Natural Gas Utilization via Small-Scale Methanol Technologies

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Prepared by
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ADI Analytics
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1.0 Executive Summary

- The Shale Gas Innovation & Commercialization Center, an initiative of Ben Franklin Technology Partners, commissioned ADI Analytics LLC to prepare this white paper with an independent assessment of the technical and economic viability of small-scale methanol plants.

- The discovery and rapid development of shale gas and unconventional oil basins has dramatically increased the supply of natural gas in North America. However, natural gas demand in the United States (U.S.) is growing much slowly in comparison to supply. As a result, natural gas supply is forecasted to significantly outstrip demand, which has led to the recent decline in natural gas prices.

- Low natural gas prices have helped in driving new attention and interest to natural gas monetization options, which will play an important role in spurring natural gas demand. One promising gas monetization option is the production of methanol using small-scale plants.

- Conceptually, small-scale methanol plants offer a number of advantages. The first advantage is that methanol prices track those of oil thereby providing a significant arbitrage to exploit if the natural gas feedstock is available as cheaply as it is in the U.S. Second, small-scale methanol plants have lower capital costs in comparison to traditional large plants making them attractive to a wider range of investors. Third, methanol is a liquid chemical product that can be transported easily and cost-effectively offering the ability to monetize natural gas from fields that are remote, have limited pipeline connectivity, or have relatively poor production or economics. Finally, methanol is a versatile chemical with multiple applications and end-uses.

- Methanol is the simplest alcohol and is a light, volatile, colorless, and flammable liquid with a distinctive odor. Methanol is produced mainly using a two-step catalytic chemical process. It is an important chemical with a wide range of applications and end-uses. Each of these applications and end-uses can be segmented into three major categories.

- The first category, which accounts for more than half of methanol demand, is the use of methanol as a chemical feedstock. The second category relates to the use of methanol in fuels and accounts for more than a third of methanol demand. Finally, methanol is used for a number of fragmented applications such as solvents, antifreeze, wastewater denitrification, and ethanol denaturing.

- Thanks to rapidly-growing applications such as olefin production and fuel use, methanol demand is growing at a robust 6% annually (some analysts believe growth rate could be as high as 8%) and is forecasted to be more than 90 million tons per year (mtpy) by 2020. In comparison to 2013, this translates to more than 60 mtpy of additional methanol demand over the next five years globally.

- China drives the bulk of this demand growth as it uses methanol for a wide variety of applications and, in particular, its use as a fuel and as a feedstock for olefins. Other Asian economies such as India account for additional demand growth in Asia. Further, the new supply of natural gas liquids (NGLs) such as ethane and propane in North America (also facilitated by the unconventional boom) has led to the announcement of a number of new petrochemical cracker projects. These projects seek to crack NGLs into ethylene and propylene that will be then converted to polymers and other chemicals some of which may require methanol as a raw material. Therefore, new petrochemical crackers in North America may lead to additional demand growth for methanol in North America.

- Several new natural gas-fed methanol plants have been announced in North America while new plants have been announced based on coal in China. Most of these new plants will have large capacities as many of the rapidly-growing applications, e.g., methanol to olefins, require large volumes of methanol. A couple of the new methanol plants announced in North America are being developed by companies in China that are seeking methanol exclusively for producing olefins.

- New methanol and methanol-derivative plants that have been announced in the U.S. collectively total over 30 mtpy of capacity. However, only a few are likely to be constructed and completed for a variety of reasons including global commodity prices, worldwide methanol demand, and investor appetite.

- Financing and total investment will likely be particularly challenging given the high capital costs as well as the high capacities planned for these projects. Capital costs for large-scale methanol plants vary from $200 to $700 per ton per year of capacity although the average is approximately $530. Collectively, the largest of these projects are anticipated to cost as much as $750 million to $2 billion.

- Although most new announcements have been for large methanol plants with capacity ranging from 1 to 2 mtpy, there may be potential for small-scale (15,000 to 20,000 tons per year of capacity) methanol plants in North America. The primary driver for small-scale methanol plants is the supply of cheap natural gas across shale plays in North America. In several shale plays, there are numerous wells that produce small or economically immaterial volumes of gas and/or are located in regions with limited pipeline connectivity.

- Economics typically drives commercial adoption of new technologies and, therefore, costs and economics of small-scale methanol plants were analyzed. Capital costs for small-scale methanol plants were assumed to range from $700 to $1,100 per ton per year of capacity based on primary and secondary research including interviews with technology developers.

- Cash costs of producing methanol from small-scale plants are well below the historical 10-year average price for methanol (corresponding to an oil price of $94 per barrel) in North America across the entire range of natural gas costs of $2 to $5 per million Btu. However, methanol production costs from small-scale plants are higher than the lowest methanol price (corresponding to an oil price of $26 per barrel) seen over the past 10 years. These economics suggest that small-scale methanol plants would be able to deliver a competitive return to investors unless methanol prices fall to the lower range seen over the past decade.

- Another factor that investors in small-scale plants will have to consider is methanol demand in their markets and the competitive landscape. Most of the U.S. methanol demand is in the Gulf Coast followed by Midwest and the East Coast. Both Midwest and East Coast regions will have methanol demand in excess of over 1 mtpy by 2020, which may be sufficient to support several small-scale methanol plants.

- Even so, small-scale methanol plants supported by natural gas from the Marcellus, Utica, or Bakken shale plays would still have to compete with methanol imports from the Gulf Coast. The cost of methanol transportation by railcar from the Gulf Coast to the Midwest or East Coast will likely range from $40 to $70 per ton based on estimates gathered from a major railroad. These railcar-based transportation costs should be added to cash costs of methanol from large-scale plants thereby potentially impacting some of the competitiveness of large-scale plants in comparison to small-scale plants.

- A third factor that will play an important role in the commercial deployment of small-scale methanol plants is the availability of process technology. Currently, no process technology has been commercially proven for small-scale methanol plants. However, a number of start-up companies are pursuing the development of small-scale methanol technology and a representative set of companies have been identified and discussed.

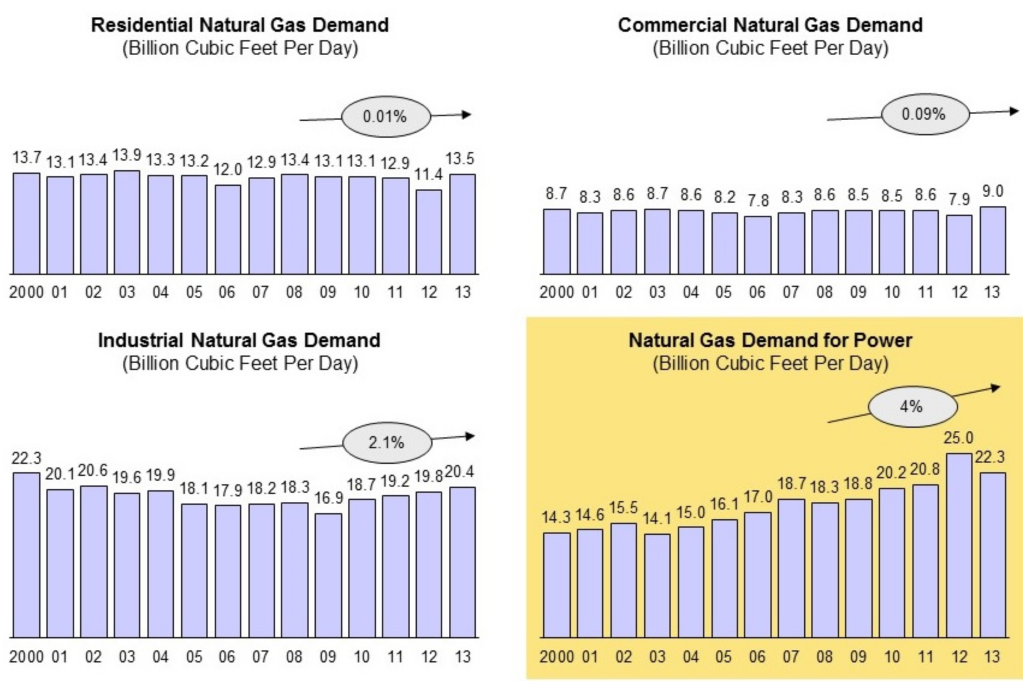
- Stakeholders should carefully consider a number of risks associated with small-scale methanol plants including (1) commodity pricing risk, (2) technology risk, (3) capital cost risk, and (4) market and competitive risk all of which have been further described in this white paper.

2.0 Introduction

The discovery and rapid development of shale gas and unconventional oil basins has dramatically increased the supply of natural gas in North America. In the U.S., natural gas from shale basins accounted for less than 1% of total natural gas supply in 2005; today shale basins provide approximately 40% of total natural gas production. In addition, there is further potential for supply growth based on the ever-growing estimates of the North American shale gas resource base.

In comparison, U.S. natural gas demand is growing much slowly than supply. Further, most of this growth in U.S. natural gas demand is coming from power generation and to a modest extent from industrial demand, while the other key segments, e.g., residential and commercial are stagnant as shown in Exhibit 1. Natural gas demand for power generation has primarily stemmed from replacement of retiring coal-fired power plants. Even so, power generation can account for only limited growth in natural gas demand because electricity demand in the U.S. is growing at only ~1% annually.[1] As a result, natural gas supply is forecasted to significantly outstrip demand leading to the recent decline in natural gas prices.

Exhibit 1. Most segments accounting for natural gas demand in the U.S. are stagnant save power generation, which has grown mainly at the expense of coal.[1]

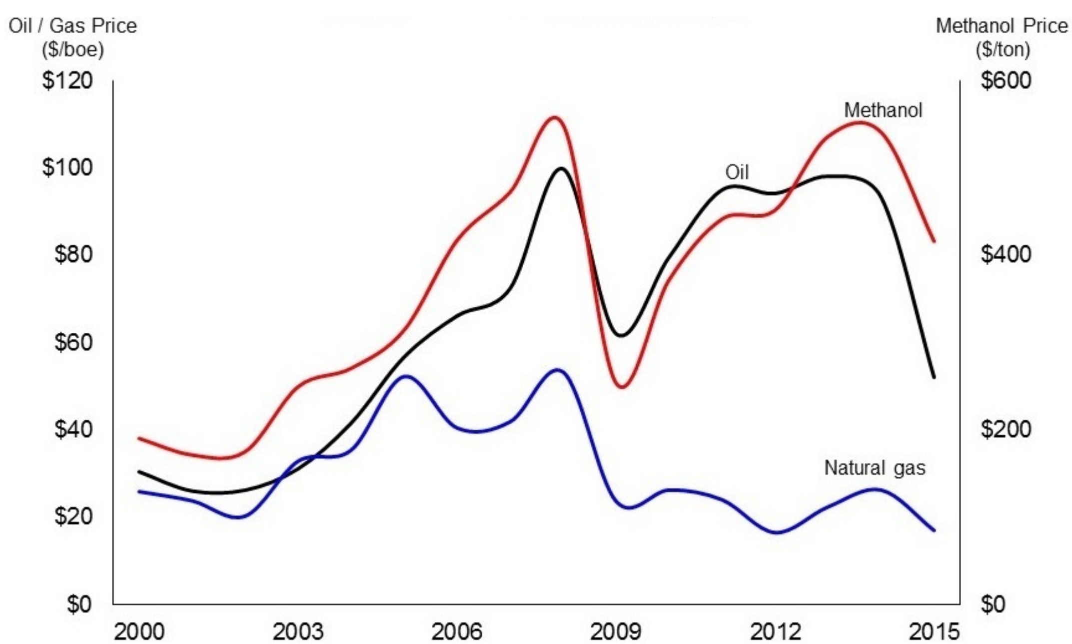


[1] U.S. Energy Information Administration

Low natural gas prices have helped in driving new attention and interest to natural gas monetization options, which will play an important role in spurring demand. However, most industry attention has focused on a few options, e.g., the production of liquefied natural gas (LNG) to export to Asia and Europe, conversion to liquid transportation fuels such as gasoline and diesel, production of chemicals such as methanol and ammonia through large plants, and use as transport fuel. A number of other options including small-scale methanol production have not received much attention or interest.

Natural gas monetization through the production of methanol using small-scale plants could be a promising option. In principle, small-scale methanol plants offer a number of advantages. The first advantage is that methanol prices track those of oil (see Exhibit 2) thereby providing a significant arbitrage to exploit if the natural gas feedstock is available as cheaply as it is in the U.S. Second, small-scale methanol plants have lower capital costs in comparison to traditional large plants making them attractive to a wider range of investors including small businesses, entrepreneurs, and project developers. Third, methanol is a liquid chemical product that can be transported easily and cost-effectively offering the ability to monetize natural gas from fields that are remote, have limited pipeline connectivity, or have relatively poor production or economics. Finally, methanol is a versatile chemical with multiple applications and end-uses.

Exhibit 2. North American methanol and oil prices move together, and natural gas has become significantly cheaper.[2]



[2] U.S. Energy Information Administration; Methanex Corporation

Given these advantages for methanol and their small-scale production, the Shale Gas Innovation & Commercialization Center (SGICC) commissioned ADI Analytics to conduct an independent assessment of the technical and economic viability of small-scale methanol plants, which has been summarized in this white paper. Although oil prices have dropped significantly and quickly since this study was commissioned, the research and analysis presented here are relevant as capital projects are designed to operate for 20 to 30 years and witness multiple commodity price cycles. Further, the findings of this study are based on analysis over a wide range of natural gas feedstock cost and methanol product pricing scenarios. As a result, this white paper assessing the feasibility of small-scale methanol production plants as an option to monetize natural gas from basins such as the Marcellus should find relevance across a wide range of stakeholders.

3.0 Methanol and its Applications

Methanol is the simplest alcohol and is a light, volatile, colorless, and flammable liquid with a distinctive odor. Although it is quite similar in appearance to alcohol consumed by human beings, methanol is highly toxic and unfit for human consumption. Methyl alcohol is popularly called methanol although it has historically also been described as wood alcohol since it was originally produced as a byproduct of the destructive distillation of wood.

Today, methanol is produced mainly using a two-step catalytic chemical process. Catalytic reforming is the first steam during which natural gas is converted to synthesis gas. In the second step, synthesis gas is converted to methanol. A number of other feedstocks including coal, biomass, and municipal waste could also be converted to synthesis gas for further conversion to methanol and are used in several regions based on their availability and cost.

Methanol is an important chemical with a wide range of applications and end-uses. Each of these applications and end-uses can be segmented into three major categories. The first category, which accounts for more than half of methanol demand, is the use of methanol as a chemical feedstock. The second category relates to the use of methanol in fuels and accounts for more than a third of methanol demand. Finally, methanol is used for a number of fragmented applications such as solvents, antifreeze, wastewater denitrification, and ethanol denaturing. Each of these categories is described in further detail below.

1. ***Methanol use as a chemical feedstock:*** Methanol is used to produce a number of chemicals with formaldehyde and acetic acid being the largest chemical derivatives. Each of these derivatives is further converted into a wide range of products including fibers, paints, resins, adhesives, insulation, and dyes. Methanol use for these traditional chemical derivatives is growing at a slow to moderate pace. However, another chemical derivative application – cracking methanol to produce olefins such as ethylene and propylene – is growing rapidly due to its widespread adoption in China. Economic growth in China has accelerated demand for plastics which are produced from olefins. However, China lacks traditional olefin feedstocks such as naphtha or natural gas liquids but has plenty of coal and has, therefore, relied on the latter to produce methanol via syn-gas produced through gasification.

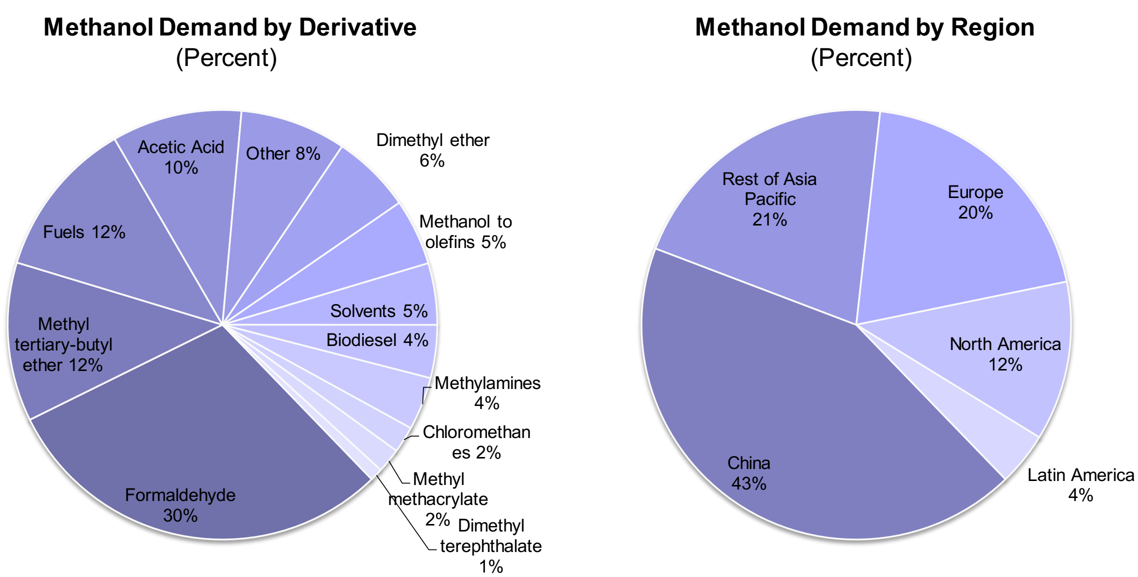
2. ***Methanol in fuels:*** With some modifications t engines, methanol can be used as a fuel for transportation. Several countries are using methanol as an automotive fuel including China. Another transportation segment is marine vessels where methanol could be a cost-effective and environment-friendly fuel in order to comply with new international environmental regulations. In addition, methanol can be converted to ethers such as methyl tertiary-butyl ether (MTBE) and dimethyl ether (DME).

   Although the U.S. had mandated and later banned the use of MTBE as a fuel additive, its use as an octane-enhancing gasoline additive has continued in several countries. A smaller application is the use of DME as a fuel to power engines that run on diesel. Finally, methanol is also used to produce biodiesel, which is typically blended with diesel in several regions including U.S. and Europe.

3. ***Other applications:*** Methanol is also used in a number of fragmented applications that individually do not consume large volumes but collectively account for approximately 10% of total demand. These include municipal and private wastewater treatment facilities that use methanol to facilitate nitrogen removal from effluent streams. Similarly, methanol could be used a carrier for hydrogen for small and large fuel cells. Finally, several high-horsepower engines, e.g., those used to produce distributed power also use methanol.

Exhibit 3 provides a breakdown of methanol demand by application. Although not shown graphically, nearly 60% of methanol demand is for traditional segments that are growing slowly, while 40% of demand is for rapidly growing applications such as methanol-to-olefins and fuel uses.[3] Finally, Exhibit 3 also shows methanol demand by region. It is clear that China and Asia drive methanol demand following by Europe and North America.

Exhibit 3. Chemical derivative production and fuel use account for most methanol use, which is dominated by China and the rest of Asia followed by Europe and North America.[4]



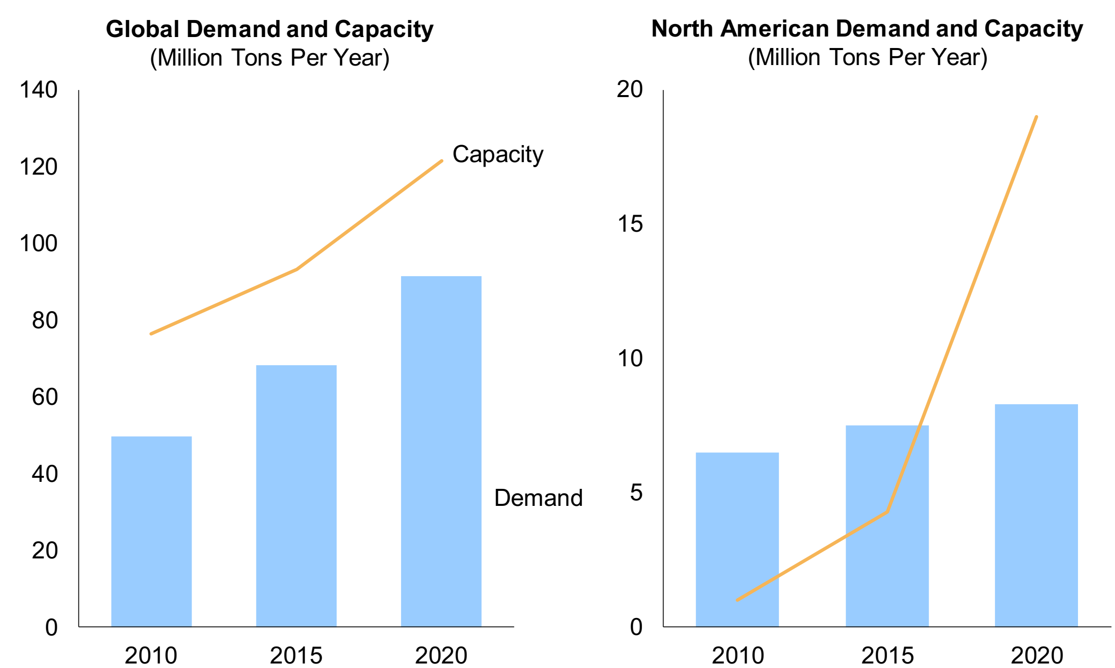
[3] Methanex Corporation
[4] Methanex Corporation; ADI Analytics

4.0 Methanol Demand and Supply

Thanks to the rapidly-growing applications such as olefin production and fuel use, methanol demand is growing at a robust 6% annually (some analysts believe growth rate could be as high as 8%) and is forecasted to be more than 90 mtpy by 2020 as shown in Exhibit 4. In comparison to 2015, this translates to more than 23 mtpy of additional methanol demand over the next five years globally.

China drives most of this demand growth as it uses methanol for a wide variety of applications and, in particular, as a fuel and as a feedstock for olefins. Other regional economies such as India account for additional growth in Asia. Further, the new supply of natural gas liquids (NGLs) such as ethane and propane in North America (also facilitated by the unconventional boom) has led to the announcement of new petrochemical cracker projects. These projects seek to crack NGLs into ethylene and propylene that will be then converted to polymers and other chemicals some of which may require methanol as a raw material. Therefore, new petrochemical crackers in North America may lead to additional demand growth for methanol in North America. North American demand and production capacities for methanol are also shown in Exhibit 1, which reflects the slower pace of demand growth relative to global demand.

Exhibit 4. Estimated global and North American demand and capacities for methanol show significant growth in global demand and North American capacity over the next five years.[5]



[5] IHS; Methanex Corporation; MMSA; Jim Jordan & Associates; Reuters; ADI Analytics

Although North American demand is growing more slowly than global demand, production capacity is forecasted to grow at a dramatic pace as methanol production has traditionally gravitated to regions with cheaper supply of feedstocks such as coal and natural gas. As a result, new supply is more likely to come up in China and North America driven by coal and natural gas, respectively, than elsewhere. Several new natural gas-fed plants have been announced in North America while new plants based on coal have been coming up in China. Most of these new plants will have large capacities of 1 to 2 mtpy as many of the rapidly-growing applications, e.g., methanol to olefins, require large volumes.

Growing global demand for methanol and low natural gas prices in North America have attracted a wide range of investors including oil refiners, investors, and entrepreneurs in large-scale methanol plants. Further, some of the new methanol plants announced in North America are being developed by Chinese companies that are seeking methanol for producing olefins.

Exhibit 5 shows a representative list of new methanol and methanol-derivative plants that have been announced in the U.S. collectively totaling over 30 mtpy of capacity. However, only a few are likely to be constructed and completed for a variety of reasons including global commodity prices, worldwide methanol demand, and investor appetite. Projects proposed by leading methanol, chemical, and refining companies such as Methanex, Celanese, Valero, and Lyondell Basell are most likely to be completed given their developers' strong balance sheets and/or active presence across the methanol value chain.

Exhibit 5. Several new methanol and methanol-derivative plants have been announced in the U.S. thanks to low natural gas prices and a robust demand growth outlook for methanol.[6]

List of Methanol Plant Announcements

Company	Location	Start-up	Cost, $B	Capacity, mtpy
Zero Emission Energy	La Place, LA	2016	1.00	1.8
Celanese Corp.	Clear Lake, TX	2015	0.79	1.3
Valero Energy Corp.	St. Charles, LA	2016	0.70	1.6
Methanex Corp.	Geismar, LA	Operational	0.55	1.0
Methanex Corp.	Geismar, LA	2016	0.55	1.0
LyondellBasell	Channelview, TX (Restart)	Operational	0.15	0.8
G2X Energy	Pampa, TX	2015	0.04	0.06
NW Innovations	Kalama, WA / Westward, OR	2018	1.80	3.6
OCI Partners LP	Beaumont, TX	2017	1.00	1.8

List of MTG and DME Plant Announcements

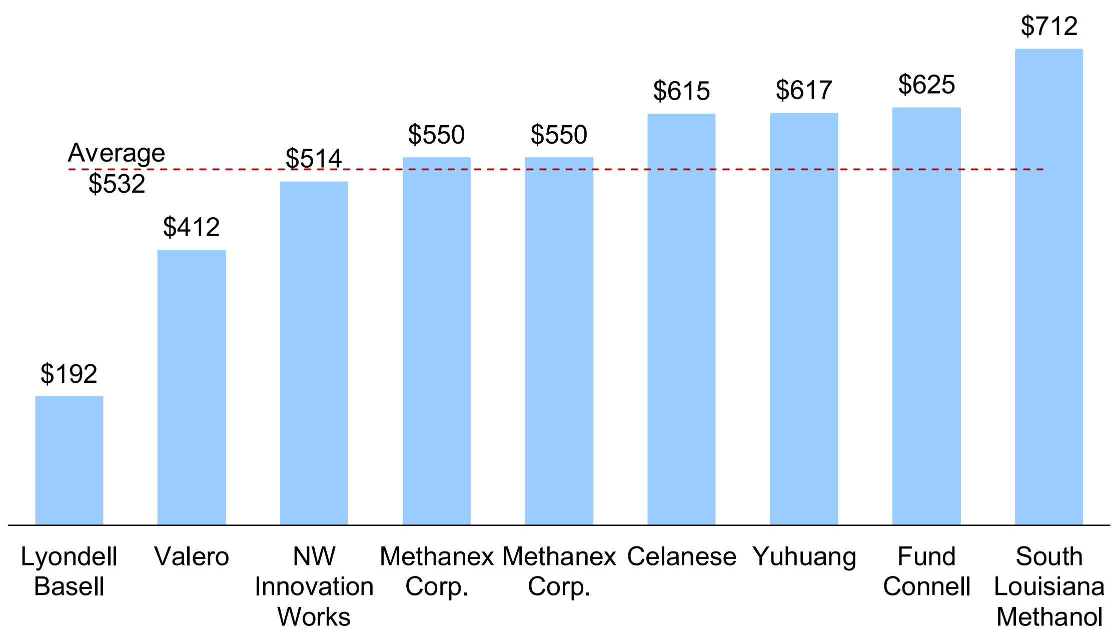
Company	Location	Start-up	Cost, $B	Capacity, bpd
Emberclear Corp. (MTG)	Natchez, MS	2017	2.80	14,000
G2X Energy (MTG)	Lakes Charles, LA	2017	1.30	12,500
Sundrop Fuels Inc. (MTG)	Alexandria, LA	2015	0.58	4,000
Marcellus GTL LLC (MTG)	Allegheny/Blair Townships, PA	2015	0.25	2,000
SoCalGas Co. (DME)	Southern California	Operational	0.05	3,000

[6] ADI Analytics

In addition to the large companies developing methanol plants, a few small players are also likely to complete their projects. Two companies that have made considerable progress are Zero Emission Energy Plants (South Louisiana Methanol project) and G2X Energy (Pampa Methanol Facility) both of which are building methanol plants that may eventually be expanded to convert methanol to gasoline. A number of other small companies that have announced methanol plants are in early stages and completion of their projects depends on a number of factors including their ability to raise financing.

Financing and total investment will likely be particularly challenging given the high capital costs as well as the large capacities planned for these projects. Exhibit 6 shows normalized capital costs for large-scale methanol plants. Capital costs for large-scale methanol plants vary from $200 to $700 per ton per year of capacity although the average is approximately $530. Collectively, the largest of these projects are anticipated to cost as much as $750 million to $2 billion.

Exhibit 6. Estimated capital costs for most large-scale methanol plants currently planned in the U.S. range from $500 to $700 with an average of ~$530 per ton per year of capacity.[7]



[7] Company estimates; ADI Analytics

5.0 Small-Scale Methanol Plants

Although most new announcements have been for large methanol plants with capacities ranging from 1 to 2 mtpy, there may be potential for small-scale – 15,000 to 20,000 tons per year of capacity – methanol plants in North America. The primary driver for small-scale methanol plants is the supply of cheap natural gas across shale plays in North America.

In several shale plays, there are numerous wells that produce small or economically immaterial volumes of gas and/or are located in regions with limited pipeline connectivity. For example, wells in the Bakken, where the primary goal is to produce crude oil, routinely flare natural gas. In others such as the eastern part of Marcellus, several gas wells have been shut down due to low natural gas prices, the lack of higher-priced liquids production, or the absence of pipelines.

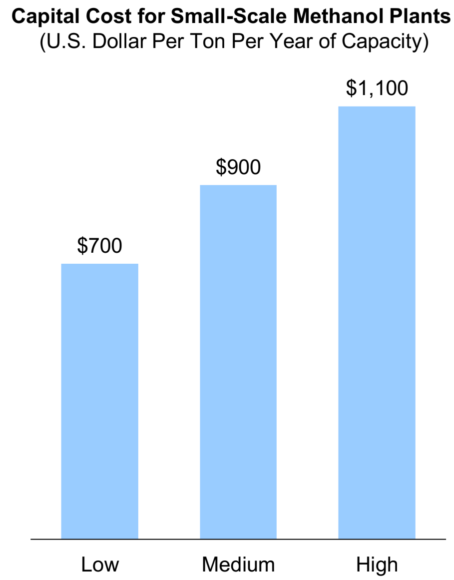
In such cases, small-scale methanol plants could be attractive due to several conceptual advantages. These include (1) oil-correlated prices for methanol providing a significant arbitrage to exploit if natural gas is cheap as it has recently been in the U.S.; (2) lower capital costs in comparison to traditional large plants; (3) production of a liquid chemical product that can be transported easily, cost-effectively, and has multiple applications and end-uses.

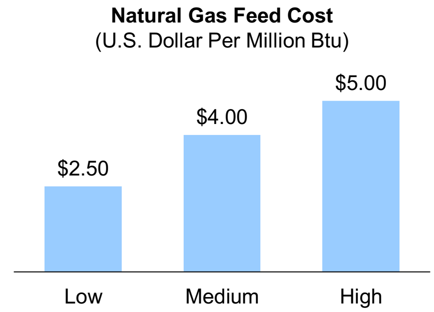
Economics drives commercial adoption of new technologies and, therefore, the costs and economics of small-scale methanol plants were analyzed. Exhibit 7 lists the key assumptions for capital costs, feedstock prices, and other financial metrics. Capital costs for small-scale plants were assumed to range from $700 to $1,100 per ton per year of capacity based on primary and secondary research including interviews with technology developers.

Most technology developers acknowledge that small-scale methanol plants will cost more than large-scale methanol plants on a normalized basis because of the lack of economies of scale. However, reliable capital costs estimates are not available since currently there are no commercially operating small-scale methanol plants. Even so, total capital costs and investment for small-scale methanol plants will be significantly lower than those for large-scale plants making them accessible to a wider range of investors.

Exhibit 8 shows how the cost of producing methanol from small-scale plants varies as a function of natural gas feedstock price as well as normalized capital costs. In general, cash costs are well below the historical 10-year average price for methanol (corresponding to an oil price of $94 per barrel) in North America across the entire range of natural gas costs of $2 to $5 per million Btu. However, methanol production costs from small-scale plants are higher than the lowest methanol price (corresponding to an oil price of $26 per barrel) seen over the past 10 years. These economics suggest that small-scale methanol plants would be able to deliver a competitive return to investors unless methanol prices fall to the lower range seen over the past decade.

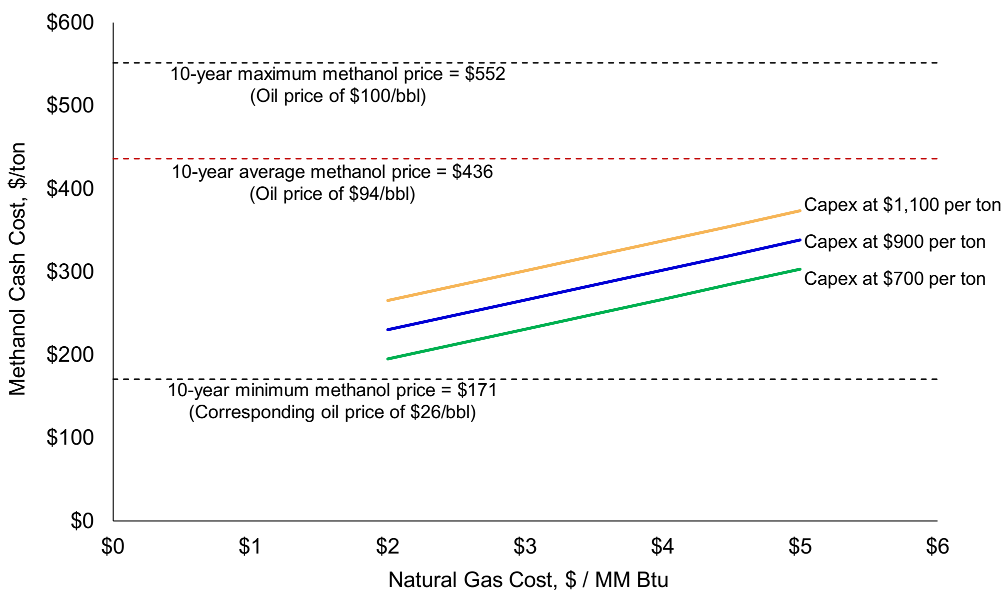
Exhibit 7. Estimated capital costs for small-scale methanol plants range from $700 to $1,100 per ton per year of capacity.[8]





Other assumptions	
Capacity, tons per day	50
Gas per ton of methanol, MM Btu	36
Plant life, years	20
Interest rate, percent	15%
Operational cost, percent of capex	10%

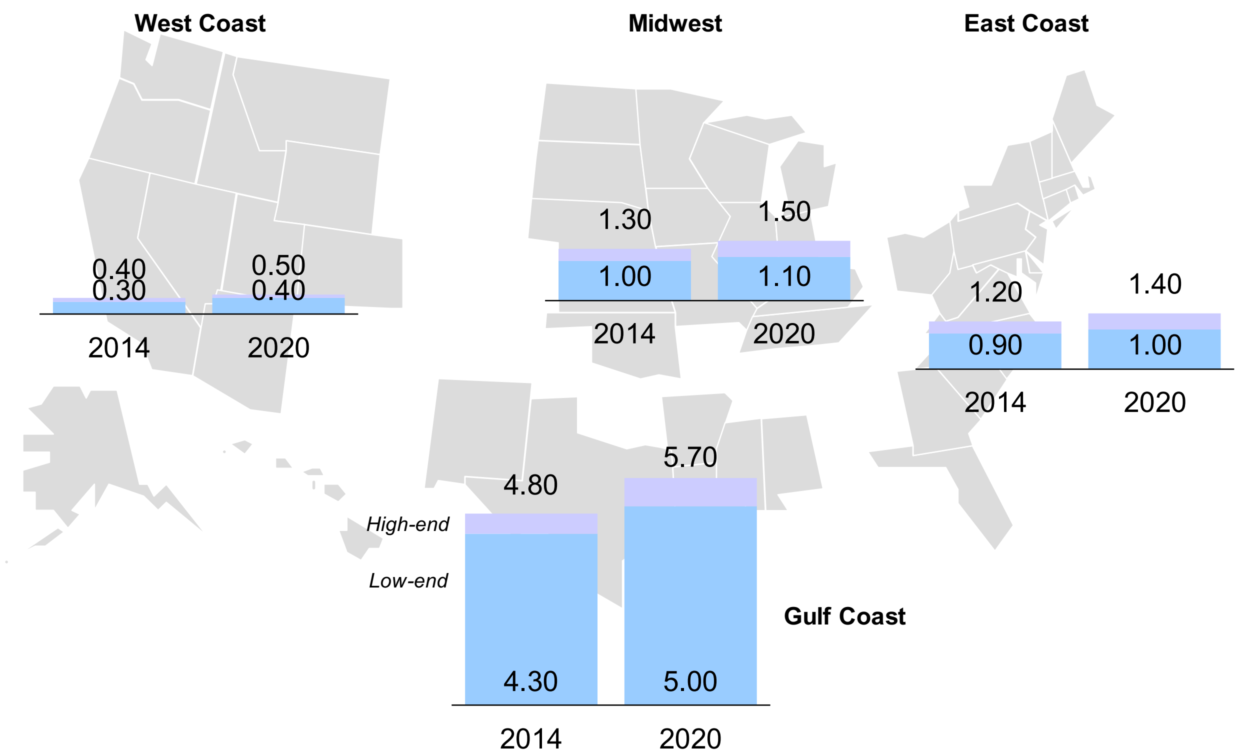
Exhibit 8. Cash cost of methanol produced from small-scale plants are quite competitive across a wide range of feedstock and capital costs and historical methanol prices.[8]



[8] ADI Analytics

Another factor that investors in small-scale plants will consider is methanol demand in their markets and the competitive landscape. Exhibit 9 provides an estimate of methanol demand across the four major regions in the U.S. Most of the U.S. methanol demand is in the Gulf Coast followed by Midwest and the East Coast. The extensive chemical industry in the Gulf Coast drives methanol demand in the region and new ethane crackers proposed in the Midwest or the East Coast may drive further demand for methanol. Even without additional chemical plants in the Midwest or the East Coast, both regions will have methanol demand in excess of over 1 mtpy by 2020, which may be sufficient to support several small-scale methanol plants.

Exhibit 9. U.S. Gulf Coast dominates methanol demand followed by Midwest and East Coast.[9]



However, small-scale methanol plants supported by natural gas from the Marcellus, Utica, or Bakken shale plays would still have to compete with methanol imports from the Gulf Coast. The cost of methanol transportation by railcar from the Gulf Coast to the Midwest or East Coast will likely range from $40 to $70 per ton based on estimates gathered from a major railroad. These railcar-based transportation costs should be added to cash costs of methanol from large-

[9] U.S. Census; ADI Analytics

scale plants thereby potentially impacting some of the competitiveness of large-scale plants in comparison to small-scale plants. Even so, investors should carefully evaluate methanol cost curves from different plants and locations as they consider small-scale plants in the Midwest or the East Coast.

A third factor that will play an important role in the commercial deployment of small-scale methanol plants is the availability of process technology. Currently, no process technology has been commercially proven for small-scale methanol plants. However, a number of start-up companies are pursuing the development of small-scale methanol technology and a representative set of companies have been identified and discussed in Exhibit 10. Although a number of companies are active in this area and are investing significant time and effort through a diversity of approaches, it is too early to definitively establish the technological viability of small-scale methanol plants. Similar to cost curves, investors will have to carefully evaluate process technology availability, maturity, and costs before considering small-scale methanol plants.

Exhibit 10. Several firms are developing small-scale gas monetization technologies with a representative few summarized here.

Maverick Synfuels	▪ Offers small-scale, skid-mounted, modular, 10-30 tons/day methanol plants using commercial steam methane reforming and methanol synthesis catalysts ▪ Claims a novel engineering design with small footprint and short delivery time ▪ Process tested at a pilot / demonstration scale but not commercialized yet ▪ Announced JV for a plant in Canada and partnership with a fabricator for plants
R3 Sciences	▪ Developing a homogeneous catalyst-based 3-30 tons/day methanol plants ▪ Claims process operates at a lower temperature and pressure with higher syngas conversion per pass and selectivity to methanol leading to lower capex ▪ Plans to transition process through pilot / demonstration scales in 2014-15 with a commercial unit targeted by the end of 2015
Oberon Fuels	▪ Developed proprietary skid-mounted, small-scale production units to convert methane and carbon dioxide to DME and methanol at 10-30 ton/day capacity ▪ Focusing development and commercialization effort on DME than methanol
GasTechno GTL	▪ Developing direct conversion process for gas to methanol and other products ▪ Process tested at pilot-scale and now targeting demonstration scale ▪ Claims ability to handle rich gas streams with limited pre-treatment and … ▪ … A wide range of scales from 1 to ~450 tons per day of products ▪ Company estimates capital costs of $400-$1,350 for 17-55 tpd plants
Primus Green Energy	▪ Developing a technology to convert syn-gas into various products including methanol ▪ Commissioned a 100,000 gallon per year demonstration plant in 2013 with plans for a commercial plant in 2015 ▪ Claims to be a simpler variant of ExxonMobil's Methanol to Gasoline process with lower capital and operating costs driven by process improvements and modular manufacturing

6.0 Key Risks

A wide range of stakeholders including but not limited to investors, entrepreneurs, project developers, oil and gas producers, technology developers, and government agencies are likely interested in the technical and commercial viability of small-scale methanol plants. These stakeholders should carefully consider a number of risks associated with small-scale methanol plants, which have been described below:

- ***Commodity pricing risk:*** The economic viability of small-scale methanol plants depends heavily on natural gas feedstock and methanol product pricing. High volatility or commodity prices beyond those assumed in the analysis presented in this report should be carefully evaluated for impacts on costs and economics.

- ***Technology risk:*** A number of companies are developing small-scale methanol technologies but none of them have commercially deployed a plant. Although methanol production is mature at larger scales, small-scale methanol plants may pose risks that are currently unknown or unanticipated mainly because existing technologies have not been scaled up to commercial levels at this time. Careful evaluation of technical viability with emphasis on scale-up risk should be conducted before investing in small-scale methanol plants.

- ***Capital cost risk:*** Given the lack of commercially operating plants, capital costs for small-scale methanol plants were assumed for the economic analysis in this report. These capital costs should be verified and validated through careful cost estimation and planning.

- ***Market and competitive risk:*** Finally, methanol demand and supply should be monitored carefully for implications on small-scale methanol plants. As several large-scale methanol plants are likely to be built in North America, it is possible that some of them may be able to produce methanol at costs much lower than those of small-scale plants. Further, the scale of some of these companies would allow them to discount transportation costs and thereby provide significant competition in the market.

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