NON-CONFIDENTIAL REPORT

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota

IHS Chemical

May 02, 2014
Final Report

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Introduction and Objectives
Introduction

• The State of North Dakota ("North Dakota Department of Commerce", "EmPower ND Commission") is seeking the assistance of an independent third-party consultancy to provide an in-depth market and feasibility analysis of the ethanol market in North Dakota, both on a national and global scale.

• IHS Global, Inc., with the combined expertise of IHS Chemical (including the former CMAI and SRI Consulting, IHS Downstream Energy (the former Purvin & Gertz), IHS CERA (Upstream Energy), and IHS Global Insight, is unique in our experience, expertise and databases and hence capability to be able to support the State of North Dakota entirely in this major initiative along the full value chain from ethanol through high-value products. Specifically, IHS has done extensive work analysing ethanol and the implication on the U.S. Chemicals Industry. Our strong position in the petrochemicals industry and our world-class experts puts IHS in an excellent position to deliver the full scope of service requested by State of North Dakota.
The Study

- North Dakota’s four ethanol plants produce nearly 400 million gallons of ethanol per year, which is more than a ten-fold increase since 2005. Approximately six percent (24 million gallons) of the 400 million gallons of ethanol produced annually in North Dakota is blended with gasoline and sold within the state, while the remaining 94 percent is shipped primarily to the east or west coast.

- Dakota Spirit AgEnergy plans to break ground in 2013 on a biorefinery to be co-located next to Spiritwood Station, a 99 Megawatt (MW) combined heat and power plant near Jamestown, ND. The biorefinery will utilize steam from Spiritwood Station to produce 65 million gallons per year (MGY) of ethanol, as well as distiller’s grains and fuel-grade corn oil. Future growth opportunities for the biorefinery are emerging with cellulosic, isobutanol and other biofuel technologies.

- There is also a public/private partnership, BeetsAll Biofuel. Through the resources of North Dakota State University and the Carrington (ND) Research Extension Center, the partnership is researching the feasibility of developing facilities across North Dakota that use locally grown energy beets, a variety of sugar beets, to create ethanol and high-value chemicals.
The study will help state officials to gain an understanding of the industry and the products, with the early stage objective of determining how to add value to ethanol by developing and commercializing the product stream. The intent is to identify niche markets/opportunities that are compatible with the state’s resources and capabilities. Further, it will define what North Dakota needs to do to attract investment by companies in the industry, including, but not limited to, identifying what barriers need to be removed or what incentives to consider. Ultimately, the study will be used to establish a business case that can be used to attract production facilities to North Dakota.
Until the late twentieth century, biochemical manufacture had been developed for the production of food and pharmaceuticals and it has been only recently that biochemical science has developed as a “cousin” to biofuels and found commercial promise in the area of industrial chemical applications. As a result of the proliferation of bio-technology advances including genetically modified organisms (GMOs), fermentation products have recently broadened dramatically from primarily ethanol fuel into a broad range of chemical platform intermediates for downstream use into polymers, and specialty and fine chemicals as well as non-ethanol renewable drop-in fuels (RDIFs).

Today, the chemical industry trade press is replete with articles and announcements concerning the global development of industrial biotechnology largely comprised of advancements in the conversion of biomass into both commodity and specialty chemicals. A sampling of the broad range of these developments and activities is shown in the following figure.
The Study (continued): Wide Range of Industrial Bio Chemical Technology Development

Note:

PMMA: polymethylmethacrylate
POM: polyoxymethylene or polyacetal resin
PGA: polyglycolic acid
PE: polyethylene
EPDM: ethylene propylene diene monomer
PS: polystyrene
PET: polyester or PET resin
PP: polypropylene
PLA: polylactic acid
BDO: butanediol
PBT: polybutylene terephthalate
TPU: thermoplastic polyurethane
PBS: polybutylene succinate
SIS/SEPS: styrene block copolymers
PA 6-6: nylon
Green PC: renewable sourced polycarbonate
PX: para-xylene

| C1s     | Methanol | PMMA/POM
|---------|----------|-----------
| C2s     | Ethanol, Glycolic Acid | PGA, PE, EPDM, PS, PET
| C3s     | Propanol, Lactic Acid | PP, EPDM, PLA
| C4s     | Succinic Acid, Butanol, BDO | Butadiene, PBT, TPU, PMMA, PBS
| C5s     | Isoprene | SIS/SEPS, Elastomers
| C6s     | Glucaric/Adipic Acid, Isosorbide | PA 66, Green-PC
| C8s +   | Functional Chemicals | Specialty Chemicals
| Aromatics | PX, benzene | PS, PET
The Study (continued)

- The vision includes the development of biochemical processes and petrochemical processes to convert sugars into intermediates from which polymers, solvents, etc., could be derived at relative low cost, especially with escalating crude oil prices.
- Reflecting the activities of Braskem, the leader in sugar-based ethanol-to-polyethylene, it is possible to see the integration bio ethanol with major petrochemical building blocks like ethylene and propylene as shown below. Moreover this approach is being developed across many different petrochemical value chains.
The Study (continued) - Potential Bio-Refinery Configurations – A Simplified View

- Ethanol
- Gasification Platform
- Ethanol Dehydration
- Bioethanol
- Fermentable Sugars
- New Intermediate
- Normal Butylenes
- Normal Butylenes Metathesis
- Octene-1
- Ethylene
- Ethylene Derivatives
- LDPE
- HDPE
- LLDPE
- EVA/VAE Resins
- Vinyl Acetate
- EPR/EPDM
- Acrylonitrile
- PP
- Isopropanol
- Cumene/Phenol
- Acrylic Acid
- Oxo Alcohols
- Propylene Oxide
- Ethylene
- Normal Butylenes
- Octene-1
- Ethylene
The Study (continued)

• On a global basis this industry could develop in size to around six to eight billion US dollars by 2020. The following illustrates major applications and regions where demand is likely to develop.

• Another interesting aspect of the renewable bio industry is that there are two fundamental differences in the relationship of bio-based fuels/chemicals versus the relationship of petrochemical-based fuels and chemicals.
The traditional relationship of energy/fuels and chemicals are that oil, gas and coal, while primarily used for power and transportation fuels, also serve as the primary feed stocks for chemicals. For the renewable sector, the bio feedstocks (of plants, vegetable, fats, wood and waste streams) have historically been focused for fuels production. As such, there are two fundamental differences in the relationship of bio-based fuels/chemicals versus the relationship of petrochemical-based fuels/chemicals. In the bio routes, 1) fuel and chemical are both created via conversion process of the bio-feedstock; and 2) the bio-fuel molecule can be a “platform” molecule where by changing the functionality of this bio-produced molecule (in a post chemical reaction) a low value fuel product can be converted to high value specialty chemical.
Overall, technology development history has shown us that the long-term success of technology advances is critically dependent on market demand and acceptance. As such, the value chain, which is complex, must be understood. At the most basic level, the chain (shown in the figure below) consists of the:

- feedstock supplier (bio-feedstock in this case)
- chemical intermediate which by definition is a “green” or bio chemical
- final product that is typically comprised of bio and petrochemical-based material
- end-use products e.g., fabricated parts or products, formulated products, etc.
With this significant opportunity for renewable chemicals market value, the industry is overcoming the aforementioned traditional market entry challenges and continuing to move forward with the commercialization of biotechnology largely based on a competitive cost strategy. Here, the success of market penetration of a renewable chemical will generally be a function of how this new material is positioned (over some time period) on the industry cost curve as shown in the figure below.

**TARGET PRODUCT INDUSTRY COST CURVE**

- Cost of Production
- Demand
- Cumulative Industry Capacity
- Production Plants
- Sustainable Cost
- Market Entry Price
- Green Price Premium
The Study (continued)

- In the short term, a price premium can be sustained due to the high cost, but in the medium and long term, the renewable material will need to become positioned to a lower cost (to the left) of the marginal producer’s cost. The counterpoint is that if a renewable maintains its position on the high side of the industry cost curve (the far right side), the product/business will not be sustainable.

- A key fundamental for the success of this industry is that there must be a sustainable interaction and cooperation between the petrochemical industry, the agricultural industry, the technology developers and customers along this value chain.
The Study Approach and Status

**COMMERCIAL**
- Market Research
- Feedstock Type and Availability
- Supply & Demand Analysis & Forecasts
- Pricing Mechanisms & Forecasts
- Product Customer Demand
- Regulatory & Policy Considerations

**FINANCIAL / STRATEGIC**
- Purpose & Objectives
- Opportunity Options (Alignment with Vision)
- Preliminary Cash Flow Analysis
- Client Review and Scenario Development
- Financial Feasibility Model
- IHS/Client Reviewed Business Plan
- Final Plan: Recommendations and Conclusions to ND Dept. of Commerce et al.

**TECHNOLOGY / ECONOMIC**
- Technology and Economic Evaluation
- Feedstock Driven Process Envelope
- Target Technology Diligence
- Technology/Capacity Selection
- Full Economic Assessment
- Product Destination
- Logistics
- State Business Investment Incentives

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Final Report, May 2014**
WHO IS IHS?
Who is IHS?

IHS’ Capabilities & Expertise are Across Multiple Industries
We are a public company (founded in the 1950s)
We currently with over 8000 staff in 30 countries
Our revenue exceeds US$ 2 billion
Who is IHS? (continued)

- We are the industry’s largest integrated source for Energy and Chemicals Research, Analysis, and Consulting Services
- During the 4 years, IHS has acquired and put under one roof...
  - CMAI
  - SRI
  - Harriman
  - Chemical Week
- IHS Chemical’s group has about 350 staff in 15 offices around the globe
Who is IHS? (continued)

Oil, Gas Production

Hydrocarbon Feed

Monomer/Base Chemicals

Derivatives & Intermediates

Plastics & Rubber

Oil Refining and Gas Processing

Separation, Conversion

Conversion

Polymerization

Customers

Retail

Manufactured Goods

Converters: Tires and Other Fabricated OEM Parts

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota Final Report, May 2014
Executive Summary

- Summary, Conclusions and Recommendations
Summary, Conclusions and Recommendations
The Feedstock-Products Value Chain

To be Advantaged here;
You need to be here

Ethane, Propane, Butanes
Intermediate Chemicals
Commodities
Specialties
End-Use Products and Polymers
Fabricated Products

NGLs
Gas Processor for (Y-cut) Pipeline Merchant
Flared Unlikely Recovered by Gas Processors

Ethanol
Biomass
Basic Bio Chemicals
Butanol
Gas Processor for (Y-cut) Contracted

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BIOmass FEEDSTOCK (Corn, Corn Stover, Wheat Straw)

- Existing Plant
  - Ethanol → Dehydrogenation → Ethylene → HDPE Resin
    - 180 kta (60 MM gal/yr)
    - 128 MM USD
    - EO: 144 kta; 399 MM USD
    - MEG: 189 kta; 122 MM USD

- New or Converted Plant
  - n-Butanol → Dehydrogenation → Butadiene
    - Converted: 105 kta (34 MM gal/yr)
    - 206 MM USD
    - Grass Roots: 105 kta (34 MM gal/yr)
    - 240 MM USD
    - 77 kta
    - 42 MMUSD
    - 69 kta
    - 71 MMUSD
  - Paraxylene → Hydrogenation → 1,3-Butanediol → PBT Resin
    - 50 kta
    - 513 MMUSD
    - 38 kta
    - 337 MMUSD
    - 25 kta
    - 132 MMUSD
    - 50 kta
    - 73 MMUSD

- New Plant
  - Succinic Acid → Hydrogenation → 1,3-Butanediol
    - 25 kta
    - 132 MMUSD
  - Converted: 105 kta (34 MM gal/yr); 206 MM USD
  - Grass Roots: 105 kta (34 MM gal/yr); 240 MM USD

SHIPPING LOGISTICS & COST

- Merchant
- Fabrication
- PB Rubber

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
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### BioChemicals: Capacity and Capital Costs – North Dakota - 2020 Basis

<table>
<thead>
<tr>
<th>Unit</th>
<th>Capacity, kMT</th>
<th>Capital, USMM$</th>
<th>MM gal/yr</th>
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<tbody>
<tr>
<td>Ethanol</td>
<td>180.00</td>
<td>128.00</td>
<td>60</td>
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<tr>
<td>Ethylene (Ethanol)</td>
<td>109.00</td>
<td>70.00</td>
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<tr>
<td>HDPE</td>
<td>108.00</td>
<td>132.00</td>
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<tr>
<td>EO</td>
<td>144.00</td>
<td>399.00</td>
<td></td>
</tr>
<tr>
<td>MEG</td>
<td>189.00</td>
<td>122.00</td>
<td></td>
</tr>
<tr>
<td>Butanol (Grass Roots Corn)</td>
<td>105.00</td>
<td>240.00</td>
<td>34</td>
</tr>
<tr>
<td>Butanol (Converted Corn)</td>
<td>105.00</td>
<td>206.00</td>
<td>34</td>
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<tr>
<td>Catalytic Dehydrogenation to Butene-1</td>
<td>77.00</td>
<td>42.00</td>
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</tr>
<tr>
<td>Butadiene (Butene-1)</td>
<td>69.00</td>
<td>71.00</td>
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<tr>
<td>Polybutadiene</td>
<td>67.00</td>
<td>216.00</td>
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<tr>
<td>Paraxylene (Corn)</td>
<td>50.00</td>
<td>513.00</td>
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<tr>
<td>Succinic Acid (Corn)</td>
<td>38.00</td>
<td>337.00</td>
<td></td>
</tr>
<tr>
<td>BDO</td>
<td>25.00</td>
<td>132.00</td>
<td></td>
</tr>
<tr>
<td>PBT</td>
<td>50.00</td>
<td>73.00</td>
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</tr>
</tbody>
</table>
1,3-Butadiene and n-Butanol Additions Would be Small Percentages of Total US Capacity

- For 1,3-butadiene (BD) IHS forecasts little or no capacity addition.
- This is largely due to the fact that the BD capacity is conventionally provided by steam cracker coproduct production from heavier liquid feedstocks, which are in decline in the US as ethane and other light feeds displace the heavier feedstocks and the cost of on-purpose BD production has been uncompetitive.
- The proposed plant represents only a very small percentage of the total US capacity in 2020 (3%) and will not cause a disruption in the market.
- The n-butanol addition is greater than forecast by IHS as speculative need in the US, but a small percent of total capacity and presents an opportunity to gain market share from cost competitiveness.

![US Capacity vs. Ethanol Plant Capacity - 2020](chart.png)
PBR Would be a Larger Impact in the Market if Added

- PBR elastomer might be attractive if State incentives are provided
- IHS forecasts no new PBR plants and, hence, the proposed plant is not viewed as necessary to satisfy production need by 2020; however, the proposed PBR plant represents only 10% of the 2020 anticipated total US capacity such that a competitive plant could displace current capacity
There is a Significant Market Within Easy Reach of a North Dakota-based Project

More than half of the consumption in US is within reach of a North Dakota Plant, while most production is centered in the U.S. Gulf Coast.
Financial Model Results – Corn Based Only

Bio-Chemicals (Corn Based): Returns (IRR, %) vs. Risk

Source: IHS
Financial Model Results – Corn Based Only

Bio-Chemicals: Returns (IRR, %) vs. Risk

- CV - Corn - ButOH to Chemicals
- CV - Corn - Butadiene
- GR - Corn - Butadiene
- CV - Corn - ButOH to Gasoline/Fuel
- CV - Corn - PBR
- Corn - PXE
- GR - Corn - PBR
- GR - Corn - ButOH to Gasoline/Fuel
- Corn - Succinic
- Corn - BDO

Source: IHS © 2014 IHS
### Financial Model Results

<table>
<thead>
<tr>
<th></th>
<th>IRR</th>
<th>NPV @ 0%</th>
<th>NPV @ 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol - North Dakota Feed - Midwest Netback - Ethanol Market Price - Ethylene - HDPE</td>
<td>6%</td>
<td>152</td>
<td>-31</td>
</tr>
<tr>
<td>Ethanol - North Dakota Feed - Midwest Netback - Ethanol Market Price - Ethylene - MEG</td>
<td>5%</td>
<td>290</td>
<td>-78</td>
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**Grass Roots**

<table>
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<tr>
<th></th>
<th>IRR</th>
<th>NPV @ 0%</th>
<th>NPV @ 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Sell Butanol to Chemicals</td>
<td>26%</td>
<td>730</td>
<td>117</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Sell Butanol to Gasoline/Fuel</td>
<td>5%</td>
<td>115</td>
<td>-26</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Butene-1 - Butadiene</td>
<td>10%</td>
<td>331</td>
<td>4</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Butene-1 - Butadiene - PBR</td>
<td>5%</td>
<td>222</td>
<td>-69</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Sell Butanol to Chemicals</td>
<td>20%</td>
<td>807</td>
<td>106</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Sell Butanol to Gasoline/Fuel</td>
<td>7%</td>
<td>213</td>
<td>-28</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Butene-1 - Butadiene</td>
<td>10%</td>
<td>427</td>
<td>0</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Butene-1 - Butadiene - PBR</td>
<td>6%</td>
<td>327</td>
<td>-71</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Sell Butanol to Chemicals</td>
<td>21%</td>
<td>763</td>
<td>105</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Sell Butanol to Gasoline/Fuel</td>
<td>6%</td>
<td>160</td>
<td>-32</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Butene-1 - Butadiene</td>
<td>10%</td>
<td>372</td>
<td>-3</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Butene-1 - Butadiene - PBR</td>
<td>5%</td>
<td>266</td>
<td>-74</td>
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**Converted from Ethanol**

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<th>IRR</th>
<th>NPV @ 0%</th>
<th>NPV @ 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn - Sell to Chemicals</td>
<td>33%</td>
<td>850</td>
<td>152</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Sell Butanol to Gasoline/Fuel</td>
<td>13%</td>
<td>249</td>
<td>14</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Butene-1 - Butadiene</td>
<td>16%</td>
<td>471</td>
<td>45</td>
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<td>Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Butene-1 - Butadiene - PBR</td>
<td>8%</td>
<td>364</td>
<td>-27</td>
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<td>Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Sell Butanol to Chemicals</td>
<td>29%</td>
<td>1003</td>
<td>168</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Sell Butanol to Gasoline/Fuel</td>
<td>14%</td>
<td>390</td>
<td>27</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Butene-1 - Butadiene</td>
<td>17%</td>
<td>666</td>
<td>74</td>
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<tr>
<td>Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Butene-1 - Butadiene - PBR</td>
<td>10%</td>
<td>570</td>
<td>5</td>
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<td>Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Sell Butanol to Chemicals</td>
<td>30%</td>
<td>959</td>
<td>167</td>
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<td>Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Sell Butanol to Gasoline/Fuel</td>
<td>14%</td>
<td>347</td>
<td>26</td>
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<td>Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Butene-1 - Butadiene</td>
<td>18%</td>
<td>611</td>
<td>72</td>
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<td>Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Butene-1 - Butadiene - PBR</td>
<td>10%</td>
<td>509</td>
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Financial Model Results

<table>
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<tr>
<th>Product Description</th>
<th>IRR</th>
<th>NPV @ 0%</th>
<th>NPV @ 10%</th>
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<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn - Succinic Acid - BDO - PBT</td>
<td>-14%</td>
<td>-471</td>
<td>-225</td>
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<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn - Succinic Acid - BDO</td>
<td>&lt;-30%</td>
<td>-1099</td>
<td>-358</td>
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<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn - Selling Succinic Market</td>
<td>-1%</td>
<td>-15</td>
<td>-69</td>
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<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn Stover - Succinic Acid - BDO - PBT</td>
<td>-17%</td>
<td>-602</td>
<td>-268</td>
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<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn Stover - Succinic Acid - BDO</td>
<td>&lt;-30%</td>
<td>-1251</td>
<td>-406</td>
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<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn Stover - Selling Succinic Market</td>
<td>-6%</td>
<td>-151</td>
<td>-114</td>
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<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Wheat - Succinic Acid - BDO - PBT</td>
<td>-17%</td>
<td>-598</td>
<td>-268</td>
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<td>Succinic Acid - North Dakota Feed - Midwest Netback - Wheat - Selling Succinic Market</td>
<td>&lt;-30%</td>
<td>-1244</td>
<td>-404</td>
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<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Wheat - Selling Succinic Market</td>
<td>-6%</td>
<td>-146</td>
<td>-113</td>
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<td>PXE - North Dakota Feed - Midwest Netback - Corn - Selling PXE Market</td>
<td>5%</td>
<td>215</td>
<td>-48</td>
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<td>PXE - North Dakota Feed - Midwest Netback - Corn Stover - Selling PXE Market</td>
<td>9%</td>
<td>390</td>
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<td>PXE - North Dakota Feed - Midwest Netback - Wheat - Selling PXE Market</td>
<td>10%</td>
<td>420</td>
<td>-4</td>
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### Financial Model Results

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<thead>
<tr>
<th>Product Line</th>
<th>IRR, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV - Corn - ButOH to Chemicals</td>
<td>33%</td>
</tr>
<tr>
<td>CV - Wheat - ButOH to Chemicals</td>
<td>30%</td>
</tr>
<tr>
<td>CV - Corn Stover - ButOH to Chemicals</td>
<td>29%</td>
</tr>
<tr>
<td>GR - Corn - ButOH to Chemicals</td>
<td>26%</td>
</tr>
<tr>
<td>GR - Wheat - ButOH to Chemicals</td>
<td>21%</td>
</tr>
<tr>
<td>GR - Corn Stover - ButOH to Chemicals</td>
<td>20%</td>
</tr>
<tr>
<td>CV - Wheat - Butadiene</td>
<td>18%</td>
</tr>
<tr>
<td>CV - Corn Stover - Butadiene</td>
<td>17%</td>
</tr>
<tr>
<td>CV - Corn - Butadiene</td>
<td>16%</td>
</tr>
<tr>
<td>CV - Wheat - ButOH to Gasoline/Fuel</td>
<td>14%</td>
</tr>
<tr>
<td>CV - Corn Stover - ButOH to Gasoline/Fuel</td>
<td>14%</td>
</tr>
<tr>
<td>CV - Corn - ButOH to Gasoline/Fuel</td>
<td>13%</td>
</tr>
<tr>
<td>GR - Corn - Butadiene</td>
<td>10%</td>
</tr>
<tr>
<td>CV - Corn Stover - PBR</td>
<td>10%</td>
</tr>
<tr>
<td>CV - Wheat - PBR</td>
<td>10%</td>
</tr>
<tr>
<td>GR - Corn Stover - Butadiene</td>
<td>10%</td>
</tr>
<tr>
<td>GR - Wheat - Butadiene</td>
<td>10%</td>
</tr>
<tr>
<td>Wheat - PXE</td>
<td>10%</td>
</tr>
<tr>
<td>Corn Stover - PXE</td>
<td>9%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product Line</th>
<th>IRR, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV - Corn - PBR</td>
<td>8%</td>
</tr>
<tr>
<td>GR - Corn Stover - ButOH to Gasoline/Fuel</td>
<td>7%</td>
</tr>
<tr>
<td>GR - Wheat - ButOH to Gasoline/Fuel</td>
<td>6%</td>
</tr>
<tr>
<td>Ethanol - HDPE</td>
<td>6%</td>
</tr>
<tr>
<td>GR - Corn Stover - PBR</td>
<td>6%</td>
</tr>
<tr>
<td>Corn - PXE</td>
<td>5%</td>
</tr>
<tr>
<td>GR - Corn - ButOH to Gasoline/Fuel</td>
<td>5%</td>
</tr>
<tr>
<td>Ethanol - MEG</td>
<td>5%</td>
</tr>
<tr>
<td>GR - Wheat - PBR</td>
<td>5%</td>
</tr>
<tr>
<td>GR - Corn - PBR</td>
<td>5%</td>
</tr>
<tr>
<td>Corn - Succinic</td>
<td>-1%</td>
</tr>
<tr>
<td>Wheat - Succinic</td>
<td>-6%</td>
</tr>
<tr>
<td>Corn Stover - Succinic</td>
<td>-6%</td>
</tr>
<tr>
<td>Corn - PBT</td>
<td>-14%</td>
</tr>
<tr>
<td>Wheat - PBT</td>
<td>-17%</td>
</tr>
<tr>
<td>Corn Stover - PBT</td>
<td>-17%</td>
</tr>
<tr>
<td>Corn - BDO</td>
<td>&lt;-30%</td>
</tr>
<tr>
<td>Corn Stover - BDO</td>
<td>&lt;-30%</td>
</tr>
<tr>
<td>Wheat - BDO</td>
<td>&lt;-30%</td>
</tr>
</tbody>
</table>
Bio - Sensitivity Analysis on IRR – Cases

- Sensitivities were run on all the products with the following cases to test their effect on IRR:
  - Raw Material Price Sensitivity
    - Pricing sensitivities were only applied to the main raw materials (Corn, Corn Stover, Wheat)
    - All other raw materials were kept at their base prices
    - + 10% of base prices
    - -10% of base prices
  - Capital Cost Sensitivity
    - +10% of base capital cost
    - -10% of base capital cost
  - Debt/Equity Ratio Sensitivity (Base Debt/Equity ratio: 70/30)
    - 100% Equity
  - When running the sensitivities on the above cases, all other parameters were kept at base assumptions.
Bio-Chemical – Sensitivity Analysis - Lower

Bio Project Sensitivity Analysis - Lower

-6%  -5%  -4%  -3%  -2%  -1%  0%  1%  2%  3%  4%  5%  6%  7%

Deviation from Base Case IRR

CV - Wheat - ButOH - Butene-1 - Butadiene
CV - Corn Stover - ButOH - Butene-1 - Butadiene
CV - Corn - ButOH - Butene-1 - Butadiene
CV - Corn - ButOH - Butene-1 - Butadiene

Capital Costs, +10%
Capital Costs, -10%
Raw Material Price + 10%
Raw Material Price - 10%
### Bio-Chemical – Sensitivity Analysis - Higher/Lower Returns on Investment

#### Raw Material

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Base</th>
<th>+10%</th>
<th>-10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV - Corn - ButOH - Sell ButOH to Gasoline/Fuel</td>
<td>13%</td>
<td>9%</td>
<td>16%</td>
</tr>
<tr>
<td>CV - Corn Stover - ButOH - Sell ButOH to Gasoline/Fuel</td>
<td>14%</td>
<td>13%</td>
<td>15%</td>
</tr>
<tr>
<td>CV - Wheat - ButOH - Sell ButOH to Gasoline/Fuel</td>
<td>14%</td>
<td>13%</td>
<td>15%</td>
</tr>
</tbody>
</table>

#### Capital Cost

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Base</th>
<th>+10%</th>
<th>-10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR - Corn - ButOH - Butene-1 - Butadiene</td>
<td>10%</td>
<td>6%</td>
<td>16%</td>
</tr>
<tr>
<td>GR - Corn Stover - ButOH - Butene-1 - Butadiene</td>
<td>10%</td>
<td>5%</td>
<td>15%</td>
</tr>
<tr>
<td>GR - Wheat - ButOH - Butene-1 - Butadiene</td>
<td>10%</td>
<td>5%</td>
<td>16%</td>
</tr>
<tr>
<td>CV - Corn - ButOH - Sell ButOH to Gasoline/Fuel</td>
<td>13%</td>
<td>9%</td>
<td>17%</td>
</tr>
<tr>
<td>CV - Corn Stover - ButOH - Sell ButOH to Gasoline/Fuel</td>
<td>14%</td>
<td>10%</td>
<td>19%</td>
</tr>
<tr>
<td>CV - Corn Stover - ButOH - Butene-1 - Butadiene - PBR</td>
<td>10%</td>
<td>6%</td>
<td>15%</td>
</tr>
<tr>
<td>CV - Wheat - ButOH - Sell ButOH to Gasoline/Fuel</td>
<td>14%</td>
<td>9%</td>
<td>19%</td>
</tr>
<tr>
<td>CV - Wheat - ButOH - Butene-1 - Butadiene - PBR</td>
<td>10%</td>
<td>5%</td>
<td>16%</td>
</tr>
</tbody>
</table>
## Bio-Chemical – Sensitivity Analysis - Lower

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Raw Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>+10%</td>
</tr>
</tbody>
</table>

| CV - Corn - ButOH - Butene-1 - Butadiene | 16% | 13% | 18% |
| CV - Corn Stover - ButOH - Butene-1 - Butadiene | 16% | 11% | 21% |
| CV - Wheat - ButOH - Butene-1 - Butadiene | 17% | 12% | 23% |
| CV - Wheat Stover - ButOH - Butene-1 - Butadiene | 18% | 12% | 24% |
Sensitivity Analysis – Products Not Recommended

- Lower raw material prices makes n-butanol marginally profitable at 15-16% IRR, depending on the biomass, for the converted ethanol plant case. It should be noted that the grassroots butanol case (as will be discussed later) does not become profitable at lower raw material cost.
- Capital cost sensitivity has a significant effect on several product chains for the grassroots butanol and converted ethanol plant cases.
- Butadiene production becomes marginally profitable for all three biomass feedstocks for the grassroots butanol plant; the converted ethanol to butanol plant has profitable cases for corn or corn stover or wheat straw to n-butanol for fuel, and for stover and straw to PBR from butadiene as intermediate.
- The effect of capital cost on PBR production is especially impactful since the production chain involves two separate plants; butadiene from biomass and PBR from butadiene.
Sensitivity Analysis – Products Recommended But Changed

• Butadiene from corn in the converted ethanol plant drops to an IRR of 13% from an acceptable 16% when the raw material cost increases by 10%
• Similarly, butadiene from all three feedstocks in the converted ethanol plant becomes unprofitable at a 10% increase in capital cost
Bio-Chemical – Raw Material Price Sensitivity

Bio Project Sensitivity Analysis - Raw Material Costs

-3% -2% -1% 0% 1% 2% 3%

Deviation from Base Case IRR

CV - Corn - ButOH - Butene-1 - Butadiene

Raw Material Price + 10%

CV - Corn - Sell to Chemicals

Raw Material Price - 10%

GR - Corn - ButOH - Sell ButOH to Chemicals
Bio-Chemical – Capital Cost Sensitivity

Bio Project Sensitivity Analysis - Capital Costs

- Deviation from Base Case IRR
- Capital Costs, +10%
- Capital Costs, -10%
- CV - Corn - ButOH - Butene-1 - Butadiene
- CV - Corn - Sell to Chemicals
- GR - Corn - ButOH - Sell ButOH to Chemicals

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Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
Final Report, May 2014
Bio-Chemical – Debt Equity Sensitivity

Bio Project Sensitivity Analysis - 100% Equity

- Deviation from Base Case IRR

- CV - Corn - Sell to Chemicals
- CV - Corn - ButOH - Butene-1 - Butadiene
- GR - Corn - ButOH - Sell ButOH to Chemicals
### Bio-Chemical – Raw Material Price, Capital Cost, Debt Equity Sensitivity

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Raw Material Price</th>
<th>Capital Cost</th>
<th>Debt/Equity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GR - Corn - ButOH - Sell ButOH to Chemicals</td>
<td>26%</td>
<td>22%</td>
<td>26%</td>
</tr>
<tr>
<td>CV - Corn - Sell to Chemicals</td>
<td>33%</td>
<td>28%</td>
<td>33%</td>
</tr>
<tr>
<td>CV - Corn - ButOH - Butene-1 - Butadiene</td>
<td>16%</td>
<td>11%</td>
<td>16%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Base +10%</strong></th>
<th><strong>Raw Material Price</strong></th>
<th><strong>Base -10%</strong></th>
<th><strong>Raw Material Price</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>GR - Corn - ButOH - Sell ButOH to Chemicals</td>
<td>24%</td>
<td>32%</td>
<td>28%</td>
</tr>
<tr>
<td>CV - Corn - Sell to Chemicals</td>
<td>30%</td>
<td>38%</td>
<td>35%</td>
</tr>
<tr>
<td>CV - Corn - ButOH - Butene-1 - Butadiene</td>
<td>13%</td>
<td>21%</td>
<td>18%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Base (70/30 Debt/Equity)</strong></th>
<th><strong>100% Equity</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>GR - Corn - ButOH - Sell ButOH to Chemicals</td>
<td>26%</td>
</tr>
<tr>
<td>CV - Corn - Sell to Chemicals</td>
<td>33%</td>
</tr>
<tr>
<td>CV - Corn - ButOH - Butene-1 - Butadiene</td>
<td>16%</td>
</tr>
</tbody>
</table>
Sensitivity Analysis –Recommended Products

- Corn to butadiene in the converted plant has its IRR drop to 13% from 16% when raw materials (the corn) is increased in price by 10%
- Similarly, the same plant and feedstock combination sees its IRR drop to 11% in the 10% higher capex scenario
- Corn to butadiene in the converted plant had only a marginal 16% IRR in the base case, explaining the change to unprofitable in the high cost scenarios
- Additionally, the 100% equity case also has the plant go to unprofitable
Conclusions

✓ Feasible opportunities for the development of bio-based (corn, corn stover, wheat straw) chemical derivative look promising

✓ There should not be any particular environmental or permitting issues for the process technologies selected if Good Engineering Design and HAZOP principles are followed

✓ Growth in the United States demand will drive significant production capacity (supply) additions of commodity chemicals and polymers

✓ North Dakota has an “Advantaged geographic” location relative the U.S. Gulf Coast for supplying commodity polymers and end-users e.g., for the fabrication of automotive and consumer-related parts and components

✓ Commodity chemical intermediates (butadiene, n-butanol) can be easily transported (railed) to the U.S. Gulf Coast
Conclusions (continued)

✓ Economics from corn, corn stover or wheat straw are relatively similar based on IHS price forecasts, permitting biomass flexibility going forward

? Project development and implementation will have challenges that must be defined and managed carefully

? Investment (cost and resources) to construct the world-scale downstream chemical production plants and build their associated business, are very significant

? By nature of bio-chemical production and feedstock collection issues, bio-chemical plant capacities are generally small in comparison to conventional petrochemical world scale plants and suffer from lack of economy of scale and cost competitiveness, limiting the options available and minimizing any product delivery logistics advantages

? North Dakota has essentially no commodity chemical business and technical infrastructure (except ammonia and fertilizers); thus market entry into “new” commodity chemicals and polymers will have challenges on many levels, including availability of skilled and professional labor
Conclusions (continued)

- Project and business development “success” can yield a variety of sustainable benefits to North Dakota State (residents) and 3rd party sponsors and developers

- To be successful, North Dakota must aggressively solicit world-class private (chemical) industry participants/sponsors on a global basis who can bring proven project development expertise, financial strength, chemical process technology and access to customer marketing channels and customers

- Participants can be along the value chain e.g., from the basic bio-commodity chemical producer considering value-add downstream investment to end-user part fabricators interested back integration to low cost secure feedstock supply

- This Project will be forging new ground in North Dakota, thus project development and implementation must be done according to a well-defined and very robust roadmap, with an iterative loop for lessons learned along the way.
Recommendations—Align Balanced Value Proposition(s) with Stakeholder/Investor(s) Strategic Goals

- Start “small” by developing a full business case for a medium return, low risk (mature) technology and single product line to test the market (and financial) interest
- Identify/define the “appetite envelope” and concerns “road bumps” of the various North Dakota stakeholders and sponsors
- In parallel but slightly sequential to a first (conservative) option, develop a range of investor solicitation packages along feedstock lines (ethane, propane and butane) with technology and value chain complexity scenarios

Immediately solicit a broad candidate list for participation across all the scenarios
Study Next Steps

• Deliverables
  • Report to Legislative Management – Energy Development and Transmission Committee - due July 2014; IHS will present its May 2014 Final Report in a face-to-face meeting or teleconference
  • Report to appropriate committees at the beginning of the 2015 Legislative Assembly – due January 2015
Post-Study Next Steps

• Recommended Follow-up Work
  • Discussion and recommendation for state initiatives that might impact investment and effect on cash flow returns
  • Investigation of potential investors
  • Effect of investment on the state
    • number of jobs created
    • Businesses created to support the plant(s); downstream value chain
    • Supporting, not directly related, social infrastructure business creation (e.g., housing construction, restaurants, entertainment, etc.)
Overview of the North Dakota Ethanol Industry
Basis and Assumptions for Alternative (to Corn) Biomass Analysis

- The fermentable sugars in biomass are the cellulose (glucans, C6 sugars) and hemicellulose (xylans, C5 sugars) portions, extracted from the biomass through a high pressure high temperature hydrolysis pretreatment.

- 9 cents per pound (dry) is the price that IHS believes the fermentable sugar-containing stream must be going into the fermenter (after a pretreatment step) to achieve feasible economics for the production of derivative chemicals (e.g. netback fermentable sugar price).

- Biomass netback pricing is based on a price for fermentable sugars of 9 cents per pound, after a pretreatment step, which further reduces the viable price of the raw biomass source as shown in a proxy bio butadiene production facility.

Sugar portion in biomass: 4.5 c/lb – Pretreatment Cost
Fermentable sugar extracted from biomass: 9 c/lb

- Pretreatment to Fermentable Sugars
- Fermentation to N-Butanol
- Dehydrogenation to 1-Butene
- Dehydrogenation to 1,3-Butadiene

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota Final Report, May 2014
Basis and Assumptions for Alternative (to Corn) Biomass Analysis (continued)

- The following slide presents bio-feedstock requirements and price netbacks for wheat, sugar beet and switchgrass, each as a possible bio-feedstock alternative to corn.
- Biomass composition is shown on a dry basis.
- The feedstock requirement calculations were based on a 100 KMTA bio-butadiene plant, back-integrated with the previous two production steps of butene-1 via n-butanol dehydrogenation, and n-butanol via biomass fermentation as previously shown.
- Based on those production yields, the n-butanol fermentation plant has an annual capacity of 158 KMTA, or 51 million gallons.
- Biomass crop market pricing and harvest yields are based on a 5 year average of the most recent market metrics in North Dakota, according to the USDA.
- Sugar beets have a high starch content, which can be extracted with a pretreatment step that is less intensive and less costly than the hydrolysis for other biomass sources. Sugar beet netback pricing is based on a dry sugar price of 9 cents per pound of fermentable sugar, or 8 c/lb before a less costly pretreatment of about 1 cent per dry pound sugar.
- For wheat and switchgrass, we assume a more costly pretreatment process of about 4.5 cents per dry pound of fermentable sugar, driving the viable price of fermentable sugars down to 4.5 c/lb.
## Feedstock Requirements and Estimated Required Netback Price

<table>
<thead>
<tr>
<th></th>
<th>Sugar Beets</th>
<th>Wheat</th>
<th>Switchgrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Estimated Required Netback Price ($/MT Dry)</td>
<td>103.62</td>
<td>50.99</td>
<td>57.09</td>
</tr>
<tr>
<td>Biomass Estimated Required Netback Price ($/MT Wet)</td>
<td>25.90</td>
<td>43.34</td>
<td>50.24</td>
</tr>
<tr>
<td>Biomass Estimated Required Netback Price (c/lb Wet)</td>
<td>1.2</td>
<td>2.0</td>
<td>2.3</td>
</tr>
<tr>
<td>ND Market Price ($/MT Wet)</td>
<td>61.72</td>
<td>253.53</td>
<td>76.81</td>
</tr>
<tr>
<td>ND Market Price (c/lb Wet)</td>
<td>2.8</td>
<td>11.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Annual Biomass Req. (MTA wet)</td>
<td>3,106,512</td>
<td>1,033,639</td>
<td>890,408</td>
</tr>
<tr>
<td>Annual Biomass Req. (lbs. wet)</td>
<td>6,848,678,328</td>
<td>2,278,781,791</td>
<td>1,963,011,335</td>
</tr>
<tr>
<td>Biomass Req. (wet lb/gal butanol)</td>
<td>133</td>
<td>44</td>
<td>38</td>
</tr>
<tr>
<td>Yield (lb/acre)</td>
<td>44,991</td>
<td>2,754</td>
<td>6,535</td>
</tr>
<tr>
<td>Total Land Required (acres)</td>
<td>152,224</td>
<td>827,444</td>
<td>300,407</td>
</tr>
<tr>
<td>Starch (dry)</td>
<td>15%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Hemicellulose (C5 Fermentable Sugars, dry)</td>
<td>21%</td>
<td>25%</td>
<td>29%</td>
</tr>
<tr>
<td>Cellulose (C6 Fermentable Sugars, dry)</td>
<td>31%</td>
<td>34%</td>
<td>37%</td>
</tr>
<tr>
<td>Lignin (dry)</td>
<td>0%</td>
<td>15%</td>
<td>19%</td>
</tr>
<tr>
<td>Moisture</td>
<td>75%</td>
<td>15%</td>
<td>12%</td>
</tr>
<tr>
<td>MT Biomass (wet) / MT BD</td>
<td>31.07</td>
<td>10.34</td>
<td>8.90</td>
</tr>
<tr>
<td>MT Sugar (C5+6) / MT BD</td>
<td>4.56</td>
<td>4.52</td>
<td>4.51</td>
</tr>
<tr>
<td>MT n-Butanol / MT BD</td>
<td>1.58</td>
<td>1.58</td>
<td>1.58</td>
</tr>
<tr>
<td>MT 1-Butene / MT BD</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>MT 1,3-Butadiene</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**NOT ECONOMICAL for the FARMER**

**NOT ECONOMICAL for the BIO PLANT**
Netback Pricing vs. Market Prices

• Based on this cost analysis, all three alternative biomass types are expected not to be viable alternatives to corn and corn-based biomass as biochemical feedstock.

![Graph showing cost analysis for different biomass types](image-url)
Sugar Beets

- The sugar beet requirement for a 100 KMTA bio-butadiene (51 MM gal. n-butanol) production plant would be about 52% of North Dakota’s current sugar beet production, or 17% of the combined production by North Dakota and Minnesota for the 2012/2013 harvest year.

- A significant issue with using sugar beet as a bio-feedstock is the high moisture content of the biomass – sugar beet pulp is 75% water. This significantly affects the collection and transportation logistics as well as the price of sugar beets, as sugar content on a wet basis is only about 17%.

- The market price of beets is over twice the calculated biomass crop netback price, based on a 9 c/lb price for dry sugar going into the fermenter.

**Sugar Beet Requirement vs. Supply**
Wheat Straw

- Due to the high demand of wheat for other end uses, namely for food, the price of wheat is much higher than the price of other bio-feedstock alternatives.
- The price of wheat is almost 6 times higher than the required crop netback price, assuming a 9 c/lb dry sugar equivalent price and including 4.5 c/lb hydrolysis cost.
- High wheat demand for other end uses in the pre-existing market, primarily in the food chain, creates a complicated market environment for high-volume wheat procurement for biofuels & chemicals.
- Relative to corn, switchgrass and in particular sugar beets, wheat has a much lower crop yield per area of land planted.
- Because of the low crop density of farmed wheat, a lower unit price of wheat is not feasible for the farmer as a bio fuel & chemical feedstock, and the higher market price of wheat is believed not to feasible for economically viable production of bio-chemicals.
Switchgrass

- Switchgrass market price (a cost plus margin proxy) is also above the price netback for the crop based on an economically viable sugar feed price for biochemical production.
- Switchgrass market price used is a proxy estimated from data from Iowa. The basis of this estimate is production cost (excluding the cost of collection and transportation logistics) plus a 20% margin.
- The crop density of switchgrass is over 20% lower than that of corn, contributing to making switchgrass a less attractive logistical option.
- With no alternative food value, the overall market for on-purpose switchgrass is expected to be very limited and would need to be an on-purpose crop with questionable economics incentives for the farmer.
Products Analysis

- Butanol
- Butadiene
- Monoethylene Glycol
- Polyethylene by Resin Type
- para-Xylene
- Succinic Acid
- Polybutylene Terephthalate
- Alternative Chemicals and Bio-plastics

Content of this Section Removed Due to IHS Confidential Content
Domestic Customer Analysis

- **Target Industries**
- **Rust Belt/Midwest US Product Destination**
- **Derivatives**
- **2014 State Product Revenue**
Target Industries
### Product Landscape End-Use Applications

<table>
<thead>
<tr>
<th>END USE</th>
<th>Automotive</th>
<th>Computers/Electronics</th>
<th>Construction</th>
<th>Textiles</th>
<th>Packaging/Consumables</th>
<th>Industrial/Intermediate</th>
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The Products With Acceptable IRR are Commodity Intermediates

• For any of the bio-feedstocks, only chemical n-butanol and butadiene show sufficiently high return on investment to warrant consideration
• Both of these are commodity intermediate chemicals with greatest markets in the USGC
• Due to their nature as commodity chemicals, the companies producing them can perform with minimal SG&A expenses and staffing:
  • There is no product differentiation; one grade
  • There are bulk purchasers
• Market strategy is straightforward
  • Low cost based strategy for these two bulk commodities
  • Regional market penetration through price, favorable logistics
Commodity Chemical Customer Buying Requirements and Supplier Key Success Factors

- Butanol and butadiene follow typical commodity rules

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<th>Customer Buying Requirements - Dimension</th>
<th>Attributes</th>
<th>Supplier Key Success Factors</th>
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<td>Product information</td>
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<td>Basic product support, technical specifications, MSDS</td>
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<td>Technical support</td>
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<td>Product testing capabilities, basic trouble shooting capabilities</td>
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<td>Supply availability/reliability</td>
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<td>Product performance, on time delivery</td>
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<td>Price</td>
<td>Very High</td>
<td>Advantaged ethane access, commodity production and supply chain asset competitiveness, optimized overhead, competitive delivered logistics costs</td>
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<td>Relationships throughout the customer organization, procurement, technical, commercial</td>
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<td>Credit terms, financial soundness</td>
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<td>Local Inventory</td>
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<td>Supply chain response, speed, inventory proximity</td>
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Commodity Chemical Customer Buying Requirements and Supplier Key Success Factors

- Key Success Factors

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## Commodity Chemical Customer Buying Requirements and Supplier Key Success Factors

- Customer Buying Requirements

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### United States n-Butanol Producers

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Source: IHS Directory of Chemical Producers
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### United States Butadiene Producers

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<tr>
<th>PRODUCT</th>
<th>COMPANY</th>
<th>PLANT CITY</th>
<th>PLANT STATE</th>
<th>CAPACITY</th>
<th>CAPACITY UNITS</th>
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Source: IHS Directory of Chemical Producers

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## United States Butadiene Capacity Integration

### US Butadiene Capacity Integration - 2013

(-000- Metric Tons)

**Capacity to Consume Butadiene**

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>LOCATION</th>
<th>Butadiene Capacity</th>
<th>ABS Resins</th>
<th>Chloroprene</th>
<th>Nitrile Rubber</th>
<th>Poly-Butadiene</th>
<th>S.B. Latex</th>
<th>Emulsion SBR</th>
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## United States Butadiene Capacity Integration (Continued)

### US Butadiene Capacity Integration - 2013

(-000- Metric Tons)

#### Capacity to Consume Butadiene

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>LOCATION</th>
<th>Butadiene Capacity</th>
<th>ABS Resins</th>
<th>Chloroprene</th>
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<td>TOTAL - United States</td>
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© 2014 IHS
# United States Polybutadiene Rubber Producers

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<th>COMPANY</th>
<th>PLANT CITY</th>
<th>PLANT STATE</th>
<th>CAPACITY</th>
<th>CAPACITY UNITS</th>
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<td>American Synthetic Rubber Company, LLC</td>
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Source: IHS Directory of Chemical Producers

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Rust Belt/Midwest US Product Destination
Plastics and Elastomers (Rubber) Value Chain Can be Complex

Resin Suppliers:
- Work directly with fabricators, OEMs and distributors when OEMs and/or volumes are large. Will also work with large compounders.
- Diligent Marketing/R&D/Application development to understand product roadmaps of OEMs; specifications and new product developments
- Wide selection of materials – custom materials to meet OEM specifications
- Some customer resin tailoring for large buyers

Distributors:
- Typically low volume material flows.
- Handles small/medium sized resin buyers.
- Big distributors also export large volumes
- Provide resin packaging requirements
- Aggregate material from multiple resin suppliers
- Add value through JIT delivery, smaller order quantities, multiple resins available

Compounders work to tailor material properties.
- Create custom-formulated engineered plastic compounds, plastic concentrates and additives for Flame Retardant Resin, Toughened Resin, Reinforced Resin and Elastomeric Compounds.
- Try to focus on select markets and applications, offer broad range of capabilities
- Add value through service, customized products, and some also have distribution arms

Molders
- Typically independent players; yet often partnered with OEM or contract manufacturers (CM). Deliver product to OEM specifications.
- Develop manufacturing IP
- Try to be close to OEMs and/or end-user seeding
- Very competitive, price sensitive

OEMs design products and specify component needs, including writing the material specifications. Typically have sourcing departments for plastics - understand dynamics of markets
- Often negotiate directly with resin supplier or compounders
- Treat plastics as a commodity - drive costs out of the system
- Might do in-house molding

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Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
Final Report, May 2014
The Rust Belt is a Likely Destination for Products Produced in ND

- The Rust Belt is the informal description for a postindustrial region straddling the Northeastern and the East North Central States, referring to economic decline, population loss and urban decay due to the shrinking of its once powerful industrial sector.
- The Rust Belt begins in central New York and predominantly includes Pennsylvania, West Virginia, Ohio, Indiana, and the Lower Peninsula of Michigan, ending in northern Illinois and eastern Wisconsin and northern Kentucky.
- This geographical sector also includes the center of the US automotive industry, as indicated in the map:
  - Michigan
  - Ohio
  - Indiana
Several of the First and Second Derivative Products in Our Evaluation Are Used in the Automotive Industry - PE

- High Molecular Weight HDPE is typically used in blow molded coextruded fuel tanks
- HDPE is also used for motor oil containers and portable gas cans
- Under-hood applications include reservoirs and wire insulation
- Other auto/truck applications:
  - Battery boxes
  - Air ducts
  - Splash shields
  - Air duct/channels which are part of the lower part of the dashboard.
Several of the First and Second Derivative Products in Our Evaluation Are Used in the Automotive Industry - PBT

- PBT can be found in both automotive exterior and interior parts and most particularly, in auto electrical system components.
- Typical examples include windshield wiper covers, mirror housings, cowl vents, handles, fans, fuel system components, connectors, sensor housings, fuse boxes, actuator cases, power relays, switches, motor components, and ignition system components.
- PBT alloys are most commonly used in body exterior and safety applications including airbag covers and containers, brake and fuel line clips, cable liners, and power distribution boxes.
Several of the First and Second Derivative Products in Our Evaluation Are Used in the Automotive Industry – PET, polyester

- PET is used in interior and exterior auto applications such as door handle systems, multifunction switches, mirrors, door trim, window lift brackets, roof racks, wiper tubs and numerous automotive electrical/electronic components
- Filled or reinforced PET is used in automotive molded electrical connectors, switches, and relays
- Polyester nonwovens are used in automotive headliners and hood and trunk liners
- High-tenacity polyester filament yarn or staple has a particularly high tensile strength and reduced elongation. It is used for industrial applications that require high strength and low creep. End uses include tire cord, automotive seat belts, hoses, belts, rope and cordage and substrate fabrics.
- Transportation upholstery end uses for polyester staple nonwoven webs include paneling, hood linings, trunk liners and molded trim in automotive and other transport vehicles; marine fabrics; and coverings
Several of the First and Second Derivative Products in Our Evaluation Are Used in the Automotive Industry - PBR

- Polybutadiene has a high resistance to wear and is used especially in the manufacture of tires, which consumes about 70% of the production.
- Styrene-Butadiene Rubber (SBR) is a copolymer of butadiene and styrene. It has a wide range of applications in the automotive industry due to its high durability, resistance to abrasion, oils and oxidation. SBR applications vary from tires to vibration isolators and gaskets.
- SBR is also used in tuned dampers which aim to reduce and control the angular vibrations of crankshafts, acting as an isolator and energy absorber between the tune damper's hub and the inertia ring.
Several of the First and Second Derivative Products in Our Evaluation Are Used in the Automotive Industry - PIB

- Polyisobutylene added in small amounts to the lubricating oils used in machining results in a significant reduction in the generation of oil mist and thus reduces the operator's inhalation of oil mist.
- As a fuel additive, polyisobutylene has detergent properties. When added to diesel fuel, it resists fouling of fuel injectors, leading to reduced hydrocarbon and particulate emissions.
- Butyl rubber, the copolymer of isobutylene with isoprene, provides excellent inflation pressure retention for bicycle, truck, agricultural, industrial and specialty tires.
- Butyl rubber’s barrier properties, high damping, resistance to ozone and heat aging makes it ideal for automotive vibration control, hoses and gaskets.
For HDPE, MEG and PX, the proposed plant represents a reasonably small percent of total capacity in the US in 2020 and of the required capacity addition (announced and anticipated) required to satisfy US supply/demand dynamics.

IHS forecasts no new PBR or BDO plants and, hence, the proposed plants are not viewed as necessary to satisfy production need by 2020; however, the proposed PBR plant represents only 10% of the 2020 anticipated total US capacity and the proposed BDO plant only 6.9%, such that a competitive plant could displace current capacity.
For 1,3-butadiene (BD), polybutylene terephthalate (PBT) and polyisobutylene, IHS forecasts little or no capacity addition.

For BD, this is largely due to the fact that the BD capacity is conventionally provided by steam cracker coproduct production from heavier liquid feedstocks, which are in decline in the US as ethane and other light feeds displace the heavier feedstocks and the cost of on-purpose BD production has been uncompetitive.

PBT capacity is not expected to grow and the proposed plant capacity (30%) represents a large percentage of US capacity and, as such, might upset the US supply dynamic.

For BD, the proposed plant represents only a very small percentage of the total US capacity in 2020 (3%) and will not cause a disruption in the market.
Derivatives

- *PBR (opportunity with incentives)*
There is a Significant Market Within Easy Reach of a North Dakota-based Project

More than half of the consumption in US is within reach of a North Dakota Plant, while most production is centered in the U.S. Gulf Coast.
# United States/Canada Tire Manufacturer Plants

<table>
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<th>Company</th>
<th>Plant City</th>
<th>Plant State</th>
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2014 State Product Revenue
State Breakdown

- **Rust Belt**
  - New York
  - Pennsylvania
  - West Virginia
  - Ohio
  - Illinois
  - Indiana
  - Michigan
  - Wisconsin

- **USGC**
  - Texas
  - Louisiana

- **Automotive States**
  - Ohio
  - Michigan
  - Indiana

- **Other States**
Global butadiene demand is dominated by the production of synthetic rubber. Production of the two major commodity types of synthetic rubber, namely polybutadiene rubber (PBR) and styrene butadiene rubber (eSBR and sSBR), presently accounts for more than 50% of global butadiene demand.

The major end use of polybutadiene rubber is for production of tires and tire products.

Tires and tire products accounts for 71% of total global consumption. Polybutadiene is highly resistant to heat buildup, abrasion resistance, and wear resistance, but has poor processing, oil resistance, and wet traction.

In the sidewall of truck tires, the use of PBR helps to improve fatigue-to-failure life improving blowout failures under extreme service conditions. Usually, polybutadiene is combined with SBR, natural rubber, or chloroprene in the final product. PBR is usually combined with SBR in the manufacture of tire treads.
Tire Manufacturing Revenue Projection, 2014

- Tires and tire products have always been the largest end-use category for natural rubber in the United States. In 2010, tires and tire products accounted for about 741 thousand metric tons of natural rubber, or 80% of total U.S. natural rubber consumption.
- Until the advent of World War II, all of the rubber used in tires was natural rubber. Since that time, most tires have used blends of natural and synthetic rubber, depending on the type of tire and the cost performance balance that is desired.
- There are three routes to which a U.S. company can obtain natural rubber—purchasing the rubber directly from a dealer, purchasing the material from producers in the Far East (or other producing regions) through its own buying offices, or importing natural rubber produced by the company’s own plantations (tire companies).
- Some natural rubber dealers have their own plantations, purchasing offices in the Far East (or other producing regions) and/or special arrangements with producers in producing regions. In addition to selling natural rubber to consumers, dealers also buy and sell natural rubber among themselves.
In the United States, polybutadiene rubber is consumed mainly in tires and tire products at about 70-75% of total consumption in recent years. BR has another important outlet for impact modification of plastics/resins, particularly high-impact polystyrene and ABS.

U.S. consumption of BR is projected to increase at an average annual rate of 3% through 2018. If and when mandated tire-labeling in the United States comes into existence, the BR consumption growth rate is expected to rise by 1-2%.

Tire components containing BR include sidewalls, body plies, tread, chafer and bead compounds. These components make use of the high resilience, abrasion resistance and good flex fatigue characteristics of polybutadiene.

BR in tires helps reduce rolling resistance (especially high-cis content BR, for example, Nd-BR), which thus brings on fuel efficiency, an important aspect in today’s society.

Polybutadiene contributes to low-temperature flexibility in tires and increases their resistance to aging, resulting in longer service life.
Process Technology Assessment
- Proposed Product Configurations for North Dakota
- Ethanol Chain – Ethylene
- High Density Polyethylene
- Ethylene Oxide & Monoethylene Glycol
- n-Butanol
- Butylenes
- Butadiene
- Polybutadiene Rubber
- Para-Xylene
- Succinic Acid
- PBT Resin
Proposed Product Configurations for North Dakota

Biomass Feedstock (corn, corn stover, wheat straw)

Existing Plant

- Ethanol → Dehydrogenation → Ethylene → HDPE Resin

New or Converted Plant

- n-Butanol → Dehydrogenation → Butadiene

New Plant

- Paraxylene → Hydrogenation → 1,3-Butanediol → PBT Resin
- Succinic Acid → Hydrogenation → MEG

Shipping Logistics & Cost

- Butylenes → Butadiene
- Paraxylene → MEG
- PB Rubber
- Merchant
- Fabrication
- Merchant
- Merchant

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
Final Report, May 2014
Ethanol Chain – Ethylene
Catalytic dehydration of ethanol yields ethylene.

\[
\text{C}_2\text{H}_5\text{OH} \rightarrow \text{CH}_2=\text{CH}_2 + \text{H}_2\text{O}
\]

Catalyst (typically alumina or silica-alumina) is placed inside the tubes of multi-tubular fixed-bed reactors. Because of the rate of coke deposition, the catalyst must be regenerated frequently. Large production capacities require the use of several multi-tubular reactors in parallel, and thus become very capital intensive.
Ethanol Dehydration to Ethylene – Technology Overview

• Petrobras, a pioneer in ethanol dehydration, developed a process using an alumina catalyst and fixed-bed reactors with adiabatic operation.

• In recent years, fluidized-bed reactor systems have been developed to pilot-plant scale. These processes have better temperature control and a higher steady-state degree of catalyst activity than the fixed-bed system, resulting in improved yields (as high as 99% of theoretical).

• ABB Lummus developed a fluidized-bed process to dehydrate ethanol in the late 1970s. The fluidized-bed system offers excellent temperature control in the reactor, thereby minimizing by-product formation.

• No commercial plant using the technology has been built, in part because industry interest declined after the oil crises of the 1970s.

• The dehydration process generates considerable quantities of by-product water compared to traditional ethane steam cracking, resulting in a theoretical yield of 60% ethylene vs. 95% for the ethane route—a distinct economic disadvantage.
Ethanol to Ethylene – Technology Overview

Ethylene from Ethanol by Adiabatic Fixed-Bed Catalytic Dehydration

- Ethanol → Catalytic Dehydration
  → Purification
  → Ethylene
  → Wastewater
Ethylene Oxide/Monoethylene Glycol (EO/MEG) – Technology Providers & Licensors

• EO/MEG technology is commercially proven and can be licensed from several companies:
  • Scientific Design
  • Chematur
  • BP
  • Dow
  • Braskem
High Density Polyethylene
High Density Polyethylene (HDPE) – Technology Overview

- HDPE homopolymer is made in the low pressure (solution, slurry and gas phase) processes by polymerizing ethylene, and HDPE copolymer is made by polymerizing an alpha olefin co-monomer (butene-1, hexene-1, or octene-1) with ethylene.

- The amount of co-monomer used determines the branching in the polymer chains, thus varying the density.

- As the density or crystallinity decreases in the homopolymer or copolymer, an improvement in impact resistance and flexibility occurs; but stiffness, chemical resistance, temperature range and resistance to water vapor permeation are diminished.

- Most HDPEs produced are copolymers.
High Density Polyethylene (HDPE) – Technology Overview

![Diagram of High Density Polyethylene Production Process]

High Density Polyethylene Production Process

- **Unreacted monomer**
- **Ethylene Comonomer**
- **Solvent**
- **Catalyst**

Diagram details:
- **Purification**
- **Loop Reactor**
- **Flash**
- **Dryer**

**HDPE**
High Density Polyethylene (HDPE) – Recommendation

- HDPE technology is commercially proven and can be licensed from several companies.
- Solution-phase processes:
  - NOVA Sclairtech
  - Dow
  - DSM
  - SABIC SABTEC
- Bulk loop reactors:
  - LyondellBasell Spherilene
Ethylene Oxide & Monoethylene Glycol
Ethylene Oxide/Monoethylene Glycol (EO/MEG) – Technology Overview

• Compressed oxygen, ethylene and recycled gas are mixed and fed to a multi-tubular catalytic reactor. Boiling water in the shell side of the reactor controls the reaction temperature.

• From the reactor, the effluent gases, which contain EO, are cooled and compressed. The cooling is accomplished by cross exchanging the reactor effluent with recycled gases.

• The cooled reactor effluent then passes to a scrubber where EO is absorbed as a dilute aqueous solution. Recycle gas is compressed and returned to the reactor, with a portion drawn off and diverted through a carbon dioxide removal system.

• Ethylene oxide is steam-stripped from the ethylene oxide-rich absorber bottoms and fed directly to an adjoining ethylene glycols unit or purified in a fractionation train for merchant sale as EO or consumption into other derivatives. Purification of EO is required before the product may be sold in the merchant market or used in the synthesis of other EO derivatives.
In the ethylene glycol production process, ethylene oxide and make-up process water are mixed with recycled water in the feed tank and pumped through heat exchange to the hydration reactor.

In the glycols reactor, there is typically no catalyst, but sufficient residence time is provided to react all of the ethylene oxide with excess water. A mixture of mono-, di- (DEG), tri- (TEG) and higher substituted glycols is produced and sent on to purification.

The water-glycol mixture from the reactor is fed to the first stage of a multiple stage evaporator.

The crude glycols solution from the final evaporation stage is then stripped of remaining water and light ends. The water-free glycols mixture is then fractionated in a series of vacuum distillation towers to produce purified monoethylene glycol and co-products, diethylene glycol (DEG) and triethylene glycol (TEG).
Ethylene Oxide/Monoethylene Glycol (EO/MEG) – Technology Overview

EO/EG Production Process

Ethylene Oxygen → Oxidation → Absorber → Stripper → Ethylene Oxide

MEG → Distillation

DEG & TEG → Multi-stage Evaporator → Hydration
Ethylene Oxide/Monoethylene Glycol (EO/MEG) – Technology Overview

• EO/MEG technology is commercially proven and can be licensed from several companies:
  • Scientific Design
  • Dow
  • Shell Global Solutions
n-Butanol
n-Butanol can be produced via ABE fermentation using a GMO or non-GMO *Clostridia* bacteria. The following equation shows the butanol from glucose fermentation reaction:

\[
\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow \text{C}_4\text{H}_9\text{OH} + 2\text{CO}_2 + \text{H}_2\text{O}
\]

Glucose \quad \text{Butanol} \quad \text{Carbon Dioxide} \quad \text{Water}

- In this fermentation, acetone, butanol and ethanol are produced in the ratios 3:6:1 (0.65 gallon acetone, 1.3 gallon butanol and 0.22 gallon ethanol per bushel corn).

- Technology developers have made process improvements to optimize production by using genetic modification or strain development to minimize by-product formation, using more productive fermentation equipment and systems, and introducing novel recovery technologies.
n-Butanol via Fermentation – Technology Overview

• In addition to the C6 (glucose/fructose) sugars found in cane sugar, corn starch and cellulosic biomass that are utilized by yeast in ethanol fermentation, butanol-producing bacteria can also consume the C5 (xylose) sugars found in the hemicellulose portion of biomass.

• A major barrier to the commercialization of biobutanol has been severe product inhibition of fermentation organisms resulting in low product concentration in fermentation broth. In the integrated fed-batch fermentation and product recovery system, solvent productivities are improved significantly.

• One of the challenges associated with the commercial production of butanol by fermentation is the large potential energy consumption during separation. The separation is complicated not only due to the presence of three ABE solvents, but also because two of the solvents, butanol and ethanol, form azeotropes with water.
n-Butanol via Fermentation – Technology Overview

Carbohydrate Feedstock

Slurry & Sterilization → Fermentation → Recovery & Separation

n-Butanol
Acetone
Ethanol
n-Butanol via Fermentation – Technology Overview

- Alternative routes to bio n-butanol include:
  - Catalytic condensation of ethanol (Guerbet reaction). Abengoa Bioenergy is developing this technology for bio n-butanol production.
  - Catalytic hydrogenation of bio-based butyric acid. Butyric acid, in turn, is formed by the fermentation of carbohydrates. This technology was developed by ButylFuel LLC, which merged with Green Biologics in 2012.
  - The conventional synthesis of n-butanol via the oxo process involves the reaction of propylene with syngas (both from fossil fuels) over a cobalt or rhodium catalyst.
  - The resulting product, n-butyraldehyde, is hydrogenated to form n-butanol.
n-Butanol via Fermentation – Technology Providers & Status

• n-Butanol technology developers include:

• Cathay Industrial Biotech
  • Toll production in China
  • 100 KTMA ABE in Jilin Provence, China

• Cobalt
  • Demo plant under construction in Brazil
  • Commercial plant planned for Brazil, 2016, JDA with Rhodia
  • Commercial plant planned for Brazil, 2016, JDA with Asian strategic investor, for butadiene market

• Green Biologics
  • 300 MTA n-butanol, China, 2012, JV with Guangxi Jinyuan Biochemical and Lianyungang Union
  • 150 KMTA n-butanol (3 units, 50 KMTA each), China, 2013/14, JV with Guangxi Jinyuan Biochemical and Lianyungang Union
Butylenes
Butene via n-Butanol Dehydration – Technology Overview

• Butene can be produced via n-butanol dehydration. The following equation shows the dehydration reaction:

\[ \text{C}_4\text{H}_9\text{OH} \rightarrow \text{C}_4\text{H}_8 + \text{H}_2\text{O} \]

n-Butanol \hspace{2cm} \text{Butene} \hspace{2cm} \text{Water}

• Cobalt has a CRADA agreement with the U.S. Navy to develop and optimize a catalytic dehydration process to convert the n-butanol fermentation product into 1-butene.

• They claim the catalyst delivers high conversion and yields.

• This process, selective to 1-butene, creates a better feedstock input for butadiene conversion down stream.
• Butene dehydrogenation to butadiene is commercially proven and can be licensed:
  • Lummus Technology’s Catadiene® process (non-oxidative dehydrogenation)
  • Phillips Oxo-D process (oxidative dehydrogenation)
• On-purpose butadiene production currently only accounts for a small percentage of the total butadiene production in the world. About 95% of butadiene is currently produced as a by-product of ethylene steam cracking, using naphtha or gas oil feedstocks.
• However, ethylene crackers are switching to lighter feedstocks (butane and lighter) due to high oil prices and low natural gas prices which reduces the amount of butadiene available from ethylene cracking and presents a foreseeable market demand for on-purpose butadiene production
Mixed Butylenes Dehydrogenation to Butadiene – Technology Overview

Butadiene via n-Butene Dehydrogenation

- Steam
- Air
- n-Butenes
- Water

Reactor

Quench Tower

Waste Heat Boiler

Scrubber

Absorber

Degasser

Stripper

Compressor

Water

Vent

Crude Butadiene

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
Final Report, May 2014
Butadiene
Non-oxidative dehydrogenation to butadiene is a series of endothermic equilibrium reactions of n-butene to butadiene. This process produces a mixture of butenes and butadiene along with by-product fuel gas and coke, which rapidly fouls the catalyst.

The following equation shows the butene dehydrogenation reaction:

\[
\text{CH}_2=\text{CH}_1-\text{CH}_2-\text{CH}_3 \quad \rightarrow \quad \text{CH}_2=\text{CH}-\text{CH}=\text{CH}_2 + \text{H}_2
\]

Butene-1       Butadiene         Hydrogen

The commercialization of butadiene production from mixed butylenes and n-butanes began in the 1940s with the construction of dehydrogenation plants using the Houdry process.

An improved Houdry butadiene process is now licensed by Lummus as the Catadiene® process.
Several processes and many catalyst systems have been developed for the oxydehydrogenation of either n-butane or n-butene feedstocks. N-butenes are much more reactive, and require less severe operating conditions than n-butane to produce an equivalent amount of product.

In general, in an oxydehydrogenation process, a mixture of n-butene, air and steam is passed over a catalyst bed generally at low pressure and 500-600 degrees C. Excess heat from the exothermic reaction is used to generate steam.

Conversion is favored by high temperature and low pressure. Reaction yields and selectivities range from 70-90%, making it unnecessary to recover and recycle feedstock. Yield losses are generally as CO₂.

Alumina-chromia catalysts are best suited for butene dehydrogenation under vacuum conditions. Iron oxide-magnesium oxide catalyst promoted with copper oxide and potassium oxide is highly efficient for steam-diluted processes.
Advantages of the Lummus Catadiene® process include:

- High tolerance to feedstock impurities
- Inexpensive catalyst
- No catalyst losses
- Demonstrated catalyst life
- No significant fouling problems
- Minimum start-up time after shut-down
- Low sulfur injection (to obtain 15 ppmw based on reactor feed if feed does not contain this level)
- Can be designed for a wide variety of feedstocks
The Oxo-D process is by definition a oxidative catalytic dehydrogenation-based process.

The following equation shows the butane oxo-dehydrogenation reaction:

\[
\begin{align*}
\text{CH}_2=\text{CH}_1\text{-CH}_2\text{-CH}_3 & + \frac{1}{2}\text{O}_2 & \rightarrow & \text{CH}_2=\text{CH}\text{-CH=CH}_2 & + \text{H}_2\text{O} \\
\text{Butene-1} & & \text{Oxygen} & \text{Butadiene} & \text{Water}
\end{align*}
\]

Accordingly, the conversion and the selectivity of the dehydrogenation of n-butenes to butadiene are significantly improved by removing the hydrogen from the equilibrium. The addition of oxygen causes the oxidation of hydrogen to water, thus accomplishing that.
The advantages of the Oxo-D process include:

- Low steam consumption
- Low fuel consumption
- High per pass conversion
- High 1,3-butadiene selectivity
- Long catalyst life (less coking)
- Catalyst is auto-regenerated (no separate regeneration required)
- The key to the process’ success is low energy consumption
Oxo-D Process to Butadiene – Technology Overview

• Butene dehydrogenation to butadiene is commercially proven and may be licensed from TPC; though it may have to be acquired as part of a joint venture.

• There were six on-purpose butadiene units built in the early-mid 1980’s that utilize Chinese butylene oxidative dehydrogenation technology.

• There are 2 Chinese butylene oxidative dehydrogenation technology licensors:
  • QPEC, the licensor with most updated and active on-purpose BD technology
  • Lanzhou Institute of Chemical Physics of the Chinese Academy of Sciences
Polybutadiene Rubber
Polybutadiene Rubber – Technology Overview

- Polybutadiene is produced by the polymerization of butadiene monomer, using either solution or emulsion polymerization processes. Most commercial production employs solution polymerization.

- In the commercial production of polybutadiene elastomers, the isomer composition of the final product depends on several factors, the most important of which are the catalyst system and the reaction medium (solution or emulsion polymerization).

- Several catalyst systems are used in the production of polybutadiene elastomers and yield varying percentages of the cis-1,4; trans-1,4; and vinyl 1,2 microstructures.

- The following equation shows the butane dehydrogenation reaction:

\[
\begin{align*}
n \text{CH}_2=\text{CH}-\text{CH}=\text{CH}_2 & \quad \rightarrow \quad \text{(CH}_2=\text{CH}-\text{CH}=\text{CH}_2)_n \\
1,3-\text{Butadiene} & \quad \rightarrow \quad \text{Polybutadiene}
\end{align*}
\]
Polybutadiene Rubber – Technology Licensors

- PBR technology is commercially proven and can be licensed from several licensors:
  - Zeon
  - ENI
para-Xylene
Bio-Paraxylene – Technology Overview – Gevo

- The Gevo process makes para-xylene from corn-based isobutanol that is produced by fermentation using a GMO microorganism and Gevo’s proprietary GIFT (Gevo Integrated Fermentation Technology) system for continuous product removal.

- The isobutanol is converted to para-xylene in a three-step synthesis.

- In the first step the isobutanol is dehydrated to isobutylene.

- This isobutylene is then dimerized to produce a C8 olefin.

- The olefin is then subjected to a dehydrocyclization.

- This reaction produces a mixture of xylenes, but selectivity to the para- isomer is 95%.

- The 95% para-xylene stream is pure enough for downstream applications.

- Gevo has announced that Toray has produced purified terephthalic acid (PTA) and PET from their material. Thus the Gevo process can dispense with an aromatics separation unit.
The Virent process can utilize corn, biomass or other sugar to produce paraxylene.

This glucose stream is fed to an aqueous phase reforming (APR) reaction along with an imported hydrogen stream.

The catalyst is platinum and rhenium on zirconia. The temperature is 335°C (635°F) and pressure is 640 psia.

Glucose conversion is 100%; the reaction product is a mixture of lower aliphatic oxygenates.

The oxygenate stream is passed to a condensation reactor. The condensation occurs over a gallium-promoted zeolite catalyst. Temperature is 375°C (707°F) and pressure is 265 psia.

The reaction product is an aromatics-rich hydrocarbon stream. This hydrocarbon stream is fed to a conventional aromatics processing unit operated to maximize para-xylene.
Bio-Paraxylene – Technology Overview – Virent

Sugar/Biomass → Hydrogenolysis → Hydrogenation → APR/DeOx → C5+ Hydrocarbons and Mono-Oxygenates
Bio-Paraxylene – Technology Overview – Anellotech

- The Anellotech process uses fast pyrolysis to obtain aromatics from wood.
- Wood is ground and washed with water to remove its ash content, then dried at 115°C and further ground.
- The dried, ground wood is fed to a pyrolysis reactor. This reactor is a modified fluid catalytic cracker similar to what one would expect to find in an oil refinery.
- The wood is fed to the cracker riser and contacted with hot catalyst. The catalyst is a gallium-promoted zeolite. The hot catalyst causes the wood to vaporize and the hot vapors to pyrolyze (essentially breaking down the molecular structure of the wood).
- At the top of the riser the pyrolysis vapor enters the FCC fluid bed reactor. There the catalyst works on the pyrolysis vapors producing an aromatics-rich vapor stream which also contains a substantial quantity of olefins.
- Upon disengagement in the reactor cyclones, this vapor is partially condensed and passed to a knockout drum.
Bio-Paraxylene – Technology Overview – Anellotech

- The catalyst is passed to a combustion regenerator where coke is burned off. The hot regenerated catalyst is recycled to the cracker riser.
- The by-product water and water-soluble hydrocarbons are removed in a decanter and passed to waste treatment.
- The vapor from the knockout drum is a propylene recycle which enhances the aromatics yield.
- The hydrocarbon layer from the decanter contains benzene, toluene, xylenes, styrene, and an array of heavier hydrocarbons.
- This stream is passed to a styrene recovery system where the heavy hydrocarbons are isolated by distillation, and the styrene is removed via extractive distillation.
- The heavy hydrocarbons are passed to a hydrotreating unit and the resulting stream taken as a liquid fuel product. The benzene, toluene, and xylenes from the styrene recovery unit are sent to a conventional aromatics unit. This unit is operated to maximize para-xylene production.
Bio-Paraxylene – Technology Providers & Status

• Paraxylene bio-technology developers include:

• Anellotech
  • Pilot plant in Pearl River, NY
  • Exclusive license agreement with University of Massachusetts-Amherst for biomass conversion selectively to paraxylene

• Gevo
  • Partnership with Coca-Cola for paraxylene development
  • Pilot isobutanol plant in St. Joseph, MO
  • Demo PX plant in Silsbee, TX; ribbon cutting Aug 2013

• Virent
  • 35 MTA demo plant in Wisconsin
  • 75 KMTA plant, Wisconsin, Partnership with Shell, planned operational 2015
Succinic Acid
Succinic Acid via Fermentation – Technology Overview

- Succinic acid can be produced via fermentation using either naturally producing succinic acid bacteria or GMO *E. coli* bacteria. The following equation shows the succinic acid from glucose fermentation reaction:

\[
C_6H_{12}O_6 + 2CO_2 + 2H_2 \rightarrow 2C_4H_6O_4 + 2H_2O
\]

- Glucose  Carbon  Hydrogen  Succinic  Water
  Dioxide       Acid

- In the fermentation section, sterilized glucose is converted to succinic acid in sterile fed-batch aerobic fermentors.

- After completion of fermentation, the biomass is separated from the broth by ultrafiltration, and the permeate is pumped to recovery and purification.

- By reactive extraction, the organic solvent phase consisting of succinic acid and other mixed acid by-products of fermentation are separated from the aqueous phase. The solvent phase is then pumped to vacuum distillation column for concentration and removal of volatile by-products.
Succinic Acid via Fermentation – Technology Overview

Succinic Acid Production via Fermentation

Glucose \rightarrow \text{Fermentation} \rightarrow \text{Cell Separation 
& Filtration} \rightarrow \text{Reactive 
Distillation} \rightarrow \text{Vacuum 
Distillation} \rightarrow \text{Crystallization} \rightarrow \text{Drying} \rightarrow \text{Succinic Acid 
Crystals}
Succinic acid technology developers include:

- BioAmber
  - Off-take agreement with Vinmar for Bio-BDO for US commercial plant
  - Demo plant at Pomacle, France
  - 30 KMTA planned, JV with Mitsui at Lanxess Industrial Complex, Sarnia Canada
- Myriant
  - 60 MTA pilot plant in Quincy, MA
  - 13 KMTA demo plant, Providence, LA
- Reverdia
  - JV DSM & Roquette
  - 300 MTA Biosuccinicum™, Lestrem, France
  - 20 KMTA Biosuccinium™, Cassano Spinola Italy, at Roquette’s large biorefinery
Succinic Acid via Fermentation – Technology Providers & Status

- Succinic acid technology developers include (*continued*):
  - Succinity
    - JV BASF & Corbion (Purac)
    - Demo plant in Germany, scheduled startup 2014
Butanediol can be produced via succinic acid hydrogenation. The following equation shows the hydrogenation reaction:

\[
\text{C}_4\text{H}_6\text{O}_4 \rightarrow \text{C}_4\text{H}_{10}\text{O}_2
\]

Succinic Acid \rightarrow Butanediol

Myriant has successfully converted succinic acid into BDO with partner JM Davy technologies, a technology licensor.

BioAmber has exclusively licensed Dow’s catalyst technology for succinic acid hydrogenation to BDO.
PBT Resin
PBT resin is produced by the polycondensation of 1,4-butanediol and dimethyl terephthalate (DMT) or terephthalic acid (TPA). When using DMT, the first step in the reaction is transesterification, in which 1,4-butanediol replaces the methyl groups in the DMT molecule to form bis-(4-hydroxybutyl)-terephthalate (BHBT) and methyl alcohol, as shown below.

\[
\begin{align*}
\text{DMT} & \quad + \quad \text{BDO} \\
& \quad \rightarrow \quad \text{PBT} \quad + \quad \text{Methanol} \\
\end{align*}
\]

- PBT is produced by polycondensation of BHBT usually in the presence of a catalyst (commonly based on titanium) under reduced pressure at 240-260°C.
- As polycondensation occurs, 1,4-butanediol is produced and is removed from the polycondensation reaction as a vapor.
PBT Resin via BDO Polymerization – Technology Providers & Status

- PBT technology providers include:
  - Sabic
  - DuPont
  - BASF
  - Mitsubishi
  - Toray
  - Lanxess
  - Ticona
Price and Economic Forecast Methodology

- **Price Forecasting Methodology**
- **Mass Balance**
- **Capital Cost Estimates (CAPEX) Basis**
Price Forecasting Methodology
Price Forecast Methodology

• Over the long term, international commodity petrochemical prices are ultimately a function of production costs plus some level of profitability for the high cost producer. Three elements are therefore necessary to generate a price forecast. The first is to calculate a production cost forecast, the second a margin/profitability forecast and the third, to insure price linkages between regions, a forecast of trade patterns and freight cost.

• To generate a forecast of production costs one must generate a forecast of feedstock cost and, in most cases, these feedstock are either other petrochemicals or petrochemical feedstock, such as naphtha, propane and ethane. It is therefore necessary to generate a price forecast for the feedstock first that is related to basic energy values. Yet petrochemical demand, ethylene consumption of natural gas liquids in particular, can impact the feedstock price forecast. As a result, some iteration is required.

• Supply/demand balances are used to generate the forecast of margins and profitability. High operating rates lead to good margins and low operating rates lead to poor margins. Historic trends are used to derive these forecasts. For the short-term, competitive cash cost curves set the floor prices on both a world and regional basis. In the long-term price forecast, an understanding of supply and investment economics is essential.
Price Forecast Methodology (continued)

- IHS consultants employ several different price forecasting methodologies depending on the timeframe in question.

- **Short Term** - Defined as the period inside two years, the consultant is looking carefully at current pricing in the regions, inventory levels, momentum, maintenance outage schedules and other market-oriented indicators. IHS consultants will review the month-by-month energy prices and adjust their short-term petrochemical forecasts accordingly.

- **Mid Term** - IHS considers the mid-term to be the next petrochemical pricing cycle. This of course differs from product to product, thus the length of this term differs. Price forecasting within this mid-term is done by examining the factors used in the short term, but more emphasis is placed on the supply and demand fundamentals and the underlying cost structure of production. Within the mid-term consultants will also use historical data to apply the appropriate margin levels to the cost of production. These margins are a function of the supply and demand balances as well as an understanding of how these markets behave in different parts of the cycle. Changes in energy costs will flow through and affect these prices.
• **Long Term** - The long term is the segment of the price forecast most obviously impacted by the underlying energy price change. After a complete price cycle, the product prices are forecasted on a trend basis. The cost of production for the price setting technology is examined regionally. To this cost a margin is added to derive a market price. The margin is determined by examining the returns on investment necessary to entice new construction without making them so attractive as to encourage overbuilding. It is within this long-term segment where the true effect of a base energy change is seen on petrochemical pricing.
With the Middle East unrest, declining production from the North Sea and production gains in North America, the global benchmarks in oil prices began to diverge.

West Texas Intermediate (WTI) and Brent crudes historically traded in tandem with one another, with WTI representing the Western market and Brent representing the markets in the rest of the world. The spread between the two benchmarks reached record levels in 2011, frequently trading above $20 per barrel in favor of Brent. This resulting dynamic has enabled a decoupling of WTI from the rest of the world.

Prices are high enough to encourage additional investment in drilling in higher cost locations, including ultra deep water. These underlying factors lead to a forecast of moderating crude oil prices through 2012, coupled with a narrowing of the Brent-WTI spread by 2014, then followed by increasing prices toward the middle of the decade once global supply begins to tighten in the face of higher demand from developing countries.
Mass Balance

**Biomass Feedstock** (Corn, Corn Stover, Wheat Straw)

- **Existing Plant**
  - Ethanol: 180 kta (60 MM gal/yr), 128 MM USD

- **New or Converted Plant**
  - n-Butanol: Converted: 105 kta (34 MM gal/yr), 206 MM USD; Grass Roots: 105 kta (34 MM gal/yr), 240 MM USD
  - Dehydrogenation: 109 kta, 70 MMUSD
  - Ethylene: 108 kta, 132 MMUSD

- **New Plant**
  - Paraxylene: 50 kta, 513 MMUSD
  - Succinic Acid: 38 kta, 337 MMUSD
  - Dehydrogenation: 77 kta, 42 MMUSD
  - Butylene: 69 kta, 71 MMUSD

**Shipping Logistics & Cost**

- EO: 144 kta; 399 MM USD
- MEG: 189 kta; 122 MM USD

- Butadiene: 67 kta, 216 MMUSD
  - PB Rubber: Merchant

- 1,3-Butanediol: 25 kta, 132 MMUSD
  - PBT Resin: 50 kta, 73 MMUSD
  - Fabrication

- Butylene: Merchant

- Ethylene: Merchant

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
Final Report, May 2014
# BioChemicals: Capacity and Capital Costs – North Dakota - 2020 Basis

<table>
<thead>
<tr>
<th>Unit</th>
<th>Capacity, kMT</th>
<th>Capital, USMM$</th>
<th>MM gal/yr</th>
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</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>180.00</td>
<td>128.00</td>
<td>60</td>
</tr>
<tr>
<td>Ethylene (Ethanol)</td>
<td>109.00</td>
<td>70.00</td>
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</tr>
<tr>
<td>HDPE</td>
<td>108.00</td>
<td>132.00</td>
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</tr>
<tr>
<td>EO</td>
<td>144.00</td>
<td>399.00</td>
<td></td>
</tr>
<tr>
<td>MEG</td>
<td>189.00</td>
<td>122.00</td>
<td></td>
</tr>
<tr>
<td>Butanol (Grass Roots Corn)</td>
<td>105.00</td>
<td>240.00</td>
<td>34</td>
</tr>
<tr>
<td>Butanol (Converted Corn)</td>
<td>105.00</td>
<td>206.00</td>
<td>34</td>
</tr>
<tr>
<td>Catalytic Dehydrogenation to Butene-1</td>
<td>77.00</td>
<td>42.00</td>
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<tr>
<td>Butadiene (Butene-1)</td>
<td>69.00</td>
<td>71.00</td>
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<tr>
<td>Polybutadiene</td>
<td>67.00</td>
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<tr>
<td>Paraxylene (Corn)</td>
<td>50.00</td>
<td>513.00</td>
<td></td>
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<tr>
<td>Succinic Acid (Corn)</td>
<td>38.00</td>
<td>337.00</td>
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</tr>
<tr>
<td>BDO</td>
<td>25.00</td>
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</tr>
<tr>
<td>PBT</td>
<td>50.00</td>
<td>73.00</td>
<td></td>
</tr>
</tbody>
</table>
Capital Cost Estimates (CAPEX) Basis
Capital Cost Components for a Petrochemical Project

- **ISBL** – Inside Battery Limits. This is the cost to engineer, procure, and construct on plot plant and equipment to the extent that the ISBL unit is ready to commission. ISBL estimates typically include:
  - Equipment cost
  - Direct installation
  - Indirect costs

- **OSBL** – Outside Battery Limits. This is the cost to engineer, procure, and construct plant and equipment required within a complex to support the ISBL unit. This would include storage facilities, administrative building, roads, connecting piping, utility systems like steam and electricity within the complex.

- **Owners Costs** – These include costs outside of a complex such as pipelines, tanks, railroad track connections, etc. that would be required to service a facility. For purpose of this project, we have estimated 10 percent of ISBL and OSBL. Owners cost also includes license fees and startup and commissioning costs.
AACE\(^{(1)}\) Cost Classification Matrix - Sets the Standard Definition for Capital Cost Estimates

<table>
<thead>
<tr>
<th>ESTIMATE CLASS</th>
<th>Primary Characteristic</th>
<th>LEVEL OF PROJECT DEFINITION</th>
<th>END USAGE</th>
<th>Secondary Characteristic</th>
<th>METHODOLOGY</th>
<th>EXPECTED ACCURACY RANGE</th>
<th>PREPARATION EFFORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 5</td>
<td>0% to 2%</td>
<td>Concept Screening</td>
<td>Capacity Factored, Parametric Models, Judgment, or Analogy</td>
<td>L: -20% to -50%</td>
<td>H: +30% to +100%</td>
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<tr>
<td>Class 4</td>
<td>1% to 15%</td>
<td>Study or Feasibility</td>
<td>Equipment Factored or Parametric Models</td>
<td>L: -15% to -30%</td>
<td>H: +20% to +50%</td>
<td>2 to 4</td>
<td></td>
</tr>
<tr>
<td>Class 3</td>
<td>10% to 40%</td>
<td>Budget, Authorization, or Control</td>
<td>Semi-Detailed Unit Costs with Assembly Level Line Items</td>
<td>L: -10% to -20%</td>
<td>H: +10% to +30%</td>
<td>3 to 10</td>
<td></td>
</tr>
<tr>
<td>Class 2</td>
<td>30% to 70%</td>
<td>Control or Bid/Tender</td>
<td>Detailed Unit Cost with Forced Detailed Take-Off</td>
<td>L: -5% to -15%</td>
<td>H: +5% to +20%</td>
<td>4 to 20</td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
<td>50% to 100%</td>
<td>Check Estimate or Bid/Tender</td>
<td>Detailed Unit Cost with Detailed Take-Off</td>
<td>L: -3% to -10%</td>
<td>H: +3% to +15%</td>
<td>5 to 100</td>
<td></td>
</tr>
</tbody>
</table>

(1) Association for the Advancement of Cost Engineering International

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ISBL Capital Costs Were Estimated From IHS Databases

- IHS has an extensive capital cost database for major commodity and specialty chemicals and polymers developed from our SRI legacy program, PEP.
- IHS also solicits capital cost information from technology licensors and developers where available.
- This capability is built on former CMAI and SRIC technology and engineering expertise and IHS’ SRIC PEP (Process Economics Program) methodology; one based on process simulation, development of heat and material balances and equipment sizing and pricing for capital cost development.
- **IHS Tools**
  - **ASPEN**
  - **PEPCOST:** Computer Program for Estimating Plant Investment
    - PEPCOST II is a computer program to estimate chemical plant investment and production costs. It is meant primarily for preliminary studies of alternative processes on a relative basis. The input to the program requires material and energy balances and sizing of the major process equipment items. The output includes:
      - Equipment f.o.b. and direct installation costs
      - Battery limits and off-sites investment
      - Production costs Master list of equipment and utilities requirements
    - The IHS CERA Capital Costs Analysis which is applied to all petrochemical plants for estimation of representative replacement capital cost and capital cost based fixed costs.
Capital Cost is Made Up of Specific Components

• Direct Installation Cost includes bulk material and bulk labor:
  • Bulk Material:
    • Building housing process units
    • Process and utility pipes and supports within the major process areas
    • Instruments, including computer control systems
    • Electrical wires and hardware
    • Foundations and pads
    • Structures and platforms
    • Insulation
    • Paint/corrosion protection
  • Bulk Labor: the Construction Labor associated with construction of the plant:
    • Structural, piping, equipment mounting, electrical, instrumentation, etc.
Capital Cost is Made Up of Specific Components

- **Indirect Costs:**
  - Indirect Costs are costs that are not directly accountable to the plant installation
  - Indirect Costs may be either fixed or variable
  - Indirect costs include administration, personnel and security costs
  - These are those costs which are not directly related to production. Some indirect costs may be overhead. But some overhead costs can be directly attributed to a project and are direct costs.

- **Indirect Costs include:**
  - Prorateable Costs
    - Fringe Benefits
    - Burdens
    - Insurance
  - Field Expenses
    - Consumables
    - Small Tools
    - Equipment Rental
    - Field Services
    - Temporary Const. Fac.
    - Field Constr. Supervision
  - **Home Office Costs + Fee (EPC)**
    - Engineering + Incidentals
    - Purchasing
    - Construction Management
OSBL Capital Costs Cannot be Accurately Estimated without a Site Survey

- OSBL capital cost is very dependent upon the site condition:
  - Greenfield
  - Developed
  - Shared with other chemical plants
- Typical OSBL Equipment
  - Tank farm + secondary containment berms
  - Cooling water piping systems
  - Converting raw water to process water
  - Sanitary waste treatment systems
  - Boiler feed water preparation and steam boiler system
  - Fuel gas networks for fired heaters
  - Inert gas and instrument air
  - Hot oil and refrigeration package systems
  - Back-up power generation
The Capital Cost for a North Dakota Site is Adjusted for by a Location Factor

- A location factor is an instantaneous, total cost factor for converting a base project cost from one geographic location to another.
- IHS’ TIP program developed a rigorous and reliable methodology for calculating location factors for the regions under consideration.
- IHS’ location factor takes into consideration the differences in cost for labor and productivity, duties, taxes and freight over imported material, and the relative cost of domestic (ND) equipment based on the differences of steel prices and labor requirement for the manufacturing of such equipment.
- The factors also include differences in local business environments, availability of nearby sources of spare materials and local currency fluctuations (irrelevant in this analysis).
- The overall factor for ND is analyzed is a multiplier relative to the base project cost.
- The final factor is determined by four major indexes: Material (composed of both imported (USGC) and domestic (ND) materials), Labor, Spares and Business Environment. The cost distribution between the material index and the labor index in the base location is determined using technology-specific construction cost data and the distribution for the other locations are calculated based on their respective indexes. Factors for spares and business environment apply as overall multipliers.
The USGC is the center of the petrochemical and Home Office expense/EPC (engineering, procurement and construction) industries in the US.

Capital costs can typically be expected to be higher outside the Gulf area:
- Longer delivery distances for equipment
- Potentially higher labor costs (definitely higher for North Dakota)
- The added cost of winterization for equipment and bulk materials
- Higher field expenses for the less developed sites

Cost components that would not necessarily be expected to change relative to the USGC include:
- Home Office costs; EPC services are global and do not vary by plant location
- Contingency; a percentage of Direct Installed cost
- Escalation; a national value, not dependent upon specific location
OSBL Capital Cost is Typically Estimated as a Greenfield (“Grassroots”) Installation as Part of a Desktop Study

- The Greenfield status is considered reasonably conservative in that existing or shared services are not assumed, which would lower the OSBL capital cost.
- In actual fact, there is opportunity to take advantage of existing infrastructure and site development in North Dakota, suitable for a petrochemical plant operation.
- For the case of the retrofit or converted ethanol plant, the plant infrastructure exists.
- If a new plant erected on the site of an existing ethanol plant, the new plant will be able to, in some respects, take advantage of the existing infrastructure.
- An example is either retrofitting or building a new plant at the site of the Blue Flint Ethanol biorefinery near Underwood, ND.
The Underwood, ND Site Affords the Capability for Minimizing OSBL Capital; the Other Ethanol Sites as Well

• Due to the nature of the installation at Underwood, one can assume that a petrochemical complex installed at or near the existing site would make available OSBL components that would be existing or obtainable with lower capital expenditure, such as:
  • Site preparation
  • Roads
  • Rail ties
  • Site security (fire department, fencing, etc.)
  • Medical facilities and staff
  • Warehousing
  • Power grid
  • Waste treatment
  • Utility generation

• It should be noted that the existence of usable services, such as utility generation and warehousing, will have to be investigated for applicability and usable capacity, but the existence of the site will certainly minimize costs for site development and access
IHS Developed a North Dakota Location Factor (relative to USGC) Using Two Methods

- **Method 1:** Developed as part of CMAI TIP Program:
  - Method 1 applies ND off-set factors (relative to the USGC) to high level in-state (domestic) and out-of-state (imported) materials and business conditions/status.
  - The methodology applies 14% higher labor rate to all applicable categories.
  - The overall Location Factor is 12% relative to USGC.

- **Method 2:** Developed from adjustment of CAPEX components:
  - Method 2 applies ND off-set factors (relative to the USGC) to the accepted cost buildup criteria.
  - The methodology applies 14% higher labor rate to all applicable categories.
  - The methodology applies 9% higher labor rate to all applicable categories.
Financial Analysis

- Raw Material/Product Prices
- Cash Flow Model Assumptions (Bio-Chemicals)
- Cash Flow Model Results (Bio-Chemicals)
The Risks to a Project’s Results Can Come From Numerous Sources and Causes

Typical risks include:

• Catastrophic event risk
• Engineering risk
• Completion risk
• Technology risk
• Supply risk
• Market risk
• Infrastructure risk

• Participant risk
• Political risk
• Bankruptcy risk
• Foreign Exchange risk
• Operating risk
• Environmental risk
• Infrastructure risk

• Force Majeure risk
• Interest rate risk
• Syndication risk
• Legal risk
• Sovereign / national risk
• Documentation risk

An accounting approach is fundamental, but the most common investment decisions result in a different emphases as to the most relevant financial measures and performance indicators:

• For Project Investment and Project Finance: Project profitability measures and debt coverage ratios:
• For M&A transactions: Transaction price/EBITDA and debt coverage ratios.
• For investing in common stock (minority owners, i.e. in publicly traded stock markets): Price/earning, and Price/Free Cash Flow ratios.
The Most Common Project Financial Measures are Probably the Following:

- Net Present Value (“NPV”) of the Project Cash Flows
  - Definition: The present value of the total cash flows (both negative during the investment phase, and positive (hopefully) during the operational phase. The net present value at the “hurdle rate” should be a positive and substantial value for the investment to be truly attractive on a financial basis.

- Internal Rate of Return (“IRR”) for the project investment and operating cash flows
  - Definition: The discount rate that when applied to each year’s cash flows, result in a net present value of precisely zero. (Note: The logic of the IRR calculation implicitly assumes that positive cash flows during operations are reinvested at the IRR rate of return.)

- Debt coverage ratios
  - Interest coverage ratios
  - Total debt service coverage ratios
  - Fixed Charges coverage ratios

- Cash Flow volatility (sensitivities on key metrics e.g., feedstock and product prices, capital investment and infrastructure cost, operating rates, debt service and financial incentives, etc.)
Raw Material/Product Prices
Product and Feedstock Prices Setting Mechanisms for North Dakota

- **Off-Shore (Export) Demand Market**
- **Conventional Petrochemical Production Hub**
- **Price Setting: Merchant Market for Petrochemicals & Polymers**
- **Price Setting Merchant Market for NGLs**
- **East North Central Product Demand Center**

**ND New Chemical Potential Production**

- Less Freight = ND Product Prices
- Less Freight = ND NGL Feedstock Prices
- Less Freight = ND Petrochemical Product Prices
- Less Freight and Handling = ND Petrochemical Product Prices

**Price Setting**

- Merchant Market for Petrochemicals
- Merchant Market for NGLs

**Central End-Use Product Prices**

- Plus Freight = E.N. Central End-Use Product Prices

**Off-Shore Demand (Export)**

- Less Freight = ND Product Prices

**Notes**

- Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
- Final Report, May 2014
Feedstock/Product Price Forecast (2020 – 2035)

Content of this Section Removed due to IHS Confidential Content
Cash Flow Model Assumptions (Bio-Chemicals)
Cash Flow Model Assumptions

- Project start-up year and operating period
  - Plant start up is assumed to be in 2020 with a three year construction period starting 2017
  - The first year is assumed to have an operating rate of 50%
  - The operating period for the cash flow model is assumed to be 15 years (ending in 2035)

- Capital spending schedule
  - Year 1: 2014 10%
  - Year 2: 2015 40%
  - Year 3: 2016 40%
  - Year 4: 2017 10%

- Depreciation
  - A 15 year term for depreciation is assumed
  - A straight line method is assumed

- Income Tax:
  - US: 35%
Cash Flow Model Assumptions

- Debt/Equity ratio assumed to be 70%
- Repayment period: 10 years
- Repayment scheme: Assume straight line principal repayment
- Interest rate is 6.5%
- Working capital
  - Inventory should match storage, cash at 7 days, and market at 30 days
- Build cash flow for each process unit
- Total cash flow is the sum of all process units
Model Setup

• For integrated units, prices are transferred from one unit to another either at market price or at cash cost
• Products transferred at cash costs are:
  • Ethylene
  • Butanol
  • Butadiene
  • Butene-1
  • Succinic Acid
  • BDO
• Model is built to allow switching between cash cost and market for each product
• The following products were modeled so that they could be either sold into the market or used to make derivatives:
  • Butanol
  • Butadiene
  • Succinic Acid
  • BDO
Bio-Based Configuration Options Modeled

• Ethanol Chain
  • Existing plant
  • Ethanol (at market price) to Ethylene
  • Ethylene to EO/EG, HDPE

• Butanol Chain
  • Option #1: Conversion capital from existing ethanol plant to n-butanol plant
  • Option #2: Grassroots n-butanol plant
  • Corn to n-butanol, Corn Stover to n-butanol, Wheat Straw to n-butanol
  • N-Butanol to Butene-1
  • Butene-1 to Butadiene
  • Butadiene to Polybutadiene

• Paraxylene Chain
  • Corn to paraxylene, Corn Stover to paraxylene, Wheat Straw to paraxylene

• Succinic Acid Chain
  • Corn to Succinic Acid, Corn Stover to Succinic Acid, Wheat Straw to Succinic Acid
  • Succinic Acid to BDO
  • BDO to PBT
Ethanol Configuration

• An existing ethanol plant (180 thousand metric tons per year) was assumed in this analysis as typical for North Dakota
• An ethanol plant was not included in the cash flow model but instead the transfer cost of ethanol into the ethylene derivatives was priced at market price
• Costing ethanol at market price allows the model to represent the value addition to existing ethanol plant (actual returns of the derivative plants) in comparison to selling the ethanol into the market.
• The capacity of the derivatives in the ethanol chain are sized based on the ethanol capacity as feedstock
• Since there is limited ethanol available, the derivatives (HDPE and MEG) are sized below world scale
• All the ethanol is consumed into its derivatives and there is no excess to be sold into the market
Butanol Configuration

• The capacity of the derivatives in the butanol chain are sized based on the butanol capacity as feedstock to those derivative plants
• There is no excess butanol, butene-1, or butadiene sold into the market.

Converted/Retrofit Plant (CV):
• The converted butanol plant assumes the existing 180 thousand metric tons ethanol plant is converted into a 105 thousand metric tons butanol plant
• The capital costs for converting the ethanol plant into a butanol plant is assumed to be 25 MMUSD
• In addition to the 25 MMUSD retrofit capital, the cash flow analysis includes the capital cost to build the original ethanol plant (i.e. we are giving consideration to the value of the existing ethanol asset).
• Maintenance fees, sustaining capital, and depreciation in the cash flow model are all calculated based on the two capital cost items discussed above

Grassroots Plant (GR):
• The grassroots butanol plant assumes a new grassroots butanol plant is being built, also with a capacity of 105 thousand metric tons.
Succinic Acid & Paraxylene

• The capacity for the succinic acid value chain is sized to feed into a 50 thousand metric ton PBT plant.
• It is assumed that even if there is no PBT plant included in the model, the sizing of the succinic acid and BDO plant is still based upon the 50 thousand metric ton PBT plant.
• The capacity for the bio-based para-xylene plant is set at 50 thousand metric tons
North Dakota Assumptions

- North Dakota location
  - Capital location factor = 1.12 x USGC
  - Labor factor = 1.4 x USGC
  - Utility costs factor = 0.9 USGC (lower fuel prices)
Target Market Assumptions

• Ethanol:
  • HDPE: The amount of HDPE produced in this complex is assumed to be more than what is required by Midwest demand. As such, 50% of the HDPE product in this complex is exported to China, where there is higher demand, with the remainder shipped to the Midwest.
  • MEG: The amount of MEG produced in this complex is also partially exported to China (25%) with the remainder assumed to be sold in the Midwest.

• For all other products in the analysis, the demand in the Midwest is assumed to be large enough to consume all production.
Cash Flow Model Results (Bio-Chemicals)
## Financial Model Results

<table>
<thead>
<tr>
<th></th>
<th>IRR @ 0%</th>
<th>NPV @ 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol - North Dakota Feed - Midwest Netback - Ethanol Market Price - Ethylene - HDPE</td>
<td>6%</td>
<td>-31</td>
</tr>
<tr>
<td>Ethanol - North Dakota Feed - Midwest Netback - Ethanol Market Price - Ethylene - MEG</td>
<td>5%</td>
<td>-78</td>
</tr>
</tbody>
</table>

### Grass Roots

| Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Sell Butanol to Chemicals | 26%    | 117       |
| Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Sell Butanol to Gasoline/Fuel | 5%     | -26       |
| Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Butene-1 - Butadiene | 10%    | 4         |
| Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Butene-1 - Butadiene - PBR | 5%     | -69       |
| Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Sell Butanol to Chemicals | 20%    | 106       |
| Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Sell Butanol to Gasoline/Fuel | 7%     | -28       |
| Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Butene-1 - Butadiene | 10%    | 0         |
| Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Sell Butanol to Chemicals | 21%    | 105       |
| Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Sell Butanol to Gasoline/Fuel | 6%     | -32       |
| Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Butene-1 - Butadiene | 10%    | -3        |
| Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Butene-1 - Butadiene - PBR | 5%     | -74       |

### Converted from Ethanol

| Butanol - North Dakota Feed - Midwest Netback - Corn - Sell to Chemicals | 33%    | 152       |
| Butanol - North Dakota Feed - Midwest Netback - Corn - Sell Butanol to Gasoline/Fuel | 13%    | 14        |
| Butanol - North Dakota Feed - Midwest Netback - Corn - Butanol - Sell Butanol to Chemicals | 16%    | 45        |
| Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Sell Butanol to Chemicals | 8%     | -27       |
| Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Sell Butanol to Chemicals | 29%    | 168       |
| Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Sell Butanol to Gasoline/Fuel | 14%    | 27        |
| Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Butene-1 - Butadiene | 17%    | 74        |
| Butanol - North Dakota Feed - Midwest Netback - Corn Stover - Butanol - Butene-1 - Butadiene - PBR | 10%    | 5         |
| Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Sell Butanol to Chemicals | 30%    | 167       |
| Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Sell Butanol to Gasoline/Fuel | 14%    | 26        |
| Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Butene-1 - Butadiene | 18%    | 72        |
| Butanol - North Dakota Feed - Midwest Netback - Wheat - Butanol - Butene-1 - Butadiene - PBR | 10%    | 2         |
## Financial Model Results

<table>
<thead>
<tr>
<th>Product</th>
<th>IRR</th>
<th>NPV @ 0%</th>
<th>NPV @ 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn - Succinic Acid - BDO - PBT</td>
<td>-14%</td>
<td>-471</td>
<td>-225</td>
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<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn - Succinic Acid - BDO</td>
<td>&lt;-30%</td>
<td>-1099</td>
<td>-358</td>
</tr>
<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn - Selling Succinic Market</td>
<td>-1%</td>
<td>-15</td>
<td>-69</td>
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<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn Stover - Succinic Acid - BDO - PBT</td>
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<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Corn Stover - Selling Succinic Market</td>
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<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Wheat - Succinic Acid - BDO - PBT</td>
<td>-17%</td>
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<td>-268</td>
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<tr>
<td>Succinic Acid - North Dakota Feed - Midwest Netback - Wheat - Succinic Acid - BDO</td>
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<td>Succinic Acid - North Dakota Feed - Midwest Netback - Wheat - Selling Succinic Market</td>
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<td>PXE - North Dakota Feed - Midwest Netback - Corn - Selling PXE Market</td>
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<td>PXE - North Dakota Feed - Midwest Netback - Corn Stover - Selling PXE Market</td>
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<td>PXE - North Dakota Feed - Midwest Netback - Wheat - Selling PXE Market</td>
<td>10%</td>
<td>420</td>
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</table>
Financial Model Results – Corn Based Only

Bio-Chemicals (Corn Based): Returns (IRR, %) vs. Risk

Source: IHS
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Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
Final Report, May 2014
Bio-Chemicals: Returns (IRR, %) vs. Risk

Developing Technology
- CV - Corn - ButOH to Chemicals
- GR - Corn Stover - ButOH to Chemicals
- CV - Corn Stover - Butadiene
- GR - Corn Stover - Butadiene
- CV - Wheat - ButOH to Chemicals
- GR - Corn - Butadiene
- GR - Wheat - ButOH to Chemicals
- CV - ButOH to Gasoline/Fuel
- CV - Corn Stover - Succinic

Mature Technology / Multiple Products
- CV - Corn Stover - ButOH to Chemicals
- CV - Corn - Butadiene
- CV - Wheat - ButOH to Chemicals
- CV - ButOH to Gasoline/Fuel
- Ethanol - MEG
- Corn Stover - Succinic

Mature Technology / Single Product
- GR - Corn Stover - ButOH to Chemicals
- CV - Corn - Butadiene
- CV - Corn Stover - PBR
- Corn Stover - PXE
- Ethanol - HDPE
- GR - Corn - PBR
- Corn Stover - PBT
- Wheat - PBT

Source: IHS

© 2014 IHS

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
Final Report, May 2014
<table>
<thead>
<tr>
<th>Product Line</th>
<th>Risk/Complexity (1-10)</th>
<th>Returns, %</th>
<th>Capital Investment, MM USD</th>
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</thead>
<tbody>
<tr>
<td>CV - Corn - ButOH to Chemicals</td>
<td>6</td>
<td>33%</td>
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<tr>
<td>GR - Corn - ButOH to Chemicals</td>
<td>6</td>
<td>26%</td>
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<tr>
<td>CV - Corn - Butadiene</td>
<td>5</td>
<td>16%</td>
<td>287</td>
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<td>GR - Corn - Butadiene</td>
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<td>Corn - PXE</td>
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<td>GR - Corn - PBR</td>
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## Financial Model Results – All Products

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<th>Product Line</th>
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<th>Returns, %</th>
<th>Capital Investment, MM USD</th>
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<tr>
<td>CV - Corn - ButOH to Chemicals</td>
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<tr>
<td>CV - Wheat - ButOH to Chemicals</td>
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<td>CV - Corn Stover - ButOH to Chemicals</td>
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<td>GR - Wheat - ButOH to Chemicals</td>
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<td>Product Line</td>
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<td>Wheat - PXE</td>
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<td>GR - Corn Stover - ButOH to Gasoline</td>
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<td>GR - Corn - ButOH to Gasoline/Fuel</td>
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<td>Ethanol - MEG</td>
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<tr>
<td>Wheat - BDO</td>
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<td>-30%</td>
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</table>
Financial Model Results – Corn Based Only

Bio-Chemicals: Returns (IRR, %) vs. Risk

- CV - Corn - ButOH to Chemicals
- CV - Corn - Butadiene
- GR - Corn - Butadiene
- CV - Corn - PBR
- Corn - P XE
- GR - Corn - PBR
- Corn - Succinic
- GR - Corn - ButOH to Gasoline/Fuel
- CV - Corn - ButOH to Gasoline/Fuel
- Corn - BDO

Source: IHS

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Financial Model Results – All Products

Bio-Chemicals: Returns (IRR, %) vs. Risk

Source: IHS

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Cash Flow Model Assumptions

• IHS considers a minimum rate of return (IRR) of 15 percent is necessary for consideration of investment in a commodity chemical plant
• Commodity chemicals include chemical intermediates, commodity chemicals and large volume plastics; products that do not incur unusually high expenditures for technical service and SG&A
• IHS would expect a higher IRR threshold for specialty products
• The 15% IRR threshold assumes minimal or manageable risk related to product acceptance (mature product) and production technology (mature, well proven commercially)
• For unproven technology, IHS recommends a higher IRR, as much as 10% higher to account for the greater risk undertaken. Technology risk can be manifested in several ways:
  • The technology will not work at all; a minima risk for the technologies included in this evaluation as determined by IHS review and assessment
  • The technology will operate but at lower overall rate and throughput as a result of difficult startup and operational learning curve
  • The technology will work but at lower prime-grade material production, causing downtime and/or lower quality product that must be sold at a lower price or disposed of
  • The technology will work but not at the cost of production anticipated (higher cost) and used in the analysis
• All of these conditions, individually or collectively, will result in lower IRR than estimated
For the Ethanol Study, Two Product Chains Show Promise

- Chemical value Butanol from either a grass-roots butanol plant (26% IRR from corn) or an existing ethanol plant converted to butanol production (33% IRR from corn)
  - The chemical butanol return is also attractive from biomass waste

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Grass-roots Butanol</th>
<th>Converted Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Stover</td>
<td>20%</td>
<td>29%</td>
</tr>
<tr>
<td>Wheat Straw</td>
<td>21%</td>
<td>30%</td>
</tr>
</tbody>
</table>

- Butadiene is only promising when produced in the converted ethanol plant, with the advantage of the lower capital cost than needed for the grass-roots butanol plant
  - Butadiene from corn: 16%
  - Butadiene from corn stover: 17%
  - Butadiene from wheat straw: 18%

- Butadiene from the grass-roots butanol plant does not display IRR greater than 10% from any of the bio-feedstocks.

- Polybutadiene rubber has returns in the 10% range and appears only viable if incentives are granted; however, there is a large potential market in the automotive industry in the East North Central region which is logistically favorable for North Dakota production.
For the NGL Study, Two Product Chains Show Promise

- The ethanol to ethylene derivatives are not promising
  - HDPE from corn-based ethanol has an IRR of 6%
  - MEG from corn-based ethanol has an IRR of 5%
- The route to ethylene is not competitive due to the process steps (dehydration) and related capital cost and very small scale (109 thousand tons per year) compared to a world-class ethylene cracker (>1,000 thousand tons per year)
- Because of the small scale ethylene production, the derivative plants are also too small to be competitive (108 thousand tons per year for HDPE and 189 thousand tons per year for MEG)
- Both bio-based HDPE and MEG are currently produced commercially. IHS is aware that both products are not produced at costs competitive to conventional petrochemical sourced material, even at large scale, and that both are only viable when priced at a “green” premium.
- Bio-HDPE and bio-MEG have limited markets and applications
- IHS does not believe the green premium is sustainable got this study and has not applied it to the forecast HDPE and MEG prices
Butanol for Fuel Application is Not Promising

- n-Butanol's gasoline blending value suffers compared to ethanol or isobutanol due to its low octane value.
- Even though its lower vapor pressure and higher heating value make up some of the shortfall, its blending value is not favored over ethanol.
- Therefore, for an equivalent production amount of n-butanol to ethanol, n-butanol has less value than ethanol.

Table 1. Selected properties of butanol isomers.

<table>
<thead>
<tr>
<th>Property</th>
<th>sec-Butanol</th>
<th>tert-Butanol</th>
<th>Isobutanol</th>
<th>n-Butanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>C₈H₁₈O₂</td>
<td>C₈H₁₈O₂</td>
<td>C₈H₁₈O₂</td>
<td>C₈H₁₈O₂</td>
</tr>
<tr>
<td>Molecular weight, g/mol</td>
<td>118.17</td>
<td>118.17</td>
<td>118.17</td>
<td>118.17</td>
</tr>
<tr>
<td>Carbon/hydrogen/oxygen, wt-%</td>
<td>64.8/3.6/21.6</td>
<td>64.8/3.6/21.6</td>
<td>64.8/3.6/21.6</td>
<td>64.8/3.6/21.6</td>
</tr>
<tr>
<td>Density at 15 °C, kg/dm³</td>
<td>0.806</td>
<td>0.791</td>
<td>0.802</td>
<td>0.810</td>
</tr>
<tr>
<td>Boiling point, °C</td>
<td>100</td>
<td>83</td>
<td>108</td>
<td>117</td>
</tr>
<tr>
<td>Melting point, °C</td>
<td>-115</td>
<td>25.7</td>
<td>-108</td>
<td>-90</td>
</tr>
<tr>
<td>Blending RON</td>
<td>101</td>
<td>104 – 110</td>
<td>113</td>
<td>94, 96</td>
</tr>
<tr>
<td>Blending MON</td>
<td>91 (32%)</td>
<td>69 – 98%</td>
<td>94%</td>
<td>78, 81%</td>
</tr>
<tr>
<td>Neat vapor pressure at 37.8 °C, kPa</td>
<td>12</td>
<td>3.9 (at 40 °C)</td>
<td>2.4 (at 40 °C)</td>
<td></td>
</tr>
<tr>
<td>Blending vapor pressure at 37 °C, kPa</td>
<td>62</td>
<td></td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>LHV, MJ/kg</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>LHV, MJ/l</td>
<td>26.1 (calc)</td>
<td>26.5 (calc)</td>
<td>26.7 (calc)</td>
<td>26.7 (calc)</td>
</tr>
<tr>
<td>Heat of vaporization, kJ/kg</td>
<td>560²</td>
<td>536, 601²</td>
<td>579, 688²</td>
<td>564, 592, 706²</td>
</tr>
<tr>
<td>Self-ignition temperature, °C</td>
<td>350, 406</td>
<td>478</td>
<td>416, 430</td>
<td>343</td>
</tr>
<tr>
<td>Ignition limits, fuel in air, vol-%</td>
<td>1.7 – 9.8</td>
<td>2.4 – 8</td>
<td>1.2 – 10.9</td>
<td>1.4 – 11.2</td>
</tr>
<tr>
<td>Stoichiometric air to fuel ratio</td>
<td>11.1²</td>
<td>11²</td>
<td>11²</td>
<td>11²</td>
</tr>
<tr>
<td>Solubility in water, 20 °C, wt-%</td>
<td>miscible</td>
<td>8.5 wt-%</td>
<td>7.7 wt-%</td>
<td></td>
</tr>
<tr>
<td>Flash point, °C</td>
<td>31</td>
<td>16</td>
<td>28</td>
<td>34</td>
</tr>
<tr>
<td>Viscosity at 20 °C, cP</td>
<td>3.95</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity at 20 °C, mm²/s</td>
<td>4.9 (calc)</td>
<td>3.6 (calc)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity at 40 °C, mm²/s</td>
<td>2.7 (calc)</td>
<td>2.3 (calc)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface tension at 20 °C, mN/m</td>
<td>20.7</td>
<td>23.0</td>
<td>24.7</td>
<td></td>
</tr>
</tbody>
</table>

*Octane number and vapor pressure of compounds do not behave linearly due to interaction with gasoline components. Blending octane numbers depend on the gasoline composition. ** Kinematic viscosity at 20 °C (cSt = mm²/s) = Dynamic viscosity (cP)/density at 20 °C (kg/dm³) Note: 1 Pa s = 10 P = 1 cP

None of the Grass-roots Products (other than Butanol) are Promising

- Succinic acid and its derivative butanediol/PBT show negative IRRs regardless of the feedstock.
- The production of succinic acid from sugar is less efficient than other sugar based processes, resulting in higher relative feedstock costs and not competitive with petrochemical based processes.
- The succinic acid market itself is small and not well defined, with lower level of profitability.
- The succinic acid to butanediol process is not fully developed, but developers are working with major petrochemical companies on this process. The catalysts needed are also not fully developed.
- The relative PBT capacity from biomass is smaller than world class from petrochemical based routes and suffers from lack of economy of scale.
None of the Grass-roots Products (other than Butanol) are Promising

• para-Xylene (PX) production shows a positive, but lower than 10% IRR for all feedstocks. PX production from biomass is in the developmental stage, though several developers are operating pilot plants.

• Bio-PX is a key component of 100% green-PET bottle resin (water bottles, soda bottles, etc.). PET is composed of, approximately, 70% terephthalic acid (PTA, which is produced from PX) and 30% MEG.

• To date, green bottles are up to 30% green, the amount corresponding to the MEG portion. Both Coke and Pepsi claim to be committed to 100% green bottles, but the commercialization of green PX is considered several years away.

• IHS understands that greenbottle production is more costly than conventional PET bottles and that the added cost has to be absorbed somewhere along the value chain.

• It is also our expectation that green PX will not be competitive with conventional petrochemical PX.

• Given the low IRR and unproven technology, IHS does not recommend PX.
Project Development and Implementation
Project Development Must Successfully “Execute” all the Fundamental Commercial and Technical Aspects

**ALIGNMENT**

State (Federal) Policy, Social & Regulatory Aspects

**EXECUTION**

Project Management

EPC Contractor

**THE PROJECT**

Technology Licensor and/or Developer

Owners & Sponsors

MANUFACTURING

Feedstock Supply/Logistics

Product Offtake

Co-Product Offtake

**FINANCING**

Strategic and/or Private Equity

Debt

Government Incentives

**UTILITIES/SERVICES**

Utilities

Site Services

Infrastructure

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota Final Report, May 2014
Project Development

• Project development must follow good business and chemical engineering fundamental (there are no shortcuts)
• The scope, timing, duration and ownership of specific project development implementation tasks are highly dependent on the owner’s financial, technical and business position i.e., “what they bring to the project”
• The stage of development/maturity of the chemical process technology also has a significant impact on the project (can add 3 to 5 years)
• Overall project develop follows four tracks:
  o Technology availability
  o Engineering and design
  o Financing
  o Procurement, construction, business formation and startup
• The interrelation, duration and critical path milestones of the “tracks” vary as a function of project type, complexity, owner capabilities & expertise, as well as the financing and ownership structure
• With mature & available technology, project development and implementation typically spans 3 - 5 years; with simple & fully owner financed ones at 2 years
Project Development Tracks Need to be Executed in Parallel with Specific Activities Highly Dependent on Project Ownership

**Concept**
- Concepts & Inventions

**Laboratory R&D**
- Pilot Development & Unit Testing

**Scale-up Technology Due Diligence**
- Performance Operating & Capital Cost Estimates

**Technical Feasibility**
- Concept

**DEVELOPING**
- 24- 60 months

**COMMERCIAL**
- 9- 24 months

**Project Development**
- Market Analysis & Pre-Feasibility & Cash Flow
- Technology Procurement (Licenser) Selection
- Front End Engineering Design (FEED) Bids
- EPC Contractor Selection & Detailed Design
- Execution of Technical Contracts

**Engineering Design**
- 12- 24 months

**Financing**
- MOU Execution of Commercial Contracts
- “Bankable” Feasibility Study
- Securing of Project Sponsors & Funding
- Project Certification & Funding Closing
- Performance & Completion Tests/ Funding Release

**Construction & Business Formation**
- Environmenta l (National EPA Review & EIS)
- Procurement and Construction
- Construction Monitoring
- Organization Formation and Product/Market Seeding
- Mechanical Completion Training & Start-up

**Commercial Operation**
- 24- 48 months

Study to Evaluate Value-Added Market Opportunities for Ethanol Produced in North Dakota
Final Report, May 2014
North Dakota Specific Analysis

- Summary of Opportunities for North Dakota
- State Incentive Programs
- Examples of State Incentive Programs
Summary of Opportunities for North Dakota
Butadiene Value Chain

Value Chain Highlights (NA)
✓ High Volume (ND proposed capacity is only 2.2% of total US capacity 2020)
✓ Growth product (at GDP levels)
✓ Additional capacity needed in the post-2020 period
✓ On-purpose capacity setting the market price

Advantages for ND Producer
† Competitive operating costs
† Large fungible market served by rail
† Relatively low capital cost

Market (Pull) Attractiveness (NA)

ND’s 69 KTPA is acceptable capacity size in market

Stand-alone product

Fungible commodity product

Market Entry Barriers for ND Producers
?
• Lack of existing infrastructure
• Capital intensive
• Need to capture market share on price
• Need to develop multiple products in the value chain
n-Butanol (Chemicals) Value Chain

Value Chain Highlights (NA)
- High Volume (ND proposed capacity is only 8.8% of total US capacity 2020)
- Additional capacity needed in the post-2020 period

Advantages for ND Producer
- Competitive operating costs
- Large fungible market served by rail
- Relatively low capital cost
- Entry via a retrofit of existing ND assets is a viable and lower cost route to entry

Market (Pull) Attractiveness (NA)
- ND’s 105 KTPA is acceptable capacity size in market
- Stand-alone product
- Fungible commodity product

Market Entry Barriers for ND Producers
- Need to capture market share on price
- Need to develop differentiated product "infrastructure"
State Incentive Programs
Economic Incentives are Dependent on Project Scope and Can Take Many Forms

• Typical Economic Development Incentives by Type:
  • Financial tax incentives: credits, deductions, abatements, payment in lieu of taxes (known as PILOTs)
  • Financial capital incentives: grants, low-interest loans, interest rate subsidies
  • In-kind services: site improvements, job training, permit assistance
  • Special districts: empowerment and enterprise zones
  • Miscellaneous incentives

• Other Support
  • Ease of permitting
  • Infrastructure Development
Examples of State Incentive Programs
Financial Tax Incentives in Ohio

- Ohio Job Creation Tax Credit
  - At least 10 full time equivalents and $660,000 in annual payroll over three years
  - Sector 325110 average annual wage in OH is $90,100 (all occupations)
  - Credit limited to 75% state personal income tax withholdings
  - Can be taken against four OH taxes, including business franchise and corporate net income tax
  - Up to 15 years
  - Refundable
  - Sample calculation assuming 300 jobs - annual credit would be $801,800

- Other Ohio Economic Development Incentives
  - Business incentive and economic development grants
  - Ohio Bond Fund and low interest loans (Section 166, refers to applicable regulation)
  - Workforce grants and in-kind services
  - R&D tax credit
  - Special districts, such as enterprise and empowerment zones, reinvestment areas, and brownfields.
Financial Tax Incentives in Pennsylvania

- **Job Creation Tax Credits**
  - Based on number of jobs created in three years
    - At least 25 new jobs or 20% increase
  - Credit per job is $1,000 and $2,500 if unemployed worker used
    - Sector 325110 average annual wage in PA is $80,300 (all occupations)
  - Credit can be taken against seven PA business taxes
  - Example assuming 300 operating jobs - annual tax credit of $345,000

- **Pennsylvania Resource Manufacturing Tax Credit**
  - Machinery and Equipment Loan Fund (MELF)
    - Availability of funds uncertain
  - Low Cost Capital through programs such as “PA First”, Pennsylvania Economic Development Authority taxable bond program, PA Industrial Development Authority
  - Infrastructure development (highly site specific)
  - Job Training
  - Special districts: Keystone Opportunity Zone/Keystone Opportunity Expansion Zone, Keystone Special Development Zones, Industrial Sites Reuse, Tax Increment Financing
Financial Tax Incentives in West Virginia

- Economic Opportunity Tax Credits (EOTC)
  - Five types of EOTC credits – general, corporate HQ, small business, high tech, and job creation
  - Only one EOTC credit per investment, but can apportion
  - EOTC tax credits can be used with other WV incentives

- General EOTC Tax Credit
  - Qualifying investment based on dollar value of initial investment, equipment life, and number of jobs
    - Qualifying investment can be up to 35% of initial investment for 520 or more jobs
    - Credit pro-rated over 10-year period
  - Credit taken against corporate net income tax
  - Credit is limited to state tax obligation
  - Not refundable or transferable, but three year carry forward after 10 years
  - If initial investment was $1.5 billion and 300 operating jobs, potential credit likely offsets virtually all of WV corporate income tax obligation
Financial Tax Incentives in West Virginia (continued)

- **EOTC Job Creation Tax Credit**
  - At least twenty new full time jobs at $32,000 with health benefits
  - Tax credit of $3,000 per job for five year period
  - Credit against four state taxes, including corporate net income
  - Not refundable or transferable
  - If 300 new jobs – annual credit is $900,000

- **Five for Ten Program**
  - Incentive: Abatement of 95% of real property taxes pro-rated for 10 years
  - Eligibility: facilities in NAICs 211112- Natural Gas Liquids Extraction, or that use products from such a facility and invest at least $2 billion
  - Sample calculation assuming:
    - Real property of $200 million
    - Assessment ratio of 60% (statewide figure for manufacturing real property)
    - Real property tax rate $2.50/$100 of assessed value
  - Annual reduction in real property taxes is $285,000
Financial Tax Incentives in West Virginia (continued)

- Manufacturing Investment Tax Credit
  - Incentive: avoid up to 60% of liability for the 3 state taxes, including the corporate net income tax
  - Credit is 5% of qualified investment, pro-rated over 10 years
    - Includes real property, tangible personal property (equipment), refurbishment
  - Not refundable or transferable, no carryover
  - With $1.5 billion in investment, 60% obligation would likely be offset

- Manufacturing Property Tax Adjustment Credit
  - Credit against local personal property taxes paid on manufacturing inventory
  - Value of credit depends on local tax rate, value of inventory
  - Cannot be estimated at this time, likely small
  - Not refundable or transferable, no carryover

- Other Economic Development Incentives in WV
  - Special property tax valuation for air and water pollution control equipment
  - On the Job training services
  - Guaranteed Workforce Program
  - WV Economic Development Authority (WVEDA) loan program
  - Special districts: empowerment zones, Appalachian Regional Commission, TIFs