January 2014

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Abstract

This study iterates the GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) Model predictions for the well-to-wheel emissions of flex-fuel vehicles (FFV) running on methanol fuel made from natural gas, when considering the emission impact of various scenarios. Specifically, Fuel Freedom Foundation (FFF) examined the impact of new natural-gas drilling regulations adopted in Colorado, a reduction in flaring and venting due to conversion of methane into methanol at or near the wellhead and the energy efficiency ratio attributed to engine optimization for alcohol fuels. When considering the factors listed above, this report found that the 2013 GREET Model, GHG (greenhouse gas) emissions and total smog-forming urban emissions for methanol derived from natural gas in an M85 (85 percent methanol and 15 percent gasoline) FFV can be improved by 16.93 percent and 29.95 percent, respectively, compared to the current estimates. When comparing the updated findings and GREET calculations to gasoline (E10 [10 percent ethanol and 90 percent gasoline]) in a gasoline vehicle, total GHG emissions and total urban emission drop by 11.92 percent and 32.10 percent, respectively. Of the urban emissions, vehicle particulate matter 2.5 emissions decrease by 31.94 percent.

We also compared different sources of natural gas. If the source of the methanol fuel is flared gas, total GHG emissions decrease by 73.84 percent, compared to a gasoline-fuel vehicle. We also assessed methanol produced from associated gas. Associated gas production is a byproduct of oil extraction and, in particular, fracking for oil produces a large amount of associated gas. We examined two sources of associated gas, the Bakken shale region located in North Dakota and Montana, and the large Wattenberg field of the Denver-Julesburg Basin in Colorado. In both cases we used the economic value of the product to attribute proportional emissions between the gas and the oil paths in GREET. Under these considerations, GHG emissions drop by an additional 84.88 percent for methanol made from Bakken-associated gas and by an additional 28.99 percent for Denver-Julesburg (D-J) Basin-associated gas.

Last, we discuss further opportunities for reduction of emissions both in the GREET Model itself and by improvement in technologies. When considering solutions for improving air quality, policymakers may consider these factors for determining future estimates of well-to-wheel emissions of methanol fuel produced from natural gas for light-duty vehicles.

Contents

Introduction

Using the GREET Model as our tool, FFF applied separate but overlapping assumptions to study potential reductions in GHG and urban emissions by adopting natural-gas derived methanol as a fuel for light-duty vehicles.

The first assumption accounts for new oil and natural gas regulations, recently approved in Colorado, which are more stringent than current Environmental Protection Agency (EPA) standards. According to the Colorado Department of Public Health and Environment, the new rules are expected to reduce CH4 (methane), VOC (volatile organic compounds) and N2O (nitrous oxide) emissions by an estimated 95 percent and can act as a model for unconventional oil and natural-gas drilling operations as they continue to increase across the country. The proposed regulations apply to the recovery and processing of methane. This means a 95 percent reduction in CH4, VOC and N2O emissions from the extraction and processing of natural gas.

We continue to develop this concept by incorporating technologies that can convert CH4 to liquid methanol at a processing facility. Performing this process would prevent downstream leakage and venting of gaseous CH4. These downstream emissions were recently estimated by the Environmental Defense Fund (EDF) to comprise 64 percent of total CH4 emissions due to leakage and venting (Alvarez).

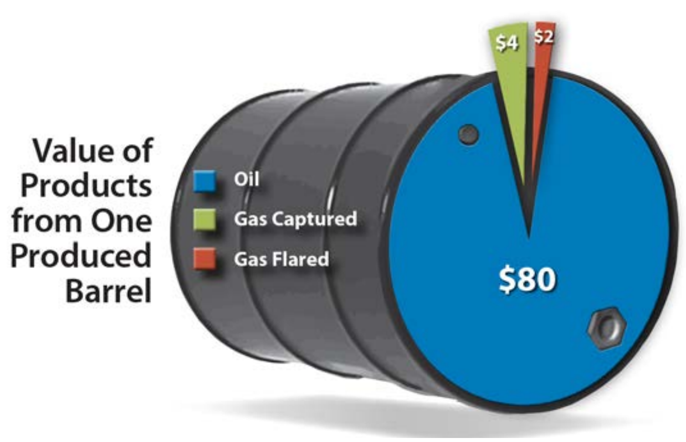
Last, we consider methanol as a transportation fuel. Due to a higher octane rating, lower temperatures within the engine and other factors, the estimated efficiency of methanol as a transportation fuel is 10 percent higher than its energy content perceives (Leonard, Margalef, Jackson, Chiang, TIAX, LLC). The Ford Motor Company conducted a study using ethanol, which has similar combustion characteristics to methanol due its high octane rating, reaching similar conclusions (Hubbard 864). For most newer cars, a software update to adjust the spark plug and exhaust valve timing, "neat methanol," or 100% methanol can achieve an efficiency that is 19 percent higher than current GREET estimates (This may require EPA re-certification). This addition can be applied proportionately to M85, a fuel blend that contains only 85 percent methanol with the remainder being gasoline (Bromberg and Cohn, MIT). Accounting for the portion of M85 that is composed of gasoline, we get a revised energy efficiency ratio (EER) of 1.16 —16 percent higher than the EER for M85 used in GREET. If proven to be true, these results would suggest that less methanol is consumed per mile than current GREET estimates, requiring less fuel production and less transporting of the fuel. Further research based on methanol use in China also suggests a 20 percent decrease in tailpipe nitrogen oxide (NOx) and carbon monoxide (CO) emissions and a 70 percent decrease in tailpipe particulate matter (PM) emissions, compared to conventional gasoline (Luft).

These factors — Colorado regulations, methanol conversion at or near a natural-gas-processing facility and improved vehicle efficiency and emissions — provide a model that is independent of the source of natural gas. For the purposes of this paper, we will refer to this as the "base scenario." Each of these three adjustments apply to a separate part of the fuel life-cycle.

A separate scenario was also applied in combination with the base scenario, to study the potential of flared gas as a feedstock. Flared gas is natural gas that is burned directly into the atmosphere at the wellhead site, rather than being collected and sold as a fuel. The GREET Model has developed a pathway for measuring the emissions of methanol produced from such gas. We used this pathway to determine the emissions of methanol derived from flared gas, given our base scenario.

Further, we know that in addition to oil, fracking also produces an abundance of natural gas. This associated natural gas is largely a byproduct of oil production and possesses a low economic value relative to oil. In many cases it is so low that it is not economically advantageous for producers to collect it to bring to market. Thus, we created alternate final scenarios to show what the reduction in GHG emissions would look like if all methanol was produced from associated gas, based on its relative economic value versus oil in the same formation.

We considered two alternate scenarios, based on the following assumptions: 1) In the GREET Model, the attribution of emissions is divided based on the classification of the wellhead. Oil wellheads roll into the oil-to-gasoline path, while natural gas wellheads roll into the natural gas path (and, in our case, into the natural gas and flared gas to methanol path). In a fracking site, a single fracked well will produce two (or more) wellheads; one for gaseous output and one or more for liquid output (oil). FFF contends that this associated gas, although it is produced from a natural gas wellhead, is in fact a byproduct of oil extraction, and would have stayed sequestrated underground were it not for oil. Under that strict assumption, converting this associated gas to methanol fuel to replace oil based gasoline is 100 percent accretive to GHG emissions. However, since the natural gas does have some economic value, we attributed the emissions based on the economic value of the feedstock. Even though the economic value fluctuates over time, we believe that the economy of the drilling is the primary factor determining whether the carbon stays in the ground or is produced in the form of oil, natural gas, etc. To determine respective values, we looked at two basins: the Bakken in North Dakota and the Wattenberg field of the Denver-Julesburg (D-J) in Colorado. In each case we compared the economic value of oil and gas production and attributed emissions accordingly.



Typical Bakken Economic Value Breakdown

Source: Energy & Environment Research Center

In general, we believe these reductions are conservative estimates and do not include certain assumptions that would further reduce emissions. Beyond the above-outlined assumptions, we added a short discussion about further opportunity for reductions in emissions, which we collated at the end of the paper. Nevertheless, the results of the analysis reflect reductions in GHGs and smog-causing urban emissions from the GREET Model when comparing gasoline in a gasoline vehicle and M85 in a methanol FFV.

Methods

We began with the data established by the 2013 GREET Model for light-duty vehicles (LDVs). The data focuses specifically on a gasoline vehicle running on gasoline (E10) and a flex-fuel vehicle (FFV) running on M85.

Developing the Base Scenario (Natural Gas to Methanol)

Applying the new Colorado Regulations (Step 1)

According to the Colorado Department of Public Health and Environment, Colorado's new drilling regulations aim to reduce CH4, VOC and N2O emissions by an average of 95 percent during the extraction and processing of natural gas (Air Quality Control Commission).

To apply this, we reduced the CH4 leakage numbers for the recovery and processing steps of natural gas by 95 percent. These numbers can be found on the "Inputs" tab of the 2013 GREET Model excel spreadsheet in table 4.3 (CH4 leakage rate for each stage in conventional NG and shale-gas pathways). In the table, columns G and H contain leakage numbers for various stages of natural gas production in terms of grams of CH4 per million metric British thermal unit (mmBtu) of natural gas with each row representing a different stage of production. Rows 110 through 115 show leakage at various stages of recovery, from well equipment through processing. These are the stages we categorize under the Colorado regulations. Thus, we reduced the leakage number for CH4 in the cells in rows 110 through 115, columns G and H, using the following formula:

(Emissions)*(1-.95) = Updated emissions

We did not make similar adjustments for VOC and N2O emissions. However, since their contributions to emissions at these stages are small (non-vehicle emissions of VOCs account for 36 percent of total life-cycle VOC emissions while for N2O that number is 25%; of these amounts, even less would likely come from venting and leakage), we believe our conclusions would not be meaningfully impacted by making such adjustments.

All changes from applying the proposed Colorado regulations data are shown in Table A-3.

Applying the Effects of On-Site Conversion of Methane to Methanol (Step 2)

Next, we applied the effects of conversion of methane to methanol at the processing facility. Converting the natural gas to a liquid (in the form of methanol) would eliminate downstream leakage of gaseous methane.

To apply this within the GREET Model, we once again updated emissions numbers on table 4.3 of the "Inputs" tab of the spreadsheet. The cells in rows 116 and 117, and columns G and H represent the CH4 leakage numbers for stages downstream of the processing facility. These cells were adjusted to reflect a zero value for grams of CH_4/mmBtu of natural gas, reflecting the complete elimination of downstream CH_4 leakage.

The cumulative changes from this Step 1 and Step 2 are shown in Table A-4.

Applying the Energy Efficiency Ratio (Step 3)

Next, we applied an energy efficiency ratio (EER) of 1.16 to the updated numbers in steps 1 and 2. To execute this, we again made changes within the GREET Model on the "Inputs" tab.

Table 15.1 (Fuel Economy and Emission Changes by Alternative-Fueled Vehicles and Advanced Vehicle Technologies) of the "Inputs" tab shows the relative gasoline equivalent mpg for various fuels in row 926. We adjusted the number in cell L926, the cell corresponding with a MeOH (methanol) Flex Fuel Vehicle. This number was adjusted from its original 100 percent to 116 percent in order to reflect the superior efficiency expected from methanol.

The results of this change are reflected in Table A-5.

Applying Improved Tailpipe Emissions for Urban Air (Step 4)

The China Association of Alcohol & Ether Clean Fuels and Automobiles (CAAEFA) reported a 20 percent decrease in CO and NOx and a 70 percent decrease in particulate matter tailpipe emissions from the use of M100 compared to gasoline. To apply these findings, we made adjustments to table 3 (Per-Mile Fuel Consumption and Emissions of Vehicle Operations) of the "Vehicles" tab in the GREET Model.

Since the CAAEFE findings are based on M100, we reduced the stated benefits by 15 percent to approximate the results for M85. For example, instead of applying a full 20 percent reduction for CO and NOx, we reduced this benefit by 15 percent. To implement this within the GREET Model, we changed the percentage of emissions relative to baseline gasoline in cells I62 and I63 (the cells corresponding with relative CO and NOx emissions for a MeOH flex fuel vehicle) of the "Vehicles" tab to 2.878 and 0.135, respectively.

We conducted a similar adjustment for particulate matter. We altered cells I64 and I66 (the cells corresponding to relative PM10 (particulate matter) and PM2.5 tailpipe emissions) in the "Vehicles" tab by changing the emissions relative to baseline gasoline by 40.5 percent. This number was determined by reducing the stated benefits of a 70 percent reduction by 15 percent to reflect the lower methanol content in M85. This gave us a value of 0.002 grams per mile for both PM10 and PM2.5.

This was the final adjustment made to establish our base scenario. The results of the base scenario are displayed in Table A-6.

Calculating Percent Change

Last, we calculated percent change of the final results compared to original GREET results with the following formula:

(New emission)/(Old emission) – 1 = Percent change from old emissions to new emissions

This final calculation allowed us to complete our base scenario. The following three scenarios represent modeling completed independently from the GREET Model, but are based off of the final numbers derived from the above-described calculations.

Applying the Effects of Capturing Flared Gas (Scenario 1)

To calculate how using flared gas as a feedstock would affect emissions, we changed the GREET Model's assumption that 100 percent of methanol comes from natural-gas drilling operations. Instead, we adjusted a pathway within the model to assume that 100 percent of methanol production comes from flared gas. This can be done by adjusting cells B and C in row 5 of the "MeOH&FTD" tab, the corresponding cells for the percentage of methanol production for natural gas and flared gas, respectively.

Once we adjusted this input in the GREET Model, we calculated the percentage difference from the original GREET results for methanol emissions and the adjusted results. Table 1 below is a summary of the changes we observed:

	Feedstock	Fuel	Vehicle Operation
CO_2 (w/ C in VOC & CO)	-13.73%	-320.26%	-13.91%
CH_4	-78.05%	-172.93%	0.00%
N_2O	-13.77%	-328.42%	0.00%
GHGs	-37.56%	-309.65%	-13.81%

Table 1. Percent Change from Original M85 GREET Model Results to Scenario 1

We formulated this assumption in combination with the above-outlined base assumptions. Thus, the emissions results for flared gas as a feedstock also reflect the decreased leakage numbers, improved EER and improved tailpipe emissions. The full results can be viewed in Table A-7 in the appendix.

Modeling Associated Gas as a Source for Methanol

The GREET Model attributes emissions from associated gas to the oil-to-gasoline path. Alternatively, we considered a method to attribute emissions based on the economic value of natural gas versus that of oil. To attribute GHGs based on the economic value, we first calculated the production value of each respective source in 2013 for each region.

For oil we used the following formula:

(Amount of oil produced in thousands of barrels) x (price of oil in $/barrel) x (1,000) = Total production value of oil

For natural gas, we took extra steps to account for natural gas liquid (NGL) and waste product output — which varies by region — and pricing. To do so we used the following formulas:

(Amount of natural gas produced in MMcf [one million cubic feet of natural gas]) x (Percentage of methane in natural gas) x (Price of natural gas in $/mcf [one thousand cubic feet of natural gas]) x (1000) = Production value of methane

(Amount of natural gas produced in MMcf) x (Percentage of NGLs in natural gas) x (Composite price of NGLs in $/mcf) x (1000) = Production value of NGLs

(Amount of natural gas produced in MMcf) x (Percentage of waste product in natural gas) x (Price of waste product in $/mcf) x (1000) = Production value of waste products

These values were then combined to get the total production value from natural gas with the following formula:

(Production value of methane) + (Production value of NGLs) + (Production value of waste products) = Total production value of natural gas

We then calculated how much of the value each product contributed to the total value of the two combined products with the following formula:

(Cost of single energy source) / (Combined cost of both energy sources) = Percent of total energy cost

The percentage make up of total cost for each energy source was then applied to the respective GHG total for GREET gasoline and the GHG we had for M85 after Step 4 in the following manner:

([Gasoline GHG total] + [Updated M85 GHG total]) x (Percent of total energy cost for respective energy source) = Economic modeling GHG number for respective energy source

The percent change was calculated as follows:

([Economic modeling GHG number] / [Original GHG number]) – 1 = Percent change from original to economic

The following section explains how we determined the values to plug into the above formulas for both natural gas and oil in the Bakken shale and Wattenberg field regions.

Applying the Economic Modeling Formula to the Bakken Shale (Scenario 2)

Both natural gas and oil production numbers from the Bakken were taken from the Energy Information Administration (EIA). Numbers were given in barrels per day (bbl/d) and mcf/d for each month in 2013. To calculate monthly production, and subsequently yearly production, we did the following calculations:

(Given month production) x (Days in given month) = Total monthly production

Sum (Total monthly production for all months) = Annual production

For natural gas production the number was 185,407 MMcf, natural gas liquids production equaled 150,691 MMcf, waste production 14,878 MMcf and for oil production the number was 322,199 thousand barrels. The percentage makeup of natural gas was calculated using the output numbers of a typical well in the Bakken shale region, acquired from the North Dakota Pipeline Authority and field owners.

For pricing we used the West Texas Intermediate (WTI) oil 2013 estimate of $97.91 per barrel, the 2013 natural gas Henry Hub spot price of $3.84/mcf, the 2012 NGL composite price of $10.98/mmBtu (which converts to $11.23/mcf) and $0.00/mcf for waste products (EIA, “Global Crude Oil Prices”) (EIA, “Short Term Energy Outlook) (EIA. "U.S. Natural Gas Liquid Composite Price (Dollars per Million Btu)”.

These numbers were then inputted into the economic modeling formula shown above and are available in Table A-8.

Applying the Economic Modeling Formula to the Wattenberg Field of the D-J Basin (Scenario 3)

Both natural gas and oil production numbers for the Wattenberg field in the D-J Basin were taken directly from the Colorado Oil and Gas Conservation Commission (COGCC).

For natural gas production the number was 206,459 MMcf, natural gas liquids production equaled 88,643 MMcf, waste production 8,752 MMcf and for oil production the number was 28,997 thousand barrels. The percentage makeup of natural gas was calculated using the output numbers of a typical well in the D-J Basin region, acquired from field owners.

For pricing we used the WTI Oil 2013 estimate of $97.91 per barrel, the 2013 natural gas Henry Hub spot price of $3.84/mcf, the 2012 NGL composite price of $10.98/mmBtu (which converts to $11.23 $/mcf), and $0.00/mcf for waste products (EIA, “Global Crude Oil Prices”) (EIA, “Short Term Energy Outlook) (EIA. "U.S. Natural Gas Liquid Composite Price (Dollars per Million Btu)”).

These numbers were then plugged into the economic modeling formula shown above and are available in Table A-9.

Results

Table 2 below shows the results of the base scenario. Tables 3 and 4 show the percent change of these results from the original GREET Model emissions numbers for M85 and gasoline vehicles, respectively.

MeOH FFV: M85, NA NG	g/mile			
Item	Feedstock	Fuel	Vehicle Operation	Total
CO2 (w/ C in VOC & CO)	21.97	79.14	303.0	404.1
CH4	0.135	0.024	0.014	0.172
N2O	0.001	0.001	0.007	0.009
GHGs	25.53	80.15	305.4	411.1
VOC: Urban	0.001	0.045	0.148	0.194
CO: Urban	0.001	0.010	2.014	2.026
NOx: Urban	0.004	0.024	0.094	0.122
PM10: Urban	0.000	0.006	0.014	0.020
PM2.5: Urban	0.000	0.005	0.005	0.010
SOx: Urban	0.003	0.000	0.001	0.004
Smog (Urban Totals)	0.010	0.090	2.277	2.377

Table 2. Base Scenario Emission Estimates of M85 Use in FFVs

MeOH FFV: M85, NA NG	Percentage Change			
Item	Feedstock	Fuel	Vehicle Operation	Total
CO2 (w/ C in VOC & CO)	-13.97%	-13.92%	-13.91%	-13.91%
CH4	-77.77%	-91.77%	0.00%	-81.02%
N2O	-13.95%	-13.92%	0.00%	-3.61%
GHGs	-37.61%	-19.54%	-13.81%	-16.93%
VOC: Urban	-13.92%	-13.90%	0.00%	-3.67%
CO: Urban	-13.94%	-13.91%	-32.00%	-31.92%
NOx: Urban	-13.94%	-13.91%	-32.00%	-28.57%
PM10: Urban	-13.93%	-13.91%	-22.41%	-19.91%
PM2.5: Urban	-13.93%	-13.91%	-43.90%	-30.67%
SOx: Urban	-13.93%	-13.76%	-13.90%	-13.93%
Smog (Urban Totals)	-13.93%	-13.91%	-30.52%	-29.95%

Table 3. Percent Change from GREET Emission Estimates of M85 Use in FFVs

Gasoline Vehicle: Gasoline	Percentage Change			
Item	Feedstock	Fuel	Vehicle Operation	Total
CO2 (w/ C in VOC & CO)	547.84%	7.86%	-17.60%	-9.08%
CH4	-68.60%	-82.79%	0.00%	-70.32%
N2O	39.04%	-92.27%	0.00%	-65.63%
GHGs	79.04%	-2.63%	-17.49%	-11.92%
VOC: Urban	-64.52%	-38.81%	-4.37%	-16.07%
CO: Urban	-34.18%	-42.71%	-32.00%	-32.06%
NOx: Urban	-57.95%	-46.52%	-32.00%	-36.64%
PM10: Urban	-67.84%	-38.07%	-22.41%	-29.64%
PM2.5: Urban	-68.54%	-8.74%	-43.90%	-31.94%

SOx: Urban	-64.35%	-100.83%	-75.75%	-92.07%
Smog (Urban Totals)	-60.31%	-52.24%	-30.73%	-32.10%

Table 4. Percent Change from GREET Emission Estimates of Gasoline use in a Gasoline Vehicle

Figures 1 and 2 contrast GHGs as well as smog (urban totals) for gasoline with the updated methanol numbers after applying our base scenario assumptions.

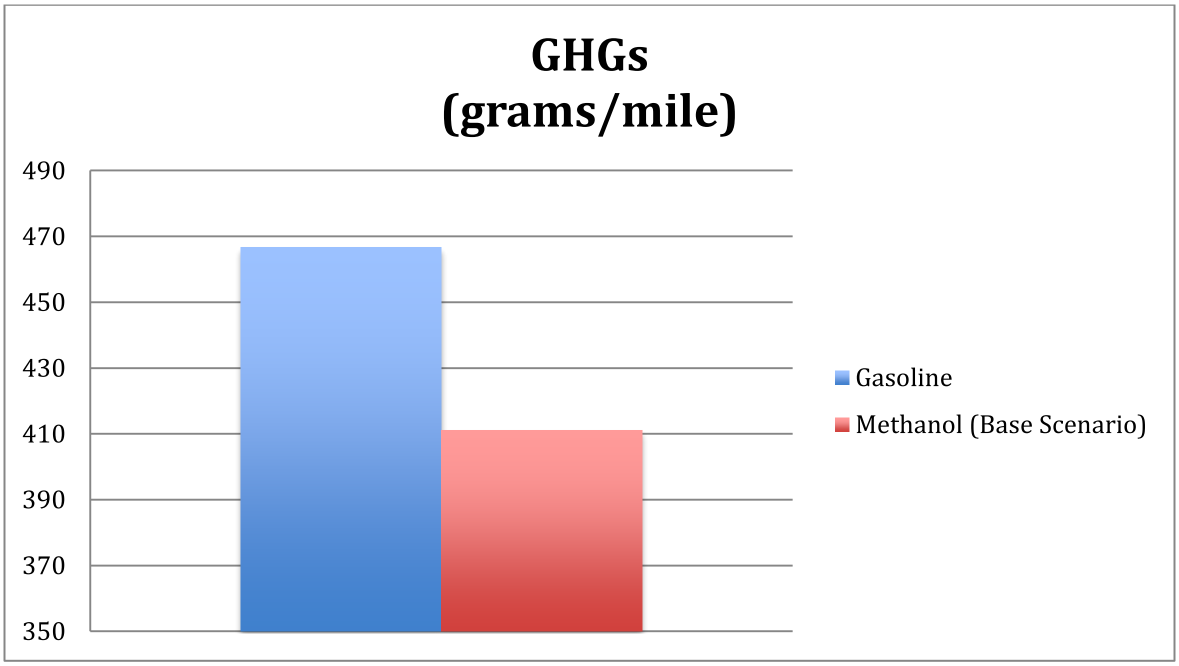


Figure 1

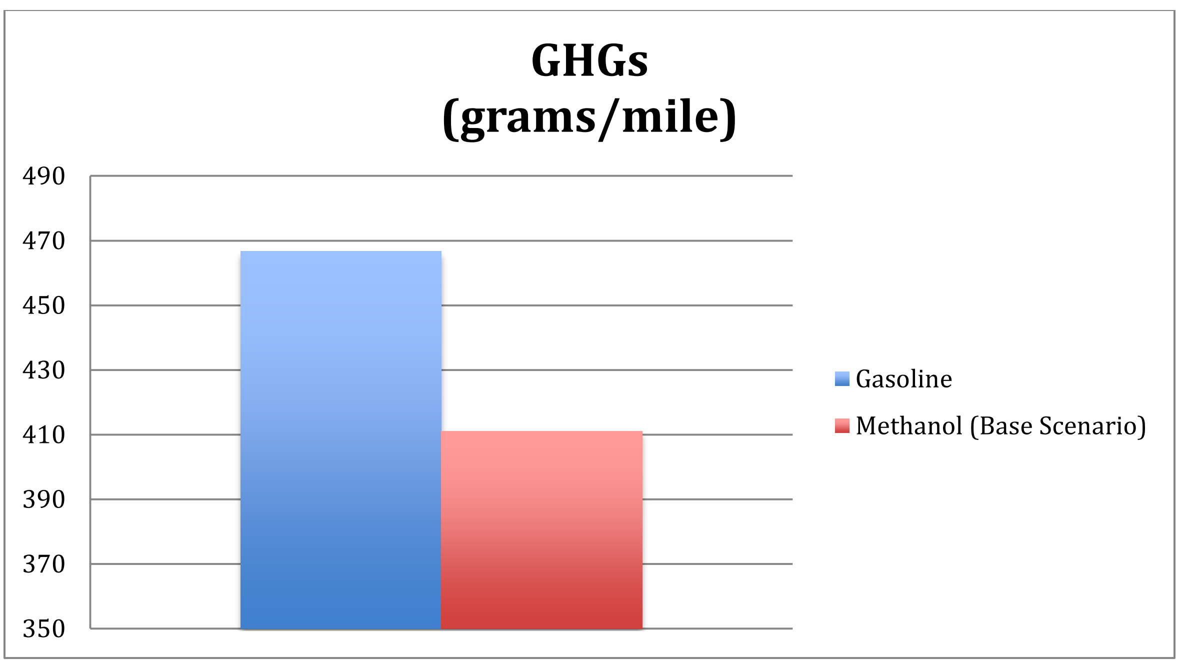


Figure 2

Again, the above data is only representative of our base scenario. The effect on GHGs when assuming that all methanol is being produced from flared gas on top of the base scenario is shown in Figure 3. Also shown in Figure 3 is the proportional redistribution of GHGs, based economic modeling on the oil and gas output from the Bakken shale and the Wattenberg field of the D-J Basin.

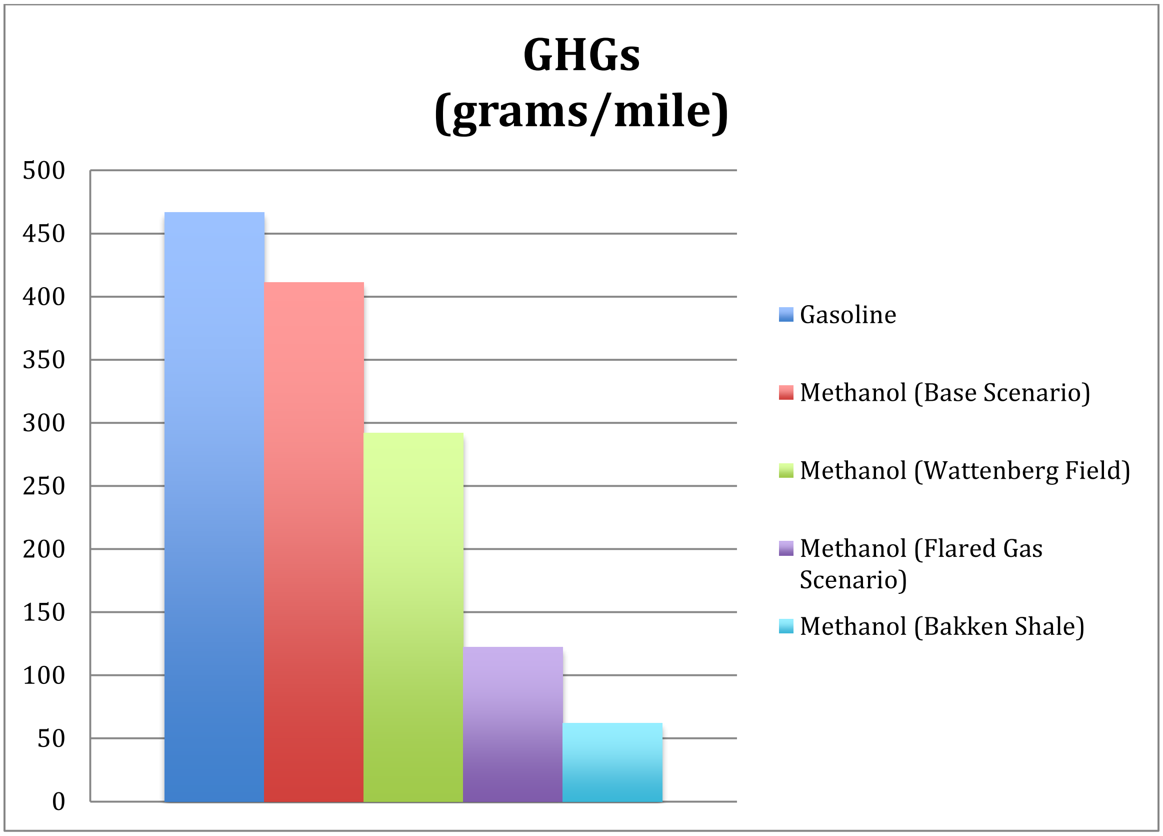
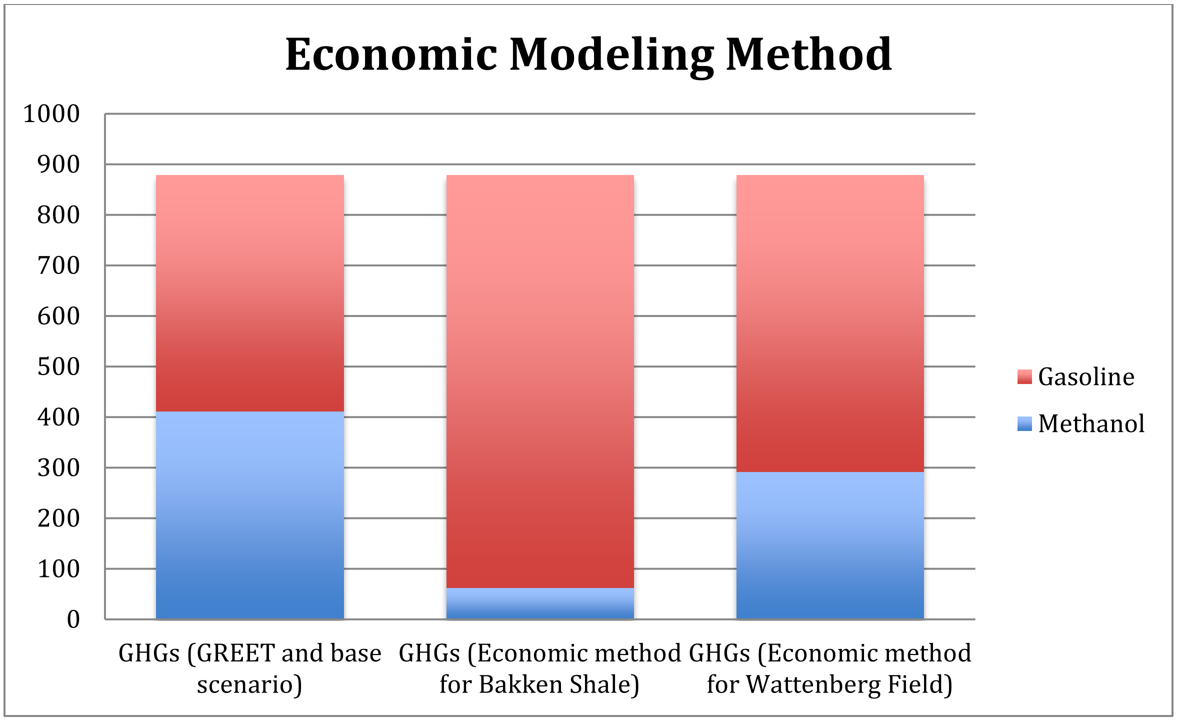


Figure 3

Figure 4 shows the GHG numbers proportionally from the GREET assumptions for gasoline and the base scenario for methanol, as well as the economic modeling results from each respective oil field.



Economic Modeling Method
1000
900
800
700
600
500
400
300
200
100
0
GHGs (GREET and base scenario)
GHGs (Economic method for Bakken Shale)
GHGs (Economic method for Wattenberg Field)
Gasoline
Methanol

Figure 4

Opportunities for Further Reductions in Emissions

First, we assumed an EER of 12 percent. The EER is applied to reflect the varying efficiency by which vehicle engines run on M85 as compared to E10. However, a 2013 Fuel Freedom Foundation study reveals evidence that an EER of 20 percent is possible when methanol is burned in properly converted and calibrated engines (Aronoff, Taft). Fuel Freedom is currently supporting further research to investigate these preliminary findings. Long term, if M85 becomes a more widely available fuel it will enable manufacturers to design higher-compression engines that can be optimized to burn methanol (even if only by adding a turbocharger), further improving the EER.

At the fuel conversion stage, the GREET Model assumes 82 percent efficiency. This means that 18 percent of the methane that goes into the process is not converted into methanol, but instead is vented or burned to produce CO2. However, a 2012 study by The Natural Resources Defense Council (NRDC) shows that an 89 percent conversion efficiency is possible (Leonard, Margalef, Jackson, Chiang, TIAX, LLC). Impending regulations that prevent venting emissions in the fuel production stage could create a financial and regulatory incentive for fuel producers to invest in developing their capabilities to achieve a higher efficiency rate at methanol production facilities. This may yield possibilities for further improvements in the well-to-wheel emissions of M85.

Next we examined the fuel distribution model. The GREET Model assumes that methanol is distributed over very long distances. We believe that the distributed nature of our natural gas infrastructure yields itself to a localized production paradigm. This is particularly true in natural gas producing states such as Colorado, Pennsylvania and Utah. These emissions are further augmented by the assumption of higher emissions from the diesel trucks that would transport the fuel. Newer diesel trucks achieve emissions reductions that are of an order of magnitude better than their older predecessors. Again, this would yield another reduction in total emissions.

Conclusion

The GREET Model is a large, complicated study that accounts for many factors that contribute to the emissions of different pollutants throughout the entire life cycle of a given transportation fuel produced from a given feedstock. Our study specifically examines methanol produced from natural gas, with some of the above steps designed to account for aspects of the fuel life cycle model not reflected in the current iteration of the GREET Model. While these steps result in significant reductions to the current GREET emissions numbers, it is important to note that we used conservative assumptions and there is room for further improvements.

Keeping that in mind, our findings show that vehicles running on M85 can realistically expect to observe reductions of GHG and urban emissions by about 11.92 percent and 32.10 percent, respectively, compared to gasoline (E10). Further, the findings display the potential to reduce GHG and urban emissions by 16.93 percent and 29.95 percent, respectively, from how the GREET Model currently accounts for natural-gas-derived methanol.

These results show many of the potential benefits of methanol. A reduction in GHG and urban emissions in our transportation sector could yield benefits for our environment and our health (and, by extension, our healthcare system). Further impacts, beyond what is currently shown in the GREET Model, may include decreased emissions through a general decreased demand for oil, resulting in less oil drilling and less worldwide oil movements.

Another potential benefit applies to states that are in noncompliance or in danger of being in noncompliance with EPA's National Ambient Air Quality Standards (NAAQS). The criteria pollutant PM2.5, which is largely contributing to noncompliance in Utah's Wasatch front and Colorado's Denver Basin, achieves a 31.94 percent reduction from vehicle emissions in M85 flex-fuel vehicles as compared to a conventional vehicle running on E10. This may be due to the lack of carbon-to-carbon bonding in methanol, a single carbon fuel. Therefore, the decreased particulate emissions may also apply in part to ethanol in E85. While ethanol is a two-carbon fuel, combustion should separate the carbon molecules, meaning tailpipe particulate emissions would come principally from the gasoline portion of E85 and any unburned ethanol.

Worth noting, is the development of a new economic analysis method for the attribution of emissions from associated gas between oil and natural gas paths in the GREET Model. Much of the natural gas flared and vented comes directly from oil wells that don't have the on-site capability to process and store that natural gas. With the development of on-site conversion, oil and gas producers wouldn't have to worry about the logistics of compressing and storing a volatile gas — even potentially using existing pipeline infrastructure to transport the liquid methanol. And because they are now shipping a liquid as a opposed to a gas, complying to stricter leakage regulations throughout the production process would become easier. Essentially, the new on-site conversion method makes methanol as a transportation fuel both economically and environmentally feasible.

When studying natural gas and oil production through an economic lens, the picture shows that, with new oil production, anywhere from 66.75 percent to 92.92 percent of the revenue from gas and oil production is attributed to oil, with the rest being attributed to natural gas. When applying these percentages to the emissions reported by the GREET Model, gasoline's emissions are 74.76 percent higher, while methanol's are 84.88 percent lower in the Bakken shale. When considering the Wattenberg field, gasoline emissions are 25.54 percent higher and methanol's are 28.99 percent lower.

Besides the environmental benefits, switching to a domestically produced, cheaper fuel like methanol could bolster our national security by easing our dependence on foreign oil, while also spurring economic growth as Americans spend less on fuel for their cars and manufacturers and retailers spend less transporting their respective goods.

It is our hope that this study encourages a discussion of our proposed methods, as well as other possible means, to reduce emissions of using methanol produced from natural gas as a transportation fuel in order to move us toward a cleaner, cheaper, American-made future.

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APPENDIX

Original GREET Assumptions

Gasoline Vehicle: Gasoline (g/mile)				
Item	Feedstock	Fuel	Vehicle Operation	Total
CO2 (w/ C in VOC & CO)	3.392	73.37	367.8	444.5
CH4	0.429	0.138	0.014	0.581
N2O	0.000	0.018	0.007	0.026
GHGs	14.26	8.322	370.1	466.7
VOC: Urban	0.003	0.073	0.155	0.231
CO: Urban	0.002	0.018	2.962	2.982
NOx: Urban	0.009	0.045	0.139	0.193
PM10: Urban	0.001	0.010	0.018	0.029
PM2.5: Urban	0.001	0.006	0.008	0.015
SOx: Urban	0.009	0.037	0.004	0.050
Smog (Urban Totals)	0.026	0.188	3.286	3.500

Table A-1

MeOH FFV: M85, NA NG (g/mile)				
Item	Feedstock	Fuel	Vehicle Operation	Total
CO2 (w/ C in VOC & CO)	25.54	91.93	352.0	469.5
CH4	0.607	0.288	0.014	0.908
N2O	0.001	0.002	0.007	0.009
GHGs	40.92	99.62	354.4	494.9
VOC: Urban	0.001	0.052	0.148	0.202
CO: Urban	0.001	0.012	2.962	2.975
NOx: Urban	0.005	0.028	0.139	0.171
PM10: Urban	0.000	0.007	0.018	0.025
PM2.5: Urban	0.000	0.006	0.008	0.015
SOx: Urban	0.004	0.000	0.001	0.005
Smog (Urban Totals)	0.012	0.104	3.277	3.393

Table A-2

Step 1: CO Regulations Reduce CH4, VOC and N2O by 95 Percent

MeOH FFV: M85, NA NG (g/mile)				
Item	Feedstock	Fuel	Vehicle Operation	Total
CO2 (w/ C in VOC & CO)	25.53	91.92	352.0	469.4
CH4	0.183	0.044	0.014	0.241
N2O	0.001	0.002	0.007	0.009
GHGs	30.31	93.52	354.4	478.2
VOC: Urban	0.001	0.052	0.148	0.202
CO: Urban	0.001	0.012	2.962	2.975
NOx: Urban	0.005	0.028	0.139	0.171

PM10: Urban	0.000	0.007	0.018	0.025
PM2.5: Urban	0.000	0.006	0.008	0.015
SOx: Urban	0.004	0.000	0.001	0.005
Smog (Total Urban)	0.012	0.104	3.277	3.393

Table A-3

Step 2: Downstream Emissions Eliminated Due to on or Near Well Site Conversion to Methanol

MeOH FFV: M85, NA NG (g/mile)				
Item	**Feedstock**	**Fuel**	**Vehicle Operation**	**Total**
CO2 (w/ C in VOC & CO)	25.52	91.92	352.0	469.4
CH4	0.157	0.028	0.014	0.198
N2O	0.001	0.002	0.007	0.009
GHGs	29.65	93.10	354.4	477.1
VOC: Urban	0.001	0.052	0.148	0.202
CO: Urban	0.001	0.012	2.962	2.975
NOx: Urban	0.005	0.028	0.139	0.171
PM10: Urban	0.000	0.007	0.018	0.025
PM2.5: Urban	0.000	0.006	0.008	0.015
SOx: Urban	0.004	0.000	0.001	0.005
Smog (Urban Totals)	0.012	0.104	3.277	3.393

Table A-4

Step 3: Applying the Energy Efficiency Ratio

MeOH FFV: M85, NA NG (g/mile)				
Item	**Feedstock**	**Fuel**	**Vehicle Operation**	**Total**
CO2 (w/ C in VOC & CO)	22.81	82.14	314.5	419.5
CH4	0.140	0.025	0.014	0.178
N2O	0.001	0.001	0.007	0.009
GHGs	26.50	83.20	316.9	426.6
VOC: Urban	0.001	0.046	0.148	0.196
CO: Urban	0.001	0.010	2.962	2.974
NOx: Urban	0.004	0.025	0.139	0.168
PM10: Urban	0.000	0.006	0.018	0.025
PM2.5: Urban	0.000	0.005	0.008	0.014
SOx: Urban	0.003	0.000	0.001	0.004
Smog (Urban Totals)	0.011	0.093	3.277	3.380

Table A-5

Step 4: Applying Improved Tailpipe Urban Emissions (Base Scenario).

MeOH FFV: M85, NA NG (g/mile)				
Item	**Feedstock**	**Fuel**	**Vehicle Operation**	**Total**
CO2 (w/ C in VOC & CO)	22.81	82.14	314.5	419.5
CH4	0.140	0.025	0.014	0.178

N2O	0.001	0.001	0.007	0.009
GHGs	26.50	83.20	316.9	426.6
VOC: Urban	0.001	0.046	0.148	0.196
CO: Urban	0.001	0.010	2.014	2.026
NOx: Urban	0.004	0.025	0.094	0.123
PM10: Urban	0.000	0.006	0.014	0.021
PM2.5: Urban	0.000	0.005	0.004	0.010
SOx: Urban	0.003	0.000	0.001	0.004
Smog (Urban Totals)	0.011	0.093	2.276	2.380

Table A-6

Scenario 1, Flared gas: If Natural Gas that Would Otherwise be Flared Accounted for 100 percent of Methanol Production

MeOH FFV: M85, NA NG (g/mile)				
Item	**Feedstock**	**Fuel**	**Vehicle Operation**	**Total**
CO2 (w/ C in VOC & CO)	22.87	-210.2	314.5	127.3
CH4	0.138	-0.218	0.014	-0.066
N2O	0.001	-0.004	0.007	0.004
GHGs	26.52	-216.8	316.9	126.6
VOC: Urban	0.001	0.046	0.148	0.195
CO: Urban	0.001	0.006	2.014	2.021
NOx: Urban	0.003	0.014	0.094	0.112
PM10: Urban	0.000	0.002	0.014	0.016
PM2.5: Urban	0.000	0.001	0.004	0.006
SOx: Urban	0.003	-0.001	0.001	0.004
Smog (Urban Totals)	0.009	0.068	2.276	2.354

Table A-7

Scenario 2, Economic Modeling for Bakken: GHG Emissions Distribution by Economic Value of Fuel Based on Bakken Field Production

Energy Source	**Amount (thousand barrels or MMcf)**	**Average cost per unit 2013 (2012 for NGL) in $/barrel or $/mcf**	**Total cost**	**Percent of total**
Oil	322,199	$97.91	$31,546,504,090	92.92%
Natural gas	185,407	$3.84	$711,964,474.43	2.10%
NGLs	150,691	$11.23	$1,692,645,065.95	4.99%
Waste	14,878	$0.00	$0.00	0.00%

Table A-8

Final Scenario 3, Economic Modeling for Wattenberg Field: GHG Emissions Distribution by Economic Value of Fuel Based on the Production of the Wattenberg field of the Denver-Julesburg Basin

Energy Source	Amount (thousand barrels or MMcf)	Average cost per unit 2013 (2012 for NGL) in $/barrel or $/mcf	Total cost	Percent of total
Oil	28,997	$97.91	$2,839,096,270.00	66.75%
Natural gas	109,064	$3.84	$418,806,569.74	9.85%
NGLs	88,643	$11.23	$995,682,929.85	23.41%
Waste	8,752	$0.00	$0.00	0.00%

Table A-9