Modeling the Impact of the Shale Gas Revolution on the Petrochemical and Crude Oil Refining Sectors of North America

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RBAC, Inc.
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The Shale Gas Revolution

- Technological innovations have brought about the “shale gas revolution”
  - Horizontal Drilling
  - Hydraulic Fracturing
  - 3D / 4D Seismic Imaging
  - Robust, Full-Scale Deployment

- Enormous market changes have occurred already and will continue into the next decades

- But there have been no generally available tools to model the effect of investments meant to address these changes
  - RBAC took up the challenge and built such a tool ...
    - “NGL-NA™”, the first modelling system available to the industry for studying and forecasting the NGL market of North America

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Study Questions

- Natural gas production has expanded enormously since 2006 – so has NGL production
  - But … demand has not kept up
- Ethane production is somewhat manageable
  - It can be “rejected” into the natural gas stream - but only up to a certain limit - due to pipeline quality constraints
    - These limits are currently being tested
  - What can the market do to restore a reasonable balance?
- Crude oil refinery feed slates are changing
  - New technologies applied to tight oil plays have resulted in a huge increase in light crude production
  - How might this impact the demand for natural gasoline (C5+) as blending stock in finished gasoline?
### NGLs – What are they?

<table>
<thead>
<tr>
<th>Natural Gas Liquid</th>
<th>Chemical Formula</th>
<th>Applications</th>
<th>End Use Products</th>
<th>Primary Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethane</td>
<td>C₂H₆</td>
<td>Ethylene for plastics production; petrochemical feedstock</td>
<td>Plastic bags; plastics; anti-freeze; detergent</td>
<td>Industrial</td>
</tr>
<tr>
<td>Propane</td>
<td>C₃H₈</td>
<td>Residential and commercial heating; cooking fuel; petrochemical feedstock</td>
<td>Home heating; small stoves and barbeques; LPG</td>
<td>Industrial, Residential, Commercial</td>
</tr>
<tr>
<td>Butane</td>
<td>C₄H₁₀</td>
<td>Petrochemical feedstock; blending with propane or gasoline</td>
<td>Synthetic rubber for tires; LPG; lighter fuel</td>
<td>Industrial, Transportation</td>
</tr>
<tr>
<td>Isobutane</td>
<td>C₄H₁₀</td>
<td>Refinery feedstock; petrochemical feedstock</td>
<td>Alkylate for gasoline; aerosols; refrigerant</td>
<td>Industrial</td>
</tr>
<tr>
<td>Pentane</td>
<td>C₅H₁₂</td>
<td>Natural gasoline; blowing agent for polystyrene foam</td>
<td>Gasoline; polystyrene; solvent</td>
<td>Transportation</td>
</tr>
<tr>
<td>Pentanes Plus*</td>
<td>Mix of C₅H₁₂ and heavier</td>
<td>Blending with vehicle fuel; exported for bitumen production in oil sands</td>
<td>Gasoline; ethanol blends; oil sands production</td>
<td>Transportation</td>
</tr>
</tbody>
</table>

*Pentanes plus is also known as "natural gasoline." Contains pentane and heavier hydrocarbons.

C indicates carbon, H indicates hydrogen; Ethane contains two carbon atoms and six hydrogen atoms.

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NGL-NA Modeling Approach

• Basic Design Principles
  • Highly granular model
    • Multiple commodities
    • Detailed infrastructure database
    • Basin level supply
    • State, market, commodity level demand
  • Multi-commodity flow model with transformation functions
    • Gaseous and liquid mixes get separated into other commodities
  • Optimization used to compute economically efficient results

• NGL market highly coupled to other markets
  • Natural gas
  • Crude oil refining
  • Petrochemicals
Infrastructure Inventory (US, Canada, Mexico)

- Gas Processing Plants ~ 1,100
  - ~ 100 with partial or full fractionation
- Stand-Alone Fractionators ~ 50
- Olefin Plants ~ 50
- Refineries ~ 170
- Import/Export Terminals ~ 20
- Storage Terminals ~ 100
- LPG Distribution Terminals ~ 250
- NGL Mix and Purity Pipelines ~ 100
  - Also Rail, Truck, Barge and Tanker Transport
Basic NGL-NA Flow Model

1. Natural Gas Production
   - Wet Gas
     - Dry Gas
   - Gas Processing
     - Residue Gas
     - NGL Mix
       - Fractionation
         - Ethane
         - Propane
         - N-Butane
         - Iso-butane
         - Pentanes+
     - Nat Gas Markets
   - Export Markets
   - Non-Petchem Propane Markets
   - Other Butane Markets
   - Diluent Market
   - Petchem Feedstock Market
   - Gasoline Blending Market

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NGL-NA Flow Model Detail

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NGL / Refinery / Petchem Interaction

NGL Mkt

Frac Plant

NGL Supply

Gas Plant

Process Gas

Ref Fuel Gas

C2, C3, C4, C5+

C4I

C4N

C5+

Refinery

Atmospheric Distillation

Crude Oil

NGL Mix

C2, C3, C4, C5+

Ref Fuel Gas

Ethylene

Propylene

Etc.

Petchem Plants

Petchem

Mkt

Gas Plant

Alkylation

C4I

C4N

C5+

Isomerizer

Isomerate

Reformer

Reformates

Hydro Cracker

FCC

FCC Gasoline

Gas-Oil

Gas-Oil

Gas-Oil

Vacuum Gas-Oil

Asphalt

Resid

Coke

Coker

Petchem

Mkt

Blender

Ethanol and Other Additives

Gasoline Blending Pool

Gasoline Market

Naphtha

Gas-Oil

Petchem

Mkt

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## Typical Steam Cracker Yields as a Function of Feedstock

<table>
<thead>
<tr>
<th>Output</th>
<th>Light Feeds</th>
<th>Heavy Feeds</th>
<th>Naphtha</th>
<th>GasOil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethane</td>
<td>Ethane</td>
<td>Butane</td>
<td>Naphtha</td>
<td>GasOil</td>
</tr>
<tr>
<td>Hydrogen &amp; methane</td>
<td>Ethane: 13%</td>
<td>Butane: 24%</td>
<td>Naphtha: 26%</td>
<td>GasOil: 18%</td>
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<tr>
<td>Ethylene</td>
<td>Ethane: 80%</td>
<td>Butane: 45%</td>
<td>Naphtha: 30%</td>
<td>GasOil: 25%</td>
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<tr>
<td>Propylene</td>
<td>Propylene: 2%</td>
<td>Butane: 18%</td>
<td>Naphtha: 13%</td>
<td>GasOil: 14%</td>
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<tr>
<td>Butadiene</td>
<td>Butadiene: 1%</td>
<td>Butane: 2%</td>
<td>Naphtha: 5%</td>
<td>GasOil: 5%</td>
</tr>
<tr>
<td>Mixed butenes</td>
<td>Mixed butenes: 2%</td>
<td>Butane: 6%</td>
<td>Naphtha: 8%</td>
<td>GasOil: 6%</td>
</tr>
<tr>
<td>C5+</td>
<td>C5+: 2%</td>
<td>Butane: 13%</td>
<td>Naphtha: 8%</td>
<td>GasOil: 7%</td>
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<tr>
<td>Benzene</td>
<td>Benzene: 0%</td>
<td>Butane: 0%</td>
<td>Naphtha: 5%</td>
<td>GasOil: 5%</td>
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<tr>
<td>Toluene</td>
<td>Toluene: 0%</td>
<td>Butane: 0%</td>
<td>Naphtha: 4%</td>
<td>GasOil: 3%</td>
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<tr>
<td>Fuel oil</td>
<td>Fuel oil: 0%</td>
<td>Butane: 0%</td>
<td>Naphtha: 2%</td>
<td>GasOil: 18%</td>
</tr>
</tbody>
</table>

Source: *Chemistry Of Petrochemical Processes*. Sami Matar, Lewis Frederic Hatch
### Ethylene and Propylene Plant Projects in North America

<table>
<thead>
<tr>
<th>Project</th>
<th>Type</th>
<th>Exp/New</th>
<th>InService</th>
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<tr>
<td>Dow Freeport LHC7 TX</td>
<td>Ethylene</td>
<td>Expansion</td>
<td>Jan-2015</td>
</tr>
<tr>
<td>Dow Plaq LHC2 LA</td>
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<td>Expansion</td>
<td>Jan-2015</td>
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<tr>
<td>Dow Plaq LHC3 LA</td>
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<td>Expansion</td>
<td>Jan-2017</td>
</tr>
<tr>
<td>Equistar Corpus TX</td>
<td>Ethylene</td>
<td>Expansion</td>
<td>Jan-2015</td>
</tr>
<tr>
<td>Equistar Channel 1 TX</td>
<td>Ethylene</td>
<td>Expansion</td>
<td>Jan-2015</td>
</tr>
<tr>
<td>Equistar LaPorte TX</td>
<td>Ethylene</td>
<td>Expansion</td>
<td>Jan-2016</td>
</tr>
<tr>
<td>INEOS Choc Bayou TX</td>
<td>Ethylene</td>
<td>Expansion</td>
<td>Jan-2014</td>
</tr>
<tr>
<td>Sasol Lake Charles LA</td>
<td>Ethylene</td>
<td>Expansion</td>
<td>Jan-2017</td>
</tr>
<tr>
<td>Westlake Calvert City KY</td>
<td>Ethylene</td>
<td>Expansion</td>
<td>Apr-2014</td>
</tr>
<tr>
<td>Westlake Sulphur 1 LA</td>
<td>Ethylene</td>
<td>Expansion</td>
<td>Jan-2015</td>
</tr>
<tr>
<td>WMB Geismar LA</td>
<td>Ethylene</td>
<td>Expansion</td>
<td>Apr-2014</td>
</tr>
<tr>
<td>Formosa Pt Comf 3 TX</td>
<td>Ethylene</td>
<td>NewBuild</td>
<td>Jul-2016</td>
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<tr>
<td>Exxon Baytown 3 TX</td>
<td>Ethylene</td>
<td>NewBuild</td>
<td>Jul-2016</td>
</tr>
<tr>
<td>ChevPhil Baytown TX</td>
<td>Ethylene</td>
<td>NewBuild</td>
<td>Jan-2017</td>
</tr>
<tr>
<td>Dow Freeport LHC9 TX</td>
<td>Ethylene</td>
<td>NewBuild</td>
<td>Apr-2017</td>
</tr>
<tr>
<td>OxyChem/Mexichem</td>
<td>Ethylene</td>
<td>NewBuild</td>
<td>Jul-2017</td>
</tr>
<tr>
<td>ShellChem Monaca PA</td>
<td>Ethylene</td>
<td>NewBuild</td>
<td>Jan-2018</td>
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<td>Etileno XXI MX</td>
<td>Ethylene</td>
<td>NewBuild</td>
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<tr>
<td>C3 Petro PDH TX</td>
<td>Propylene</td>
<td>NewBuild</td>
<td>Oct-2015</td>
</tr>
<tr>
<td>Dow Freeport PDH TX</td>
<td>Propylene</td>
<td>NewBuild</td>
<td>Jan-2015</td>
</tr>
<tr>
<td>Formosa PDH TX</td>
<td>Propylene</td>
<td>NewBuild</td>
<td>Jan-2016</td>
</tr>
</tbody>
</table>

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Some Possible NGL-NA Scenarios

- Alternative shale gas production buildups
- Changing patterns of dry and wet gas play development
- Wetness and composition assumptions for new plays
- Proposed new NGL pipelines or expansions of existing ones
- Re-purposing of gas pipelines for NGL mix or purity products
- New gas processing plants and fractionators
- New ethylene and PDH plants or capacity expansions
- Changes in refinery feedstock slates
- LPG import & export capacity expansion
- Propane market growth assumptions
- Diluent market growth in Alberta
Base Case Assumptions

- 13Q4 base supply scenario from RBAC using GPCM®
- All existing and announced NGL infrastructure projects
  - Gas processors, fractionators, storage, pipelines, export facilities
- Refinery capacity utilization stays at 2013 levels
- Include all announced ethylene plant capacity expansions
- Petchem capacity utilization increases to 95%
- Other demand for propane and butane stays constant
- Steady fast rise in AB oil sands demand for diluent
- Imports and exports with non-North American countries (Rest of World - ROW) balance the market
Alternative Scenarios

- **“Big Build”**
  - All of Base Case assumptions and ...
  - Also includes announced new greenfield ethylene crackers and propane dehydration plants - 95% capacity utilization

- **“Light Feed”**
  - All of Base Case assumptions and ...
  - 50% reduction in gasoline blending requirement for C5+
    - Increased production of light crudes in the US plus use of light naphtha and C5+ as diluent in “dilbit” and “railbit” from AB could reduce the amount of C5+ used in gasoline blending
  - Actual amount of effect is under study. This study assumption could give a preliminary estimate for the magnitude of possible impact.
“Big Build” vs “Base Case”

- US ethane production increases steadily from 2015 to 2020 reaching 1.4 (Base Case) and 1.5 (Big Build) million bbl per day by 2020 (see figure next slide)
  - Increasing ethane production at fractionators a result of increasing C2+ NGL mix production (more NGL mix, less C2 rejection)
  - Additional supply is generated by a reduction in C2 exports to other countries (increase in “net imports”)
- Mexico produces more C2 to satisfy requirements of new build Etileno XXI ethane-fed cracker
- Canadian production declines slightly – no demand expansions fed from Western Canada

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"Big Build" vs "Base Case"

C2 Supply Disposition (bbl/day)

<table>
<thead>
<tr>
<th>Country</th>
<th>Com</th>
<th>Year</th>
<th>Plant Prod</th>
<th>Net Imports</th>
<th>Net Stor WD</th>
<th>Net Supply</th>
<th>Chem Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAN</td>
<td>C2</td>
<td>2015</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>CAN</td>
<td>C2</td>
<td>2016</td>
<td>-5,000</td>
<td>5,069</td>
<td>-69</td>
<td>0</td>
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<td>CAN</td>
<td>C2</td>
<td>2017</td>
<td>-5,793</td>
<td>5,145</td>
<td>69</td>
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<td>-579</td>
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<tr>
<td>CAN</td>
<td>C2</td>
<td>2018</td>
<td>-6,645</td>
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<td>-1,148</td>
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<td>CAN</td>
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<td>2019</td>
<td>-6,535</td>
<td>5,387</td>
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<td>-1,148</td>
<td>-1,148</td>
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<td>C2</td>
<td>2020</td>
<td>-4,126</td>
<td>2,978</td>
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<td>-1,148</td>
<td>-1,148</td>
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<td>MEX</td>
<td>C2</td>
<td>2015</td>
<td>15,854</td>
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<td>17,366</td>
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<td>C2</td>
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<td>41,053</td>
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<td>2020</td>
<td>43,113</td>
<td>0</td>
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<td>C2</td>
<td>2015</td>
<td>170</td>
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<td>25,915</td>
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<td>63,468</td>
<td>40,607</td>
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<td>104,075</td>
<td>104,075</td>
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</tbody>
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Ethane Prices

- **Base Case:** ethane price drops 30% (from 2013 levels)
  - Increasing production of natural gas and NGLs make ethane too plentiful to be absorbed by the petchem market, even with expansions, supplemented by a small volume of exports

- **Big Build:** ethane price increases by 15%
  - In addition to expansions and feedstock conversions of existing plants, *new builds* of ethylene plants *fed by ethane* are required in order to produce a modest recovery of ethane prices
  - More builds or substantially greater ethane exports are needed for more substantial price increases

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“Light Feed” vs “Base Case”

- US C5+ production experiences a modest decline in the Light Feed scenario compared to Base Case
  - Canadian C5+ production increases slightly to make up for reduced imports from the US (for diluent)
  - Mexican production is virtually unaffected
- Imports of C5+ (natural gasoline) are lower in the Light Feed scenario for US, Canada, and Mexico
  - The decline in demand for C5+ in the refinery sector is mostly accounted for by these reductions in imports into North America
- C5+ price is about 3% lower in the Light Feed scenario
### “Light Feed” vs “Base Case”

#### C5+ Supply Disposition (bbl/day)

<table>
<thead>
<tr>
<th>Country</th>
<th>Com</th>
<th>Year</th>
<th>Plant Prod</th>
<th>Net Imports</th>
<th>Net Stor WD</th>
<th>Net Supply</th>
<th>Ref Use</th>
<th>Mkt Dlvs</th>
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<tbody>
<tr>
<td>CAN</td>
<td>C5+</td>
<td>2015</td>
<td>1,036</td>
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<td>2,397</td>
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<td>C5+</td>
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<td>-7,435</td>
<td>-7,435</td>
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<td>USA</td>
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<td>2016</td>
<td>-2,364</td>
<td>-81,007</td>
<td>191</td>
<td>-83,180</td>
<td>-83,184</td>
<td>4</td>
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<tr>
<td>USA</td>
<td>C5+</td>
<td>2017</td>
<td>-1,621</td>
<td>-80,592</td>
<td>-1,019</td>
<td>-83,231</td>
<td>-83,200</td>
<td>-31</td>
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<tr>
<td>USA</td>
<td>C5+</td>
<td>2018</td>
<td>-885</td>
<td>-82,617</td>
<td>208</td>
<td>-83,294</td>
<td>-83,284</td>
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<tr>
<td>USA</td>
<td>C5+</td>
<td>2019</td>
<td>-815</td>
<td>-83,387</td>
<td>756</td>
<td>-83,483</td>
<td>-83,474</td>
<td>-9</td>
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<tr>
<td>USA</td>
<td>C5+</td>
<td>2020</td>
<td>-248</td>
<td>-83,309</td>
<td>66</td>
<td>-83,492</td>
<td>-83,488</td>
<td>-3</td>
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Study Conclusions

- Without substantial increases in demand for ethane, its price will continue to deteriorate and it is likely that more and more will be rejected into the natural gas stream, to the limits of pipelines’ willingness and ability to accept it.
  - Exports of ethane through announced expansions would be insufficient by themselves to support a price recovery in the ethane market. New ethane-fed ethylene plants are needed.
  - Building all the announced new ethylene plants for the US and Mexico would halt the decline in ethane prices which could increase by a modest 15%.
  - Higher prices would need additional plants or more export projects.

- The principal effect of increasingly lighter refinery crude slates with higher levels of condensate is likely to be a reduction in the amount of C5+ required for gasoline blending.
  - Lower C5+ demand is balanced by substantially lower imports.
  - C5+ price is not affected significantly by such a reduction in demand.

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Data Sources

- US Energy Information Administration
  - Natural Gas: marketed production, gas processed, shrinkage, plant fuel, liquids extracted (by state)
  - NGL/LPG: production, storage, imports, exports, movements (by PADD), EIA-757: Gas processing plant data, refinery inputs and production
- Federal Energy Regulatory Commission
  - NGL pipeline tariffs
- US Surface Transportation Board
  - Rail transport costs
- Statistics Canada
  - Canadian natural gas and NGL supply and demand data
- Canadian Energy Research Institute (CERI)
  - Canadian NGL industry operations and infrastructure
- PEMEX / SENER
  - Mexican natural gas and NGL supply, demand and infrastructure
- LPG Almanac (Sulpetro)
  - Processing plant, fractionator, refinery, and terminal location info, capacity, storage, and production history (US/Canada)
- Oil Price Information Service (OPIS)
- Individual Company Websites

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