Natural Gas Industry In Peru

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Camisea Natural Gas Reservoir

- The Camisea natural gas reserve located in Peru
- Discovered in 1980 by Shell Oil
- Approximately 11 trillion ft³, estimated 600 million bbl reserve
Objective: Present business plan based on varying initial investments

GOALS:

- Research Peruvian market
- Research petrochemical products produced using natural gas
- Find imported petrochemical products
- Use business model to compare different options
Project Scope

- Investigate entire natural gas market
- Eliminate processes
- Determine fixed capital investment and operating costs for processes
- Product prices
- Product demands
- Deterministic Model
- Stochastic Model
Camisea Pipeline Project

- Route: Camisea Reservoir to Pisco
- Current rate: 400 million cubic feet per day
- Two pipelines
  - NGL (natural gas liquids)
  - Natural Gas
Pipeline Economics

- Length of pipeline: 155 miles ~ 250 km
- Total cost: $2.7 billion US dollars
- Cost per mile: $17.4 million
Plant Design
Deterministic Model

- Optimization software
  - GAMS

- Function
  - Calculates net present worth
  - Selects if and when a process is to be constructed
  - Selects process capacities
  - Regulates expansions
Deterministic Model

- Data required
  - Pipe cost from Camisea to Pisco
  - Fixed capital investment
  - Operating cost
  - Chemical prices
  - Demand
Process Selection
Eliminated Processes

- Acetic Acid
- Formaldehyde
- Urea
- Phenol
- Styrene
Acetic Acid/Formaldehyde

- Acetic Acid
  - Products not in high demand for market

- Formaldehyde
  - Market in region dominated by Brazil
  - Demand satisfied


*Chemical Week; June 30-Jul 7, 2004. pg 40
Urea Process

- Decreasing demand for product
- More economical products can be made by natural gas

Phenol/Styrene

- Phenol
  - Increasing prices, low margins
  - Market is saturated

- Styrene
  - Market for phenol currently satisfied by local companies

Product Evaluation

- Not selling individual gases
  - Ethane
  - Pentane

- These products used in other processes to yield higher profit products
Different Investment Options

- Need to determine
  - What processes to build
  - Capacities
  - Expansions
  - Reinvestment
Methods To Calculate Fixed Capital Investment

- Equipment cost breakdown
  - Process flow diagrams
    - Pressure drop
    - Change in temperature
    - Duties
    - Residence time
    - Conversion
    - Heat transfer coefficients
  - Direct Costs/Indirect Costs
- Research provided by other companies
Ethylene Synthesis

• Initiation

\[ C_{n}\text{H}_{2n+2} \rightarrow C_{m}\text{H}_{2m+1}. + C_{(n-m)}\text{H}_{2(n-m)+1}. \]

• Propagation

\[ C_{n}\text{H}_{2n+2} + C_{m}\text{H}_{2m+1}. \rightarrow C_{n}\text{H}_{2n+1}. + C_{m}\text{H}_{2m+2} \]
\[ C_{n}\text{H}_{2n+1}. \rightarrow C_{m}\text{H}_{2m} + C_{(n-m)}\text{H}_{2(n-m)+1}. \]

• Termination

\[ C_{n}\text{H}_{2n+1}. + C_{m}\text{H}_{2m+1}. \rightarrow C_{n}\text{H}_{2n} + C_{m}\text{H}_{2m+2} \]
\[ C_{n}\text{H}_{2n+1}. + C_{m}\text{H}_{2m+1}. \rightarrow C_{n}\text{H}_{2n+2} + C_{m}\text{H}_{2m} \]
\[ C_{n}\text{H}_{2n+1}. + C_{m}\text{H}_{2m+1}. \rightarrow C_{n+m}\text{H}_{2(n+m)+2} \]
Ethylene Synthesis Technology

ABB Lummus Global SRT Cracking Technology

- 1.5 MMTA
- Residence time of <1s
- Good environmental performance
Fixed Capital Investment vs. Capacity of Ethylene Synthesis

\[ y = 2.2169x + 29.716 \]
Operating Cost vs. Capacity

Cost: $y = 6.0234x + 2.1775$

Capacity (kg/s) vs. Operating Cost (million $/yr)$
Low Density Polyethylene

- Overall polymerization reaction:
  \[ n(CH_2=CH_2) \rightarrow (-CH_2-CH_2-)_n \]
- Peroxides provide the source of free radicals
- Catalyst is a Ziegler-Natta
ExxonMobil High-Pressure Process for Low Density Polyethylene
Low Density Polyethylene Technologies

Polimeri Europa High-Pressure Process

- **Benefits**
  - Ziegler-Natta catalyst allows for flexibility of products
  - 400,000 MTA
  - Conversions up to 30%
Low Density Polyethylene Technologies

ExxonMobil High-Pressure Process

- Benefits
  - Predominant polyethylene process
  - 400,000 MTA
  - Control of product properties and quality
  - Conversion up to 40%
Phillips Polypropylene Process

- Ziegler-Natta catalyst

- Overall Reaction

\[ \text{Ti-Et} + n(\text{CH}_3\text{CH}_2=\text{CH}) \rightarrow \text{Ti(CH}_3\text{CH}_2\text{CH})_n\text{-Et} \]
Phillips Polypropylene Process Description

**Mixture fed to pipe loop reactor**
- High-purity propylene
- Ethylene comonomer
- Catalyst
- Modifiers

**Separator**
- Catalyst residues
- Soluble polymer slurry

**Flash drum**
- Soluble polymer slurry

**Dryer**
- Soluble polymer

**Extruder**
- Polymer pelletized
Polypropylene Technologies

BASF Novolen

- Benefits
  - Excellent homogeneity
  - Flexible
  - Emission result only from leaks
  - Low utility costs

Phillips

- Benefits
  - Simplest, most efficient process
  - Flexible
  - Operate on a wide variety of catalysts
  - Low waste
High Density Polyethylene

- Manufactured using 3 process technologies at low pressure
  - Slurry
  - Solution
  - Gas Phase
- Ziegler-Natta catalyst or chromium oxide
- Highest crystallinity
Phillips High Density Polyethylene Process
High Density Polyethylene Technologies

- Hoechst
  - Control of molecular weight
  - Optimal steady state behavior
  - Low investment costs

- Phillips
  - Predominant technology
  - Simple
  - Low investment costs
Linear-Low Density Polyethylene

- Processes
  - Gas Phase
  - Solution

- Catalysts
  - Ziegler (titanium)
  - Phillips (chromium)
• Fixed Capital Investment
  • Tanker cost
• Operating costs
  • Crew cost
  • Lubes & Stores
  • Maintenance & Repair
  • Insurance
  • Administration
  • Fuel

Liquid Natural Gas
Ammonia Synthesis

CH₄ + H₂O → CO + 3H₂
CO + H₂O → CO₂ + H₂

2CH₄ + O₂ → 4H₂ + 4N₂

CO + H₂O → CO₂ + H₂

N₂ + 3H₂ → 2NH₃
Ammonia Synthesis

- Five technologies
  - ICI process
  - Haldor – Topsoe process
  - Uhde Ammonia process
  - Kellogg Brown & Roots Advanced Ammonia plus process (KAAPplus™)
Ammonia Synthesis

KAAP plus™:

- Lower capital cost
- Improved reliability
- Reduced operating cost
- Lower energy consumption
Fertilizer - Ammonium Nitrate

- Ammonium Nitrate from Ammonia

  - Nitric acid formation:
    - \( \text{NH}_3 (g) + 2\text{O}_2 (g) \leftrightarrow \text{HNO}_3 (aq) + \text{H}_2\text{O} (l) \)

  - Ammonium nitrate fertilizer:
    - \( \text{HNO}_3 (aq) + \text{NH}_3(g) \leftrightarrow \text{NH}_4\text{NO}_3 (aq) \)
Nitric Acid

$4\text{NH}_3 + 5\text{O}_2 \rightarrow 4\text{NO} + 6\text{H}_2\text{O}$

$3\text{NO}_2 + \text{H}_2\text{O} \rightarrow 2\text{HNO}_3 + \text{NO}$

$2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2$
Nitric Acid

- Uhde Nitric acid
  - High pressure
  - Medium pressure
  - Dual pressure

- Dual pressure
  - Lower operating pressure
  - Lower electricity cost
  - Lower catalyst lost (platinum)
Ammonium Nitrate
Vinyl Chloride

- **Vinnolit vinyl chloride process**

\[
\begin{align*}
C_2H_4 + Cl_2 & \rightarrow C_2H_4Cl_2 \\
C_2H_4 + 2HCl + \frac{1}{2}O_2 & \rightarrow C_2H_4Cl_2 + H_2O \\
2C_2H_4Cl_2 & \rightarrow 2C_2H_3Cl + 2HCl
\end{align*}
\]

\[
2C_2H_4 + Cl_2 + \frac{1}{2}O_2 \rightarrow 2C_2H_3Cl + H_2O \text{(overall)}
\]
Vinyl Chloride
Polyvinyl Chloride

\[ nCH_2 = CHCl \rightarrow [-CH_2 - CHCl -]_n \]
Polyvinyl Chloride (PVC)

Suspension-PVC (S-PVC)
- pipes
- constructions
- bottles
- cable
- bags

Emulsion/Paste-PVC (E/P-PVC)
- flooring
- coated fabrics
- wall coverings
Fischer Tropsch

- Converts natural gas into long chain hydrocarbons and oxygenates

- Alternative Production Route
  - Transportation fuels
  - Petrochemical feedstock

- Large capital investment

- Increased interest
  - High crude oil price
Process Steps

- **Synthesis gas manufacturing**: produces a mixture of CO and H$_2$ from natural gas

  \[ \text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2 \] (steam reforming)

- **Fischer-Tropsch synthesis**: converts syngas into a large range of linear hydrocarbons (synthetic crude oil)

  \[ n\text{CO} + 2n\text{H}_2 \rightarrow -(\text{CH}_2)_n- + n\text{H}_2\text{O} \]

- **Product upgrading**: classic crude oil refinery technique
Sasol Technology Fisher Tropsch Process
Technologies

**Sasol Technology**
- Uses coal-derived gas as feedstock
- Autothermal reformer
- Cobalt catalyst FT slurry reactor

**Advanced Gas Conversion (AGC-21)**
- Circulating fluidized bed reactor for syngas
- Slurry cobalt catalyst FT reactor
- Developed by ExxonMobil

**Shell Middle Distillate Synthesis (SMDS)**
- Non-catalytic combined reforming process for syngas generation
- Fixed-bed Arge-type FT reactor
Methanol Production

1. Feed Gas Preparation
   produce mixture of CH₄ and steam from Natural Gas

2. Synthesis Gas Generation
   Steam reforming  \[ \text{CH}_4 + \text{H}_2\text{O} = \text{CO} + 3\text{H}_2 \]
   Shift reaction  \[ \text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2 \]

3. Methanol Synthesis
   \[ \text{CO} + 2\text{H}_2 = \text{CH}_3\text{OH} \]
   \[ \text{CO}_2 + 3\text{H}_2 = \text{CH}_3\text{OH} + \text{H}_2\text{O} \]
Flow diagram of a Leading Concept Methanol Plant
Technologies

Low Pressure Methanol (LPM)
- LPM uses low pressure reformer
- Produces 60% of the methanol in the world

Gas Heated Reformer (GHR)
- Enables manufacture of greater volumes of methanol
- Reduces the cost of production

Leading Concept Methanol (LCM)
- LCM brings together GHR with the LPM
- More compact
- More economical
Ethylene Glycol

- Most ethylene glycol plants use hydration of ethylene oxide
- Consisted of two processes
  - Production of ethylene oxide from ethylene
    \[ \text{CH}_2=\text{CH}_2 + \frac{1}{2} \text{O}_2 \rightarrow (\text{CH}_2)_2\text{O} \]
  - Production of ethylene glycol from ethylene oxide
    \[ (\text{CH}_2)_2\text{O} + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{OH} - \text{CH}_2\text{OH} \]
Halcon SD Group Ethylene Oxide Process
Ethylene Glycol Process

Schematic flow diagram of Halcon SD ethylene glycol plant
Deterministic Model
## Planning Model Input

<table>
<thead>
<tr>
<th>Process</th>
<th>Fixed Capital Investment</th>
<th>Operating Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethylene Synthesis</td>
<td>$FCI = 2.22Q + 29.72$</td>
<td>$OC = 6.02Q + 2.18$</td>
</tr>
<tr>
<td>Low Density Polyethylene</td>
<td>$FCI = 4.46Q + 9.88$</td>
<td>$OC = 1.30Q + 2.49$</td>
</tr>
<tr>
<td>High Density Polyethylene</td>
<td>$FCI = 9.76Q + 12.83$</td>
<td>$OC = 2.10Q + 2.18$</td>
</tr>
<tr>
<td>Linear-Low Density Polyethylene</td>
<td>$FCI = 9.76Q + 12.83$</td>
<td>$OC = 21.87Q + 2.18$</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>$FCI = 12.92Q + 26.30$</td>
<td>$OC = 1.74Q + 2.18$</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>$FCI = 0.58Q + 6.70$</td>
<td>$OC = 2.92Q + 5.10$</td>
</tr>
<tr>
<td>Polyvinyl Chloride</td>
<td>$FCI = 1.26Q + 16.26$</td>
<td>$OC = 1.85Q + 0.16$</td>
</tr>
<tr>
<td>Ammonia Synthesis</td>
<td>$FCI = 28.45Q + 30.59$</td>
<td>$OC = 6.97Q + 6.75$</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>$FCI = 1.66Q + 10.58$</td>
<td>$OC = 2.04Q + 11.86$</td>
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<tr>
<td>Methanol</td>
<td>$FCI = 6.46Q + 16.11$</td>
<td>$OC = 1.68Q + 22.83$</td>
</tr>
<tr>
<td>Ethylene Glycol</td>
<td>$FCI = 2.05Q + 9.38$</td>
<td>$OC = 2.16Q + 39.22$</td>
</tr>
<tr>
<td>Fischer Tropsch</td>
<td>$FCI = 6.23Q + 156.31$</td>
<td>$OC = 1.33Q + 50.23$</td>
</tr>
<tr>
<td>Liquid Natural Gas</td>
<td>$FCI = 4.47Q + 620.69$</td>
<td>$OC = 0.0027Q + 35.4$</td>
</tr>
</tbody>
</table>
Deterministic Parameters

- Natural Gas Flow Rate
  - Maximum: 10,000,000 ft$^3$/day
  - Minimum: 50,000 ft$^3$/day
- Maximum Initial Investment - $7 Billion
- Taxes – 10%
- Interest Rate – 5%
- Reinvestment – 20%
Initial Model Design Results

- NPW - $40.5 Billion
- FCI - $6.50 Billion
- Expansion Costs - $2.56 Billion
- Natural gas flow rate – 3.5 Million ft³/day
**Reinvestment**

- Reinvestment initially set to 20%
  - Inefficient
- Reinvestment allowed to vary
  - Maximum Value: 100%
  - Minimum Value: 0%
- Increased NPW $12 Billion
## Deterministic Model Results

<table>
<thead>
<tr>
<th>Maximum Initial Investment (Billions)</th>
<th>NPW (Billions)</th>
<th>Actual Initial Investment (Millions)</th>
<th>Reinvestment (Millions)</th>
<th>Capital (Millions)</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>$6</td>
<td>$50.9</td>
<td>$6,000.0</td>
<td>$2,838.83</td>
<td>$8,838.8</td>
<td>57.6%</td>
</tr>
<tr>
<td>$7</td>
<td>$52.5</td>
<td>$6,504.7</td>
<td>$2,558.40</td>
<td>$9,063.1</td>
<td>57.9%</td>
</tr>
<tr>
<td>$8</td>
<td>$53.3</td>
<td>$6,504.7</td>
<td>$2,558.40</td>
<td>$9,063.1</td>
<td>58.8%</td>
</tr>
<tr>
<td>$9</td>
<td>$55.0</td>
<td>$8,963.4</td>
<td>$0.00</td>
<td>$8,963.4</td>
<td>61.4%</td>
</tr>
</tbody>
</table>
NPW Related to Initial Investment

Initial Investment (Billions) vs. NPW (Billions)

- $6: NPW = $50.9 billion
- $7: NPW = $52.5 billion
- $8: NPW = $53.3 billion
- $9: NPW = $55.0 billion
Sensitivity Analysis

- Vary product prices
  - Determine the effect of price on process flow rate
  - Range of prices that does not affect overall results
## Cost Analysis

<table>
<thead>
<tr>
<th></th>
<th>Initial Price ($/kg)</th>
<th>Profitable Price ($/kg)</th>
<th>NPW (Billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Density Polyethylene</td>
<td>$1.65</td>
<td>$3.50</td>
<td>$54.1</td>
</tr>
<tr>
<td>High Density Polyethylene</td>
<td>$1.59</td>
<td>$3.00</td>
<td>$54.2</td>
</tr>
</tbody>
</table>
Cost Analysis

- Polyvinyl Chloride, Initial Price - $1.26/kg
  - New Price - $1.10/kg
    - Built 1\textsuperscript{st} year, not 2\textsuperscript{nd}
    - Smaller process flow rate
  - New Price - $1.00/kg
    - Polyvinyl Chloride not sold

<table>
<thead>
<tr>
<th>PVC Price</th>
<th>NPW (Billions)</th>
</tr>
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<tbody>
<tr>
<td>$1.26/kg</td>
<td>$52.5</td>
</tr>
<tr>
<td>$1.10/kg</td>
<td>$48.7</td>
</tr>
<tr>
<td>$1.00/kg</td>
<td>$45.8</td>
</tr>
</tbody>
</table>
Cost Analysis

- Methanol, Initial Price - $0.316/kg
  - New Price - $0.27/kg
    - NPW - $48.9 Billion

- New Price - $0.10/kg
  - Process still built
  - NPW - $38.4 Billion

<table>
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<th>Methanol Price</th>
<th>NPW (Billions)</th>
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<td>$0.316/kg</td>
<td>$52.5</td>
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<td>$0.25/kg</td>
<td>$48.9</td>
</tr>
<tr>
<td>$0.10/kg</td>
<td>$38.4</td>
</tr>
</tbody>
</table>
Stochastic Model
Stochastic Model

- Stochastic model
  - Uncertainties
    - Price, demand
  - First Stage Variables
    - “Here and Now Decision”
    - Plants built in first five years
  - Second Stage Variables
    - “Wait and See Decision”
    - Capacities, feed flow rate, plants built after fifth years
Stochastic Model

- What is scenarios?
  - A set of prices and demands of each product in each year
- How to generate scenarios?
  - Sampling distribution probability
El Final

Questions?