-cycle GHG emissions attributable to KMMEF methanol production, and the range of net global GHG change likely to result from methanol or other end-use product displacement. The most essential findings and recommendations in regards to GHG life-cycle emissions are as follows:

- In the long-term, KMMEF is likely to produce methanol at lower than global average emissions intensity in a manner consistent with low carbon pathways, including the IEA 2018 Clean Technology Scenario (CTS). Even deeper-carbon reduction pathways than the CTS project increasing methanol supply multiple times over current levels by 2050.

- The global GHG benefit of methanol is highly dependent on assumptions of the degree to which it displaces more carbon intensive fuels and products in the marketplace. While a full-range net global GHG benefit of *minus* 1.7 to *plus* 13.6 $MtCO_2e$/year GHGs avoided can be supported based on a range of hypothetical displacement pathways, a conservative most likely range is between 2.3 and 7.2 $MtCO_2e$/year through at least 2030, assuming full production capacity.

- The primary displacement options are using natural gas based methanol as a substitute for coal based methanol production, to create olefins (an intermediary step in plastics for consumer products), or the blending of methanol with transport fuel. To have a breakeven impact on global GHG levels, about 5% to 20% of the KMMEF output that displaces other fossil fuels must be used in a manner that displaces coal based methanol production. Achieving a greater share of coal-methanol displacement relative to petroleum-product displacement would provide net global GHG benefits. Based on a review of market trends and literature it is unlikely that displacement would favor a scenario with high enough petroleum product displacement to prevent GHG benefits.

- The most detailed assessments (IEA 2018; DSEIS) indicate the likeliest ratio favors coal-methanol displacement, resulting in a net global GHG benefit. In particular, the CTS projections are entirely consistent with the KMMEF facility, projecting coal-based methanol in "Asia Pacific" is increasingly and almost exclusively substituted by natural gas-based methanol, with rapid growth in North American production. Any KMMEF methanol that displaces coal-based methanol from the market would result in substantial emissions reductions, no matter the eventual end-use of that methanol.[1]

- In order to provide more certainty and confidence of substantial net global GHG benefits, this analysis offers several recommendations:
    - In the near-term: (1) actively ensure that the sourced natural gas is low emissions intensity by partnering with suppliers and industry groups who monitor, use, and promote best practices in limiting methane leaks and flaring; and (2) use voluntary mitigation strategies that are of the highest confidence in providing additional, permanent GHG reductions, with an emphasis on those that provide the greatest local benefit;
    - Over the longer-term, in order to ensure continuing compatibility with the lowest possible GHG pathways, evaluate and consider strategic partnerships for carbon capture & biogas sources of natural gas, and;
    - To the extent possible through purchasing agreements and regulatory structures, include safeguards to provide even stronger confidence that coal methanol is the most likely displaced product, and that coal does not instead get consumed for other purposes.

In summary, this analysis concludes that KMMEF methanol is very likely to provide GHG benefits in the short to medium term (at least through 2030) of between 2.3 to 7.2 $MtCO_2e$/year. The methanol from the KMMEF facility would be entirely consistent with longer-term low carbon pathways that project an increasing role of natural gas based methanol, including much higher North American supply as an essential component of the strategy. The need for methanol production would be much greater in an even deeper carbon pathway according to the best available analysis (IEA, 2018). Pathways that lead to an increase in global GHG emissions associated with KMMEF exist, but remain unlikely. To mitigate risk we provide several recommendations regarding limiting natural gas leakage, implementing highest quality mitigation approaches, evaluating long-term carbon capture and/or biogas capability, and seeking regulatory and/or purchase agreement certainty that coal methanol displacement is the primary outcome of KMMEF methanol entering the marketplace.

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[1] For methanol production, under the 100-year GWP scenarios evaluated in both the DSEIS as well as Erickson & Lazarus, the emissions savings range from around 50% to 85% per ton of coal-methanol replaced.

Project Background

The proposed Kalama Methanol Manufacturing and Marine Export Facility (KMMEF), operated by Northwest Innovation Works, LLC (NWIW), would be sited on 100 acres at the Port of Kalama's North Port on the Columbia River in Cowlitz County, Washington. Natural gas would be delivered via a new, 3.1-mile, 24-inch pipeline spur (Kalama Lateral Project) connected to the existing Northwest pipeline system and natural gas would likely be almost exclusively supplied from British Columbia (draft supplemental EIS).[2] The project also includes an upgrade of existing transmission lines from the Kalama Industrial Substation. Project background materials are publicly available at: https://kalamamfgfacilitysepa.com/.

Over 100 TBtu of natural gas annually, around one-quarter of Washington State's yearly consumption, would be delivered to the KMMEF to produce methanol - a chemical used to create other chemicals (formaldehyde, acetic acid, and others) or as a fuel and for fuel blending (Alvarado, 2016).[3] Methanol production capacity would be 3.6 million tonnes (Mt-MeOH) per year. Pending approval, the KMMEF is expected to begin storing and shipping methanol to global markets sometime between mid-2021 and mid-2023.

Recent growth in the methanol market has centered on methanol-to-olefins (MTO) (Alvarado, 2016). Olefins are primarily an intermediary step in plastics for consumer products. Olefins from MTO are produced in roughly equal amounts of ethylene (C_2H_4) and propylene (C_3H_6), yielding one t-olefins per 2.6 t-MeOH (Banach, 2017). Asia Pacific consumes a little more than half of global methanol, with both short- and long-term growth anticipated to be led by that market (IEA 2018). The largest growth in methanol demand through at least 2021 is forecast to be for MTO production (IHS Markit Toolkit, 2017).

Status of Permitting

A final environmental impact statement (FEIS) was completed in 2016. Appeal of permits and FEIS to the Washington State Shorelines Hearing Board resulted in a required review under the State Environmental Policy Act (SEPA) for a draft supplemental EIS (DSEIS). The DSEIS includes "additional analysis and consideration of mitigation for greenhouse gas (GHG) emissions attributable to the project" (DSEIS), including life-cycle analysis. A public hearing is scheduled for the evening of December 13, 2018. All other environmental elements in the FEIS were approved without the need supplemental review.[4]

Scope of this Review

This analysis was commissioned under contract between the Low Carbon Prosperity Institute (LCPI) and NWIW. The scope of the analysis is to review available assessments of and determine the likely life-cycle greenhouse gas emissions impact of the proposed KMMEF. The analysis is limited to GHG impacts only and relies on three primary sources:

- Erickson, P. and Lazarus, M. (2018). Towards a Climate Test for Industry: Assessing a Gas-Based Methanol Plant. Discussion brief. Stockholm Environment Institute

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[2] Under the baseline scenario, 99.4% of the natural gas is from British Columbia and 0.6% is "Rocky Mountain Gas".

[3] For a short primer on methanol uses, see also https://www.mgc.co.jp/eng/rd/technology/methanol.html

[4] These environmental elements in the FEIS include: Earth, Water Resources, Plants and Animals, Energy and Natural Resources, Environmental Health and Safety, Land and Shoreline Use, Housing and Employment, Aesthetics and Visual Resources, Historic and Cultural Resources, Transportation, Public Services and Utilities, Air Quality, and Noise.

- The Draft Supplemental EIS (DSEIS) (November 2018), including life-cycle analysis by Life-Cycle Associates (Appendix A).
- OECD / IEA (October 2018). The Future of Petrochemicals: Towards more sustainable plastics and fertilisers.

This review and the conclusions thereof are LCPI's alone.

Review of Prior GHG impact Assessments

Final Environmental Impact Statement (FEIS)

In compliance with the Washington State Environmental Policy Act (SEPA), the Port of Kalama and Cowlitz County submitted a Final Environmental Impact Statement (FEIS) in 2016 considering two alternative technologies for producing 3.6 million metric tons of methanol annually: a "combined reformer" technology and an "ultra low-emissions" technology (ULE), a new approach for methanol. In the FEIS, the proposed technology for the project was changed from combined reforming to ULE, lowering the net air quality impacts of the proposed project. The FEIS estimated a total of 1.28 million metric tons of carbon-dioxide equivalents ($MtCO_2e$) covered under SEPA, including on-site manufacturing emissions, emissions from purchased power, and methanol transport by vessels in Washington waters. Following the FEIS submittal, the Washington State Shorelines Hearing Board determined a supplemental EIS was needed to provide, according to the DSEIS, "additional analysis and consideration of mitigation for greenhouse gas (GHG) emissions attributable to the proposed project."

Towards a Climate Test for Industry

A Discussion Brief published in early 2018 (Erickson & Lazarus 2018), which used the methanol plant as an illustrative case study to develop a "climate test" for major industrial infrastructure processes, identified two "serious flaws" in the FEIS GHG emissions analysis. Those were the production and transportation of natural gas to the facility, and the approach to determining the emissions of off-site power generation needed to supply the facility.

The FEIS assumed the methanol facility would have no impact on natural gas production and transportation emissions since it would not necessitate new natural gas wells, and that increasing production and transportation from existing natural gas infrastructure does not necessarily increase emissions. Erickson & Lazarus find these claims "defy good practice" and that it is "implausible" for existing natural gas wells to satisfy the natural gas demand of the proposed facility. They determine that including a 1% leakage rate of methane during upstream natural gas production and transportation would nearly double the emissions impact reported in the FEIS.[5] The analysis further finds that for a 3% leakage rate and 100-year global warming potential (GWP), upstream methane would have a greater emissions impact than all other GHG sources related to KMMEF methanol production.

With regards to the off-site power generation emissions, rather than the total annual average of all electricity-generating resources throughout the NW, Erickson & Lazarus suggest that "analysts should use marginal emission rates that reflect plants that would be run and/or built in response to additional electricity demands". Applying this perspective, they report off-site power emissions should be 20% to 150% higher than reported in the FEIS (a 4% to 32% increase in overall emissions reported under the FEIS).

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[5] This includes the combined effect of natural gas supply emissions of methane plus carbon, using a policymaker standard of a 100-year emissions carbon dioxide equivalent impact known as the *global warming potential (GWP)*.

Erickson & Lazarus also introduce a "climate test" focus on the downstream end-uses of methanol, cautioning that methanol from the KMMEF facility could lead to higher GHG emissions. This would result from displacement of more common, and potentially lower GHG, olefin pathways, or the use of methanol for transportation purposes such as gasoline blending that could both raise the GHG emissions from fuel use and induce greater fuel demand.[6] This caution in assessing market impacts leads Erickson & Lazarus to conclude that "it seems just as or more likely that it [methanol from KMMEF] would displace the other, lower-GHG olefin routes that appear likely to dominate globally" which therefore "suggests that the Kalama facility would likely not reduce the emissions associated with olefin manufacture". Despite this caution in evaluating market effects, Erickson & Lazarus acknowledge that "if indeed gas-based methanol from Kalama could directly displace the production of methanol from coal, GHG savings could be quite significant."

At their most stringent, Erickson & Lazarus make the case to address a "bigger question: is gas-to-methanol part of a low carbon economy". This represents a global, long-term perspective in assessing GHG impacts, a perspective that seeks to consider market and technology developments, and to consider the scale effects of increased supply. A timely publication by the IEA examining The Future of Petrochemicals offers a new opportunity to evaluate KMMEF under this bigger question, and is explored later in this analysis.

Draft Supplemental Environmental Impact Statement (DSEIS)

In response to findings by the Washington State Shoreline Hearings Board and the Cowlitz County Superior Court Order, a DSEIS was recently released with a full life-cycle GHG evaluation, including sensitivities. The co-lead agencies on the DSEIS are the Port of Kalama and Cowlitz County. Life Cycle Associates produced the life-cycle analysis under contract with Northwest Innovation Works, which is included as Appendix A to the DSEIS (DSEIS LCA).

The report focuses on the production of methanol, with an alternative source of methanol from coal in China, while also including some analysis of methanol pathways to olefin or transportation fuels. On a full life-cycle basis, the DSEIS reports a range of annual life-cycle emissions between 1.96 to 2.62 $MtCO_2e$ per year (DSEIS Table 1.1, copied below). Roughly half of these emissions are assessed to be from upstream natural gas, assuming a 0.7% methane leak rate attributed to KMMEF methanol, followed by direct combustion of natural gas at the facility.[7] The greatest uncertainties are the source of grid power used by the facility, and the upstream natural gas emissions. On a per ton of methanol basis, this is 0.54 tCO_2e/t-MeOH to 0.73 tCO_2e/t-MeOH.[8]

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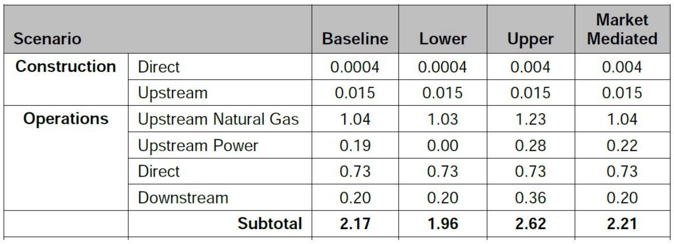
[6] Based on Erickson & Lazarus (2013) analysis of Keystone XL pipeline, induced demand from additional transport fuels on the market could be as high as a 60% increase in consumption beyond the amount of fuel supplied at per barrel oil prices in the $100 range. Current prices (12/6/18 according to oilprice.com) are in the $50s per barrel and IEA (2018b) forecasts long-term oil prices under a low-carbon future hovering in the $60s (Table A.7). At these lower oil-prices, the supply curve is much more flat than at $100 per barrel, such that induced demand would be relatively muted compared to the Keystone XL analysis (Erickson & Lazarus 2013).

[7] The report uses a 100-year global warming potential (GWP) in determining carbon dioxide "equivalents" (CO_2e) using the IPCC 4th Assessment Report (AR4) 100-year GWP for methane of 25. These are current standards for policy evaluation in most states. Erickson & Lazarus use the updated 5th Assessment Report (AR5) value of 34 for methane and also explore the 20-year GWP perspective where methane GWP is 86 times that of carbon dioxide. While using the best science, and thus the AR5 GWPs, is desirable, policy precedent continues to rely on AR4 values. There is less precedent for using 20-year rather than 100-years GWPs in evaluating industrial infrastructure projects.

[8] Under a similar upstream natural gas methane leakage rate and 100-year GWP Erickson and Lazarus (2018) estimate a value consistent with the higher range (0.72 tCO_2e/t-methanol), including a higher GWP for methane,

Table 1: Estimate of Annual KMMEF Life-Cycle Emissions, Copied from DSEIS (Table 1-1)



Scenario		Baseline	Lower	Upper	Market Mediated
Construction	Direct	0.0004	0.0004	0.004	0.004
	Upstream	0.015	0.015	0.015	0.015
Operations	Upstream Natural Gas	1.04	1.03	1.23	1.04
	Upstream Power	0.19	0.00	0.28	0.22
	Direct	0.73	0.73	0.73	0.73
	Downstream	0.20	0.20	0.36	0.20
	Subtotal	**2.17**	**1.96**	**2.62**	**2.21**

The alternative methanol assumed to be displaced in the DSEIS comes from coal-to-methanol production, ranging from 12.3 to 13.7 $MtCO_2e$/year. Under such a displacement outcome, the net annual global GHG savings would be -9.6 to -12.6 $MtCO_2e$/year - roughly an 80-85% reduction in emissions per ton of coal-based methanol displaced. Looking at the full sensitivity range (DSEIS Appendix A Figure 6.2) widens the lower range to roughly -9.0 $MtCO_2e$/year.[9]

Of the emissions associated with the production of methanol at KMMEF, just under 1 $MtCO_2e$ per year is projected to occur either in-state or from off-site electricity, including 0.73 $MtCO_2e$ per year at the facility itself. The Shoreline Conditional Use Permit (SCUP) requires a reduction or offset of facility emissions over time - either under the proposed Clean Air Rule (CAR) or at a rate similar to that proposed under CAR (1.7% per year decrease), down to 0.57 $MtCO_2e$ in 2035. The project developers have proposed to greatly exceed the SCUP by voluntarily mitigating all of the in-state emissions, including any off-site power, over the life of the project. At initial project emissions rates, voluntary mitigation could reach 40 $MtCO_2e$ over a 40 years facility lifetime through approaches including the purchase of verified carbon credits, payment to a GHG mitigation fund, or reduction of in-state emissions directly relating to the facility. This analysis considers net impacts, with and without crediting for this voluntary mitigation.

The DSEIS LCA includes a chapter on Market Assessment and Economics, including displacement effects of marginal producers and macroeconomic effects, methanol supply options to the East coast of China, methanol and end product demand, and methanol production costs.

Based on that market analysis, methanol destined for Chinese markets is forecast to displace exclusively coal to methanol production on the margins and this is the primary DSEIS LCA scenario. Market effects examined in the LCA include displacing marginal methanol plants, the effect of making more coal available in China for other uses, and the market effect of new methanol on olefins and other methanol markets such as fuel. The DSEIS LCA forecasts a potential 10-15% increase in the emissions per ton of methanol from displaced coal being otherwise consumed, which is 3% or less of the net emissions reduction projected from displacing coal from methanol production in the first place.[10]

Compared to the relative displacement effects of natural gas versus coal derived methanol, displacement effects on direct olefin substitution are much smaller, especially if methane leakage does not exceed 1%. The DSEIS LCA finds that the KMMEF methanol pathway would result in roughly 0-20% lower emissions than a

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greater upstream leakage (1.0%), and greater upstream power emissions.

[9] Under a higher methane GWP, such as the 20-year metric explored by Erickson & Lazarus, while emissions attributable to methanol production at KMMEF increase, an alternative of coal-to-methanol increase by even more such that the net GHG emissions from natural gas to methanol, such that net displaced emissions actually slightly *increase* (DSEIS LCA Figure 6.2).

[10] Out of a 0.5 to 0.7 tCO_2e/t-methanol produced at KMMEF, or a net savings of 2.7 to 3.5 tCO_2e/t-methanol. This is based on either an assumed 10% price elasticity or an 2016 study on a coal export terminal (ICF International, 2016), the coal returned to the Chinese market from KMMEF methanol displacement would add about 0.06 to 0.09 tCO_2e/t-methanol.

petroleum naphtha steam cracking pathway, the "historically predominant role as an olefin feedstock". By contrast, Erickson & Lazarus 2018 report that KMMEF methanol derived olefins are roughly 1-2 times as carbon emitting as naphtha or ethane to olefin, given 1% upstream methane leakage. A coal-based methanol to olefin pathway would be roughly 5 to 10 times more emissions intensive than alternate olefin pathways.[11]

The DSEIS LCA also examines methanol as a fuel or fuel blending agent, ranging from a home-cooking or industrial fuel displacing coal to gasoline-replacing substitutes. As a replacement for coal, the GHG benefits remain substantial. As a gasoline-blending agent, the KMMEF methanol in a M15 gasoline fuel is estimated to be almost exactly the same as petroleum gasoline (DSEIS LCA Figure 5.4). Coal-derived M15 is roughly 10% higher emitting than KMMEF methanol or petroleum gasoline. The DSEIS LCA anticipates no additional secondary market effects on GHG emissions.

Discussion of the LCA approaches

A Conservative Central Estimate, Based on Global Average Methanol CO_2 Intensity

According to the IEA Petrochemical outlook (IEA 2018), carbon dioxide emissions intensity of methanol production averaged around 2.25 tCO_2/t-MeOH in 2017 and in a lower emissions future scenario would be a bit lower, at 1.75 tCO_2/t-MeOH by 2030. This analysis considers the lower value as representative of either more efficient technology that KMMEF methanol could displace in the short-term, or the likely displaced methanol into the 2030s. Notably, these estimates are for carbon dioxide only and do not include methane leakage. Adding methane to the IEA modelling could shift the technology mix somewhat. Given that coal-based methanol may have higher methane emissions than KMMEF methanol, one of the most likely outcomes of IEA (2018) considering methane is a more rapid shift from coal to natural gas methanol. KMMEF methanol emissions, including significant GHG emissions from methane as well as carbon dioxide, and without crediting for voluntary emissions mitigations would be between 0.53 and 1.11 tCO_2e/t-MeOH. The primary difference in this range is the methane leakage rate, ranging from 0.07% to 3%.

Relative to the global average CO_2 emissions intensities in the IEA report, this range of emissions intensity represents a 0.6 to 1.7 tCO_2e-t/MeOH benefit. At full capacity of 3.6 Mt-MeOH per year, this translates to a net global savings of 2.3 to 6.2. $MtCO_2e$/year. Including credits for 1 $MtCO_2e$/year would raise net global savings to 3.3 to 7.2 $MtCO_2e$/year.

This range, 0.6 to 2.0 tCO_2e/t-MeOH up to an annual potential of 2.3 to 7.2 $MtCO_2e$/year, should be viewed as a conservative likely outcome in the near to medium-term, since the IEA outlook (IEA 2018) does not include methane emissions which have been shown to be a large share of methanol life-cycle emissions (DSEIS; Erickson & Lazarus 2018). Adding methane emissions to the IEA average CO_2 intensities would favor greater emissions intensity benefits from KMMEF methanol, and would likely outweigh any market effects that could hypothetically result from an increased supply of methanol on the global market. Thus, this range presents a conservative range of net global GHG benefits.

Coal vs Olefin Displacement

To the degree that KMMEF methanol displaced coal-based methanol from the market, the emissions reductions are substantial and significant no matter the eventual end-use of that methanol.[12] Reading of the full

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[11] Methane leakage would need to be in the 20-25% range to make KMMEF methanol emissions intensity equivalent to coal-based methanol.

[12] For methanol production, under the 100-year GWP scenarios evaluated in both the DSEIS and Erickson &

range of DSEIS LCA sensitivities (Appendix A, Figure 6.2) suggests net GHG benefits from KMMEF methanol that displaces coal are estimated to be 2.5 to 3.8 tCO_2e/t-MeOH (to a maximum of 9.0 to 13.6 tCO_2e/year).[13]

In the case of olefin displacement from predominantly petroleum products, a best estimate is the IEA reports 1.0 tCO_2 per tonne of “high value chemicals”, largely olefins, which again does not include any non-CO_2 emissions. This is in-line with the emissions intensities reported in Erickson & Lazarus, and can be compared with a range of emissions intensities reported in Erickson & Lazarus of 1.6 to 2.2 tCO_2e/t-olefins from KMMEF methanol. On a per t-MeOH basis (with 2.6 t-MeOH needed to produce one t-olefins, Banach 2017), this net *added* emissions from a KMMEF to methanol displacement of petroleum olefins is 0.2 to 0.5 tCO_2e/t-MeOH. Including credits for voluntary mitigation, the range is a slight benefit (*less than* 0 tCO_2e/t-MeOH added) to 0.2 tCO_2e/t-MeOH added.

Perhaps the most useful framing of uncertainty in the net life-cycle benefits from KMMEF methanol is to determine at what ratio of petroleum-olefin to coal methanol displacement would the net GHG benefits be zero. Under a scenario of no crediting for voluntary emissions reduction, the displacement would need to be between 5% and 20% share of coal-methanol displacement versus petroleum-olefin displacement for a breakeven GHG impact. If crediting the voluntary emissions mitigation, the range decreases to a 0% to 5% share of coal-methanol versus petroleum-olefin displacement for a breakeven GHG impact. A higher displacement share of coal-methanol would result in net GHG emissions reductions.

This is admittedly a simplified comparison. There are many complex factors regarding the availability and carbon-intensity of refinery products (Ren et al. 2008),[14] potential market and displacement effects (which the DSEIS indicates are small), and supply curve considerations beyond strict economics - such as supply and job security of domestic production.

Erickson & Lazarus (2018) raise some critical considerations before long-lived and capital intensive infrastructure projects are green-lighted. They correctly highlight that there is uncertainty as to whether the KMMEF methanol will offer long-term benefits in GHG reductions, while emphasizing various pathways by which adding that methanol to the market could result in more emissions. However, despite “finding reason to doubt” that coal displacement is more likely than other olefin displacement, and arguing that “it seems just as or more likely that it would displace the other, lower-GHG olefin routes that appear likely to dominate globally”, Erickson & Lazarus do not provide sufficient evidence that in the case of KMMEF olefin displacement would be in the 80% or greater share of petroleum-olefin pathways relative to coal methanol. Therefore, the conclusion that “the facility would be just as likely to increase global GHG emissions as to decrease them” is not justified. A “just as likely” starting point for coal displacement, meaning 50-50, KMMEF would still offer a 1.0 tCO_2e/t-MeOH net benefit even with high-leakage (3%) natural gas and no crediting of voluntarily mitigated emissions.

Lazarus 2018, emissions savings range from around 50%-85% per ton of methanol produced.

[13] Includes consideration of crediting or no crediting for voluntary mitigation, plus additive effects of the following categories: coal upstream, coal use rate, power generation mix, NG upstream, and methanol delivery.

[14] Due to the complexity of different feedstocks producing differing amounts and types of olefins, comparisons of MTO with petroleum derived olefins is extremely challenging, and beyond the scope of this analysis. Expanding capacity from petroleum-based olefins may also be tied to increased fuel consumption or help keep fuel cheap, such that stand-alone olefin production may be more desirable since no fuel production is locked in while natural gas demand and cost would increase if from MTO.

The market analysis produced for the LCA gives compelling evidence that, at the very least more coal methanol substitution should be expected than naphtha-olefin substitution. Therefore, a 1 tCO_2e/t-MeOH net benefit is a very conservative estimate, one that could potentially be kept as a worst-case expectation for GHG benefits through some sort of regulatory arrangement for the market destination of KMMEF methanol.

With a concerted focus on displacing coal-based methanol production, keeping upstream methane leakage towards or at best practice levels, and finding high-quality approaches to voluntary mitigation of remaining emissions, the per t-olefin benefit could be substantially greater, potentially exceeding 8 tCO_2e/t-olefin.

Transportation Petroleum Gasoline Displacement

Somewhat comparable to the KMMEF analysis, Erickson & Lazarus (2018) report that "an 85% blend of gas-derived methanol would yield life-cycle GHG emissions 15% to 19% higher than conventional gasoline" while also inducing added liquid fuel consumption and perhaps slowing a transition to electric vehicles by keeping fuel prices lower.[15] Erickson and Lazarus (2018) does not appear specific to KMMEF methanol. The DSEIS expects end-use demand changes through secondary market effects to not result in any increase in GHG emissions, since:

> "China methanol plants operate at relatively low capacity factor with expensive methanol. Since the existing excess capacity is not fully deployed to serve the fuel market, a new source of methanol should not shift expensive coal methanol into the fuel market."

Regardless of the exact impact including secondary displacement effects, the comparison is similar to that with olefins. To the extent that KMMEF methanol displaces coal-based methanol (and oil-prices remain low), the GHG benefits of KMMEF methanol as a fuel will be significant. To the extent that KMMEF methanol as a fuel replaces petroleum gasoline and oil-prices are high (greater induced demand from high supply-side price elasticity), the benefits will be close to zero and possibly negative.[16]

The Bigger Question: KMMEF in the Low-Carbon Economy

There are many hypothetical pathways for KMMEF methanol to be used in global markets, while also reason to anticipate negligible impact in a competitive global methanol market (supply would simply come from somewhere else). Yet, there appears to be high-level agreement on several points:

- KMMEF methanol that displaces coal-based methanol will result in a substantially greater, by up to an order of magnitude, decrease in net

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[15] The induced market effects do merit discussion. Erickson & Lazarus (2013) report a potential 60% additional net emissions impact from induced demand based on an earlier study focused on Keystone XL adding to global fuel supplies. Under lower oil prices, such as currently or those projected in future low-carbon scenarios (IEA 2018b), additional net emissions impact is likely to be much lower. With low oil prices and assuming marginal to negative GHG benefits from methanol (making fuel switch unlikely due to carbon pricing), methanol is much less likely to gain a foothold in the transportation fuel market.

[16] Of note regarding competing methanol pathways, as oil-prices rise and the likelihood of methanol competing economically as a fuel increase, at the same time the competitiveness of coal-based methanol for both fuel use and for olefin production increases. High oil-prices should shift the market towards even greater odds of coal-methanol displacement, thereby mitigating and perhaps overcoming any market induced demand impacts that might increase net GHG emissions.

global emissions than any effect of substitution for petroleum-based products. KMMEF methanol that displaces petroleum-based products, such as olefins and transport fuels, may result in a per unit of methanol basis small net decrease to a 10% net increase in emissions (particularly if induced market effects are large). Unless KMMEF methanol predominantly replaced petroleum-products on the market (80% or greater), net global GHG benefits would be positive on a life-cycle basis.

- The market for methanol is rapidly expanding globally, at around 9% annually from 2010 to 2015 (Alvarado, 2016), a trend expected to continue.[17] Production has been driven by MTO demand, at roughly 50% of demand growth from 2010-2015 (Alvarado, 2016). Future MTO growth is expected through 2030 - roughly doubling from 2017 expected values, most significantly Chinese coal MTO production (DSEIS, IEA 2018). Methanol as a fuel additive has also seen strong annual growth which is expected through at least 2021 (Alvarado, 2016).

Given these general areas of agreement, the overarching question from a long-term climate perspective appears to be what methanol production volumes and sources of supply are most likely consistent with a low-carbon future. To accurately assess the exact annual emissions impact of the KMMEF methanol plant requires much more certainty in predicting a methanol to end-product scenario than we can reasonably make.

Short to Medium-Term Global GHG Impacts

Erickson & Lazarus flag legitimate concerns about the potential pitfalls of large, fossil-fuel consuming infrastructure projects. This topic is frequently described in terms of carbon lock-in, where capital intensive infrastructure investments (e.g. coal power plants, gasoline-powered vehicles) in effect prevent future lower-carbon technologies from entering the market (Erickson et al., 2015). In their discussion brief, Erickson & Lazarus (2018) identify pathways whereby the net GHG effects of KMMEF would lead to an increase in emissions, however provided no confidence that such pathways are likely to be realized to the degree necessary to erase most or all of the GHG benefits of displacing coal methanol. The DSEIS has taken a deep look at the methanol market and separately proposed voluntary emissions mitigation for all in-state emissions, including imported power, associated with the KMMEF methanol production.

The DSEIS paints a more complete picture of market conditions over the short-to-medium term, enough to assert that it is highly likely that displacement will exceed a conservative maximum ratio of coal displacement to petroleum displacement (roughly 1:5 under a very conservative set of assumptions) needed to have a net GHG benefit.[18] Erickson & Lazarus make a tenuous case based on a general, current, global market share that displacement may be at least as likely or more likely in petroleum-based products than coal-based methanol. They do not demonstrate with any confidence how the substitution ratio would exceed 5 to 1 or greater. The preponderance of the evidence points to a much lower ratio of petroleum substitution, and thus suggests a likely significant net global GHG benefit.

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[17] IEA (Methodological Annex, 2018) projects over 50% growth globally from 2017 to 2030, and nearly 90% growth from 2017 to 2050. This includes a "Clean Technology Scenario" or CTS with around a four-fold increase in North American methanol production from 2017 to 2030 (about 15 Mt-methanol/year) and remains around three-times greater in 2050 than in 2017.

[18] It is also likely that the ratio needed to exceed is indeed lower, perhaps as little as 1:20, given the likelihood of natural gas sourced from relatively low methane leakage wells, and the decision to voluntarily mitigate in some form roughly 0.28 tCO_2e/t-methanol produced (0.97 $MtCO_2e$ per 3.6 Mt-methanol based on DSEIS findings).

Long-Term GHG Impacts

Over the long-term, the question of the role of natural gas based methanol remains. One way to address the long-term low-carbon compatibility is, in the words of Erickson & Lazarus (2018), to:

> "...look to available long-term, low-emissions scenarios for added insights. Do these scenarios suggest that the technology in question (or others of similar or higher emissions) would expand in market share? How might demand, supply, and prices for key feedstocks (e.g. coal, naphtha or natural gas) and products (e.g. methanol or olefins) change, and how might that affect the viability of the proposed facility?"

The timely release of a comprehensive analysis by the IEA, The Future of Petrochemicals (IEA 2018), has offered valuable insight on these questions. IEA (2018) projects several scenarios, including detailed *Reference (RTS)* and *Clean Technology (CTS) Scenarios* with 60% lower CO_2 emissions in 2050 and 25% lower cumulative emissions through 2050 (15 billion tCO_2) than the RTS. A major drawback of the IEA report is the exclusion of non-CO_2 GHGs, most importantly for the methanol discussion is not tracking methane emissions. Nonetheless, a few major points regarding the supply of methanol in the RTS and the CTS bear highlighting:

- **Natural gas based methanol use is much greater under the CTS than the RTS** in both 2030 (40% or 26 Mt-methanol) and 2050 (70% or 58 Mt-methanol). Total methanol supply is more or less unchanged through 2050 (less than 2% difference between RTS and CTS), and is actually greater through at least 2030 in the CTS.
- **Through 2030, MTO is expected to more than triple from 2015 levels** (4 Mt) in the RTS (to 14 Mt) or more than quadruple in the CTS from to 17 Mt. Net growth from 2030-2050 does not continue, as MTO remains a marginal global source of "high-value chemicals" (HVCs) production.
- Coal-derived methanol increases from 2015 to 2030 in both scenarios, although is nearly 25% (17 Mt-methanol) lower in the CTS. By 2050, coal-derived methanol is 75% (65 Mt-methanol) lower in the CTS than the RTS, down to roughly half of 2017 levels. **With similar overall levels of methanol production, the reduction in coal-methanol supply is almost entirely the result of increased natural gas methanol production** - which includes substantial net growth in North American methanol production through 2030 (IEA Figure 5.10).

Scenario projections towards a lower-carbon CTS are completely consistent with the KMMEF project: Coal-based methanol in "Asia Pacific" is increasingly displaced by natural gas-based methanol. North American production of natural gas based methanol rapidly increases through 2030 and remains several times greater than current levels through 2050.

In the IEA scenarios, coal to natural gas fuel-switch represents 25% of cumulative petrochemical industry emissions reduction through 2050. Roughly half of the coal to natural gas shift in the CTS occurs in methanol production with the remainder in Ammonia production. Coal to natural gas fuel shift is the second largest carbon reducing approach, behind carbon capture.[19] Even at half of the coal to natural gas related carbon dioxide

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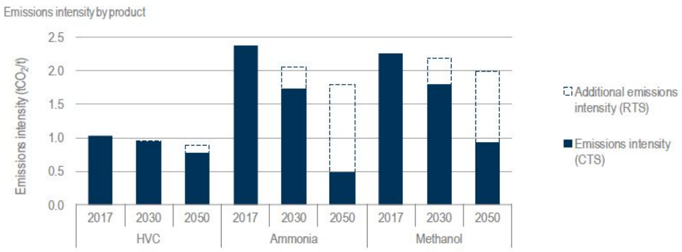
[19] While some carbon capture occurs in the methanol industry, 11% of the cumulative total, or roughly 4% of the global total CO_2 emissions reduced under the CTS across the entire petrochemical industry, which is substantially lower than the impact of coal to natural gas fuel shifts.

reductions, the switch to natural gas methanol would rank above both plastic recycling of all petrochemical products, and alternative feedstocks (bio-feedstocks) in terms of quantity of carbon dioxide avoided relative to the RTS.[20]

Were KMMEF to become less consistent than forecast under evolving low-carbon pathways such as the CTS (e.g. dropping below global averages), adding carbon capture could be an additional long-term strategy, as Washington could be uniquely positioned for a long term carbon storage industry. Adding shares of pipeline-quality biogas instead of fossil fuel natural gas is another possible long-term strategy.[21] Biogas scenarios have been evaluated in Washington-specific E3 Low Carbon 2018 Scenarios for the Public Generating Pool and the Washington Deep Decarbonization Project.

Beyond this global methanol supply perspective, two additional long-term perspectives offer valuable insights regarding KMMEF's emissions reduction role. The first is comparison of the average emissions intensity of methanol to that of KMMEF, IEA 2018 Figure 5.11 copied here:



Note that IEA reports only on the carbon dioxide emissions intensity, meaning that methane emissions are not counted. It is also unclear if this emissions intensity is life-cycle or only for energy consumption and process emissions at the facility. Adding either would increase the emissions intensity on a tCO_2e/t-methanol perspective for comparison with KMMEF methanol.

In the "upper" projection, the DSEIS LCA estimates an emissions intensity of 0.73 tCO_2e/t-methanol, which is consistent with the Erickson & Lazarus (2018) estimate given a 1% upstream methane leakage and a 100-year GWP perspective. **Such an emission intensity would place KMMEF methanol well under the CO_2-only global average emissions intensity in 2050 as forecast under the Clean Technology Scenario.** Even with 3% methane leakage (again, methane is not considered in the IEA (2018) estimate), the full life-cycle KMMEF methanol emissions intensity would be only slightly above CO_2-only global average emissions intensity in 2050.[22] Crediting voluntary mitigation of roughly half the emissions intensity for KMMEF methanol, and adding methane leakage to make the IEA emissions intensities directly comparable to an LCA perspective means that the KMMEF emissions intensity would be significantly lower than the average 2050 CTS emissions intensity, even with a 3% methane leakage rate. Nevertheless, KMMEF should actively seek to ensure that natural gas supplies conform to lowest leakage practices to ensure the greatest GHG benefit.

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[20] The CTS does not project any biomass gasification through 2050 for methanol production. There is some electrolysis production based in Europe (1-2% of the global total from 2030 on).

[21] Based on a total NG feed of 241.5 tonne/hour (Table 3.12, DSEIS LCA) and a heating value of 23,180 btu/lb (Table 3.7, DSEIS LCA), annual demand would be 106 TBTU. In the 2018 Scenarios from the E3 low-carbon study this is roughly equal to the total Washington plus Oregon biomethane potential in 2040 at costs less than \$20/MMBTU and less than half of Washington plus Oregon biomethane potential using purpose grown crops in 2040 at less than \$20/MMBTU. Recent natural gas Henry Hub spot prices have sat at around \$3/MMBTU (according to EIA Natural Gas Weekly as accessed on 12/10/2018). Biogas could also be sourced from outside of region, particularly if the BC pipeline route could be utilized. This merits further study.

[22] At a minimum, KMMEF will be required to reduce emissions by 0.16 $MtCO_2e$ per year under CAR or similar requirements. This would reduce the emissions intensity by roughly 0.05 tCO_2e/t-MeOH by 2035.

Another valuable perspective regarding long-term low-carbon pathways is to examine the role of methanol in an even deeper carbon reduction scenario. IEA (2018) models two such scenarios that go beyond the CTS: an exclusively bioenergy pathway and electricity-based processes exclusively from renewables (e.g. electrolysis). IEA (2018) finds that "By 2050, about 380 Mt of methanol is required in the bioenergy pathway, and 1,000 Mt (more than total primary chemical demand in the CTS) in the electricity pathway."[23]

Over twice as much methanol is required in the bioenergy pathway while five-and-a-half times more is required in the electricity pathway - those that would reduce CO_2 emissions even deeper than the CTS pathway.

IEA (2018) sees methanol not just increasing, but multiplying, under even lower carbon scenarios (although KMMEF as proposed would likely require a pipeline quality source of biogas). Such scenarios convincingly show that natural gas based methanol is very likely consistent with a low-carbon future.

Conclusions and Recommendations

The production of methanol at KMMEF appears highly likely to provide a net global GHG benefit in the short, medium, and long-term. We quantify annual emissions benefits in a likely band of 2.3 to 7.2 $MtCO_2e$/year through at least 2030 - which includes a range of methane leakage (0.7% to 3.0%) and voluntary mitigation of between zero and one $MtCO_2e$/year. It is not impossible, though very unlikely, that methanol from KMMEF could contribute to displacing lower-carbon petroleum-olefin or transportation options. This analysis did not find any credible analysis that such displacement is expected to be the majority, let alone dominant displacement pathway. A full range that bookends petroleum-dominated displacement and coal methanol dominated displacement would broaden the hypothetical range to a -0.5 to 13.6 $MtCO_2e$/year range.

In general, this analysis of a proposed new industrial facility indicates that such facilities have a strong role to play in a low-carbon future so long as two major factors are in place: (1) That the feedstock displaced is primarily coal; and (2) that much lower GHG pathways are unlikely to provide a substantial market share over the lifetime of the facility AND the facility cannot reasonably convert to at least match emissions intensities of those lower GHG pathways. In both cases, KMMEF appears likely to meet those criteria.

Several approaches can deliver even greater certainty that KMMEF is compatible with a current and future low-carbon economy. These include:

- Playing a leading role in actively sourcing and promoting industry best practices for low-leakage natural gas, which also limits the amount of unused or waste natural gas;
- Ensuring a robust voluntary mitigation program to annually offset the in-state share of emissions, one that relies on highest-standard markets and methodologies with regards to permanence and additionality of emissions reductions;
- To the extent they exist, seeking purchasing agreements and accepting clear regulatory frameworks that prioritize the displacement of coal to methanol production; and
- With an eye to long-term industry evolution, research and consider opportunities through

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[23] The demand is so much greater in the electricity scenario since ethylene production under such a pathway can only be produced indirectly, via methanol.

grants and partnerships, to further improve the global GHG impact of KMMEF. Such approaches could include carbon capture and storage in Washington's unique ocean basalt formations and / or adding alternative low-carbon feedstocks such as biogas to the feedstock mix.

Given an already positive general outlook on the consistency of KMMEF methanol with a lower-carbon future, pursuing these recommendations can establish with more certainty the role of such a Washington-state based facility in a deeply decarbonized economy.

About Low Carbon Prosperity Institute

The Low Carbon Prosperity Institute (LCPI) system design work delivers on the need for technically accurate long-term greenhouse gas reduction strategies to guide policy decisions. We explore the opportunities and complex risk factors associated with creating climate policy from the state level up. We share a belief in the power of business leadership, bipartisan problem solving, and data-driven public policy.

The Low Carbon Prosperity work began in 2014, as a project of the Washington Business Alliance and its PLAN Washington agenda. At the LCP Institute, we use research and analysis to frame challenges and potential solution sets. We treat policy perspectives respectfully and in depth, thinking critically without adhering to binary frameworks. In so doing, we create the space for the discovery of better answers, and seed the ground for smarter political action.

The LCPI approach is complemented by our Greenhouse Gas Reduction Explorer modeling tool, which is considered the "Gold Standard" for evaluating legislation to place a state-based price on carbon or establish a limit on emissions. Learn more about the tool here.

The Low Carbon Prosperity Institute publishes articles and reports, participates in the formation of policy, and hosts discussion events across the state. We are frequently consulted on the following subject matters: energy waste reduction and technology adoption; carbon-free energy resources, deploying energy efficiency, and encouraging low-carbon fuel switching; congestion relief and carbon reduction through the electrification of transportation and adoption of Automated, Connected, Electric, and Shared (ACES) vehicles; the sequestration potential and revival of rural economies; capturing the value of our carbon competitive manufacturing sector; and innovation, entrepreneurship, and the CleanTech opportunity.

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