NGL-NA Overview

- **Model Impetus**
  - **Shale Gas Revolution**
    - Technological innovations: horizontal drilling, hydraulic fracturing, 3&4D seismic + standardized, factory-like drilling processes
    - Result 1: record gas production levels and crashing gas prices
    - Result 2: lower prices drive drilling from dry gas to wet gas then to oil
    - Result 3: record gas liquids production and crashing prices
    - Result 4: stampede to build new infrastructure to process new gas and transport, fractionate, store, and “crack” record volumes of NGL

- **Industry Need**
  - Realistic analytical tool to help firms do better planning and make prudent infrastructure investment decisions

- **Application areas**
  - Midstream: processing, fractionation, transportation, storage
  - Downstream: petrochemicals, refineries, international trade
  - Trading/Marketing: hedging, origination, logistics

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### 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>C(_2)H(_6)</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>C(_3)H(_8)</td>
<td>Residential and commercial heating; cooking fuel; petrochemical feedstock</td>
<td>Home heating; small stoves and barbecues; LPG</td>
<td>Industrial, Residential, Commercial</td>
</tr>
<tr>
<td>Butane</td>
<td>C(_4)H(_10)</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>C(_4)H(_10)</td>
<td>Refinery feedstock; petrochemical feedstock</td>
<td>Alkylate for gasoline; aerosols; refrigerant</td>
<td>Industrial</td>
</tr>
<tr>
<td>Pentane</td>
<td>C(_5)H(_12)</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 C(_5)H(_12) 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>

C indicates carbon, H indicates hydrogen; Ethane contains two carbon atoms and six hydrogen atoms. "Pentanes plus is also known as "natural gasoline." Contains pentane and heavier hydrocarbons.
NGLs – How do they get made?

Figure 1. Generalized Natural Gas Processing Schematic

* Optional Step, depending upon the source and type of gas stream.
* Source: Energy Information Administration, Office of Oil and Gas, Natural Gas Division.
Regional Distribution of Gas Processing
Regional Variation in Gas “Wetness”

Source: NPC Paper #1-13 “Natural Gas Liquids (NGLs), 15Sep11
Major NGL Pipeline & Storage Map
“Raw Mix” NGL Pipelines

Source: Bentek

Existing and Proposed Raw Mix Pipelines

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NGL-NA Modeling Approach

- Similarities to GPCM® N/G Market Forecasting System
  - Highly Granular Infrastructure
  - Node/Arc Structure
  - Competitive Market Model

- Consistency with GPCM
  - Consistent supply area – play definition
  - GPCM supply forecast is vital input to NGL-NA
  - NGL-NA solution feeds back to GPCM (C2 rejection)

- Primal-Dual Optimization Model (Market Clearing)
  - Primal solution: Product Flows
  - Dual solution: Market Prices

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NGL-NA Flow Model: Structure

- **Gas Supply**
  - Production and price (by supply area and play)
  - Composition (by supply area and play)
    - “Wetness” (gallons of liquids per thousand cubic feet of gas)
    - NGL Composition (relative amounts of each NGL component)

- **Processing and Conversion**
  - Gas processing, NGL fractionating, NGL “cracking” into ethylene, propylene, butadiene, other olefins

- **Transportation** (NGL mix and purity products)
  - Pipeline, rail, truck, barge

- **Storage**
  - Underground caverns, aboveground tanks at terminals

- **Markets**
  - Space heating, crop-drying, transportation, feedstock, exports

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NGL-NA Flow Model: Granularity

- Infrastructure Inventory
  - Gas Processing Plants ~ 600
  - NGL Raw Mix Pipelines ~ 60
    - Other Modes of Transport
      - Rail
      - Truck
      - Barge/Vessel
  - Fractionation Plants ~ 100
  - Terminals and Storage Facilities ~ 300
  - Petchem Plants ~ 40
  - Refineries ~ 150
NGL-NA Flow Model: Other Factors

- Petchem plant factors
  - Feedstock slate
  - Feedstock yields
  - Planned utilization vs downtime
  - Chemical industry demand
  - By-product value

- Refinery factors
  - Crude oil assay trends
  - Gasoline blending stock demand
  - Naphtha and gas-oil production

- Global market factors
  - North American market balance
  - Global market prices and demand

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NGL-NA Flow Model-Phase 2

- Oil & Gas Production
- Crude Oil Imports
- Crude Oil
- Condensate
- Wet Gas Processing
- NGL Mix
- Residue Gas
- Fractionation
- Refined Products
- Refining Complex
- Dry Gas
- Gas Processing
- Ethane
- Propane
- N-Butane
- Iso-Butane
- Pentane+
- Naphtha Gas-Oil
- Other Butane Markets
- N-Butane
- Pentanes+
- Butadiene
- Butenes
- BTX
- Diluent Markets
- Export Markets
- Export Markets
- Non-Petchem Propane Markets
- Ethylene
- Propylene
- Butadiene
- Butenes
- BTX

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NGL-NA Flow Model
Node-Arc Structure

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NGL-NA Flow Model: Combined Processing and Fractionation

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NGL-NA / GPCM Interaction

GPCM Model (Simplified)

Gas Production

NGL-NA Model (Simplified)

Pricing Models
- Driven by Supply and Demand Balancing Mechanisms
- Ongoing R&D to determine drivers and feedback methodology

Yes

Natural Gas Pipelines

Storage

Natural Gas Pipelines

Rejection

No

Gas Processing Plant

Mixed NGL Pipelines

NGL Fractionation

NGL Storage

NGL Exports

NGL Pipelines

NGL Wholesale

Gas Production

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NGL-NA Pricing Model: Factors

- **Value-Added Processes**
  - Gas Processing (Cryogenic, Absorption, Refrigeration)
  - NGL-Mix Transportation
  - Fractionation
  - Storage
  - Purity Product Transportation
  - Conversion of NGLs to Olefins

- **Market Prices**
  - Natural Gas – Exogenous (GPCM or other source)
  - Raw Mix NGLs – Market Clearing (NGL-NA)
  - Purity NGLs – Market Clearing (NGL-NA)
  - Olefins – Exogenous
  - Naphtha / Gas-Oil – Exogenous

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Model Implementation

- **NGL-NA Mathematical model developed in AMPL**
  - **Sets**: supply areas, GPPs, fractionators, terminals, transportation links, etc.
  - **Parameters**: costs, capacities, and efficiencies for processing, storage, transportation, etc.; exogenous inputs (gas production and price, other prices)
  - **Variables**: transport flows, storage levels, process feeds and outputs, deliveries to markets
  - **Constraints**: input-output balances at gas processing plants, fractionators, petchem facilities, storage facilities; capacity constraints; min-max feed restrictions and storage levels
  - **Objective Function**: maximize system-wide economic surplus
  - **Solution algorithm**: primal/dual simplex (Gurobi)
Making NGL-NA Solvable

• To be practical a model must solve quickly
• Large non-linear models solve very slowly if at all
• Linear optimization models can be solved quickly by modern codes, even when VERY large
• NGL-NA is a highly granular, multi-period, large-scale non-linear model of the North American NGL market
• Thus linearizing NGL-NA is a really good idea
NGL-NA Non-Linearity Problem #1

- What to do with market clearing models where the objective function has non-linear terms?
  - Integrals of price-dependent supply and/or demand curves over the price domain: shaded areas in figure to right.
NGL-NA Solution #1

- Solution:
  - Step function approximations for supply/demand curves
  - Objective function becomes linear
  - Clean separation of primal and dual variables
  - Solvable using fast primal-dual simplex algorithm

\[ \begin{align*}
  p & \quad (p_0, p_1, p_2, p_3, p_4, \ldots) \\
  q & \quad (q_0, q_1, q_2, q_3, q_4, \ldots) \\
\end{align*} \]

- The width of each vertical segment is the incremental demand available if and when the price decreases to the next level.
- The total demand available at price \( p_4 \) is \( q_0 + q_1 + q_2 + q_3 + q_4 \).
- As price decreases, total demand increases at an increasing rate until it approaches a maximum “saturation” demand level.
NGL-NA Non-linear problem #2

- NGL Composition and Mixing
  - Natural gas supply has different compositions in each area and play
  - Gas processing plants produce NGL mixes with different compositions
  - Mixing NGL mixes forms new compositions which depend on the volumes mixed, resulting in a model non-linear in the constraint set (very bad)
    - E.g. Composition C is a mixture of NGL mixes A and B
    - Let’s compute the fraction of C₂ in this mixture:
      - \( f(C, C₂) = \frac{q(A) * f(A, C₂) + q(B) * f(B, C₂)}{q(A) + q(B)} \)
      - Even if \( f(A, C₂) \) and \( f(B, C₂) \) are constant, \( f(C, C₂) \) is non-linear in the flow volumes \( q(A) \) and \( q(B) \)
      - Mixture compositions are non-linearly flow dependent
NGL-NA Solution #2

Solution

• Define “NGL composition” as the fraction of C2 through C5+ in the wet gas (i.e. excluding methane)
  • Define a set of such NGL compositions based on industry reports of gas composition in different regions and plays
• Specify a set of processing efficiencies for each type of gas processing plant and mode (C2 recovery vs rejection)
  • The number of unique compositions is no more than the product of these two sets (might be less)
• Define each such combination as a unique commodity
• Each such NGL mix commodity is transported and stored separately from others until fractionated
  • The transformation matrix for fractionation is the NGL mix composition times the fractionation efficiency for each component
• Modeling issue: the number of such mixes could get large, increasing the size of model substantially
  • Modeler needs to define a workable number of unique compositions
• But ... model is still linear – so solvable in a reasonable time

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Development Progress and Plan

- Phase 1 – NGL Market with Assumed Petchem Demand
  - 1a - PADD Level (done)
  - 1b - Detailed infrastructure (done)
  - 1c – Calibration: Data and Methods (started)
  - 1d – Beta testing: August 2013
  - 1e – Full-scale deployment: Q4 2013

- Phase 2 – Extending the Model: Q4 2013 - 2014
  - More detailed petrochemical sector
  - More detailed refinery interaction with NGL market
  - Integration of Canadian infrastructure and markets
  - Integration of Mexico (lots of unknowns)
PADD Level NGL-NA Model
## PADD Level Performance Tests

<table>
<thead>
<tr>
<th>Scenario</th>
<th>7 year</th>
<th>30 year</th>
<th>60 year</th>
<th>100 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>From Date</td>
<td>Jan-2006</td>
<td>Jan-2006</td>
<td>Jan-2006</td>
<td>Jan-2006</td>
</tr>
<tr>
<td>Thru Date</td>
<td>Dec-2012</td>
<td>Dec-2035</td>
<td>Dec-2065</td>
<td>Dec-2105</td>
</tr>
<tr>
<td>NVars</td>
<td>296,782</td>
<td>1,161,226</td>
<td>2,282,626</td>
<td>3,777,826</td>
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<tr>
<td>NCons</td>
<td>191,723</td>
<td>779,447</td>
<td>1,544,087</td>
<td>2,546,807</td>
</tr>
<tr>
<td>Obj Fn Value ($bn)</td>
<td>590</td>
<td>3,206</td>
<td>7,014</td>
<td>12,516</td>
</tr>
<tr>
<td>SolveTime (sec)</td>
<td>31</td>
<td>262</td>
<td>685</td>
<td>1,843</td>
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<tr>
<td>AMPLTime (sec)</td>
<td>54</td>
<td>199</td>
<td>396</td>
<td>671</td>
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<tr>
<td>MiscTime (sec)</td>
<td>6</td>
<td>25</td>
<td>55</td>
<td>88</td>
</tr>
<tr>
<td>TotalTime (sec)</td>
<td>91</td>
<td>486</td>
<td>1,136</td>
<td>2,602</td>
</tr>
</tbody>
</table>
Run Time Quadratic in Problem Size

\[ y = 0.0012x^2 + 0.1214x + 29.575 \]

\[ R^2 = 0.9985 \]
Sample Result: Shadow Price: Fractionation Capacity

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Sample Result: Ethane Rejection

C2 Rejection%
Data Sources

- **US EIA**
  - Natural Gas
    - Marketed production, gas processed, shrink, fuel
  - NGL/LPG
    - Production, storage, imports, exports, movements (by PADD)
    - EIA-757: Gas processing plant data
- **DI Desktop (HPDI) from Drillinginfo, Inc.**
  - Gas processing data (Texas, Louisiana)
- **Sulpetro LPG Almanac**
  - Processing plant location info, capacity, production history
  - US and Canada
- **Company Websites**
  - Individual plant descriptions and information

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