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## **Sarnia-Lambton Propylene Investment Opportunity Study FINAL REPORT**

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## **I. Introduction**

The Sarnia-Lambton region is home to a number of oil, petrochemical and other energy companies with NOVA having the largest petrochemical facility. NOVA purchased the Sarnia ethylene and polyethylene plants from DuPont Canada and additional ethylene and the polyethylene assets at Corunna from Union Carbide. The Nova ethylene cracker was based on heavy feedstock supplied from the company's on-site, low-complexity refinery. The refinery was fed with Algerian crude, and a gas-oil stream was refined and used as cracker feedstock. These crackers also produced propylene which was sold in the merchant market with the largest customer being the Flint Hills polypropylene plant in Marysville, MI.

ExxonMobil and Shell have refineries in the region which produce propylene. This propylene is either sold in the merchant market or consumed internally. Propylene produced at Exxon's Imperial Oil refinery in Sarnia is used to produce oligomers. The refinery grade propylene made at Imperial Oil's Nanticote refinery can be used as an alkylation feedstock or alternately be shipped via railcar to be sold to other refineries or for upgrading to chemical or polymer grade propylene.

The situation has changed dramatically due to the development of low-cost ethane from shale gas in the northeast US, primarily in Pennsylvania and Ohio (Marcellus and Utica). Based on this development, NOVA decided to convert its liquid-based cracker to ethane and mixed LPG which is fractionated to separate the components. The Mariner West pipeline was built (MarkWest West) to transport ethane to the sites. The base capacity is 50,000 barrels per day which is sufficient feed for the 1.85 billion lbs. /yr. Nova cracker in Sarnia. This feedstock change has reduced propylene production and the propylene supply to the Flint Hills polypropylene plant which has since shut down. This pipeline only transports purity ethane at the current time but could transport some propane if needed. However, if propane were to be added, fractionation would be required. This would require either a separate fractionation facility or an expansion of an existing fractionator.

There are two additional pipelines under construction that will supply natural gas and one more pipeline that will supply NGLs to Sarnia-Lambton:

- Rover: due to start up in the second quarter, 2017 which will transport natural gas. The developer is Energy Transfer Partners
- NEXUS: due to start up in the fourth quarter, 2017 which will transport natural gas. The developers are Spectra energy and DTE Energy
- Utopia: due to start up the first quarter, 2018. This will transport natural gas liquids which may contain some propane. Currently, the plan is either to transport ethane or E/P mix. The project developer is Kinder Morgan

With the potential availability of additional propane from Marcellus and Utica, and the well-developed infrastructure and logistics available in the region, the Sarnia-Lambton Economic Partnership (SLEP) would like to determine the possibility of developing a propane/propylene project in Sarnia-Lambton that would attract investors. To understand the potential for such an investment, SLEP has retained Chemical Market Resources (CMR) and Polymer Consulting International (PCI) to analyze the potential for a propane/propylene investment and to prepare a report that identified the specific products that would be viable and the companies that could be potential investors. This report will be available to all interested parties.

## **II. Summary and Conclusions**

A propylene based investment in Sarnia-Lambton is viable with the potential to provide superior returns (IRR) under the right conditions for a new PDH/polypropylene investment. The key to the viability of the project will be the propane supply and cost. Based on the findings of the study, propane from the Marcellus and Utica shale gas plays, which can be supplemented with locally available propane (from Western Canada) can provide the necessary volumes and pricing for the project.

Of all of the propylene derivatives looked at for the project, polypropylene offers the best opportunity based on its simplicity to produce, technology availability, market conditions and logistics. The study analyzed the cost and IRR for two cases:

- 375 KTA PDH unit with 400 KTA of polypropylene
- 750 KTA PDH unit with 800 KTA of polypropylene

For a 375 KTA PDH unit, 15,000 Bpd of propane is needed and for a 750 KTA PDH unit, 30,000 Bpd of propane is needed. With an E/P mix of 80/20 the amount of NGL feedstock would be 70 KTA for the 375 KTA and 140 KTA for the 740 KTA PDH unit. With an E/P mix of 50/50 the NGL feedstock requirements are 30 KTA for the 375 KTA PDH unit and 60 KTA for the 750 KTA PDH unit.

Approximately 65,000 Bpd of propane is currently produced from the Plains fractionator. Of this, about 30,000 Bpd is consumed locally and 35,000 Bpd is exported to the United States (primarily Michigan). The 100,000 Bpd fractionator can be expanded to produce more propane. Additional propane is brought in by rail from Western Canada. The transportation cost is about 22 cents/gallon and storage costs are about 10-25 cents per gallon. While there is sufficient propane for the PDH plants, the pricing would be a problem. The Sarnia propane prices are higher than Mt. Belvieu due to higher cost structure and it is isolated in the sense that essentially all of the propane comes from Western Canada. The premium varies according to the weather. In a cold winter, the premium would be 30 cents/gallon and in a mild winter, the premium would be about 10 cents/gallon. However, long-term contract propane prices in the Marcellus and Utica shale gas plays are well below Mt. Belvieu due to the oversupply of propane. This would indicate that a propane supply from Marcellus/Utica would be required for the majority of the feedstock which would also likely moderate the current high propane price in Sarnia. There is a possibility that the propane could be brought in as a mixed NGL stream in an existing pipeline (or one currently under construction). Otherwise, a new pipeline would be required.

The economics favor an investment at current and future US propane/propylene price spreads. The economics would improve dramatically with discounted propane from Marcellus/Utica.

An economic model has been developed for an integrated PDH/PP unit constructed at the Sarnia Bluewater Energy Park, which is an available brownfield site. A similar analysis was performed for a greenfield site. This model was used to evaluate project IRR projections at various capital levels and polypropylene-to-propane spreads. The costs, based on Lummus PDH technology and a gas phase technology for polypropylene technology have been used for the analysis. A 2017/2018 propane/propylene spread of \$0.45/lb was used decreasing by \$0.02/lb every two years. The results for the brownfield site are summarized:

**Case 1- 750 KTA per year propylene; 800 KTA per year polypropylene**

- Capital of US\$1.425 billion including \$1.3 billion ISBL and \$125 million OSBL
- Working capital: \$200 million including a spare catalyst charge

## Case 2 - 375 KTA per year propylene; 400 KTA per year polypropylene

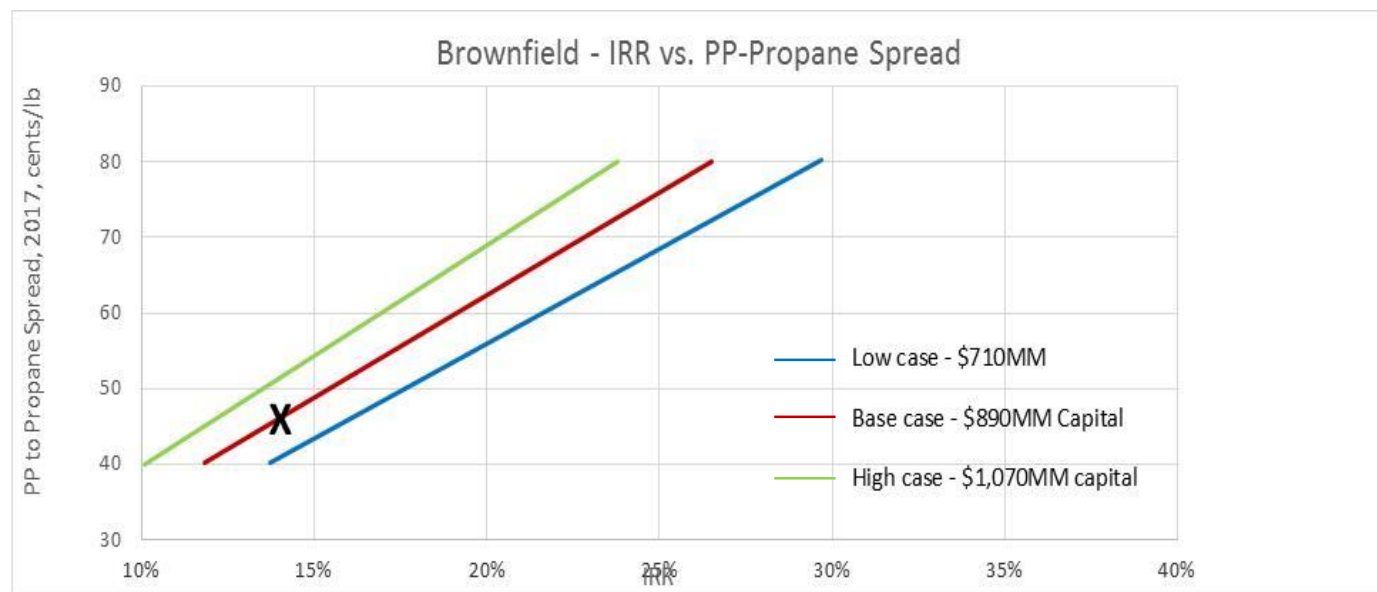
- Capital of US\$ 890 million including \$800 million ISBL and \$90 million OSBL
- Working capital: \$125 million including a spare catalyst charge

Start of pre-project engineering and permitting: Q1 2016, project approval Jan 2017, start-up Q1 2019

A project sensitivity analysis is provided in Figure II.1 based on the integrated PDH/PP project economic model. The assumed 2017 polypropylene-to-propane spread is located on the y-axis. The base case of \$0.45/lb is represented by the “X” in the chart. For Case 2, the capital cost is \$890 million (excluding \$125 million working capital), the computed project IRR is 14%.

The three lines in the chart show capital sensitivity to IRR with low and high cases representing 20% deviations from the assumed base case capital level.

Figure II.1  
Economic sensitivity of Outputs for Integrated PDH/PP Economic Model

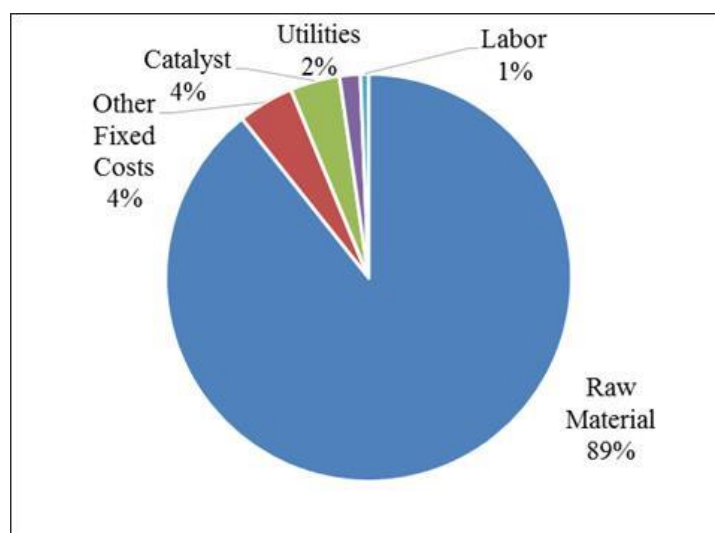


Source: PCI/CMR

## Polypropylene Manufacturing Cost

The most critical aspect of a polypropylene project is the cost of the propylene. Raw material costs account for almost 90% of the total cost of producing polypropylene in USGC. Labor costs include operator, supervision, and maintenance costs. Utilities include cost of electricity, cooling water, etc. Other fixed manufacturing costs include general plant overhead, insurance and property taxes, and depreciation of equipment and buildings. This is shown in Figure II.2

Figure II.2  
Polypropylene Cost of Production



The PDH plant proposed for Sarnia would have an advantaged propylene cost compared to propylene produced on the US Gulf Coast due to the discounted propane. The polypropylene manufacturing cost analysis is based on the assumptions as shown in Table II.1.

Table II.1  
Polypropylene Capital Cost Analysis

		Case 1	Case 2
Capacity	KTA	800	400
Battery limits	M\$	375	188
Ex-battery limits	M\$	100	75
Working Capital	M\$	150	75
Total Investment	M\$	625	338

### Total Project Cost

The total cost for an integrated PDH/polypropylene plant is shown in Table II.2 for the two PDH/polypropylene capacities for greenfield and brownfield sites. Depending upon the configuration and size of the plants the range of the investment would be between 1 and 2 billion dollars.

The project economics and IRR would improve substantially with discounted propane from Marcellus/Utica shale gas plays as the spread would widen considerably. The maximum propane price would likely be Mt. Belvieu minus freight. However, based on discussions with companies currently involved in propane pricing in the region, the discount is likely to be higher due to the large overcapacity of propane. The specific discounts offered are confidential but can likely be obtained through individual discussions with the propane providers.

If a mixed gas stream were to be the best propane supply option, the 100,000 Bbl/day Plains fractionator would either have to be expanded or another fractionator would have to be built. For further discussion, contacts with Plains Midstream Canada can be provided upon request.

Table II.2  
Summary Project Cost Analysis, MM\$

	Low Capacity		High Capacity	
	Greenfield	Brownfield	Greenfield	Brownfield
PDH capacity, KTA	375	375	750	750
PP Capacity, KTA	400	400	800	800
PDH unit				
ISBL	660	610	1,000	925
OSBL	100	16	150	25
Working Capital	50	50	50	50
<b>Subtotal</b>	<b>810</b>	<b>676</b>	<b>1,200</b>	<b>1,000</b>
Polypropylene				
ISBL	190	188	375	375
OSBL	100	75	175	100
Working Capital/owner's cost	75	75	150	150
<b>Subtotal</b>	<b>365</b>	<b>338</b>	<b>700</b>	<b>625</b>
<b>Total</b>	<b>1,175</b>	<b>1,014</b>	<b>1,900</b>	<b>1,625</b>
excluding working capital	1,050	890	1,700	1,425

In spite of the sharp oil price drop, US ethylene and propylene derivatives have maintained a strong competitive position vis-à-vis ethylene and propylene derivatives produced from naphtha due to the simultaneous drop in US natural gas prices. The oil-to-gas ratio has been in the 15 to 25 range since the oil price drop (ethane is more competitive than naphtha when the ratio is above 7).

In summary, a propane/propylene/polypropylene investment in Sarnia can provide a strong investment opportunity for the following reasons:

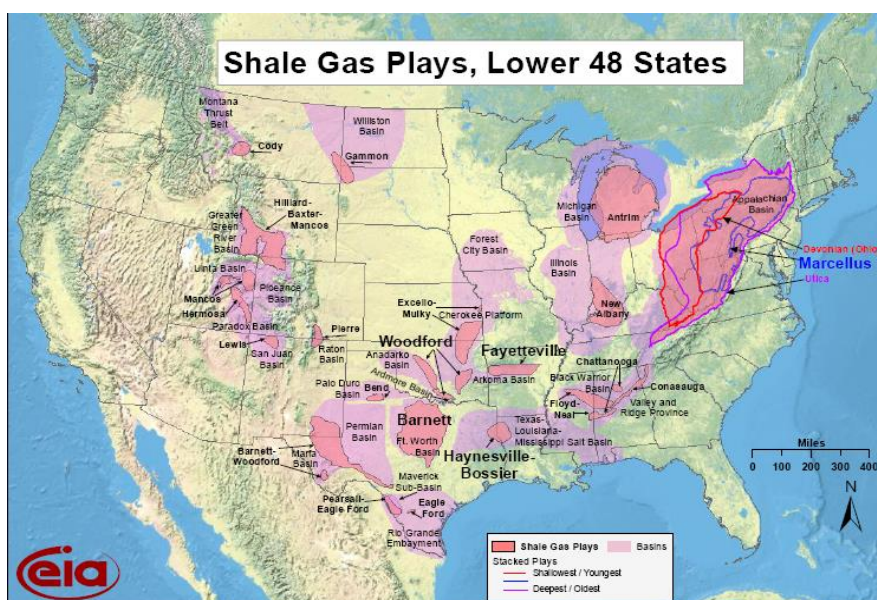
- Well-developed industry infrastructure (road, rail and water) with some chemical companies and refineries located there
- Access to the Marcellus and Utica shale gas plays which are oversupplied with propane
- Proximity to major polypropylene customers which provides logistics cost and delivery time advantages
- Enhanced IRR with discounted propane from the Marcellus/Utica shale gas plays with supplemental propane that is currently available in Sarnia from the Plains fractionator
- SLEP support and assistance for a new investment

### III. Shale Gas Development and its Impact on the Petrochemical Industry



Shale gas is located throughout North America as can be seen in Figure III.1a. It has been there for thousands of years but its extraction was not economically viable until 2008/2009 when two technological developments, horizontal drilling and fracturing (fracking) were developed for shale oil and applied for shale gas. In spite of some environmental concerns about fracking, shale gas development has proliferated throughout the country.

Figure III.1a  
Shale Gas Deposits (Plays) in North America



Source: EIA

The EIA recently revised this map that shows additional shale gas plays with some additional information but the level of clarity is diminished from the older one. It was decided to include both maps. The new map is shown in Figure III.1b and can be viewed on the EIA website.

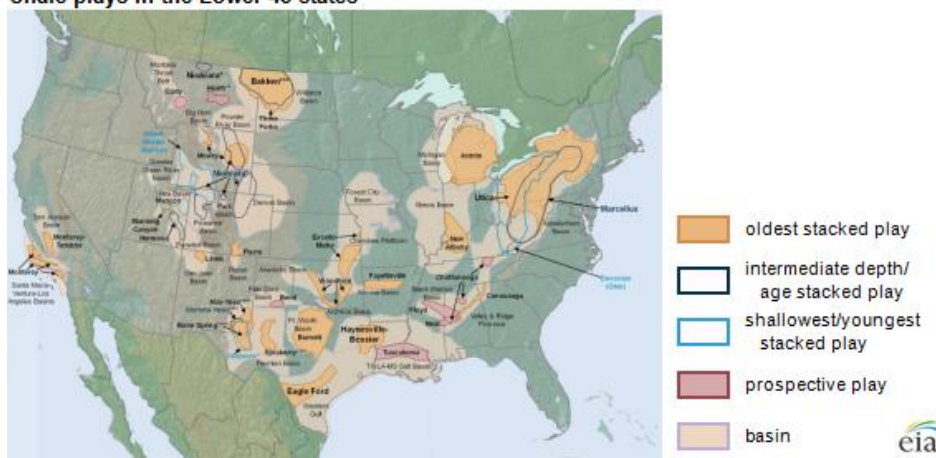
Shale gas is primarily methane with a varying amount of other components (primarily ethane and propane). The concentration of these other hydrocarbons can range from about 4 percent (dry gas) to more than 20 percent (wet gas).

Due to the strong economic advantage, there was an immediate rush to tap into the shale gas formations which resulted in an oversupply of methane as methane demand growth was much lower than the new supply. Methane prices dropped to the point where it was below its production cost. However, the selling prices of the other hydrocarbons compensated for the lower methane selling price. As a result, drillers shut in dry wells and maximized production at sites with higher non-methane hydrocarbons. The result was the availability of abundant supplies of ethane and propane at a substantially reduced cost (price).

The initial response of the petrochemical industry was to maximize the use of ethane in existing crackers to produce ethylene at the expense of naphtha and other liquid feeds. The feedstock ratio to ethylene crackers changed from 65 percent NGL (primarily ethane) and 35 percent liquids (primarily naphtha) before 2008 to 81 percent NGLs and 19 percent liquids in 2014 according to the American Fuel and Petrochemicals Manufacturers (AFPM) with still some additional cracker conversions proceeding. Naphtha crackers produce propylene, C<sub>4</sub>s (e.g., butadiene) and aromatics (e.g., benzene) as co-products. The shift from heavies to NGLs reduced propylene supply by about 25 percent

Figure III.1b  
EIA Revised Shale Gas Map

Shale plays in the Lower 48 states

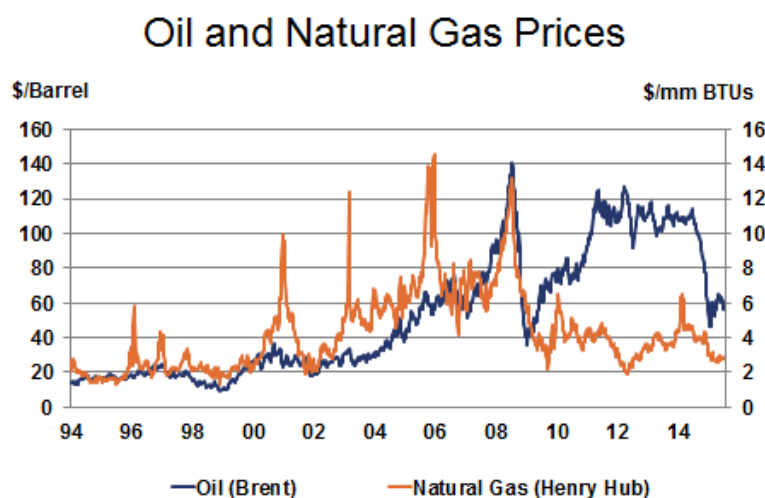


Source: EIA

Refineries, which until 2008 were supplying about 50 percent of US propylene demand, had already maximized propylene production, a large portion of which was being used in the alkylation process to improve octane components going into the gasoline pool. Refinery operators were not interested in reconfiguring their refineries to produce more propylene for the petrochemical industry, especially since it could be a short-term requirement due to the potential to produce propylene from propane.

Historically, natural gas and oil prices closely followed each other except during the winter when natural gas prices spiked due to the sudden increase in demand for home and industrial heating. The abundance of low-cost natural gas resulted in a decoupling of the prices from 2009 until late 2014 as can be seen in Figure III.2.

Figure III.2  
Comparison of Brent Oil and Mt. Belvieu Natural Gas Prices



Source: Energy Information Administration

The relative pricing between oil and gas is a critical factor in the competitiveness of ethylene produced from natural gas liquids (primarily ethane) and ethylene produced from oil-based liquids (primarily naphtha). According to a study contracted by the American Chemistry Council (ACC) when the oil-to-

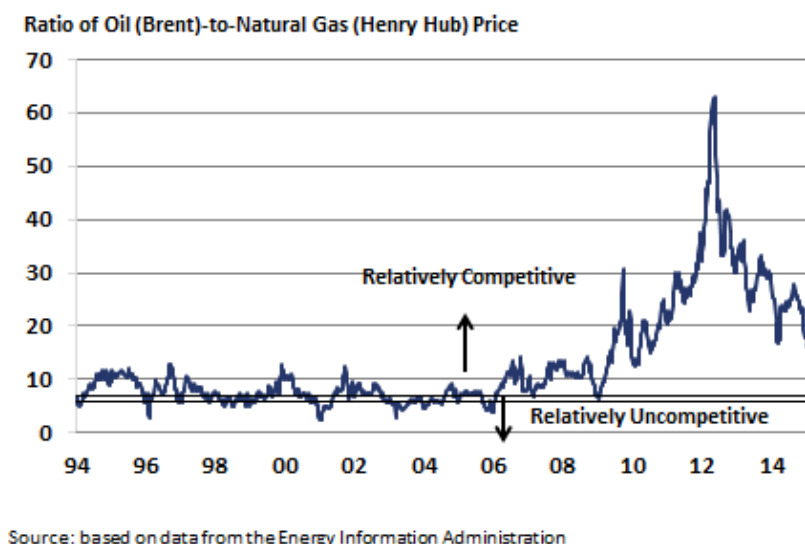


gas price ratio is below 7, ethylene produced in naphtha crackers is more competitive. When the ratio is above 7, then natural gas based ethylene is more competitive. This is important for the price sensitive export market which will purchase the lowest cost products such as polyethylene. The dramatic shift in competitiveness can be seen in Figure III.3. At its peak in 2012, the ratio was greater than 30.

With oil prices hovering at approximately \$100 per barrel with expectations of further price increases, and natural gas at around \$3 to \$4 per MM BTU North America became the second lowest cost producer of ethylene and ethylene-based derivatives. Only the Middle East was lower with gas prices between \$0.75 and \$1.25 per MM BTU. This scenario would have North American exports displacing higher cost naphtha-based exports from Asia and Europe. This resulted in a wave of new crackers announcements.

Figure III.3

### Ratio of Oil and Natural Gas Prices Proxy for Gulf Coast Based Petrochemicals



According to another study contracted by the ACC, more than \$100 billion of new investments have been announced based on shale oil and shale gas. It is estimated that about \$40 billion of this will be for new ethylene and propylene plants and their derivatives. The amount of ethylene that will be produced is substantially more than the domestic market can support. However, due to the strong competitive position that US ethylene and propylene derivatives would have in the export market, producers were confident that all excess production could be exported. Overall, more than 20 companies announced plans for new crackers with seven companies starting construction in 2013 - 2015. In addition, six companies announced that they would expand existing ethylene crackers rather than build new crackers. These expansions will be the equivalent of three new world-scale crackers. On the propylene side, eight companies have announced that they would build on-purpose propylene plants of which three are under construction.

Suddenly and unexpectedly, oil prices dropped below \$40 per barrel towards the end of 2014. This sent shock waves throughout the oil, gas and petrochemical industry. The impact can be seen by comparing oil and natural gas prices (Figure II.2) and the ratio of oil to natural gas prices (Figure II.3).

The industry reacted quickly to the change:

- Oil companies announced reductions in new exploration
- Production from higher cost oil wells was reduced and wells were shut in
- Gas exploration and production from higher cost wells were also reduced
- Some announced petrochemical projects that were not already under construction have been postponed pending a re-evaluation of the project economics

Prices of propylene from refineries also dropped but are expected to moderately recover by year-end as propylene derivative demand increases. This includes exports as the US still has a competitive cost advantage vis-à-vis propylene produced from naphtha crackers. High propylene prices should continue until the three PDH plants currently under construction start up in 2016/2017.

Ethylene projects under construction (seven new crackers and seven expansions) will proceed but construction delays will occur. Similarly, the three PDH plants under construction will proceed but may also experience some construction delays.

While oil prices have declined substantially, natural gas prices have also declined. On July 22 the Brent oil price was \$55.13 and the gas price was \$2.91 resulting in a ratio of 18.9. This is still a highly competitive position against naphtha. In fact, since the decline in oil and natural gas prices, the oil-to-gas price ratio has not fallen below 15. This still favors North American ethylene and propylene derivative exports. Based on this, and on the strategic direction of the companies involved, a second wave of new crackers is very likely. In fact, Chevron Phillips recently announced that it is considering another “mega-project”.

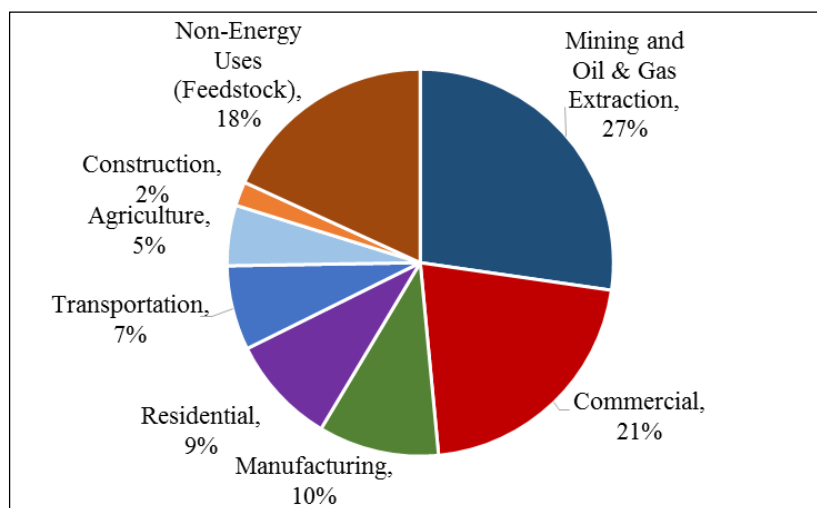
## **IV. Propane**

### **Current Situation**

Canadian propane demand for 2014 is shown in Figure IV.1. Propane is primarily used for fuel (e.g., residential heating) and in the mining/gas/oil/agriculture industries. Propane demand growth is forecast to be in the range of 1

to 2 percent per year, which is much lower than the projected increase in supply. As such, exports necessary to balance overall supply and demand. There is increasing competition in certain US markets from the various US shale gas plays, which are also long on propane. The net result will be continued downward pressure on propane prices. Current propane oversupply in Western Canada is about 25-30 thousand Bbl/day. This is projected to increase to about 40-45 thousand Bbl/day during the next few years.

Figure IV.1  
Canadian Propane Demand, 2014



Source: Canadian Propane Association

Due to minimal local demand, Western Canada is very long on LPG and propane and this problem will increase in the future depending on the William's decision to move forward with its proposed PDH/polypropylene project. A key problem for this area is that there is not enough condensate available there for blending and the Cochin West pipeline was converted from propane service to ship condensate from Eastern Canada. This pipeline had been used to transport propane from Western to Eastern Canada. Current soft propane prices reflect this flow reversal. The resulting low propane prices have provided the incentive for Williams to consider building a PDH unit in Alberta.

There is a propane storage cavern owned by Pembina. This could be expanded as it is a salt cavern. Propane is delivered in a mixed NGL stream via pipeline from Western Canada (e.g., Enbridge pipeline) to the Plains 100,000 Bbl/day fractionator, which is owned by Plains Midstream Canada (61%), Pembina (19%) and Shell (20%). Propane also is transported to Sarnia by rail from Western Canada, Bakken, Marcellus and Utica. The propane in Sarnia typically has a premium price compared to the US Gulf Coast due to the higher supply cost and market/weather conditions. The propane transportation cost from Western Canada to Sarnia by railcar is approximately 22 cents per gallon. Storage costs are approximately 10-15 cents per gallon.

Propane pricing is seasonal and is tied to other energy hub benchmark prices. OPIS prices published for the Sarnia hub may not be consistently valid as a benchmarks as they depend upon the specific sources that they use on a daily basis (e.g., buyers or sellers). The Sarnia area premium over Mt. Belvieu prices in the winter is strictly dependent on the weather and ranges from a 5-10 cent per gallon premium in a mild winter, to 30 cents or more in a severe winter. Conway is a more representative price setter for Western Canada.

About 65,000 Bbl/day of propane are produced in the Sarnia region of which about 35,000 Bbl/day is exported to the United States. The main market is Michigan (e.g., St. Clair and Marysville and there are also some caverns used for storage). Exports to Michigan have been declining since 2008 due to the poor economic conditions in the state. While this would be enough propane to supply a new PDH unit, the key impediment is the premium prices above Mt. Belvieu for propane in Sarnia which would not make the project economically viable. Therefore, additional

sources of propane are required which would have to come from the Marcellus and Utica shale gas plays. Propane is available from both plays and is heavily discounted for long-term contracts due to the oversupply. This is discussed in more detail in subsequent sections.

The following is a quoted from the Canadian National Energy Board:

“Historically, Canada has produced more propane than it consumes and this surplus production is exported to the U.S. Unlike other hydrocarbons (namely oil and natural gas), Canadian propane is primarily exported by rail. Until March 2014, Western Canada had the option of moving propane to markets in the U.S. Midwest via eastward flow in the Cochin Pipeline. In March, the Cochin Pipeline ceased this service, preparing to reverse direction to import condensate, leaving propane producers more reliant on rail, other pipelines (where propane is mixed with other hydrocarbons, such as Enbridge or Alliance), and to a lesser extent truck, to export propane to the U.S. As a result, midstream firms in Alberta such as Keyera and Plains Midstream are adjusting to the new landscape. Keyera is developing a 40 Mb/d rail terminal in Josephsburg, Alberta while Plains is adding rail capabilities to its Fort Saskatchewan fractionation and storage facility that previously was only served by truck and pipeline.

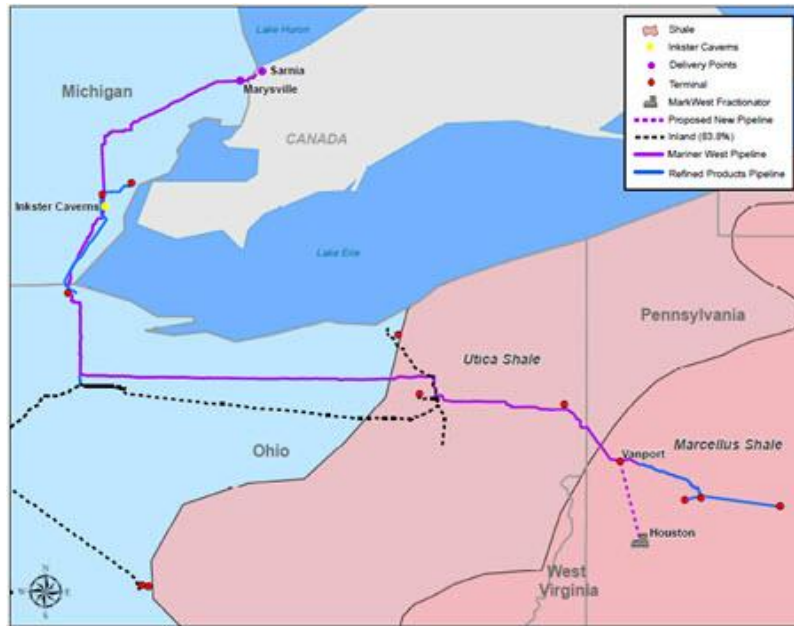
Some in the propane industry have proposed selling propane to new markets outside of North America. In August 2014, the Board received an application from Pembina for a license to export propane from Canada for a period of 25 years. Pembina’s 37 Mb/d export terminal would be located in Portland, Oregon but would source propane from Western Canada. Pembina has proposed to begin exporting in 2018. Other firms considering liquids exports from the west coast include AltaGas/Petrogas Energy/Idemitsu Kosan (to be located in Ferndale, Washington), and Sage Midstream (to be located in Longview, Washington).”

### **Pipelines**

There are a number of gas and liquids pipelines in the Sarnia region. The MarkWest ethane pipeline, the two natural gas pipelines (NEXUS and Rover) would likely not be large enough to supply the propane required for a word-scale polypropylene plant assuming that they would even be willing to add propane to the stream which would then require new or additional fractionation capacity. However, the Kinder-Morgan pipeline has the ability to substantially increase its throughput. If propane or a mixed stream were to be added, additional fractionation capacity would be needed. This could come from an expansion of the Plains fractionator or by building a new fractionator. If the Kinder-Morgan option was not available, a new NGL or dedicated propane pipeline would be required. The ability to build a new pipeline may not be a big issue if one of the right-aways from an existing pipeline could be used. A new pipeline would obviously add to the cost and reduce the IRR but it is believed that the discounted price for the propane would more than compensate for the increased cost.

The MarkWest “Mariner West” pipeline was commissioned in the fourth quarter 2013. It is designed to deliver 50,000 barrels per day of ethane to NOVA for petrochemical use. It can be scaled up to deliver more ethane as needed. However, the likelihood of being able to add enough propane to the pipeline for a PDH unit is low. A mixed ethane/propane stream would require a very large fractionator to split the propane out of the stream which would be the original 50,000 barrels per day plus the propane. Moreover, NOVA had considered a new cracker and polyethylene plant in Sarnia. This was canceled due to market conditions but could be reactivated in the future. It is unlikely that NOVA would agree to include a large amount of propane that would preclude adding more ethane for future ethylene/polyethylene expansions. The system is shown in Figure IV.2.

Figure IV.2  
Mariner West Pipeline system



Source: Sunoco Logistics

There are two additional propane supply options:

- Utopia Pipeline
- New NGL or dedicated propane pipeline

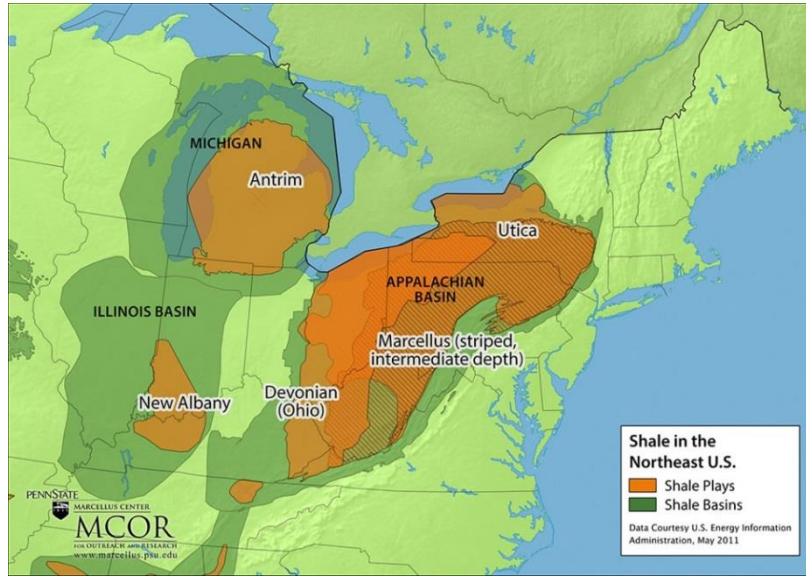
The Utopia pipeline (2018 startup) is a conversion of the 12-inch Cochin East pipeline by Kinder-Morgan. The current plan is to transport 50,000 Bbl/day of ethane and E/P mix. It is expandable to 175,000 Bbl/day. There is a possibility that this could be used to transport propane or a propane-rich mixed stream and fractionate it in Sarnia. This would require additional fractionation capacity.

If the Utopia pipeline option is not available, then a new dedicated propane or propane-rich mixed stream pipeline will be required to supply sufficient quantities of propane to the PDH unit. There are two sources for propane: Marcellus and Utica.

There has been considerable development of NGL separation plants in Ohio. Momentum Energy has a large gas separation plant in Scio (Harrison County) and Mark West has a large gas separation plant in Jewett (Harrison County). These plants include storage and transportation facilities. A third plant is also being planned. The distance from these sites to Sarnia, which would skirt around Lake Erie, is about 325 miles (565 kilometers). This could be further enhanced with respect to propane if the announced ethane cracker by PTT Thailand and Marubeni proceeds. This would remove a large portion of the ethane and result in a more concentrated propane stream. A final decision on this cracker has not been taken.

Based on the proven gas reserves in Marcellus and Utica, there would be more than enough propane for a PDH plant in Sarnia. The regional shale gas plays can be seen in Figure IV.3.

Figure IV.3  
Northeast Shale Gas Plays



Portions of the Marcellus play are dry gas but there are a number of locations, particularly in southwest Pennsylvania, that have wet gas. The Utica shale gas is generally wet. The propane content in wet Marcellus shale gas is shown in Table IV.1. The wet gas in Utica is believed to have a similar composition.

There is currently enough propane for a new Sarnia-based PDH unit from the Marcellus and Utica plays, with Antrim as another potential source should it be developed in the future. However, the Antrim shale play has a much lower priority for development. The Marcellus and Utica shale gas plays are targeting northeast domestic international export markets for the ethane, propane and butane production on a long term basis, with a potential for one or more petrochemical plants. Marcellus and Utica have some advantages compared to Michigan that includes a more developed infrastructure and the proximity and access to coastal export and domestic markets.

Table IV.1  
Example of a Marcellus Wet Gas Composition

Component	content, %
Methane	74.2
Other	0.5
NGLs/condensate	25.3
Total	100
NGLs/condensate	
Ethane	15.6
Propane	5.5
n-butane	1.4
isobutane	0.7
n-pentane	0.5
isopentane	0.5
Hexanes/others	1.1
Total	25.3
Source: GES paper 3/11/13	

The volume will depend on how the propane is used in the future as follows:



- Pipelines to the Gulf Coast: There are currently no dedicated propane pipelines from Marcellus or Utica to the Gulf Coast. Enterprise is considering a 150 mile propane pipeline that would connect the Marcellus play to the Mid-America propane pipeline. There are some NGL pipelines planned but their timing or their likelihood of proceeding is uncertain. The proposed Bluegrass pipeline has been canceled due to opposition in Kentucky. The Utica-based UNTX pipeline to the US Gulf Coast (200,000 barrels/day) is due to be commissioned in 2017. There are no other known propane pipelines planned to go to the Gulf Coast.
- Pipelines to the East: A number of companies are looking at this potential such as MarkWest, Sunoco Logistics and others. This would be for regional markets, fuel and PDH.
  - MarkWest Energy Partners recently began operating a gas processing facility and high-pressure gas-gathering system in Harrison and Doddridge counties in West Virginia. Antero Resources is currently transporting about 90 million cubic feet of gas per day through the plant from a portion of its horizontal Marcellus wells, which are producing more than 400 million cubic feet per day of shale gas in West Virginia. Antero will have access to MarkWest's midstream services in the Marcellus Shale, as well as to all of MarkWest's ongoing propane and ethane pipeline projects. Also, pending is the completion of MarkWest's current fractionation projects, including the 100,000 barrels per day fractionation complex that is being developed in Harrison County, Ohio. MarkWest's total NGL fractionation capacity serving the Marcellus and Utica shale plays will be about 275,000 barrels per day. The fractionation capacity includes nearly 120,000 barrels per day of propane and heavier NGL fractionation.
  - Sunoco Partners Marketing & Terminals LP has awarded a \$270 million contract to CB&I for the construction of a turnkey propane terminal and de-ethanizer facility in Marcus Hook, PA. CB&I is currently constructing the ethane storage tank terminal for Sunoco at the site. Marcus Hook has become a key destination for natural gas liquids emanating from the Marcellus and Utica shale plays in the region. New infrastructure will help boost Marcus Hook's capability to provide propane and ethane to local, regional and international markets. The Sunoco Logistics project is described on their website:

### ***“Project Mariner East Phase I***

Project Mariner East is a pipeline project to deliver propane and ethane from the liquid-rich Marcellus Shale areas in Western Pennsylvania to the Marcus Hook facility, where it will be processed, stored, and distributed to various domestic and waterborne markets. The project is anticipated to have an initial capacity to transport approximately 70,000 barrels per day of natural gas liquids and can be scaled to support higher volumes as needed. Mariner East commenced initial operations in the fourth quarter 2014. Mariner East is scheduled to be fully operational to deliver propane and ethane in Mid-2015.

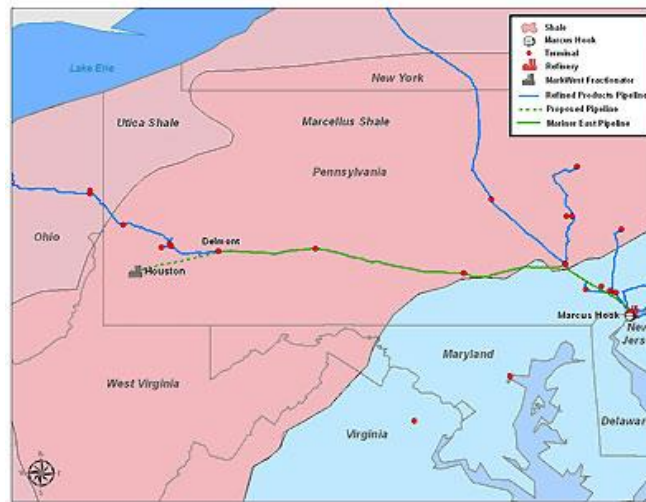
Sunoco Logistics will construct a pipeline from MarkWest Energy Partners' Houston, Pennsylvania processing and fractionation complex to an interconnection with an existing Sunoco Logistics pipeline at Delmont, Pennsylvania. The natural gas liquids will then be transported to the Marcus Hook facility where Sunoco Logistics will construct new facilities to process, store, chill, and distribute propane and ethane to local, regional and international markets.

### ***Project Mariner East Phase II***

Sunoco Logistics announced a successful Open Season for Mariner East 2 project in November 2014. For Mariner East 2, Sunoco Logistics plans to construct a pipeline from processing and fractionation complexes in Western Pennsylvania, West Virginia and Eastern Ohio for transport to the Marcus Hook Industrial Complex. Sunoco Logistics plans to construct new facilities at Marcus Hook Industrial Complex to store, chill, process and distribute propane, butane and ethane for distribution to local, domestic and international markets. Sunoco Logistics plans to offer intrastate and interstate movements to meet the demands of various markets. Mariner East 2 will expand the total takeaway capacity to 345,000 barrels per day. The Mariner East 2 pipeline is expected to be operational in Q4 2016, subject to regulatory and permit approvals.”

This is shown in Figure IV.4.

Figure IV.4  
Mariner East Pipeline System



Source: Sunoco Logistics

“The Marcus Hook Industrial Complex on the Delaware River near Philadelphia, PA is an LPG, refined products and crude terminal as well as a fully functioning process complex. There are approximately 2 million barrels of NGL storage capacity in underground caverns, and related commercial agreements. The facility can receive NGLs via marine vessel, pipeline, truck and rail, and can deliver via marine vessel, pipeline and truck.

The Mariner East 1 and Mariner East 2 pipeline are designed to deliver NGLs from the Marcellus and Utica Shale areas in Western Pennsylvania, West Virginia and Eastern Ohio to the Marcus Hook Industrial Complex. Mariner East 1 commenced initial operations in the fourth quarter 2014. Mariner East 2 is expected to commence operations in the fourth quarter 2016.” (end quote)

Kinder Morgan is proposing a \$5.3 billion pipeline that would transport NGLs from the Utica/Marcellus shale gas plays to Louisiana. The Utica Marcellus Texas Pipeline (UMTP) will convert the existing 24 inch and 26 inch Tennessee Gas Pipeline Company’s natural gas pipelines to transport NGLs from Ohio to Natchitoches - a distance of approximately 964 miles. The project will require about 200 miles of new pipeline from Natchitoches to the Mt. Belvieu area. The initial volume will be approximately 150-200 thousand barrels per day with a maximum capacity of about 430,000 barrels per day. The pipeline is shown in Figure IV.5

The project is in its first open season that began on June 17, 2015 with a target startup of late 2018. It is estimated that the initial entry price for the pipeline is approximately 15 cents. This cost increases with storage, and delivery to each end user, which will likely require another new pipeline. Based on the current market conditions, the high cost of the project and the extra costs associated with each subscriber, and potential action against the pipeline by the Kentuckians for the Commonwealth (2013 press release), some industry sources believe that this may not proceed.

Figure IV.5

## UMTP Project Overview



Source: Kinder Morgan

The planned Mariner East 3 and 4 pipelines are much more likely to proceed which could reduce the volumes available to the UMTP pipeline.

In addition to regional traditional propane demand, there are two further options:

- Propane exports: A number of companies are looking at this potential such as MarkWest, Sunoco Logistics and others. A new terminal is under construction at Marcus Hook, PA.
- PDH: There are potential PDH projects in the northeast. Shell is reportedly considering a PDH plant if it proceeds with its planned ethylene cracker in Pennsylvania. Shell has some propane available from its Marcellus shale operations which could be supplemented with purchased propane. Sunoco Logistics will very likely build a PDH plant in Marcus Hook. Sunoco Logistics acquired Sunoco's Marcus Hook Industrial Complex and related assets. The acquisition included terminals and storage assets with a capacity of approximately 3 million barrels, located in Pennsylvania and Delaware, including approximately 2 million barrels of NGL storage capacity in underground caverns, as well as commercial agreements. The propane will be supplied from the Mariner East pipeline which is being built with MarkWest. Braskem has postponed its West Virginia cracker project and has shifted its emphasis to polypropylene. While the company may not build a new PDH unit, it would be a customer for the propylene from a local PDH unit. This could be used to replace higher-cost propylene currently supplied by rail or for a new polypropylene line at its Marcus Hook, PA site.

While there is substantial propane in Western Canada, a dedicated propane pipeline to Sarnia is not likely according to sources contacted for this study. The alternative, exporting propane to Asia offers a much better return. Pembina is building a pipeline and a propane export terminal in Portland, OR with a target completion of 2018. Other LNG export terminals are being considered in British Columbia. China is the prime customer. Chinese companies have announced numerous PDH plants that would be based on imported propane.

In order for the high capital cost PDH investment to be viable in Sarnia-Lambton, the propane price has to be significantly less than the US Gulf Coast. This is likely to occur based on the projects being considered for PDH capacity in Pennsylvania and West Virginia. At minimum, Marcellus-Utica propane pricing would likely be the US Gulf Coast reference price less freight for these plants to be considered. Potential pricing could even be better based on the probable oversupply of propane which could worsen. As a result of cheap natural gas (methane) it has become much more economical to substitute methane for propane for residential heating and some other applications. The cost savings more than compensates for the cost of the pipeline connection to a local natural gas pipeline. This has reduced the growth rate for propane in the northeast, which will place additional downward price pressure on propane from Marcellus and Utica.

There is yet another issue. Long-distance transportation of natural gas has a limit on the ethane and propane content (heavies) in the pipeline due to operational and regulatory constraints. If too much heavy NGL is blended with the natural gas, at higher pressures the mixture may approach the dew point and a two-phase flow could result. This could damage the pipeline system. In addition, many states regulate the BTU content of natural gas to a maximum of 1,300 BTU/SCF. Since ethane has a higher BTU content than methane, this limits the amount of ethane that can be blended. Currently there is a variance that allows for a higher ethane/propane content but that could change which would provide additional ethane and propane in the northeast.

Even with these projects the estimated amount of propane substantially exceeds these projects, especially if the propane from the Antrim play becomes viable in the future.

## V. Propylene

Historically in North America, propylene was produced in liquids-based ethylene crackers and refineries with about 50 percent from each source. The crackers typically used naphtha as a feedstock, which also came from refineries. The main driver for the cracker was to produce ethylene; propylene was treated as a co-product (as were benzene, butadiene and xylenes). Typically, naphtha crackers produce 20 to 30 percent propylene. When ethane is used as a feedstock the only product produced in commercial quantities is ethylene. The capital cost of a naphtha cracker is 30 to 40 percent higher than an ethane cracker which is an additional incentive for building an ethane cracker.

A PDH plant requires approximately 1.3 tons of propane to produce 1 ton of propylene.

Due to the reduction in propylene and the resultant high prices, the low cost of the propane now favored the production of propylene by other methods (referred to as on-purpose propylene). The most prevalent technology is Propane Dehydrogenation (PDH). It is a high-cost (capital intensive) process which is only economical with low propane prices. PDH technology is readily available from three primary licensors, Lummus, ThyssenKrupp and UOP. Another on-purpose propylene technology converts methane to methanol and then to propylene (MTP). This is a more recent development with very few operating plant globally as it has a very high capital cost (much more than PDH). Here again, the availability of low-cost methane compensates for the high capital cost. BASF has announced that it will build the first North American MTP unit.

The eight North American companies that have announced propylene investments based on both technologies are listed in Table V.1. While the total announced capacity is almost 5 million tons per year, less than one-half of this is actually under construction primarily due to the sharp drop in oil prices which improves the competitiveness of naphtha-based crackers in other countries. Williams is considering a PDH unit in Alberta. Reportedly, negotiations are still being held with one or more interested parties for the propylene. In addition, one other company (confidential) is considering a new PDH unit in Texas but has delayed a formal announcement due to the aforementioned drop in oil prices. On-purpose technologies account for the majority of the new propylene capacity in North America as there will be some incremental propylene produced in ethylene cracker expansions.

Table V.1  
Planned On-purpose Propylene Capacity

Company	Project	Location	Capacity, KTA	PP	PO	Other	Merchant	Startup	Cost, \$B*	Site	Comments
Ascend/C3	PDH	TX	1,100			X	X	2018+	1.2	Brownfield	Delayed (captive for nylon/AN)
BASF	MTP	LA	750			X	X	2018/19	NA	Brownfield	No final approval
Dow	PDH	TX	750		X	X	X	2016	NA	Brownfield	
Enterprise	PDH	TX	750				X	2016/17	NA	Greenfield	Selling to Braskem and Eastman
Formosa Plastics	PDH	TX	600	X				2016/17	1.7	Brownfield	Cost includes an LDPE plant
RexTac	PDH	TX	300	X				NA	NA	Brownfield	Not likely (financing issue)
Sunoco Logistics	PDH	PA	NA				X	NA	2.5	Brownfield	Cost includes pipeline and NGLs
Williams	PDH	Alberta	500				X	2018/19	1.17 \$C	Greenfield	Need PP partner to proceed
<b>Total</b>			<b>4,750</b>		*US dollars except Williams						
<b>Under construction</b>			<b>2,100</b>								

By comparison, there are 12 PDH units operating and announced for China with startups through 2020. If all of these are built the total capacity will be approximately 8 million metric tons per year. A large portion of the propane will be imported primarily from the Middle East and North America. China also uses a coal-based technology (MTO) that produces 50% ethylene/50% propylene.

The US propylene supply/demand balance is shown in Table V.2 and in Figure V.1

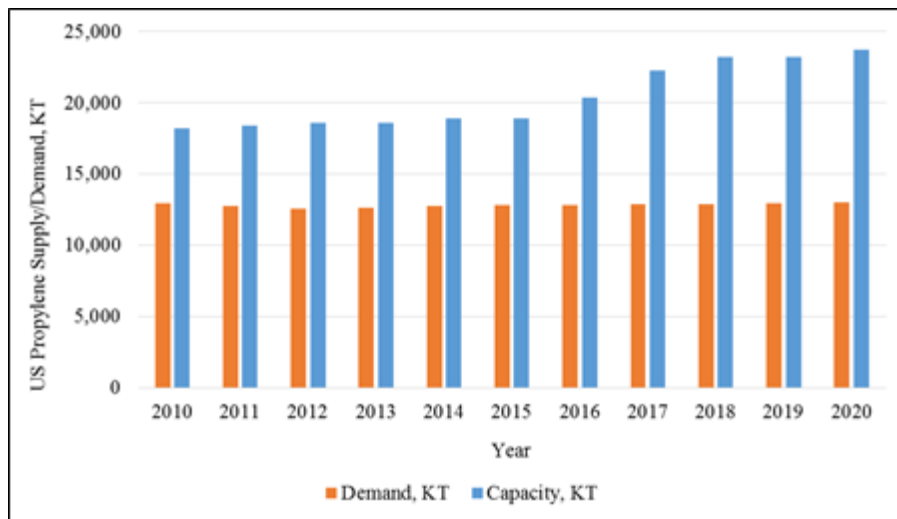
Table V.2

### US Propylene Supply/Demand Balance\*

Year	Demand	Supply
2010	12,963	18,195
2011	12,769	18,395
2012	12,577	18,597
2013	12,615	18,597
2014	13,988	18,886
2015	14,030	18,886
2016	14,072	20,386
2017	14,114	22,236
2018	14,157	23,236
2019	14,199	23,236
2020	14,242	23,711

\*Nameplate capacity of polymer and chemical grades only

Figure V.1  
US Propylene Supply/Demand Balance



The supply/demand balance is misleading. While there is a large installed propylene nameplate capacity, the production of propylene is limited by the configuration of steam crackers and refineries to about 70 percent of nameplate capacity. Taking this into account, the effective operating rate is about 90% or higher.

The domestic demand for propylene is also growing faster than for ethylene. With limited propylene availability, the propylene market could become tight again by the end of 2015. The tightness in the propylene market has led to an increasing premium of propylene pricing over ethylene. Propylene prices are expected to increase in the short term in North America as some additional propylene capacity is lost due to the changing cracker feedstock mix. Currently, there is only one propane dehydrogenation (PDH) plant operating in the United States by Flint Hills in Texas. Propylene prices will likely decrease then stabilize when the three PDH plants under construction start up. Prices will likely follow the same pattern as additional PDH units start up depending upon the timing and amount of overcapacity. Based on projected pricing, North American propylene derivatives will have a cost advantage in foreign markets compared to propylene produced in naphtha crackers but the competitive advantage has decreased with the lower oil prices.



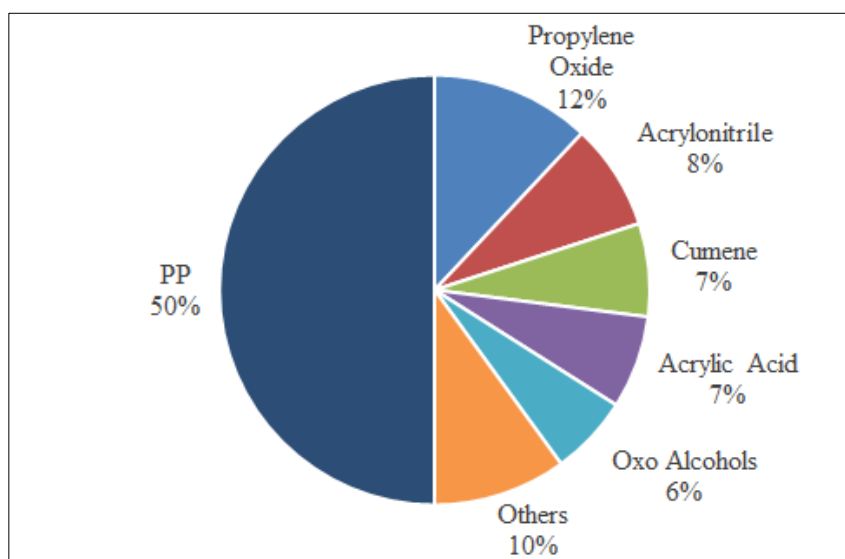
In the Sarnia region, Shell is a net merchant buyer of propylene while Imperial Chemical (Esso Canada) is using all of the propylene produced at the Sarnia refinery for its oligomerization plant. Some propylene would be available from NOVA that is currently being shipped to USGC via railcar (approximately 70 KTA). In addition, limited quantities of propylene may be available from Imperial Chemical. It is estimated that this would be about 15 KTA. The total amount of regional propylene would be about 85 KTA which is not enough for a world-scale polypropylene plant (350 KTA). The rest would have to come from a PDH plant.

As there is no likelihood for additional regional propylene, on-purpose propylene is the only viable option for a new propylene/polypropylene plant using the PDH process.

## **VI. Propylene Derivative Opportunities**

US propylene demand by derivative is shown in Figure VI.1. Total demand in 2014 was approximately 14 million tons.

Figure VI.1  
US Propylene Demand by Derivative, 2014



Source: CMR

Polypropylene, which accounts for 50 percent of demand, is the most viable product that could be produced in Sarnia-Lambton. All of the other derivatives require additional raw materials which would not be available in Sarnia-Lambton and are more complex projects requiring a larger capital investment compared to polypropylene. Some also have by-products that would need to be sold or be disposed. Moreover, most are either over supplied (poor profitability), have technology availability issues and need to have additional investments to use the product on site. The only other raw material required for polypropylene is ethylene for copolymer production. This is not a very large volume so NOVA could be a potential supplier. In addition, with the exception of the fiber market which is concentrated in the southeast (Carolinas), there is a large northeast/north central US regional market for polypropylene for automotive and packaging applications which could also provide a logistics cost advantage compared to polypropylene delivered from plants located on the Gulf Coast. This should be another driving force for a potential Sarnia-Lambton polypropylene investment. A summary of the analysis is appended.

## VII. Polypropylene

## Supply

The current polypropylene capacity in the United States is approximately 8.3 million tons per year which represents about 12% of the global capacity. Only two new capacity additions/expansions have been announced for the 2015-2020 period. Formosa has announced that it will build a new polypropylene plant (890 KTA) to consume the propylene that will be produced in its PDH plant currently under construction by ThyssenKrupp, with additional propylene from other sources. RexTac, a producer of specialty propylene-based products in Odessa, TX has announced that it is seeking investors for a PDH/polypropylene plant at their site based on the regional availability of low-cost propane. However, industry sources doubt that this will proceed for financial reasons. More recently, Braskem Americas has announced that it is shifting its focus from the West Virginia ethane cracker (ASCENT) to propylene/polypropylene. While the company is currently not considering its own PDH unit, an investment in one of the announced PDH plants could occur. A new polypropylene line would be built at one of its existing sites based on propylene availability. Currently, Braskem purchases 100 percent of its propylene at its Marcus Hook, PA site.

As previously mentioned, a key reason for the few new capacity announcements is that there is more polypropylene capacity available than the current propylene supply. When the PDH plants start up, some of this will be used in existing capacity which precludes the immediate need for a new plant. The amount of idle capacity varies by producer which will determine their need for new capacity. The other major suppliers of polypropylene include Braskem, ExxonMobil, LyondellBasell and Ineos. So far, only Braskem has announced plans for new capacity. Expansions by one or more of these companies are likely. The potential new polypropylene capacity is shown in Table VII.1.

Table VII.1  
Potential New Polypropylene Capacity Additions (2016-2020)

Company	Location	Capacity (KTA)	Startup
Formosa	Point Comfort, TX	890	2017/2018
Braskem*	PA or TX	350	2019
Williams (Partner)	Alberta	500	2019
Others*	LA, TX	700	2019/2020
RexTac**	Odessa, TX	270	Not likely
<b>Total</b>		<b>2,440</b>	
*speculative, **not included in the total			

## Domestic Demand

The United States polypropylene demand is projected to grow at an annual rate of about 2.5% from 2016 through 2020. Demand is forecast to increase by 805 KT by 2020 from a consumption level of 6,075 KT in 2015 to about 6,880 KT in 2020. Injection molding, compounding, fiber, and film will continue to be the major applications for polypropylene in the United States. US polypropylene demand by major application is presented in Table VII.2

The fiber and raffia markets are located in the eastern central part of the United States (Carolinas). These are typically the lowest end grades (price-wise) of the polypropylene market. A Sarnia location would not have any logistics advantage selling into this market. The key markets for a Sarnia plant would be injection molding, compounding, and film & sheet. It is estimated that about 60-65 percent of these markets are in the northeast and north central states. This would represent a volume of about 3.5 million metric tons where the Sarnia plant would have a logistics cost advantage and would also have a shorter rail delivery time. It is expected that rail service out of Houston may be severely constrained with all of the new polyolefins capacity being built there. It is already congested today. The Houston port is also congested. Some companies are looking to export polyolefins out of other ports such as Charleston and Savannah.

Table VII.2  
US Polypropylene Demand by Application (2010-2020), KT

<b>Demand</b>	<b>2010</b>	<b>2015</b>	<b>AAGR 2011-2015</b>	<b>2020</b>	<b>AAGR 2016-2020</b>
Injection Molding	1,913	2,105	1.90%	2,384	2.60%
Compounding	1,587	1,806	2.60%	2,045	2.50%
Fiber & Filament	902	994	2.00%	1,126	3.00%
Film & Sheet	842	952	2.50%	1,079	1.50%
Raffia	102	113	1.90%	128	2.20%
Blow Molding	94	105	2.30%	119	6.00%
<b>Total</b>	<b>5,440</b>	<b>6,075</b>	<b>2.20%</b>	<b>6,880</b>	<b>2.50%</b>

Source: CMR

### Supply/Demand Balance

Based on the PCI/CMR polypropylene supply/demand forecasts as shown in Table VII.3 and Figure VII.1, additional polypropylene capacity will be needed by 2020 which will require more propylene. This would favor a Sarnia-Lambton investment if the propane volume and pricing will be competitive.

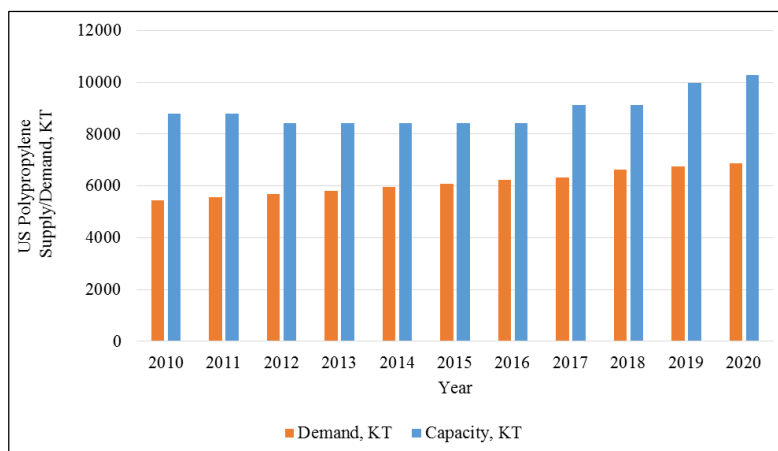
Table VII.3  
US Domestic Polypropylene Supply/Demand Balance\*

<b>Year</b>	<b>US Polypropylene Demand (KTA)</b>	<b>US Polypropylene Supply (KTA)</b>
2010	5,440	8,789
2011	5,560	8,789
2012	5,680	8,424
2013	5,815	8,424
2014	5,960	8,424
2015	6,075	8,424
2016	6,230	8,424
2017	6,310	9,124
2018	6,630	9,124
2019	6,740	9,974
2020	6,880	10,274

\*RexTac capacity not included; exports are also not included

The supply/demand balance for polypropylene is misleading due to the fact that high propylene/polypropylene prices and propylene supply constraints have resulted in low operating rates. When lower cost propylene becomes available, much of it will be used in existing plants which will result in a rapid increase in production and operating rates. The domestic market would not be able to absorb this much capacity so most of the additional production would have to be exported.

Figure VII.1  
US Domestic Polypropylene Supply/Demand Balance



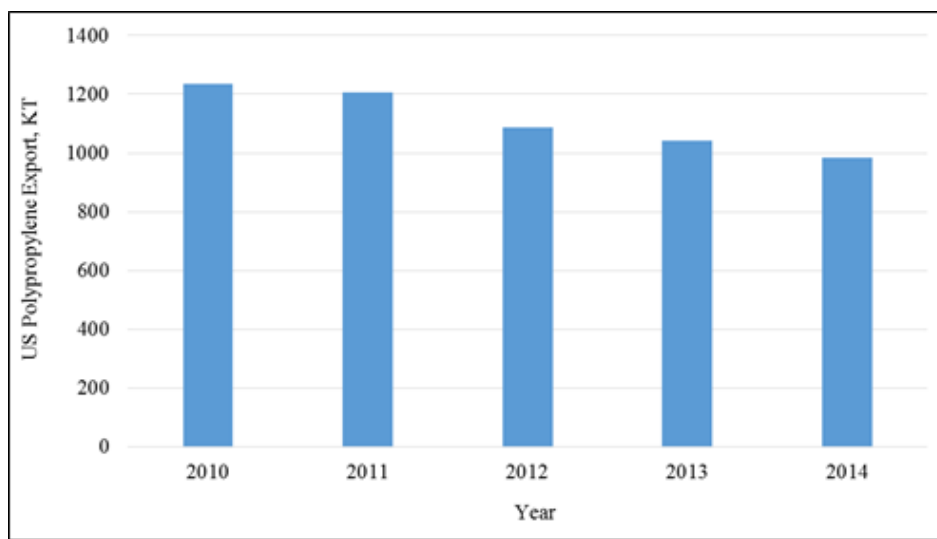
## Exports

With the shale gas propane advantage, US polypropylene exports are projected to increase to balance production with capacity. This would bring exports above the pre-recession level.

US exports of polypropylene have been declining annually since 2009 due the high propylene prices due to the decreased propylene production. The polypropylene price increase substantially reduced the economic competitiveness of US exports.

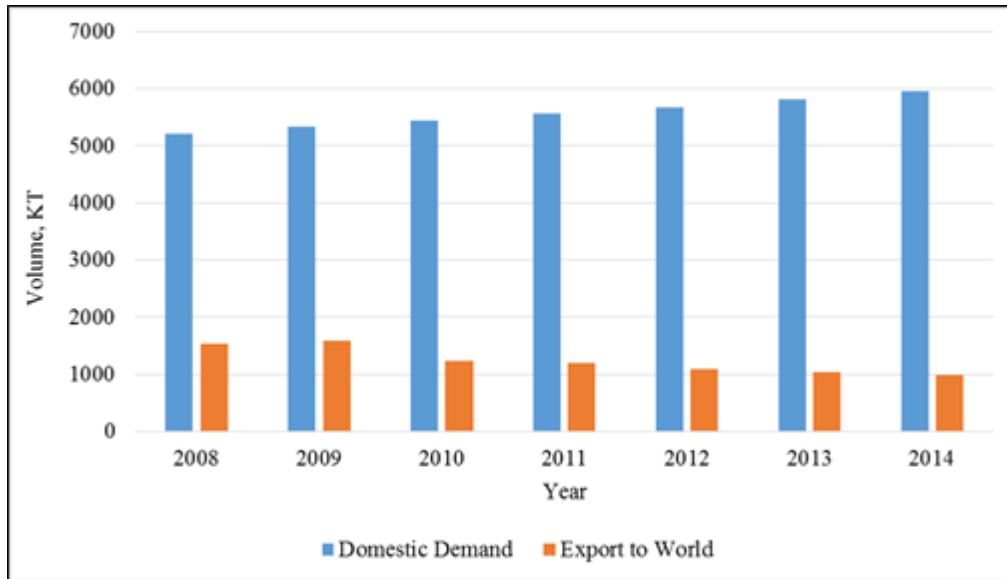
When the PDH plants start up, propylene prices are highly likely to sharply decline. This will restore the competitive advantage of polypropylene in the export market vis-à-vis propylene from naphtha (oil). Exports could increase by as much as 500 KT which would result in higher operating rates. US polypropylene exports are shown in Figure VII.2.

Figure VII.2  
US Polypropylene Exports, 2010-2014



The comparison of domestic demand to exports is shown in Figure VII.3. The exports do not include Canada.

Figure VII.3  
US Polypropylene Domestic Demand and Exports





## VIII. Project Economics

### Propane Dehydrogenation (PDH)

There are several processes that produce propylene from propane. What they have in common is use of heat and a catalyst to “crack” propane (to remove hydrogen and create the olefinic double bond associated with propylene). The two most common processes currently used in the United States are the UOP process that employs fluidized bed technology, and the Lummus process that employs fixed catalyst beds located in heat exchangers. ThyssenKrupp also has a proprietary technology (Uhde STAR) that is being used by Formosa in its PDH plant currently under construction. Each process has characteristics that may be viewed as advantages or disadvantages vis-a-vis the other, including operational characteristics and utility requirements. For the economic evaluation, the Lummus process was selected. It was used in the first operating PDH unit in the US. This was the PetroLogistics unit located in Houston, TX that began operation in late 2010. If a PDH project moves forward at Sarnia, technology selection might use a different technology. However, it is believed that there will not likely be a large difference in project economics.

- **Capital Summary**

Based on published numbers for similar projects, PCI/CMR estimates that the capital required for a typical greenfield PDH unit of 750 KTA to be in the range of \$1.2 to 1.3 billion. For example, the smallest PDH plant planned is for 500 KTA by Williams Energy in Alberta. According to Williams Canada, the capital cost for this plant will be 1.17 billion Canadian dollars. This includes site and infrastructure development.

This capital is comprised of ISBL and OSBL capital portions that are estimated at approximately \$1.0 billion and \$200 million respectively. Working capital is estimated at \$25-50 million. This is summarized in Table VIII.1

Table VIII.1  
PDH Greenfield Cost Analysis

Greenfield Assumptions - base case			
	Battery limits	M\$	1000
	Ex-battery Limits	M\$	150
	Working Capital	M\$	50
	Total Investment	M\$	1200

There is an available brownfield site at the Transalta Bluewater Energy Park, which is described in more detail in a subsequent section. The economic analysis for this site is approximately \$1.0 billion in total which includes \$925 million ISBL, \$25M OSBL, and \$50M working capital. PCI/CMR has not conducted an engineering estimate on a defined project, and these estimates are for evaluation-purposes only. This is summarized in Table VIII.2

Table VIII.2  
PDH Brownfield Cost analysis

Brownfield Assumptions - base case			
	Battery limits	M\$	925
	Ex-battery Limits	M\$	25
	Working Capital	M\$	50
	Total Investment	M\$	1000

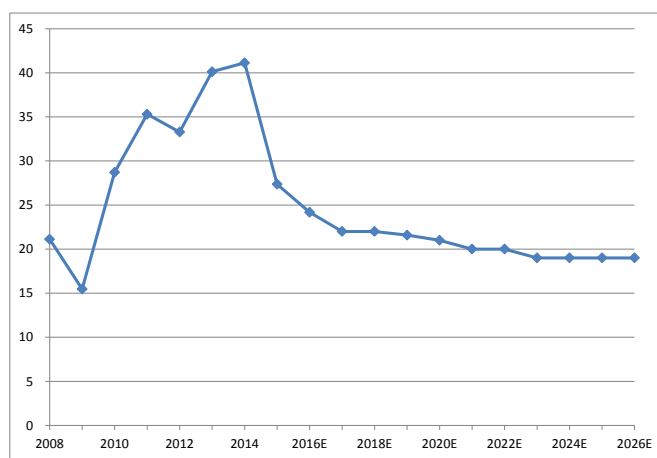
- **Project Economic Drivers**

The primary economic driver for a PDH unit is the propylene-to-propane spread. This spread is calculated from the contract polymer grade propylene price (cents per pound basis) minus the price of propane times both usage and gallon weight factors. The historic spread peaked at \$0.50 per pound in the first quarter of 2013. The annual average spreads are shown in Figure VIII.1. This spread is a function of the tightness of the polypropylene and propylene markets, and the price of propane has historically been highly correlated to crude oil prices. Since propane's primary use is as a fuel, the spread follows seasonal trends and is lower in the winter, but expands in the second quarter of the year. To convert a propylene-to-propane spread to EBITDA per pound for a PDH unit, one can subtract about \$0.10 per pound of fixed and other variable costs.

The emergence of shale oil and gas production beginning in 2008 significantly improved the propylene-to-propane spread due to the fact that low hydrocarbon feedstock pricing incentivized ethylene producers to crack the lightest feed slate possible. This trend reduced the co-production of propylene and improved its pricing. However, in the future the start-up of PDH units both in North America and in Asia, will provide on-purpose propylene product, and will likely negatively impact this spread.

With the global re-set of crude oil prices in late 2014, US contract propylene prices re-set from \$0.775 per pound in October of 2014 to \$0.475 in April of 2015. The propylene-to-propane spread has decreased approximately \$0.15 per pound from late 2014 and is currently forecast at \$0.27/lb in 2015 and \$0.24/lb in 2016. Beyond 2016, the spread will depend on several factors including global demand growth, crude oil prices, and the completion of announced new capacity for on-purpose propylene production. Our view is that the propylene-to-propane spread will likely ease down from current levels and our model assumes a 1¢/lb average drop in spread each of the following 2-year periods. This can be seen in Figure VIII.1.

Figure VIII.1  
Propylene-to-propane spread, cents/lb



Source: Historic data and PCI/CMR assumptions after 2016

- **PDH Economic Model Basis Assumptions**

PCI/CMR has developed an economic model for a PDH unit constructed at the Transalta Bluewater Energy Park. Using this model, PCI/CMR has evaluated project IRR projections at various capital levels and propylene-to-propane spreads which are the two factors that PCI/CMR considers to be the most critical for the project economics. The basic assumptions are:

- **Project site** – Transalta Bluewater Energy Park brownfield site in Sarnia

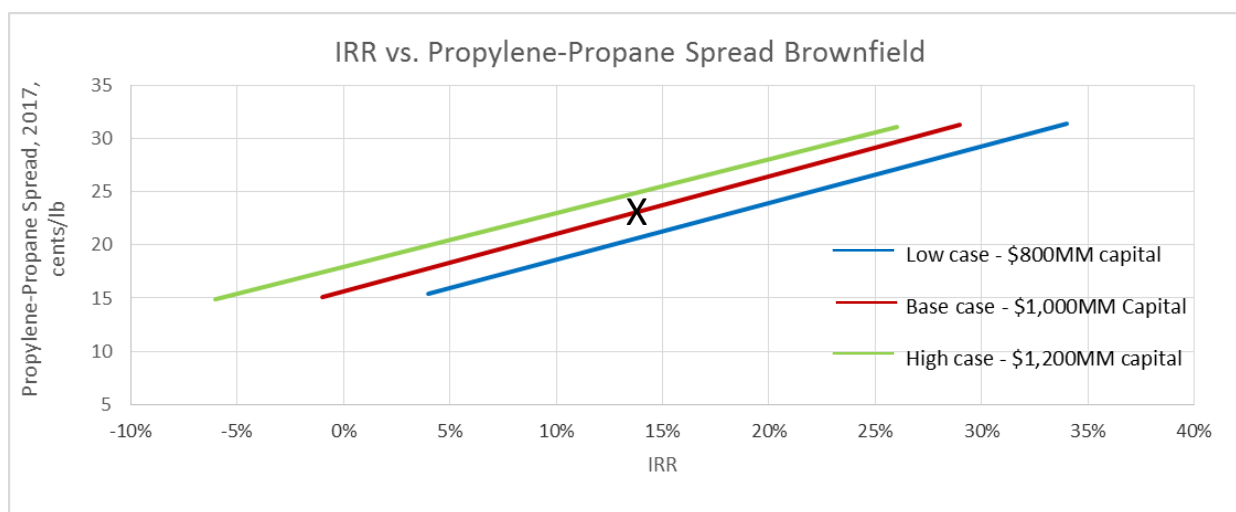
- **Assumed project capital** – Total capital of US\$950 million including \$925 million ISBL and \$25 million OSBL.
- **Capacity** – 750,000 tonnes per year propylene
- **Technology** – Lummus technology
- **Working capital** - \$50 million including a spare catalyst charge
- **Key timing milestones** – Start of pre-project engineering and permitting Q2 2016, project approval Jan 2017, start-up Jan 2019
- **Propane sourcing** – Via pipeline from third party plus local supply
- **Propylene customer** – third party polypropylene manufacturer, located on-site. Assumed product value at typical US propylene contract levels
- **Base case spread** – 2017-2018 spread of \$0.22/lb, decreasing \$0.01/lb every two years

### • Economic Model Output

A project sensitivity analysis based on the PDH project economics model is shown in Figure VIII.2. The assumed 2017 propylene-to-propane spread is shown on the y-axis,. The base case of \$0.22/lb is represented by the “X” in the chart. At the assumed base case capital level of \$1.0 billion, the computed project IRR is 14%.

The three lines in the chart show capital sensitivity to IRR with low and high cases representing 20% deviations from the assumed base case capital level.

Figure VIII.2  
Economic sensitivity of Outputs for PDH Economic Model



Source: PCI/CMR

### • Integrated PDH/PP Economic Model Basis Assumptions

An economic model has been developed for an integrated PDH/PP unit constructed at the Sarnia Bluewater Energy Park. This model was used to evaluate project IRR projections at various capital levels and polypropylene-to-propane spreads. The basic assumptions used are:

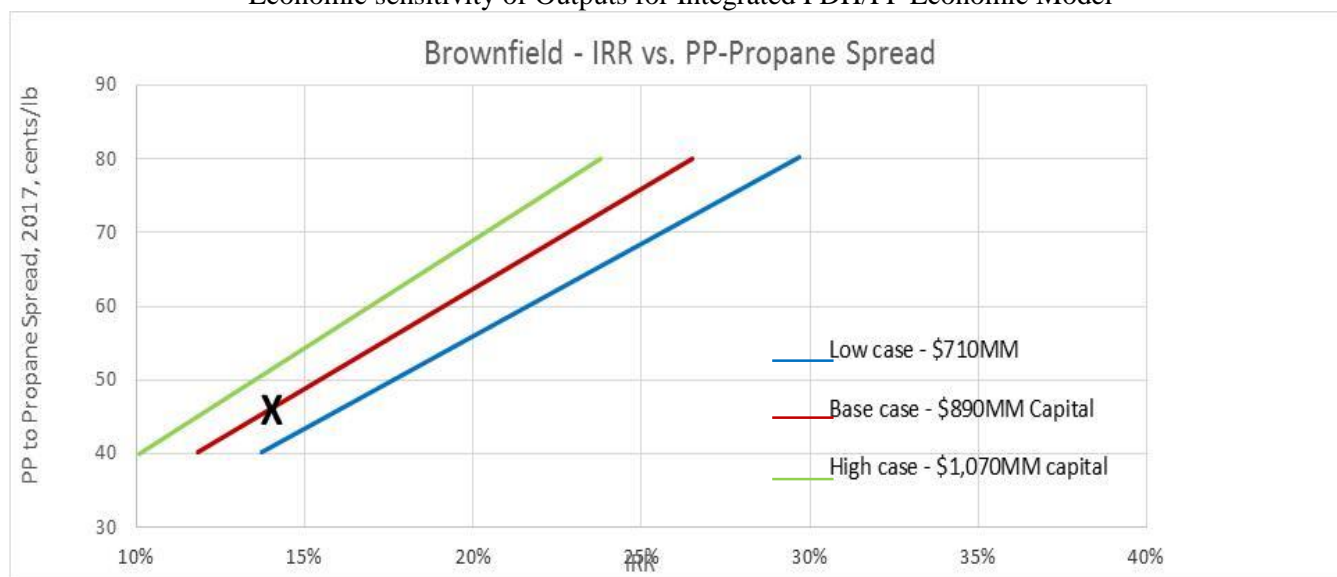
- **Project site** – Transalta Bluewater Energy Park brownfield site in Sarnia
- **Assumed project capital** –  
**Case 1** - Capital of US\$1.425 billion including \$1.3 billion ISBL and \$125 million OSBL  
**Case 2** - Capital of US\$ 890 million including \$800 million ISBL and \$90 million OSBL
- **Capacity** – Two cases:  
**Case 1**- 750 KTA per year propylene; 800 KTA per year polypropylene  
**Case 2** - 375 KTA per year propylene; 400 KTA per year polypropylene
- **Technology** – Lummus technology for propylene; gas-phase technology for polypropylene
- **Working capital** –  
**Case 1**- \$200 million including a spare catalyst charge  
**Case 2** - \$125 million including a spare catalyst charge
- **Key timing milestones** – Start of pre-project engineering and permitting Q1 2016, project approval Jan 2017, start-up Jan 2019
- **Propane sourcing** – Via pipeline from third party
- **Polypropylene customers** – external PP merchant market.
- **Base case spread** – 2017-2018 spread of \$0.45/lb, decreasing \$0.02/lb every two years

## • Economic Model Output

A project sensitivity analysis is provided in Figure VIII.3 based on the integrated PDH/PP project economic model. The assumed 2017 polypropylene-to-propane spread is located on the y-axis. The base case of \$0.45/lb is represented by the “X” in the chart. At the assumed Case 1 capital level of \$890 million (excluding \$125 million working capital), the computed project IRR is 14%.

The three lines in the chart show capital sensitivity to IRR with low and high cases representing 20% deviations from the assumed base case capital level.

Figure VIII.3  
Economic sensitivity of Outputs for Integrated PDH/PP Economic Model



Source: PCI/CMR

## Polypropylene Cost

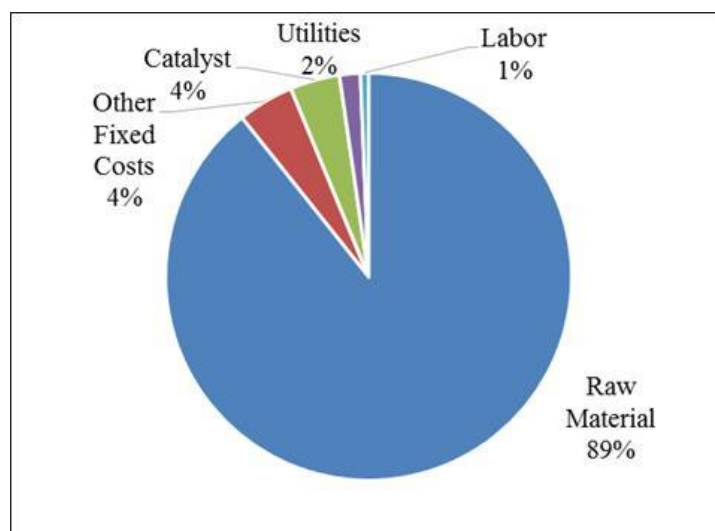
To match the PDH plants, two polypropylene options are considered

- 400 KTA (to match 375 KTA PDH)
- 800 KTA (to match 750 KTA PDH)

### • Manufacturing Cost

The most critical aspect of a polypropylene project is the cost of the propylene. Raw material costs account for almost 90% of the total cost of producing polypropylene in USGC. Labor costs include operator, supervision, and maintenance costs. Utilities include cost of electricity, cooling water, etc. Other fixed manufacturing costs include general plant overhead, insurance and property taxes, and depreciation of equipment and buildings. This is shown in Figure VIII.4

Figure VIII.4  
Polypropylene Cost of Production



The PDH plant proposed for Sarnia would have an advantaged propylene cost compared to propylene produced on the US Gulf Coast due to the discounted propane. The polypropylene manufacturing cost analysis is based on the assumptions as shown in Table VIII.3.

Table VIII.3  
Polypropylene Capital Cost Analysis

		Case 1	Case 2
Capacity	KTA	800	400
Battery limits	M\$	375	188
Ex-battery limits	M\$	100	75
Working Capital	M\$	150	75
Total Investment	M\$	625	338

### • Total Project Cost

The total cost for an integrated PDH/polypropylene plant is shown in Table VIII.4 for the two PDH/polypropylene capacities for greenfield and brownfield sites. Depending upon the configuration and size of the plants the range of the investment would be between 1 and 2 billion dollars.

Table VIII.4  
Summary Project Cost Analysis, MM\$

	Low Capacity		High Capacity	
	Greenfield	Brownfield	Greenfield	Brownfield
PDH capacity, KTA	375	375	750	750
PP Capacity, KTA	400	400	800	800
PDH unit				
ISBL	660	610	1,000	925
OSBL	100	16	150	25
Working Capital	50	50	50	50
<b>Subtotal</b>	<b>810</b>	<b>676</b>	<b>1,200</b>	<b>1,000</b>
Polypropylene				
ISBL	190	188	375	375
OSBL	100	75	175	100
Working Capital/owner's cost	75	75	150	150
<b>Subtotal</b>	<b>365</b>	<b>338</b>	<b>700</b>	<b>625</b>
<b>Total</b>	<b>1,175</b>	<b>1,014</b>	<b>1,900</b>	<b>1,625</b>
excluding working capital	1,050	890	1,700	1,425

- **Pipeline Considerations**

There is limited published information on the capital costs of the various pipelines from the Marcellus-Utica plays that could serve as a reference point should there be a need to include a new propane or mixed feed pipeline in the project. Those that are published are listed in Table VIII.5

Table VIII.5  
Published Pipeline Costs

<u>Pipeline</u>	<u>Companies</u>	<u>Material</u>	<u>Capacity, 1,000 bbl/d</u>	<u>Diameter</u>	<u>Length, miles</u>	<u>Cost, \$MM</u>	<u>Formation</u>	<u>Start</u>	<u>Terminal</u>
Utopia (Cochin East)	Kinder-Morgan Cochin	E and E/P	50	12"	240	500	Marcellus/Utica	Harrison County, Ohio	Windsor, Ontario
Mariner East 1	MarkWest/Sunnoco	E/P	70		330	500	Marcellus	Houston, PA	Sunoco Markus Hook, PA
Mariner East 2	Sunoco Logistics	E/P/B	275	16"	400	2,500	Marcellus	WV, W Pa	Delaware River, PA
ATEX	Enterprise	E	125	20"	1,230	1,400	Marcellus	Marcellus	Mt. Belvieu, TX

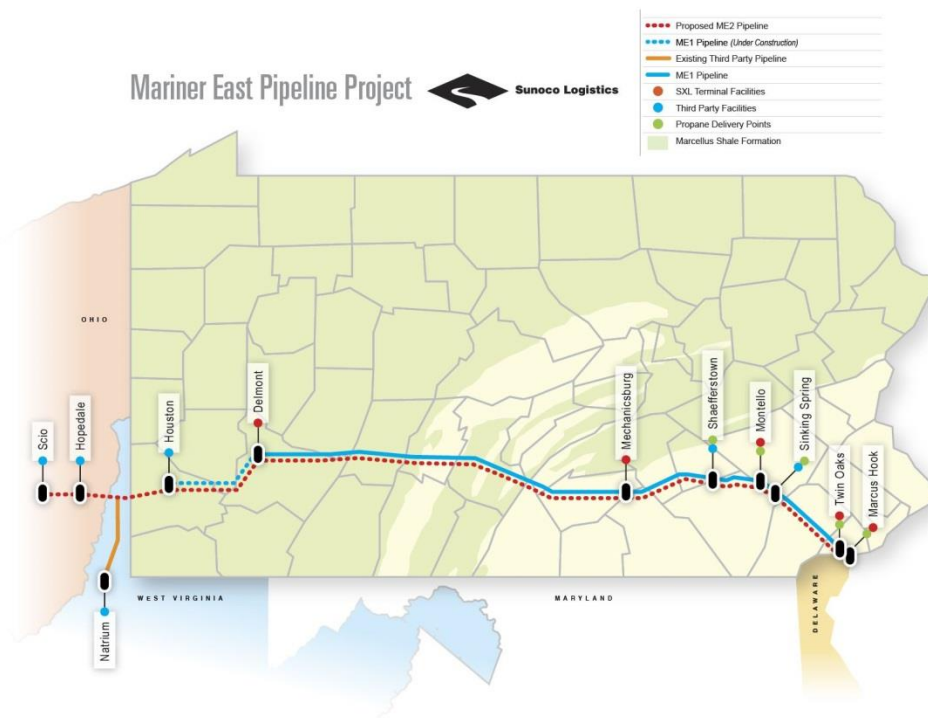
Using the Utopia and Mariner East costs as a guide, the average cost is \$1.75 million per mile. A propane pipeline from Harrison County, OH to Sarnia would be approximately 325 miles and would cost about \$570 million.

It may be possible to utilize part of the Mariner East 2 pipeline to transport NGL to Sarnia as a supplementary supply source. Fractionation would be required. The pipeline system is shown in Figure VIII.5.

Figure VIII.5



## Mariner East 2 Pipeline System



Source: Sunoco Logistics

Crossing the river to get to Sarnia should not be a problem. There are currently twelve pipeline crossings adjacent to Sarnia's industrial areas comprised of twenty-three pipelines. A detailed map and list of the pipelines is appended. The information was provided by MIG Engineering ([www.migeng.com](http://www.migeng.com)), a Sarnia-based consultancy active in the infrastructure development in the oil, gas and other industries.

### • Project Tax Considerations

Compared to a USGC site, one advantage that a Canadian plant would have is a lower corporate tax rate versus a US-based corporation. The total corporate tax rate for a Canadian company engaged manufacturing and processing is 25%, consisting of a 15% federal tax rate and a 10% provincial tax rate. While this total is lower than a typical tax statutory rate of 35% for a US corporation, the US IRS code provides the possibility of setting up a PDH business in the form of an MLP (Master Limited Partnership). The MLP pays no federal taxes but dividends net earnings to partners (shareholders) that pay taxes at their individual tax rates.

Under current Canadian law, the Government of Canada allows businesses to claim accelerated capital cost allowance equivalent to 50% of eligible machinery and equipment for the first two years. While this allowance is set to expire at the end of 2015, this provision has been extended several times.

There may also be an opportunity to negotiate for investment incentives such as a lower tax rate which the local, provincial and federal governments. This has not been taken into account in the economic analysis;

## IX. Site availability

There are a few potential sites that would be available for a petrochemical investment. One very viable brownfield site that was identified was the Transalta Bluewater Energy Park in Sarnia, formerly the location of Dow Chemical's Sarnia Plant that had been shut down and dismantled beginning in 2006. This site was purchased by Transalta that operates an underutilized co-generation plant on the same site. Transalta provides services for adjacent sites including a co-located refinery and chemical plant.

There are some positive attributes for this location that a prospective investor should consider during site selection:

- The Transalta Bluewater Energy Park is a brownfield site and could provide significant capital savings primarily associated with OSBL (outside battery limits) and site development costs
- Co-location of a PDH unit at this site could provide a customer for co-product hydrogen
- The site provides excellent transportation and utility infrastructure
- The site is available based on conversations with the company

A detailed analysis of this site is in the appendix.

## APPENDIX

## Propylene Derivative Analysis

Although the chemical grade or polymer grade propylene produced from a PDH unit can be transported and sold to a dedicated customer or into the merchant market, competitive economics usually dictate that a propylene production unit be close-coupled to a derivatives unit. These derivatives are typically polypropylene, acrylic acid, oxo-alcohols, and acrylonitrile as shown in Table A.1

Table A.1  
Propylene Derivative Analysis

<u>Derivative (%)</u> <u>propylene)</u>	<u>Major</u> <u>Producers</u>	<u>Markets/Downstream</u> <u>Uses</u>	<u>Profitability</u>	<u>Growth %</u>	<u>Comments</u>
Polypropylene (50%)	LyondellBasell, ExxonMobil, Formosa, Baskem, Total	Injection Molding, Film & Sheet, Fiber & Filament, Blow Molding	Cyclical	2.50%	PP partners will be recommended as part of this project
Propylene Oxide (12%)	LyondellBasell, Dow Chemical, BASF, Shell	Polyether polyols into polyurethanes; propylene glycols	Depends on process. POSM poor due styrene co-product	3.00%	New LBI NA plant by 2019 based on PO/TBA but HPPO route currently most popular for new plants
Acrylonitrile (8%)	Ineos, Solutia, Asahi, Sinopec	ABS/SAN, acrylic fiber, nylon 6,6	Poor	3.60%	NA acrylic fiber shutdown due to Asian competition
Cumene (7%)	Axiall	Phenol and derivatives phenol formaldehyde, polycarbonate	Very poor;	2.00%	Axiall is selling its aromatics due to years of industry overcapacity and poor margins. Polycarbonate CD market declining
Acrylic Acid (7%)	BASF, Dow Chemical, Arkema, Nippon Shokubai	Paint, super-absorbent polymers, polyacrylic acid polymers	Good	2.70%	Good growth dominated by major players. Potential strong growth for super-absorbent polymers in Asia (diapers)
Oxo process; such as 2-EH, Butanols, etc. (6%)	BASF, Eastman, Oxea, Dow, Mitsubishi, LG Chem, Chinese producers	50% of 2-EH goes into phthalate plasticizers for flexible PVC; solvent uses for butanol	Poor	2.20%	Push for non-phthalate plasticizers will limit 2EH growth in US and Europe
Isopropanol, oligomers, other (10%)	<b>IPA:</b> Dow, ExxonMobil, Shell, LyondellBasell, Ineos, Mitsui and Chinese	Solvents, paints, de-icers, household, cosmetics, personal care products, pharmaceuticals, and pesticides		2.10%	Growth is expected to be stable in future due to maturity of demand for the product

## Infrastructure Discussion

A primary advantage of locating a PDH and derivatives unit at the Transalta Bluewater Energy Park in Sarnia is the potential to minimize capital compared to a greenfield site. These savings are primarily associated with OSBL and utility infrastructure requirements. While this site had been a Dow Chemical manufacturing site, the process equipment has been removed and the site has been levelled. The site is undergoing the last phase of remediation for which Dow Chemical is managing and paying.

A preliminary review of the manufacturing footprint for the brownfield site and the requirements of a PDH and downstream production unit have been conducted with the fit to being reasonably good. In Table A.2, project requirements are compared to availability of infrastructure and utilities.

**Table A.2**  
**Comparison of Bluewater Energy Park to PDH Project Requirements**

<b>Site considerations</b>	<b><u>Availability</u></b>	<b><u>Requirements</u></b>	<b><u>Discussion</u></b>
Land	268 acres	about 100 acres required	Included polypropylene plant
Remediation	Expected to be complete in 2015		Dow Chemical is nearing end of activity
Buildings	Large administration building on site		100,000 ft <sup>2</sup> building, 1/3 office, 2/3 lab
Rail access	Local connection to CSX and CN	rail access	Existing rail spurs in plant
Water Access	Access to St. Lawrence Seaway via St. Clair river; dock available	Likely not required	
Highway access	Local connections to major highways		Good access to housing
Residential	Location close to Sarnia		
<b>Utilities</b>			
Cooling water	River water from St. Clair river, 40k GPM	Appx. 25k GPM required	Adequate
Electrical	grid and 15kVA co-gen power, 75 MW	Appx. 20 MW required	7.6c/kwh is competitive, negotiable
Steam	3MM lb/hr available, 165PSI to 1,400PSI		
Natural Gas	Available	700k SCFH	
Fire Water	existing system maintained		Pump house and two pump stations at river
Sanitary sewer	existing		
<b>Co-products</b>			
Hydrogen	Praxair on site	co-product hydrogen	possible sale for refinery use
Liquids	Local customers	1 to 2 tank trucks/wk	sale as fuel
<b>Environmental</b>			
Zoning	zoned for heavy industrial	not significant	
Biox	Available capacity at Lanxess plant	Need permits from Ministry of Environment	
Permits			

Source: Transalta and PCI/CMR

The following items can be included in the appendix as desired

- MIG PIPELINE GRID (REFERENCED IN THE TEXT)
- TAXATION DOCUMENT
- PERMITTING DOCUMENT
- LABOR COST DOCUMENT