THE FUTURE OF METHANOL FUEL

An Analysis on the Feasibility of Methanol as an Alternative Fuel

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Methanol Plants in Chile
Abstract: Despite its various industrial applications, methanol as a transportation fuel is a relatively obscure topic that has not received much public attention. This paper investigates the historical reasons behind the unsuccessful attempts to promote methanol as a transportation fuel, and discusses the viability of methanol as a transportation fuel in both land-based and marine fields given the current industry and legislative environment. The paper concludes with a preliminary economic analysis demonstrating that the private sector has enough incentives to invest in methanol production in the future, and our cost-benefit analysis shows that the social benefits of using methanol as a transportation fuel considerably outweighs the costs associated with switching to methanol.

Introduction

When most people hear the term “alternative fuels”, they think about ethanol or electric vehicles. However, the less well-known chemical methanol also provides a viable and clean alternative to gasoline despite its relative obscurity. This paper will provide a comprehensive analysis of methanol’s feasibility as a motor fuel and marine fuel in the USA. Our quantitative analysis will focus solely on light duty vehicles due to availability of data and low barriers to adoption.

Despite our focus on the USA, this paper will provide a basic overview of the methanol industry worldwide, and a holistic discussion of the advantages and disadvantages associated with methanol fuel use. We have also conducted case studies into past and ongoing methanol initiatives in California and China to determine optimal policies that need to be implemented for successful methanol use. In addition to analyzing the past, we have also looked at the present and the future. For the present day, recent price declines in crude oil, methanol, and natural gas have potentially changed the price economics for methanol fuel and we have sought to determine to what extent that has happened. For the future, we have discussed the possibility of using methanol as a marine fuel, which has huge potential to reduce pollution but will not be viable in the short term.

Finally, we have conducted quantitative analysis on the various parameters of methanol fuel usage in order to determine 1) under which conditions will the private sector be incentivized to produce the additional methanol required and 2) whether the present value of all benefits from future methanol usage outweigh the costs associated with increasing its consumption.
Analysis on Methanol’s Basic Properties and Applications

Methanol is an alcoholic chemical compound that is considered to be the simplest alcohol. It is a light, colorless, flammable liquid at room temperature, and contains less carbon and more hydrogen than any other liquid fuel. The chemical formula for methanol is CH₃OH (often abbreviated as MeOH). Methanol appears naturally in the environment, and quickly breaks down in both aerobic and anaerobic conditions.¹ Methanol is often called wood alcohol because it was once produced chiefly as a byproduct of the destructive distillation of wood.

Today, the most common feedstocks for production are natural gas and coal. As an energy fuel, methanol has chemical and physical fuel properties similar to ethanol. Given the fact that it is currently one of the cleanest sources of energy available, methanol is used directly as a fuel or fuel additive in significant markets, particularly China which is the largest consumer and producer or methanol fuel globally. This simple alcohol can be made from virtually anything that is, or ever was, a plant. This includes common fossil fuels – like natural gas and coal – and renewable resources like biomass, landfill gas, and even power plant emissions and CO₂ from the atmosphere.²

To produce methanol, synthesis gas needs to be created from the feedstock first. Through gasification, synthesis gas can be produced from anything that is or ever was a plant, which includes biomass, agricultural and timber waste, solid municipal waste, recycled carbon dioxide and a number of other feedstocks in addition to natural gas and coal. In a typical facility, methanol production is carried out in two steps. The first step is to convert the feedstock into a synthesis gas stream consisting of CO, CO₂, H₂O and hydrogen. This is usually accomplished by the catalytic reforming of feed gas and steam with partial oxidation as an alternative route. The second step is the catalytic synthesis of methanol from the synthesis gas.

**Step 1:** \[2 \text{CH}_4 + 3 \text{H}_2\text{O} \rightarrow \text{CO} + \text{CO}_2 + 7 \text{H}_2 \text{ (Synthesis Gas)}\]

**Step 2:** \[\text{CO} + \text{CO}_2 + 7 \text{H}_2 \rightarrow 2 \text{CH}_3\text{OH} \text{ (Methanol)} + 2 \text{H}_2 + \text{H}_2\text{O}\]

\[\text{CH}_4 + \frac{1}{2}\text{O}_2 \rightarrow \text{CO} + 2 \text{H}_2 \rightarrow \text{CH}_3\text{OH} \text{ (Methanol)}\]

Since the 1800s, methanol has been widely used as an industrial chemical compound to produce a variety of traditional chemical derivatives, including formaldehyde and acetic acid, dimethyl terephthalate, methyl methacrylate, and methyl chloride to manufacture a wide range of end products, including plywood, particleboard, foams, paints, silicones, resins, plastics, and LED/LCD screens. Its stable biodegradable chemical property is used in a number of industrial and commercial applications. With its diversity of production feedstocks and array of applications, methanol is one of the world’s most widely used industrial chemical. Currently, approximately 60% of the global demand for methanol comes from the industrial chemical market demand, and more countries are investing in more efficient ways of producing, including China’s most recent $5.2 billion investment in a methanol plant in the United States that specializes in producing methanol for the plastic production process.4

In the 1970s, a new milestone discovery was made in the methanol market; the methanol to hydrocarbons process was discovered at Mobil Oil in 1977, and thus methanol became a possible alternative energy source in daily use. The astonishing discovery was the first major new synthetic fuel development in 50 years since the development of the Fischer–Tropsch process, which allowed gasoline to be used as motor fuel.5 The process is known as the methanol-to-gasoline (MTG) process. It provides a direct route that converts coal or natural gas to high-octane gasoline in the MTG process, represents a competing technology to the traditional FT synthesis approach for making synthetic gasoline. Currently, the remainder of methanol demand that is not for industrial applications comes mostly from energy-related applications. Methanol is used directly for blending into gasoline or as a cooking fuel, or indirectly as a feedstock in the production of Dimethyl ether (DME), biodiesel, MTBE, MTO, marine fuel, and methanol-to-gasoline (MTG).6

According to the research report from Methanex, the largest methanol-producer in the world, global methanol demand is approximately 61 million tons on an annualized basis.7 While methanol demand in energy-related applications is strongest in China, a number of countries around the world, including Australia and Israel, have projects in place or are considering

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adopting these applications on a wider scale. In China, methanol is used as a motor fuel in various blends ranging from 5% methanol in gasoline (M5) to 100% methanol (M100).\textsuperscript{8} Methanol accounts for roughly 10% of China’s transportation fuel pool.

As of 2014, methanol demand for energy-related use continued to grow at a CAGR of 12% and represented approximately 40% of total global methanol demand. This demand was comprised of methanol for the production of MTBE, which represented about 12% of total 2014 demand, fuel applications (direct blending of methanol into gasoline, DME, MTG and biodiesel), which together accounted for approximately 22% of total 2014 demand, and merchant MTO, which represented 6% of global demand in 2014.\textsuperscript{9}

![Figure 1. Methanol Demand by Products, by Regions in 2014\textsuperscript{10}](image)

Methanol is blended into gasoline for use as a transportation fuel because of its competitive pricing relative to gasoline as well as for its clean air benefits. Methanol-gasoline blending in China has grown rapidly over the last several years. As of 2014 there were six methanol to gasoline (MTG) plants in China. Additionally, China’s state and provincial governments have implemented a range of fuel-blending standards in the form of official advice for methanol that promotes the use of methanol as a fuel. In 2014, the estimate for demand for methanol for fuel applications in China was approximately 7 million tons.

DME (dimethyl ether) is a clean-burning, non-toxic, potentially renewable fuel that is also highly correlated with methanol. DME has been used for decades in the personal care

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industry as a benign aerosol propellant, and is now increasingly being exploited for use as a clean burning alternative to LPG (liquefied petroleum gas), diesel and gasoline. DME, which is typically produced from methanol dehydration, can be blended up to approximately 20% with liquefied petroleum gas and are used for household cooking and heating. However, while the technology for using DME as a diesel fuel substitute is well advanced, it has not yet entered widespread commercialization stage. However, in recent years, DME development has advanced on two particular fronts: In February 2014, ASTM International, a globally recognized organization that develops technical standards, released a specification for DME as a fuel. Then in August 2014, Oberon Fuels, a California company that manufactures DME, received U.S. Environmental Protection Agency approval for the fuel’s inclusion under the Renewable Fuel Standard.\(^\text{11}\) In 2014, global methanol demand for use in DME was estimated at approximately 3.6 million tons. In addition to DME production plan in China, DME is being produced and projects are under development in other countries including Japan, Taiwan, Turkey, Trinidad, the United States, India, Indonesia and parts of Europe.

Methanol is a major feedstock to olefins products such as ethylene and propylene, which are the basic building blocks used to make many plastics. Olefins can be produced from various feedstocks, including naphtha, LPG (liquefied petroleum gas), ethane and methanol. In China, olefins have historically been produced using naphtha, an oil product. Over the past three years, methanol demand for olefins has emerged as a significant new energy-related derivative for methanol. The first merchant MTO plant in China started up in 2012, and by the end of 2014 there were seven plants operating in China, with the capacity to consume just under 7 million tons of merchant methanol annually.\(^\text{12}\)

Methyl Tertiary Butyl Ether (MTBE), primarily made from methanol, is used primarily as an oxygenate additive in gasoline to increase octane level and reduce the amount of Carbon Monoxide emissions from motor vehicles. Pure MTBE has a high octane rating of 110 (comparing to octane rating of roughly 100 for M85 blend). MTBE is an efficient and cost-competitive gasoline additive and, as such, is increasingly used in developing countries targeting gasoline pool extension and clean air benefits at a cost lower than that of alternatives. However,


MTBE has received some pressure and resistance as it was banned in New York and California due to water pollution issues during its production process.\textsuperscript{13} Despite domestic resistance, MTBE is becoming popular overseas, where environmental standard is relatively lower; China is currently the world’s largest automotive market and the combination of its growing gasoline demand, as well as China’s desire to reduce exhaust emissions, is driving new MTBE capacity additions.\textsuperscript{14}

Due to its status as an alternative fuel substitute, markets tend to favor energy sources like methanol when the oil price is high. While the impact of lower energy prices has created some short-term methanol market uncertainty, methanol demand over the longer-term is expected to increase in order to meet the world’s increasing need for clean-burning energy products. In 2014, total methanol production increased by 3.5% to 59 million tons. On the methanol to gasoline side, there are now eleven completed MTO plants in China which are dependent on merchant methanol supply, and these have the capacity to consume over 10 million tons of methanol annually. Despite lower oil pricing, demand for direct methanol blending into gasoline in China has remained strong and we believe that future growth in this application is supported by numerous provincial fuel-blending standards. Going forward, we will primarily analyze the effects of direct methanol blending into gasoline. Within the United States, methanol has been identified as a renewable resource by the EPA, which means substantial federal and state subsidies in the development of methanol applications.

\textbf{Advantages and Disadvantages of Methanol Fuel}

Past studies have shown that methanol possesses various advantages and disadvantages compared to conventional energy sources that make it a viable source of motor fuel, albeit subject to financial hurdles.

The key merits of methanol as a motor fuel include: (1) cleaner combustion, including reduction in emissions of greenhouse gas and toxic gas; (2) established production infrastructure;


(3) can be directly used in existing vehicles under lower concentration blend (up to M15); (4) wide range of accessible feedstock and end market uses, thus high flexibility and adaptability.

The key hurdles of methanol as a motor fuel include: (1) lower energy content than gasoline; (2) more corrosive and volatile than other fuel sources, thus restricting its material and vehicle compatibility; (3) more expensive than gasoline when taking account into the installation cost for relating fueling station conversion.

Cleaner Combustion

Methanol has long been hailed as a possible alternative motor fuel to gasoline as its combustion produces significantly less CO2 and other toxic chemicals than gasoline, thereby alleviating the increase of greenhouse gas around the world. The effectiveness of reducing CO2 emission takes into account of two phases: the WTT (well-to-tank, i.e. the production of methanol fuel) portion and TTW (tank-to-wheel, i.e. the combustion of methanol fuel in vehicles) portion, with methanol possessing advantages over other viable energy sources in both fields.

Various methanol producers have produced and distributed renewable methanol with dramatic reduction in CO2 emission.\textsuperscript{15} The table below (Table 1) shows that carbon production benefits in the WTT process for renewable methanol ranges from 65% to 95%. However, natural-gas-based methanol, which is the more prevalent production method in the United States, incurs a -2% carbon reduction relative to gasoline in the WTT cycle (i.e. its CO2 emission is higher in this phase), which is caused by higher emission during fuel distribution and feedstock transmission.\textsuperscript{16}

<table>
<thead>
<tr>
<th>Major Renewable Methanol Producers</th>
<th>Carbon Reduction Relative to Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>BioMCN</td>
<td>78%</td>
</tr>
<tr>
<td>Blue Fuel Energy</td>
<td>65% - 84%</td>
</tr>
<tr>
<td>Carbon Recycling International</td>
<td>85%</td>
</tr>
<tr>
<td>VärmlandsMetanol</td>
<td>80% - 90%</td>
</tr>
</tbody>
</table>

Table 1 Carbon Reduction of Major Renewable Methanol Producers


The carbon reduction during the WTT cycle of renewable methanol is impressive comparing to that of other alternative energy sources, as shown in Table 2:

<table>
<thead>
<tr>
<th>Alternative Energy Sources</th>
<th>Carbon Reduction Relative to Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol (Corn)</td>
<td>-2%</td>
</tr>
<tr>
<td>Ethanol (Sugar Cane)</td>
<td>31%</td>
</tr>
<tr>
<td>CNG (Pipeline)</td>
<td>32%</td>
</tr>
<tr>
<td>LNG (Pipeline)</td>
<td>18%</td>
</tr>
<tr>
<td>Electricity</td>
<td>-15%</td>
</tr>
</tbody>
</table>

Table 2 Carbon Reduction of Alternative Energy Sources, NA

For the TTW portion, methanol possesses two key advantages over conventional fuel sources: lower tailpipe emissions in combustion and more efficient combustion engine associated with its use. When used to fuel a conventional combustion engine, methanol blend has been shown to emit less CO2 than pure gasoline. In a study of tri-fuel blends containing varying levels of methanol, ethanol, and gasoline, methanol fuel blends show approximately 10% - 15% reduction in carbon emission than pure gasoline (Figure 2), although such reduction does not necessarily increase with the increase in methanol concentration. Furthermore, as an alternative to combustion, methanol can also be used in fuel cells, an advanced vehicle technology where the fuel is used to generate electricity for motive power, without producing hydrogen gas in the process (Figure 3). Proton exchange membrane fuel cells are estimated to be 2.6 to 3.5 times more efficient than combustion engines; tailpipe emission is further reduced when fuel consumption is reduced.

![Figure 2. CO2 emission of drive cycle tailpipe using different fuel blends](image)

Anode: \( \text{CH}_3\text{OH} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + 6\text{H} + 6e^- \)

Cathode: \( 1.5\text{O}_2 + 6\text{H} + 6e^- \rightarrow 3\text{H}_2\text{O} \)

Total: \( \text{CH}_3\text{OH} + 1.5\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \)

**Figure 3. Chemical Mechanism of Direct Methanol Fuel Cell**

Together, the carbon reduction benefits in the WTT and TTW portions of methanol production/consumption are compelling, especially for renewable methanol, where carbon reduction is significant in the WTT phase.

Furthermore, compared to gasoline, methanol emits less nitrogen oxides and other volatile, harmful organic compounds that form smog or ozone when burned as fuel. This is due to the fact that methanol is much less reactive than gasoline in the atmosphere, with the only toxic component of the emissions being formaldehyde, as compared to dozens of carcinogenic components of gasoline emissions including formaldehyde. The use of heated catalytic converters has shown that methanol-fueled auto emissions meet and exceed California’s stringent Ultra Low Emission Vehicle (ULEV) emission targets for formaldehyde. Methanol fuel also does not contain the toxic BTEX (benzene, toluene, ethylbenzene, and xylenes) additives found in gasoline. These compounds are highly carcinogenic, do not readily biodegrade in the environment, and are capable of contaminating groundwater supplies. The following graphs (Table 3 & 4) compares the air toxic exhaust emissions and ozone-forming potential between gasoline and two different methanol-fuel-blends; they show that the fuel blend with higher methanol concentrations emits less toxic exhaust (except for formaldehyde) and possesses lower ozone-forming potential, thus proving the superiority of methanol.

<table>
<thead>
<tr>
<th>Vehicle-Fuel</th>
<th>1,3-Butadiene</th>
<th>Benzene</th>
<th>Formaldehyde</th>
<th>Acetaldehyde</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg (mg/ml)</td>
<td>CV</td>
<td>Avg (mg/ml)</td>
<td>CV</td>
</tr>
<tr>
<td>FFV-RFG</td>
<td>0.83</td>
<td>0.15</td>
<td>4.50</td>
<td>0.11</td>
</tr>
<tr>
<td>FFV-M50</td>
<td>0.37</td>
<td>0.13</td>
<td>2.96</td>
<td>0.15</td>
</tr>
<tr>
<td>FFV-M85</td>
<td>0.10</td>
<td>0.00</td>
<td>1.39</td>
<td>0.23</td>
</tr>
<tr>
<td>STD-RFG</td>
<td>0.30</td>
<td>0.19</td>
<td>2.15</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Table 3. Average Air Toxic Exhaust Emission (RFG indicates gasoline, FFC indicates flexible fuel vehicle, STD indicates standard vehicle)\(^9\)

Table 4. Ozone Forming Potential and Specific Reactivity

Established Production Infrastructure and Low Production Cost

As one of the most flexible organic molecules, methanol is widely used globally in a diverse set of industries; it thus has a widely established production and distribution infrastructure, with more than 90 production bases globally. Moreover, existing production of methanol for industrial uses is functionally identical to production to energy and fuel uses. Methanol can also be converted to other specialty chemicals like olefins and propylene with little additional cost, since most of current production plants are downstream integrated. Currently, global annual production of methanol is more than 60 million tons and is set to reach nearly 90 million tons within 5 years, among which approximately 10 million tons are used as fuel.21

Additionally, methanol is cheap to produce. The cost of production for methanol from natural gas is $1.30 to $1.60 per gasoline gallon equivalent, while that of corn-based ethanol is about $3.80 per gasoline gallon equivalent.22 Methanol thus offers a much cheaper solution than ethanol in meeting demand for reduced greenhouse gas emission. Moreover, since these figures are calculated in 2010, the difference between could only get bigger at the current stage, since the price of natural price has halved, while that of corn only decreased approximately 40%.23 Lastly, even the production cost of renewable methanol is still similar to that of corn-based ethanol, as it is 2 – 3 times of that of natural gas – depending on the scale of production for methanol.24 Therefore, when the demand for methanol increases as shown in Figure 4, the cost for increasing production scale for methanol can be lifted very soon at relatively lower cost.

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21 Ibid.
Lower Level Methanol Blends can be Adapted by Existing Vehicles

Lower level methanol-blends (M5, M10, M15) can be directly used in most existing vehicles with little to no modification, as industry experience confirms. The small range of modifications that may need to be pursued are upgrades to the non-metal parts of the fuel system for anti-corrosiveness, the installation of corrosion inhibitors and the use of corrosion inhibitors and some cosolvent alcohols for increasing water tolerance. Although older vehicles with carbureted fuel systems (non-pressurized) would be negatively impacted in drivability with the addition of methanol, vehicles with fuel injector systems (pressurized) are relatively insensitive to the addition of methanol. Since most of the global automakers are producing vehicles with fuel injection systems, the use of lower level methanol blend would produce little impact on the vehicles on the road. Additionally, by altering the computer program for fuel injection system, a car can be easily converted into a flexible fuel vehicle with adaptive mechanisms that allows it to use both methanol and gasoline at maximum energy output.

Wide Range of Accessible Feedstock and End Market Uses

As discussed in previous sections in this paper, methanol can be produced from a wide variety of feedstocks, including coal, natural gas, and various other renewable sources. The flexibility of its production renders it less affected by price fluctuations of commodities and enables production in different parts of the globe where access to resources differs. For example,

while methanol is largely produced from natural gas in the U.S., it is mainly produced from coal in China.

Methanol’s wide range of applications and homogeneity in production technology is also a key advantage, as producers can easily shift capacity from producing methanol-based fuel to its other uses when experiencing market downturns, thus providing extra incentive for producers to invest in this area where downside is partially protected. Moreover, greater scale of production, which ties to methanol’s usage in other areas, could also benefit the use of methanol-based fuel as this would reduce the cost of production.

**Low Energy Content**

Methanol has one of the lowest energy content among all fuels. As seen in Figure 5, its energy content is only half of that of gasoline and is also lower than ethanol, diesel, propane, etc. Its low level of energy content means that a user of a methanol-powered vehicle must use a larger oil tank to drive the same amount of distance. This creates limitations for vehicle design and creates additional hassles that could incur range anxiety and deter potential users. Furthermore, more fuel stations are needed in order to resolve the range issue, which will increase the difficulty of promotion at the beginning stage as not enough stations might be willing to sell methanol blend. Although methanol fuel cells are likely to be more efficient than combustion engines, which could solve this issue, they are still underrepresented in the current market and thus do not provide a feasible solution.

![Figure 5. Energy Content of Various Fuels (Lower Heating Value)](image)

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Corrosiveness and Volatility

Unlike most other hydrocarbons, methanol is a polar molecule, which makes it corrosive for some metals and nonmetals that are widely used in fuel transmission and combustion systems. Therefore, almost all existing vehicles need modifications in order to use high-level blends of methanol fuel. In such cases, wetted surfaces in vehicles and fueling equipment must have compatible materials. For example, polyurethane is a common material used in vehicles that reacts strongly with methanol and should be replaced. Moreover, methanol’s corrosiveness also places restrictions on distribution equipment in the oil industry, including filling equipment, oil tanks, etc. Thankfully, historical use of methanol fuel in California and China has proved that the development of methanol-adapted distribution infrastructure is not a major obstacle.

Moreover, methanol has a higher level of fuel volatility (vapor pressure, RVP) that creates higher evaporative emission, which needs to be accommodated through modification. This can be seen in Figure 6. In low-level blends, a small addition (5 percent) of methanol increases the gasoline methanol vapor pressure (RVP) to 12.5 psi (or about 3.5 psi) for a 9 psi gasoline. The fact that a lot of gasoline currently are already blended with ethanol further complicates the issue since ethanol’s RVP is already higher than methanol.

![Figure 6. RVP of Alcohol-Blended Gasoline](image)


Cost-Effectiveness

In terms of cost-effectiveness, methanol is comparable to gasoline in energy-equivalent terms since currently (Nov. 2015) methanol is priced at about half of gasoline. However, this is only applicable for low-level methanol blends, since high-level methanol blends must be distributed separately (due to its anti-corrosiveness requirement), which would result in additional costs in production and delivery. This renders high-level methanol blends to be relatively unattractive on cost-effectiveness terms. Therefore, further considering methanol’s physical and chemical requirements, low-level blends of methanol fuel are more likely to take a stand in the market, essentially replacing ethanol as gasoline additive.

History of Methanol Usage as Motor Fuel Around the Globe

Despite the popular opinion that ethanol-compatible and electric-powered vehicles are the representation of new generation of environmentally friendly transportation means, methanol-blend fuel and pure methanol fuel are actually one of the very first types of alternative fuels available. With the nightmare of the 1970s oil embargo, the discovery of large global natural gas deposits, and cheap coal prices, methanol fuel blending research, pilot programs on methanol-fueled vehicles, and other initiatives are becoming increasingly popular, particularly within the APMECA (Asia Pacific, Middle East, and Central Asian) region, where the need for reducing reliance on imported-oil is very critical.

Australia has been testing GEM (Gasoline-Ethanol-Methanol) fuel blends in recent years; the test of A15 fuel (12% methanol, 3% ethanol, 85% gasoline) in non-modified cars has been running since 2012. In Israel, the need for energy security and environmental protection has pushed the country to complete successful M15 vehicle pilot program tests. More recently, Israeli government has also launched research on the potentiality of M70 fuel. Given the fact that Israel has just discovered two major gas fields, Leviathan and Tamar, with a combined reserve of

roughly 700 billion cubic meters of natural gas, the development in methanol-blend fuel seems more promising than ever.32

In Central Asia, which is extremely rich in natural gas deposits, countries are trying to mitigate high fuel price and utilize these assets through the development of methanol fuel and other related derivatives. Uzbekistan has tested M3 and M5 fuel blends, and Azerbaijan has constructed Central Asia’s first methanol production in 2013.33

In Europe, the European Commission initiated the Renewable Energy Directive in 2009 to promote the application of renewable energy within Europe; the Directive has established an overall policy that requires EU to fulfill at least 20% of its total energy needs with renewable energy by 2020.34 Furthermore, Europe has been the center of technical advancement for methanol-related energy source as European scientist professor Karin Anderson have proposed methanol as a possible alternative to LNG in marine fuel in his paper *Methanol as an Alternative Marine Fuel*.35

Lastly, China, the world’s largest consumer and producer of methanol, has taken initiatives throughout the nation to promote methanol fuels standards ranging from M5 (5% methanol, 95% gasoline) to M100. China’s Ministry of Industry and Information Technology (MIIT) announced the creation of a two-year pilot program in Shanxi and Shaanxi Provinces and in Shanghai in 2012, aiming at the development and promotion of M85-fuelled vehicles.36 In 2014, the MIIT further expand this initiative to include Gansu and Guizhou Provinces.37

Despite such radical promotion campaigns from multiple countries, methanol is still not accepted as a viable substitute for gasoline. Additionally, the increasingly popularity of ethanol-blend fuel and electric-power car, the future of methanol fuel is even dimmer. This paper will conduct two case studies that primarily focus on the Chinese pilot program in 21st century and

California’s pilot program from 1988 to 2004. What has caused the difficulty of methanol application in China and the United States? Why is methanol less appealing than ethanol or electricity in the competition of renewable energy? With a close examination of these two cases, we intend to uncover the source of failure and potentially propose viable policy recommendations for methanol development and promotion in the United States.

The Chinese Case Study

As the world’s fastest growing oil consuming region and the world’s second largest automobile market, China’s demand for oil has ascended over the past decades, importing over 50% of the crude oil it consumes from 2012 onwards. FGE (Facts Global Energy) expects that China’s crude imports in the second half of 2012 will rise by 12%, increasing Chinese imports to 6.75 million bpd (barrels per day), second only to U.S. imports of 7.3 million bpd. In addition, China has suffered severe environmental issues in recent years due to heavy pollution, partially caused by car exhausts. With PM 2.5 levels that match the Great Smog of 1952 in London, Beijing is the most heavily polluted major city in the world right now. With the growing need for energy security and improving environmental consciousness, China started researching on gasoline substitutes during the 8th five year plan (1991-1995). After years of development, China’s annual production capacity of methanol has grown from 2 billion gallons in 2003 to 15 billion gallons in 2015, about the size of America’s ethanol industry.

The large scale pilot test program for methanol fuel car started in 2009, with the release of vehicle methanol fuel standard and vehicle methanol-gasoline standard (M85). The program was first tested in the coal-rich north-western provinces of Shanxi and Shaanxi because methanol is mainly produced from coal in China. The low coal price has contributed to the relatively low price of methanol blended fuel. Shanghai was also one of the three first locations. In 2014, the program was extended to include Guizhou and Gansu, and many Chinese automobile manufactures like Chery, Geely, FAW, and Shanghai Automotive were invited to create pure

methanol cars. Many regional governments have also responded to this initiative; 26 provinces also promote methanol blend fuel at local levels, mostly with low percentage fuel (Figure 7).

**Figure 7. China’s Methanol Blend Programs by Provinces**

Although methanol has been much more popular in China than in the states, the promotion of methanol fuel in China still meets massive pressure from the oil companies, who believe that the installation cost for methanol fueling station is too high. Furthermore, most of the methanol fuel in China is low percentage methanol fuel, and they have been sold as normal gas without letting the consumer knowing that they include methanol. In fact, one of the reason why M15 and M25 was prevalent in China was because private gas stations tried to sell these blends for the higher price of regular gasoline and make profits. Additionally, national standards for M85 have not been promoted as a law, merely an advised level, because the cost of conversion is relatively high in China when compared to the actual income of the Chinese. Therefore, more national guidance and subsidies will be necessary for the further promotion of methanol blend fuel in China.

*The California Case Study*

The state of California has always been a pioneer of new technologies in the USA. From mandating zero-emission vehicles to establishing a “hydrogen highway” for fuel-cell vehicles,
various renewable energy-related initiatives have used California as the first test field.\textsuperscript{42} In fact, methanol pilot programs were actually a huge success before they suddenly stop.

The initiative was sponsored by Senator Jay Rockefeller of West Virginia and Senator Tom Daschle of South Dakota. While Senator Rockefeller tried to promote his “coal economy”, Senator Daschle tried to generate extra income for his constituents, who are primary farmers, by utilizing farm waste in the methanol-producing process. The end result was the Alternative Motor Fuel Act of 1988, which was signed into law by President Reagan on October 14\textsuperscript{th}, 1988.\textsuperscript{43} This law provided a waiver of EPA regulations to allow methanol to be used in cars and earn extra fuel economy to lower auto-maker’s sales-weighted harmonic average miles per gallon (mpg).\textsuperscript{44} The governmental support was strengthened when President George H.W. Bush announced a major alternative fuel vehicle program by Executive Order that promised to put 500,000 new type vehicles by 1996 and one million by 1998.

The response from the private sector was led by automobile manufacturer Ford Motors, which delivered 40 methanol fueled Escorts, offering 20\% more power and 15\% improvement in fuel efficiency, to Los Angeles County.\textsuperscript{45} The pilot program later expanded to 500 vehicles, but the mere 200 miles range and 18 fueling stations weren’t enough to offset range anxiety. What was a technical success eventually turned into an emotional failure. Ford later developed Flexible Fuel Vehicles (FFVs), which could run interchangeably on a variety of fuels, including E85, M85 or pure gasoline. Furthermore, ARCO Petroleum agreed to build 25 methanol fueling facilities in California first, and soon after the deal was finalized, Chevron and other big oil corporations all sought and approved agreements to establish and operate 25 M85 retail stations. By 1995, there were about one hundred publicly accessible major retailer M85 fueling sites.\textsuperscript{46}

With all the progress made in the promotion of methanol fuel, the states started to consider “ratcheting down” the nitrous oxide (NOx) requirement to the point where methanol or

\textsuperscript{46} Ibid.
ethanol additions to gasoline would be necessary. However, oil corporations suddenly announced that they could meet the same emission standard by adding MTBE (Methyl tert-butyl ether), a gasoline additive used to raise octane number. Since methanol was one of the feedstock for the production of MTBE, supplies were diverged. Although MTBE was later banned due to water pollution issues, the timing for methanol promotion was unfortunately passed as the public and farming industry started to view ethanol as a gasoline substitute. The failure of the California methanol experiment was also due to the fact that M85 pump price was 99 cents (methanol alone costs 50 cents) and gasoline retail price was between $1.08 and $1.15. The mere $1 to $2 difference per tank wasn’t enough incentive for the consumer to switch to FFV. Additionally, the Alternative Motor Fuel Act didn’t provide enough subsidies to gas stations, which subsequently had no incentive to voluntarily purchase additional oil tanks and gas pumps which were methanol-compatible. However, with technological advancement, shale gas became accessible for many oil corporation; the price spread between oil and natural gas has continued to widen and natural gas surplus was expected to exist until 2017 (Figure 8). One could expect the price of methanol to drop in the state as the majority of methanol was created from natural gas, and it is worthwhile now to revisit why California failed.

![Figure 8. Oil vs. Natural Gas Prices on an Energy Equivalent Basis](image)


49 Ibid.
The US Legislation Effort

Despite the failure of the California program, legislators have been continuously trying to promote renewable fuels throughout the nation. Although many of the proposals mainly concern ethanol blended fuel due to the Federal Ethanol Mandate, the Open Fuel Standard Act of 2011, introduced by Representative John Shimkus, actually proposed a viable solution that separates the automobile manufactures from the oil companies by requiring a certain portion of the light-passenger vehicles sold in the U.S. be alternative fueling vehicles capable of running on GEM fuel (blended fuel containing gasoline, bio-ethanol, and bio-methanol). The original bill proposed that, by 2014, 50% of the new cars sold should be GEM FFV, and the percentage should reach 95% by 2017.

Although such a program sounds like a massive undertaking, the invention and prevalence of fuel injection systems and on-board computers have greatly simplified the process of manufacturing and converting GEM FFVs. According to research from the Institute for Energy Resourcefulness, the engine onboard a Buick Regal Turbo Flex Fuel car, which is already compatible with regular gasoline and E85, can also use GEM mixture with up to 40% gasoline, 10% ethanol, and 50% methanol without any modifications. If the software can be reprogrammed, the engine can use M85 or anything in between. While the bill was blocked in the 112th Congress, the introduction of fuel competition creates incentive for the promotion of renewable fuel because the user of GEM FFVs won’t have to be concerned about the range issue. Furthermore, they will have more incentive to choose renewable fuel when available as they will not be obliged to one type of fuel.

Viable Policy Recommendations

Combining our analysis of the advantages and disadvantages of methanol as a motor fuel, the history and case studies of previous methanol initiatives, and the possible future development of methanol related derivative products, we propose the following policy recommendations that

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51 Ibid.
could introduce fuel competition and further promote the use of methanol in American society, particularly in the transportation industry.

Providing subsidies to renewable energy has long been a popular means for the government to promote new energy, yet various studies have shown that subsidies aren’t socially optimal. Thus, this paper tries to promote an alternative method of subsidies through the modification of fuel tax. The prevailing method of fuel taxation, especially at the state level, is on the gallon, and such methods will inevitably penalize non-petroleum fuel as they have lower energy density. For example, methanol contains 50% less energy per gallon than gasoline.⁵³ A customer will have to pay double the tax by using methanol and this raises the barrier to consumer acceptance. Therefore, the first policy recommendation is for the National Governors Association to review tax policy and consider changing into a fair system in which fuel tax is applied on energy content provided instead of volume.

Among all the cars sold in the United States every year, 44 million are used cars while only 14 million are new. Older cars tend to be less fuel efficient. Furthermore, the majority of these used cars are light-duty trucks, which are one of the least fuel efficient models.⁵⁴ If these old vehicles with either diesel or gasoline engines could switch to flexible fuel systems, consumer could save money and protect the environment. However, the cost of conversion is extremely high in the United States; roughly $10,000 per vehicle – much more than the $3,800 average price in other parts of the world.⁵⁵ The major cause of the price difference is the EPA (Environmental Protection Agency), as only EPA certified specialists and materials can be involved and used in the conversion process.⁵⁶ If the conversion kit market can be deregulated to offer safe, but low-cost conversion, more consumers will be willing and able to choose alternative fuels, and the environmental benefits received from such conversions will be much greater given older vehicles are less fuel efficient.

⁵⁶ Ibid.
When the general public thinks of fuel efficiency, the most popular metric they tend to adopt is miles per gallon, which is naturally less favorable to renewable fuel because non-petroleum fuels are less energy dense per volume compared to gasoline. People are accustomed to think how many miles they can drive for a tank of gas while omitting the fact that a full tank of gasoline, despite offering longer range, could be more expensive than M85 on a cost per mile basis. The process of developing methanol fuel is as much a technological issue as a public opinion issue. Thus, the last policy recommendation is to adopt the metric of cost per mile in order to create a favorable image for renewable fuels.

Therefore, through our analysis of current methanol development and promotion process, we recommend that the government should change its fuel tax system, lower used car conversion costs and regulation, and adopts a new metrics of cost per mile when evaluating car fuel efficiency.

**Methanol as Potential Marine Fuel**

The international shipping industry is the foundation of the global economy, and it accounts for around 90% of the global trade by volume. It is also widely considered as one of the most environmentally friendly mode of transportation in terms of CO2 emissions per ton per mile. However, due to the large size of the industry and the polluting nature of low-grade marine bunker fuel, it is far from environmentally friendly in an absolute sense and pollution from marine fuel emission can be very costly to society.

While automobile emission has been heavily regulated in the past three decades, regulations regarding marine fuel emission were not enforced until recently. With stricter emission standards set up by the International Maritime Organization (IMO), the regulating body of the international shipping industry, and the designation of Emission Controlled Areas (ECAs) around the world, the industry landscape is changing dramatically as firms are seeking new ways to comply with the new emission standards. Methanol is widely regarded by the industry as one of the most promising alternatives for marine fuel in the medium to long term. However, due to the current lack of control systems for legislation enforcement and the lack of government support, it is unlikely many firms will adopt this option in the near term. In the long run, we

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firmly believe the future of marine fuel will be methanol and or methanol blend fuel as world oil deposits continue to decrease over time.

*Overview of Global Shipping Industry and Air Pollution from Ships*

Over the past few decades, the global shipping industry has experienced tremendous growth, with more than 50,000 commercial vessels sailing internationally every day. According to the International Chamber of Shipping (ICS), about 90% of world trade is carried by the international shipping industry. According to IHS, a market research agency, world seaborne trade is expected to reach around 17 billion tons by 2030, growing in line with global GDP growth and the growing population (Figure 9 & 10).

![Figure 9. Predicted Increase in World Seaborne Trade, GDP, and Population](image)

![Figure 10. 50 Years of Container Ship Growth](image)

In terms of CO$_2$ emissions per ton of cargo transported per mile, shipping is recognized as the most efficient form of commercial transport (Figure 11). However, the enormous scale

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of the industry means that it is nevertheless a significant contributor to the world's total greenhouse gas emissions, contributing to around 3% of total global CO2 emissions.

Figure 11. Comparison of Typical CO2 Emissions Between Modes of Transport

Most of the commercial vessels are operating on Heavy Fuel Oil (HFO), which is the residue from the fractional distillation process of oil refining. This fuel has a very long hydrocarbon chain and as a result, it is extremely thick and viscous. Not only will it cause enormous environmental damage in the case of an oil spill, it is also heavily contaminated with many toxic substances that are extremely polluting to the atmosphere when burned. It is estimated that ships emit around 8% of global sculpture oxide (SOx) emissions and 15% of global nitrogen oxide (NOx) emissions annually. In addition, a recent article published by The Guardian suggests that health risks of shipping pollution have been underestimated, and it claims that “15 of the world’s biggest ships may now emit as much pollution as all the world’s 760 million cars”.

The pollution from marine fuel emission can be extremely costly to society. Recent scientific studies have shown that air pollution from international shipping accounts for approximately 50,000 premature deaths in Europe every year, at an annual cost of more than €58 billion. Despite the falling health costs in Europe from air pollution between 2000 and 2020,

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the contribution of shipping to overall health costs is likely to increase from 7% (€58.4 billion) to 12% (€64.1 billion) by 2020.64

Since auto emissions have already been reduced to a minute amount, it is therefore more cost-effective to cut back on emissions from marine transportation. Moreover, it is widely accepted by the industry that technical measures to cut emissions from marine transportation by 80% to 90% are easily implementable, with the adoption of cleaner fuels, adding “scrubbers” or other exhaust gas cleaning devices to ships or wider use of alternative sources of energy.65 The benefits would considerably outweigh the costs involved.

Current Regulatory Landscape Regarding Emissions from Marine Fuel

Established in 1948, the International Maritime Organization (IMO) is the regulating body of the international shipping industry and an agency of the United Nations. The concerns over air pollution from ships were raised as early as 1973, during the “International Convention on the Prevention of Pollution from Ships”, known as MARPOL 73/78. The Annex VI of MARPOL 73/78, titled “Regulations for the Prevention of Air Pollution from Ships”, was introduced in 1997 and enforced in 2005, setting limit on sulfur oxides (SOx) and nitrogen oxides (NOx) emissions from ship exhausts, and prohibiting deliberate emissions of ozone depleting substances.

The subsequent amendments to Annex VI have also designated Emission Controlled Areas (ECAs) around the world. These control areas currently cover the North Sea, the Baltic Sea and the English Channel in Europe as well as North American coasts, and the number of ECAs are expected to increase in the future (Figure 12). In these areas, the emission standards for the atmospheric pollutants (SOx, NOx and PM) are much stricter than elsewhere.

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The emission standards set up by the IMO have been increasingly stringent in recent years. Based on the 2008 Amendment to Annex VI, as of January 2015, ships in Sulphur Emission Control Areas (SECAs) cannot use fuel with more than 0.1% of sulfur. The global sulfur cap will be reduced progressively from 4.5% to 0.5% by 2020. This target will be reviewed by the IMO in 2018 (Figure 13). Moreover, in accordance with the IMO regulation, the European Commission has decided to also enforce the 0.5% sulfur cap in non-ECA areas by 2020.67

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Currently there are several ways that shipping companies can meet the new fuel standards: 1) switching to low sulfur fuel, 2) installation of scrubbers, 3) the use of LNG and 4) the use of methanol/methanol-diesel dual-fuel systems. A comparison of these proposed methods will be discussed in the next section.

Comparison of Proposed Methods to Meet New Fuel Standards

The most straightforward solution for the shipping companies to comply with the new fuel standards is obviously by switching to low sulfur fuels. The advantage of this option is that engines do not need to be retrofitted in order to accept this type of fuel. However, this will lead to additional costs for the shipping companies. The price of marine gas oil with 0.1% Sulphur content is roughly 50% more expensive than the price of regular bunker fuel, and shipping companies expect the additional costs to be solely passed along to the consumers.\textsuperscript{69} Moreover, the application of these global specification changes could cause significant disruption to oil markets, by affecting fuel oil prices and refinery investment as the cost could vary greatly with various rules.\textsuperscript{70}

In addition, several other technological alternatives do exist. Scrubbing is a method by which ships install on-board devices (called scrubbers) to remove SOx from exhaust gases. In this way, ships can continue burning high sulfur fuel while meeting the new emission standards. The most advanced scrubbers are capable of removing up to 97% of the sulfur dioxide emissions.\textsuperscript{71} However, the cost of installing scrubber equipment can vary between €1 million and €5 million per ship, depending on the ship size.\textsuperscript{72} The investment decision will depend on specific factors like the amount of time spent in ECAs, the spread between high, and low-Sulphur fuels and the age of the ship.\textsuperscript{73}

The use of liquefied natural gas (LNG) is considered to be a longer term solution, as it emits less toxic substances. The switch to LNG-fueled engines is expected to contribute to a 95%
reduction in SOx emissions, and to a nearly 90% reduction in PM and NOx emissions.\(^74\) One of the main obstacles at present is refueling, as significant infrastructure investments are still needed for this to become a viable solution.\(^75\) The US opened its first LNG bunkering facility in Port Fourchon (Louisiana) in early 2015 and trial refueling tests have already been carried out.\(^76\) Nonetheless, LNG does not offer a profitable business model yet, as high capital costs outweigh fuel savings for many companies.\(^77\)

Finally, methanol is also considered as a possible alternative under the current regulatory landscape, and it offers similar pollution reduction as LNG in terms of greenhouse gas (GHG), NOx, SOx and PM (Figure 14). In addition, methanol can be more economically viable and offer more benefits than LNG. First of all, methanol is a big commodity market with an annual production of 55 million tons. It is readily available and can be produced from various feedstocks such as natural gas, coal and biomass. It is liquid at room temperature, therefore it does not require high pressure or cryogenic storage onboard or ashore as in the case of LNG. Furthermore, it is considered a good solution for existing vessels as conversion to dual fuel engines is significantly easier than for LNG.\(^78\) Methanol has modest fuel and conversion costs (Figure 15). Moreover, unlike LNG, methanol is not subject to methane slip. Methane is a 21 times more powerful than CO2 as a greenhouse gas and it is estimated that with 4% methane slip the GHG benefit of LNG is eliminated.\(^79\) Lastly, while the energy content of methanol is low, it’s not a problem for marine fuel application since there is plenty of room on a containership to carry methanol onboard.

\(^{74}\) Ibid.
\(^{75}\) Ibid.
\(^{76}\) Ibid.
\(^{77}\) Ibid.
Because of more stringent regulations and the attractive features of methanol as an alternative marine fuel, some industry leaders have rolled out projects that aim for wider application of methanol as a marine fuel: Stena Lines, Europe’s largest ferry operator, is converting its 1,500 passenger ship “Stena Germanica” to run on both methanol and bunker fuel using Watsilla’s 4-stroke engine. The first engine conversion was completed in March, 2015.

81 Ibid.
with the remaining 3 engines targeted to be completed by year end.\textsuperscript{82} The company is targeting to convert 25 of its Sulphur Emission Control Area (SECA) fleet to run on methanol and bunker fuel by 2018.\textsuperscript{83} Methanex Waterfront Shipping, a subsidiary of Methanex Corporation, has ordered 7 flex-fuel vessels capable of running on methanol based on MAN Diesel & Turbo’s 2 stroke engine. The ships are expected to be delivered in 2016.\textsuperscript{84} 

The future prospects of methanol as a marine fuel indeed look promising. According to a recent project for sustainable shipping, methanol is evaluated to be “the most attractive alternative fuel over short, medium and long perspectives”, due to its availability, easier and cheaper costs for installation and engine conversion, the ability to be produced using different feedstocks, including biomass and through Carbon Capture and Storage (CCS) technologies to further reduce carbon footprint.\textsuperscript{85} 

However, in the short term, the regulation requirement faces its own challenges, and methanol is not likely to be under the radar for major shipping companies in the near future. One of the major obstacles is the current lack of control systems to ensure emission limits are being applied. While the IMO creates global standards for all seafaring vessels, the enforcement is not managed by IMO.\textsuperscript{86} As discussed before, the cost of compliance is expensive for ship-owners, and in reality it may cost more than fines for non-compliance.\textsuperscript{87} Given that alternative technologies are not yet cost effective, unless control systems are properly enforced, cheating could become an attractive alternative for shipping companies, especially smaller ones for which compliance is simply too costly.\textsuperscript{88} It has been noted that an oil tanker traveling the English Channel to Russia could save up to $150,000 per voyage by skirting regulation.\textsuperscript{89} Secondly, the

use of methanol as marine fuel may need more government support in order to be viable. As mentioned earlier, right now there are only a few industry players testing for the viability of methanol through their own capabilities. A wider use of methanol as marine fuel cannot be achieved without relevant government bodies and intergovernmental organizations to initiate comprehensive studies and pilot program to further test out the viability.

**Why Now: Recent Developments**

While the impact of lower energy price has created short-term uncertainties in the methanol market, long-term demand level for methanol as a cheaper and cleaner energy source is expected to remain strong. With more and more evidences of climate change – rising ocean levels, smog, extreme weathers, droughts, heavy storms – countries around the globe are more active than before in seeking alternate energy sources to reduce greenhouse emissions. China, the largest market for methanol, is experiencing heavy air pollutions across the country, and methanol is considered to be a key energy source to reduce emission. As a result, China has more than doubled its methanol capacity in the last four years, accounting for over 50% of the world demand. Despite strong surge in, it still imports approximately 10% of its methanol demand from other countries\(^90\), which further supports the increase importance of methanol within China’s various industries.

Aside from China, which has long been the pioneer in the adoption of methanol in fuel applications in part due to environmental issues, there has been an increasing global support toward further reduction in greenhouse gas and pollutant emissions. Recently, the Obama administration outlined a new energy policy which targets an economy wide reduction in greenhouse gas emission by 80% by 2050; furthermore, it specifically mandates that light vehicles should reduce their greenhouse gas emission to 163g CO\(_2\) per mile driven\(^91\), which is more than 50% less than the figure 7 years ago, 368.4 CO\(_2\) per mile driven\(^92\). To achieve such a radical reduction in GHG requires technological advancement in gasoline production and


combustion engine design; it could also benefit the adoption of flexible fuel vehicles (FFVs), since various renewable methanol-blended fuels including M50 and M85 can reduce CO$_2$ emissions by 15% -20% per gallon of gasoline equivalent (as shown by previous chapters).

Furthermore, the biggest benefits of methanol-blended fuels are the reduction of NOx, SO$_2$ and VOC (volatile-organic-compound), which should not be underestimated. Based on 2013 number of light vehicles in the USA (184.5 million), we estimate that they can emit as much as 7.7 million tons of NOx and 0.37 million tons of SOx per year$^{93}$ by comparison, the annual emission of said pollutants from all U.S. power plants was about 3 million short tons of SO2 and 2 million short tons of NOx$^{94}$ in 2012. This indicates that gasoline powered vehicles provide an even greater threat to our society in terms of NOx emission than do all power plants in the country! As the Obama administration moves forward with its Clean Energy Act, which targets the reduction of SO$_2$, NOx emission from power plants by 90% and 72% in 2030$^{95}$ (comparing to 2005 levels), we could also facilitate the gradual adoption of methanol-blended fuels among light vehicles and ships, since M85 reduces NOx emission by almost two thirds by gallon of gasoline equivalent (Figure 16) and eliminates SO$_2$ emission altogether. The adoption of methanol-blended fuels can provide a much cheaper, scalable solution to this problem than modifying and rebuilding expensive power plants nationwide.

![Figure 16. NOx, SO2 Emission Comparison, per Gallon of Gasoline Equivalent$^{96}$](image)

Although methanol is produced from a variety of different feedstocks, one of the most common feedstock used is natural gas. Currently, the price of natural gas has reached historical

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$^{93}$ Ibid.
lows due to US fracking activities, causing methanol to be much more cost-effective than other alternative fuels. Figure 19 below shows a graph of Henry Hub Natural Gas price; spot price for natural gas is 2.11 per millions BTU, the lowest since 2000. We believe this is a great time to increase methanol production in the US to take advantage of the cheap and abundant natural gas, as production of natural gas in the U.S. has consistently grown by 4.8% CAGR in the last five years. The availability of natural gas is expected to surge even further, driven by the enactment of the Clean Energy Act, which would increase the market share of natural gas powered energy plants from 24% in 2010 to 32% in 2020. The increased usage of natural gas among various industries in the United States would propel production volume, thereby reducing the cost of production and expanding resource availability. For example, Methanex, the world’s largest methanol producer, has scheduled the construction of two new methanol production facilities in Louisiana in light of these favorable industry tailwinds.

Figure 17. Market Share of Electricity Generation in the U.S. by Sources

Figure 18. Production of Natural Gas in U.S.

However, while cheap feedstock provides an attractive entry opportunity, low oil price remains a risk for methanol demand. Many of methanol’s end products demands are directly correlated to the price of oil. The direct methanol to gasoline (MTG) blend is less economical if the price of oil remains cheap while MTBE tracks the price of oil due to its usage as an oxygenating agent to increase octane rating. With Brent currently priced around $43 per barrel, demand for methanol is expected to be less than projected. We believe the energy glut we are experiencing right now provides an attractive opportunity to differentiate methanol from many of the other alternative fuels that do not have the natural gas advantages methanol enjoys right now due to pricing. Lastly, consistent innovation of fuel technology, including in areas such as renewable methanol and methanol fuel is likely to increase the benefits of methanol-fuel even further. Therefore, we believe now is a good time for U.S private and public sector entities to make preemptive investments in the methanol-fuel space.

**Quantitative Analysis of the Feasibility of Methanol**

Until now, this paper has focused on a qualitative analysis of greater methanol consumption. We have examined the advantages and disadvantages, and conducted case studies on historical usage. In this section we will perform quantitative analysis on the conditions under which methanol production and usage is feasible. Our analysis will be divided into two parts: the feasibility of methanol production in the private sector, and a cost/benefit analysis from the government’s perspective. As with most of our research, we will focus our analysis on the USA.

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Feasibility of Methanol Production in the Private Sector

As mentioned previously, methanol is unique among alternative energy sources because it has already entered large-scale production and usage in numerous applications, but not as a motor fuel. Companies worldwide produce methanol from a variety of feedstock, and have periodically added capacity as demand has increased. In short, methanol is an established chemical, and we believe that additional capacity for use as a motor fuel should also be supplied by corporations in the private sector.

However, we feel that many of the papers we have read have unfortunately not focused on the companies that will be producing the methanol required for motor fuels. Given that corporations require sufficient profit incentives in order to deploy capital, we must be certain that these incentives exist if we want additional supply on the marketplace. This is especially important given the recent methanol price decline discussed earlier, which is harmful to producers. In our analysis, we have used publically available financial data to model the hypothetical cash flows from building a methanol production facility. We hope to determine the conditions under which methanol production can deliver a sufficient return on investment.

The first step is to determine how much initial investment is required for every metric ton of methanol capacity, and how much time is required for construction. We found data on two methanol plants currently under construction in the USA. The first is a joint venture by Celanese Corporation that is expected to cost $900 million and will have 1.3 million annual tons of capacity, which corresponds to a capital cost of under $700 per million ton per annum (mtpa).\textsuperscript{101} The second is owned by OCI, which is expected to cost $1.6 billion and will have a capacity of 1.9 mtpa, for a capital cost of $842 per mtpa.\textsuperscript{102}

However, it is important to note that these are nameplate capacity numbers, and the plants will likely operate at a lower capacity due to planned or unplanned downtime. Scotiabank research analysts who cover the methanol industry estimate that the capital cost per operating mtpa is approximately $850, which is the number we have decided to use in our analysis.\textsuperscript{103}

\textsuperscript{103} Ibid.
The next step is to determine ongoing cash flows once a plant has entered production. We define cash flow as the realized price of methanol, minus all costs and taxes paid. It represents the profit to the corporation. For simplicity, we have decided to estimate these cash flows on a per-ton basis. Our analysis centered on Methanex Corporation (NASDAQ:MEOH), the world’s largest producer of methanol with a 15% global market share and the only publically traded pure-play methanol company. Financial data from the past five years is shown in Figure 20. The main cost of methanol production is the feedstock, but producers usually lock in prices with long-term contracts. In determining the total cost, we cannot simply use the cost of raw materials, because there are additional costs including wages, transportation, and corporate overhead. Instead, we used “Cost of Sales and Operating Expenses” and divided this by the total sales volume in the same period to find expenses per ton. These costs include the aforementioned additional costs and raw material costs, but not non-operating costs such as share-based compensation or depreciation and amortization. Raw material cost was also included to provide a better picture of the cost breakdown.

We found that operating expenses per ton were surprisingly consistent across the last five years, averaging $278.3 with a standard deviation of $18.8. Average realized price for methanol averaged $388 per ton. We did not include the 2015 year-to-date financials in our average, but have included them for reference.

<table>
<thead>
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<th>2015YTD</th>
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<th>FY2013</th>
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<td>Average Realized Methanol Price ($ per tonne)</td>
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<td>437</td>
<td>441</td>
<td>382</td>
<td>374</td>
<td>306</td>
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<tr>
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<td>7991</td>
<td>7459</td>
<td>7514</td>
<td>6929</td>
</tr>
<tr>
<td>Revenue (mmUSD)</td>
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<td>3024</td>
<td>2548</td>
<td>2608</td>
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<tr>
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<td>2,464</td>
<td>2255</td>
<td>2171</td>
<td>2128</td>
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<td>Cost of Raw Materials (mmUSD)</td>
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<td>1661</td>
<td>1601</td>
<td>1622</td>
<td>N/A</td>
</tr>
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</table>

**Calculated Data**

| Expenses per tonne of sales volume ($ per tonne) | 226.3 | 289.7 | 282.2 | 291.1 | 283.2 | 245.3 |
| Margin per tonne of sales volume (%)           | 33%   | 34%   | 36%   | 24%   | 24%   | 20%   |
| Cost of Raw Materials per tonne of sales volume ($ per tonne) | N/A   | 217.2 | 207.9 | 214.6 | 215.9 | N/A   |

**Average Expenses per Tonne of Sales Volume**

| STDEV | 18.89 |

**Average Realized Methanol Price**

| STDEV | 55.15 |

*All data from Methanex Annual Report for the given period*

Figure 20. Methanex Annual Financial Information

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Now we can model the cash flows from our hypothetical methanol plant, using the following parameters: initial capital cost, construction period, average realized price, operating expenses, tax rate, and useful life of plant. We estimated the capital cost to be $850 per ton (see above), construction period to be 1.5 years, tax rate to be 30%, and useful life of plant to be 35 years. Methanex has many plants built in the 1980s that are still operational today.\textsuperscript{106} For average realized price and total cost, we used the five-year averages for the baseline rate. In Year 0, the cash flow is -850 because the company spends the money to build the factory, and production begins in Year 2.

It is worth noting that the cash flows per year in our model are constant after Year 2. Although methanol prices and expenses will fluctuate from year to year, these are virtually impossible to accurately predict over a long period of time. In addition, our model is designed to provide a general case for the returns of a methanol plant at some point in the future and not immediately. As such, we have kept these parameters constant in our forecast to provide an estimate of the returns assuming a long-run steady price of methanol.

The output of our model is the internal rate of return (IRR) shown in Figure 21, which is essentially the annual discount rate required for the present value of the cash flows to equal zero. Our IRR is 7.40% assuming five-year average methanol prices and operating expenses. A higher IRR means that the return on investment will be greater. If the cost of capital for the corporation (discount rate) is lower than the IRR, then the project is worth pursuing because it will deliver sufficient returns on investment. Figure 3 shows the sensitivity of the IRR to changes in the average realized price and total expenses per ton.

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<td>388</td>
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<tr>
<td>Expenses</td>
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</table>

**Calculated IRR** \[ \text{7.40\%} \]

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure21.png}
\caption{IRR Calculation}
\end{figure}

\textsuperscript{106} Ibid.
In this case, an IRR of 7.40% is not that high as many corporations borrow at rates of 6-7%, and investment may be limited. Our sensitivity table provides context to our results, because we can consider many different cases. The sensitivity table shows different values of IRR for different methanol price and operating expenses (Y-axis) scenarios. If we take Methanex’s most recent year-to-date figures of around $330 realized price with $220 in expenses, then the IRR is still 7.40% and investment would be low. However, methanol prices are likely to increase if the government begins moving towards methanol fuel, and if natural gas prices stay relatively constant then at the current expense level, almost any methanol price would result in a sufficient IRR to stimulate investment. This tells us that if the government begins to support methanol as an alternative to gasoline, the private sector could respond by building plants to supply the extra methanol required.

Our IRR model shows the willingness of the private sector to invest in methanol production, but it can also be used as a forecast for long run methanol prices. Namely, if the IRR is very high, then producers will enter the market and the price may decline in 1-2 years when new supply arises. If IRR is too low, then new production will not happen, and incremental demand increases will push prices up eventually. We think that this model can be usefully applied by the government when considering how the methanol industry will respond to increases in demand caused by government policies.

Cost-Benefit Analysis of Using Methanol as a Motor Fuel in Light Duty Vehicles

Although the production of methanol will be handled by the private sector, the impetus for greater adoption of methanol as a motor fuel will still be government policies aimed at increasing societal welfare. As such, we also conducted a cost/benefit analysis to using methanol blends from the perspective of the whole society. The main costs are conversion costs for
existing vehicles and gas stations, the capital cost of increasing methanol capacity to meet additional demand, and possible ongoing subsidies for methanol buyers. The main benefit from increased methanol usage is reduced pollution. From our analysis, we will evaluate whether the benefits of increased use of a cleaner fuel outweigh the costs of expansion and installation.

At present, the USA consumes almost 137 billion gallons of gasoline every year. The optimal blend of methanol is M85, in order to realize maximum benefits while reducing conversion costs. We want to replace 5% of the gasoline consumption in the USA with M85 in the future. On a constant energy basis, M85 requires 1.76 times the volume of gasoline, so this 5% corresponds to a total M85 demand of about 12 billion gallons per year. One ton of methanol corresponds to 332.6 gallons in volume, so therefore the total demand for methanol is 30.8 million tons per year once we reach this target. These numbers are presented in Figure 23.

<table>
<thead>
<tr>
<th>BASELINE ASSUMPTIONS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Gasoline Consumption per Light Vehicle in the US (gallon)</td>
<td>498</td>
</tr>
<tr>
<td>Additional M85 Demand (million gallons per year)</td>
<td>15,618</td>
</tr>
<tr>
<td>Total Methanol Demand (million tons per year)</td>
<td>40</td>
</tr>
</tbody>
</table>

**Figure 23. Assumptions for Financial Projection**

Now we estimate our costs, which include the cost of converting vehicles and gas stations, ongoing subsidies, and methanol investment costs. To estimate the costs of converting vehicles, we started with the total number of light duty vehicles registered in the USA, which was 184.5 million as of 2013. However, only 3-4% of vehicles are flexible fuel vehicles (FFVs), meaning that they can run on any blend of biofuels. This is far too small to consume our target amount of M85, so we need to increase the number of flexible fuel vehicles. According to analysts, in order for there to be enough incentive for filling stations to convert or install new infrastructure, at least 15 to 20 percent of the cars in the area need to be capable of using the new fuel. In our model, we have used the maximum of this range and assumed a target

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20% penetration of FFVs for light duty vehicles in the USA. To achieve this penetration level, we would need about 31 million new FFVs. We can increase FFV amount by making newly manufactured cars FFVs, or by converting existing cars. It costs approximately $100 more per vehicle to manufacture a FFV as opposed to a gasoline-only car.\textsuperscript{111} At the same time, the incremental cost of converting a light duty vehicle such that it can use M85 is a one-time cost of $90-$300 per vehicle.\textsuperscript{112} For a conservative estimate, we have assumed a conversion cost of $300 for every vehicle, and the total vehicle costs are $9.4 billion.

For gas station conversion costs, it is estimated that it would take $20,000 to retrofit an existing pump to be methanol-compatible,\textsuperscript{113} and there are 114,533 gas stations in the USA as of 2012.\textsuperscript{114} Assuming every gas station retrofits an average of 2 pumps, the total cost of gas station conversions is $4.6 billion. Analysts estimate an additional $12 billion in order to build the infrastructure to distribute methanol to every refueling station.\textsuperscript{115}

Our last set of fixed costs is the price of plants required to supply the methanol needed for our new cars and gas stations. From our private sector analysis earlier, we determined the capital cost of methanol to be $850 per annual ton of production. We added an additional 10% on top of this figure in order to give us more headroom, and because such a large demand for methanol plant construction would likely increase the costs of construction. To meet our projected demand of 40 million tons of methanol, we would need $37.3 billion of investment.

In addition to fixed costs detailed above, there are also potential subsidies that must be included in order to incentivize consumers to use M85. These subsidies will only kick in if the price of methanol, adjusted for energy content, is greater than the price of gasoline. Historically, this has not been the case but given recent price declines in crude oil is now a barrier to methanol usage in fuel. The subsidy will automatically reduce the M85 price per gallon to levels equivalent to gasoline, and will also add a ten cent discount per gallon. Because methanol is also produced for industrial purposes, this subsidy will be given to the gas stations that purchase methanol, allowing them to charge lower methanol prices to consumers. Assuming a price per

\textsuperscript{111} Ibid.
\textsuperscript{112} Ibid.
\textsuperscript{113} Ibid.
ton of $388 for methanol and using current gasoline prices of $2.06 per gallon, the ongoing subsidy cost for our projected consumption of M85 is $3.2 billion. Figure 24 below shows our total costs, including conversion, production, and subsidies.

### COSTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol Price in USA</td>
<td>$388.00</td>
</tr>
<tr>
<td>Methanol Price USD</td>
<td>$2.37</td>
</tr>
<tr>
<td>Gasoline Price USD</td>
<td>$2.06</td>
</tr>
<tr>
<td>Potential Pricing Shortfall USD</td>
<td>$0.31</td>
</tr>
<tr>
<td><strong>Ongoing Subsidy Cost</strong></td>
<td><strong>2,331.64</strong></td>
</tr>
<tr>
<td>Light Duty Vehicles in USA</td>
<td>184.50</td>
</tr>
<tr>
<td>Target Percentage of FFVs</td>
<td>20.0%</td>
</tr>
<tr>
<td>Existing Number of FFVs</td>
<td>5.54</td>
</tr>
<tr>
<td>Shortfall of FFVs</td>
<td>31.37</td>
</tr>
<tr>
<td>Conversion Cost USD</td>
<td>300.00</td>
</tr>
<tr>
<td><strong>Total Vehicle Conversion Costs</strong></td>
<td><strong>9,409.50</strong></td>
</tr>
<tr>
<td>Distribution Conversion Cost</td>
<td>12,000.00</td>
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<tr>
<td>Gas Station in the US</td>
<td>114,533</td>
</tr>
<tr>
<td>Convert Pump Per Station</td>
<td>2</td>
</tr>
<tr>
<td>Proposed Conversion Percentage</td>
<td>100%</td>
</tr>
<tr>
<td>Cost of Conversion</td>
<td>20,000.00</td>
</tr>
<tr>
<td><strong>Total Gas Station Conversion Cost</strong></td>
<td><strong>4,581.32</strong></td>
</tr>
<tr>
<td>Intra Cost for methanol production</td>
<td>850.00</td>
</tr>
<tr>
<td>Intra Cost for additional methanol</td>
<td>37,318.30</td>
</tr>
<tr>
<td><strong>Total Intra Conversion Cost</strong></td>
<td><strong>53,889.52</strong></td>
</tr>
</tbody>
</table>

**Figure 24. Costs Breakdown and Calculation**

Our benefits are reduced air pollution, which begin once M85 enters widespread usage and are ongoing afterwards. We divided up the main pollutants found in conventional gasoline, and obtained dollar amounts for the damage done per kilogram of these molecules.\(^{116}\) We were able to convert and sum these numbers into the amount of damage in USD per gallon, and

compared this to the damage done from a gallon of M85\textsuperscript{117}. We then multiplied the difference by the total gallons of M85 consumption, to find that the total benefit from M85 consumption is approximately $74 billion. Our calculations and data for benefits can be seen in Figure 25 below. We have elected not to include potential carbon savings from the production of methanol versus gasoline because it is dependent on the methanol feedstock and is also difficult to estimate.

### Figure 25. Benefits Breakdown and Calculation

When summing up our costs and benefits for future years in our projections, we assumed that all gas station conversion costs and methanol manufacturing plant costs would be spent in equal installments from 2016-2020. From our private sector analysis, methanol plants take around 2 years to build, so this four-year lag is justified for such a large increase in methanol demand. In the next five years from 2021-2025, we assume that demand for FFVs will take off, and the cost for converting FFVs will be spent in equal increments over these years. Concurrently, as methanol demand increases, the benefit from reduced pollution will increase incrementally until it reaches 100% level in 2025. Similarly, the cost of subsidies will be incurred from 2021 onwards.

Our complete cost-benefit analysis with calculated IRR is included in Figure 7 below. With our baseline assumptions, the IRR is 29.32%. This is very high, especially compared to the private sector results. As explained in the previous part, the IRR is the discount rate required to bring the present value of all benefits and costs to zero. Hypothetically, if the government were to assume all costs associated with the M85 project, then as long as their discount rate was lower than the IRR then it would be worthwhile for them to pursue this project as the present value of all benefits would outweigh the costs. Given the difficulty of choosing an appropriate discount rate, we think that the IRR is a much more useful metric in comparing the benefits of a project. The IRR doesn’t just tell us whether the benefits outweigh the costs for a given discount rate, but it shows us the maximum acceptable discount rate in order to deliver a positive return.

In this case, since we have estimated the costs to society and not just the government, a higher IRR means that a given project provides greater returns to society, and as such the IRR can also be used to compare the cost-effectiveness of different projects. Given many possible projects, the one with the highest IRR should be chosen to provide the greatest returns to society.

<table>
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</thead>
<tbody>
<tr>
<td>Benefit from Reduced Pollution</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14,798</td>
<td>23,996</td>
<td>44,995</td>
<td>59,193</td>
<td>73,991</td>
<td>73,991</td>
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<tr>
<td>Cost of Subsidies</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2,332</td>
<td>2,332</td>
<td>2,332</td>
<td>2,332</td>
<td>2,332</td>
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<tr>
<td>Upfront Cost</td>
<td>-10,780</td>
<td>-10,780</td>
<td>-10,780</td>
<td>-10,780</td>
<td>-1,882</td>
<td>-1,882</td>
<td>-1,882</td>
<td>-1,882</td>
<td>-1,882</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Total Benefit or Cost</td>
<td>-10,780</td>
<td>-10,780</td>
<td>-10,780</td>
<td>-10,780</td>
<td>-10,780</td>
<td>10,585</td>
<td>23,383</td>
<td>40,181</td>
<td>54,979</td>
<td>69,777</td>
<td>71,659</td>
</tr>
</tbody>
</table>

Calculated IRR: 29.32%

**Figure 26. Free Cash Flow Calculation**

In practice, we think it is unlikely that the government would need to handle all of the costs of the M85 project. This would be prohibitively expensive, especially because the benefits are all in non-cash reduced pollution charges. The increased methanol production can be handled by the private sector, for instance. However, it is likely that at least some part of the cost will have to be paid by the government, such as the ongoing subsidy costs, and incentives to convert cars and gas stations to be M85 compatible. We have refrained from separately modelling out the government’s cost because it is difficult to determine exactly what amount of costs they should shoulder, and how much benefit they would actually realize from reduced air pollution. But we do believe that the IRR output of our model provides a relevant metric from which to compare...
the benefits of greater methanol consumption to potential benefits from other projects in alternative fuels.

**Conclusion**

Like many alternative fuels, the largest benefits to using methanol instead of gasoline are environmental. As shown by our cost-benefit analysis, the reduced damage from cleaner air far outweighs the potential upfront and ongoing costs that are required to bring methanol into wider use.

However, methanol is unique because it has already seen widespread usage as an industrial chemical, such that its production process has already been refined and perfected. The private sector can quickly add capacity to satisfy additional demand, with only two years required to build a methanol facility. In addition, it requires only minimal investment in order to convert cars and gas stations to be methanol compatible.

Even more fascinating is that light duty vehicles are only the tip of the iceberg. As we have mentioned, methanol usage in the future could spread far beyond vehicles to include marine vessels, and the feedstock of production could eventually become renewable biomass instead of natural gas. For next steps, we think these two areas have the greatest potential for further research. We hope this paper can generate more widespread support and research into methanol so that its benefits can be evaluated more extensively and so that methanol can potentially be used as a fuel source in the future.
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