Overview of the Shale Gas Boom and its Impact on the Chemical Industry

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Chemical Industry - Simplified
Chemical Industry Key Concepts

• Capital
• Risk
• Scale
• Purity
• Commoditization
Birth of Modern Chemicals

In 1920, Union Carbide built the first plant for the production of synthetic organic chemicals from natural gas on a site directly across Elk River. From this nucleus grew the nation’s giant petrochemical industry, employer of thousands.
Chemical Industry Snapshot

Raw Materials
- gas
- oil
- coal
- C3/C4
- Ethane
- Naphtha/Gas Oil
- Other

Cracker
- Propane PDH
- MTO
- steam cracker

Products
- CO₂
- Polypropylene (65%)
- Propylene (7%)
- Oxo Alcohols (7%)
- Acrylonitrile (6%)
- Dimethylterephthalate (4%)
- Acrylic Acid (4%)
- Other (4%)
- Polyethylene (60%)
- Ethylene (15%)
- EO (15%)
- VCM (15%)
- styrene (6%)
- Other (4%)

Source: ICIS CB

Source: CMAI 2012
Polyolefin Growth

<table>
<thead>
<tr>
<th>Year</th>
<th>PE</th>
<th>PP</th>
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<tr>
<td>1990</td>
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<td>200</td>
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<tr>
<td>2014</td>
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</table>

Source: IHS

4.4% CAGR
Our Previous Reality.....
Ethylene Cumulative Supply - 2003

Cash Cost for Ethylene ($/metric ton)

Cumulative Capacity, million metric tons/yr

Source: IHS, Morgan Stanley, ICIS
Global Feedstock Slates Differ
Shale Gas Growth

- U.S. Dry Natural Gas Production (tcf)
- shale gas
- tight gas
- coal-bed methane
- Alaska
- non-assoc offshore
- associated gas
- non-assoc onshore

Time: 1990 to 2040
Growth in NGLs
Rapid Change

from disadvantaged to advantaged

Cash Cost for Ethylene ($/metric ton)

Cumulative Capacity, million metric tons/yr

source: IHS, Morgan Stanley, ICIS
Economic Impact of Shale Gas

- **$72 billion** in new capital investment
- **310 thousand** direct & indirect jobs by 2020
  - 226K add’l jobs generated by household spending
- **$201 billion** in new economic output
- **$14 billion** in new tax revenue by 2020

*97 new chemical industry projects due to shale gas*
Industry Growth

Value of chemical shipments

- 2004: $541B
- 2009: $624B
- 2014: $801B

+48% OVER THE PAST DECADE

Chemical exports

- 2004: $105B
- 2009: $146B
- 2014: $191B

x2

Research and development funding from the chemical industry

- 2004: $39B
- 2009: $49B
- 2014: $59B

+50% OVER THE PAST DECADE

Capital expenditure from the chemical industry

- 2004: $19B
- 2009: $24B
- 2014: $33B

+77%
Exciting Times
Energy Cost

- **Natural Gas** (Henry Hub spot)
- **Oil** (WTI)

**Key Events**:
- **Deterioration of Gas Advantage**
- **Constrained Gas Supply**
- **Oil Drops**
- **Gas Reestablishes Cost Advantage**
- **Major Natural Gas Shale Plays Start Production**

**Graph Details**:
- **X-axis**: Year (1996 to 2014)
- **Y-axis 1**: $/MM BTU (both oil and gas)
- **Y-axis 2**: $/barrel (oil only)
Falling Oil Prices

Cash Cost for Ethylene ($/metric ton)

Cumulative Capacity, million metric tons/yr

Source: IHS, Morgan Stanley, ICIS
NGLs Still Advantaged In The U.S.

- Ethylene Cash Cost (¢/lb)

- Data source: IHS

- Deterioration of Gas Advantage
- Constrained Gas Supply
- Recession

- US data

- Ethane
- Naphtha
Naphtha vs Ethane Cracking Comparison

- CH₄ / H₂ / lights
- fuel oil
- toluene
- benzene
- pygas
- C5
- other C4
- butadiene ~5%
- propylene ~15%
- ethylene ~30%

~3.5 lb/lb C₂=

- CH₄ / H₂
- butadiene
- propylene
- ~80% ethylene
- ~1.1 lb/lb C₂=

same amount of ethylene
All Reaction Products Find Uses

It’s All Good!
U.S. trend is toward lighter gas cracking and it is an old trend.
What’s Gone Away?

C3

C4

C5
NGL Export

Million Barrels (monthly actual)

- Propane
- Butane
- Ethane
If you are moving mass and heat around, and cost of production is most important, scale always wins.
Source of Confusion

A mixture containing a valuable chemical is not the same as a valuable mixture of chemicals.
Make The Cracker Better

Cryogenic Separations
(large capital cost, energy intensive)

Cracking Furnaces

Energy Use

Alternatives

Adsorbent Separations

Membrane Separations

LHC-8 Freeport, TX

Splitter column >200 ft tall

Ethane Cracker Specific Energy Consumption

Separation 31%
Cracking 47%
Compression 22%
New Addition to Feedstock Slate

Gas-based

Middle East
- ethane
- propane

North America
- ethane
- propane

Oil-based

Asia
- naphtha

Western Europe
- naphtha
Methanol-to-Olefins

Oxygen

Hydrogenator

Desulfurization

Saturator

Autothermal Reformer

C$_2$H$_4$ + C$_3$H$_6$ + H$_2$O

Methanol

Methanol-to-Olefins

Reformer

Water

Condensate

Air

CO$_2$

Natural Gas
Announced Projects
**Shale** is a fine-grained sedimentary rock that forms from the compaction of silt and clay-size mineral particles that we commonly call "mud".
Distribution of proved gas reserves: 1994, 2004 and 2014

Percentage

- Middle East
- Europe & Eurasia
- Asia Pacific
- Africa
- North America
- S. & Cent. America

1994 Total 119.1 trillion cubic metres

2004 Total 156.5 trillion cubic metres

2014 Total 187.1 trillion cubic metres
Methane
Direct Methane Use

2008 industry data from BP and CMAI
Long History
Dr. Madan M. Bhasin
Retired Corporate Fellow

The Dow Chemical Company

Elected 2006

For the development of efficient catalysts for the production of ethylene oxide and for contributions to the fundamental understanding of catalysts.

Currently:
Chief Scientific Adviser, Mid-Atlantic Technology, Research & Innovation Center
Activity Peaked and Fell
Constraints

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Methane
Oxygen Storage Riser Idea

- Solids density in riser sets concentration of “oxidant”
- Riser velocity sets reaction time
- Reactor constrains both capacity and rate

For it to work, must have oxygen capacity, rate and regenerability.
Methane

![Price ($/MM BTU) chart showing trends for WTI, ethane, and natural gas from 2008 to 2015.](image_url)

data source: EIA
Case Study
Energy Cost

$\text{$/MM BTU} \quad \text{(both oil and gas)}$

$\text{$/barrel (oil only)}$

- **Natural Gas** (Henry Hub spot)
- **Oil** (WTI)

Events:
- **Deterioration of Gas Advantage**
- **Constrained Gas Supply**
- **Major Natural Gas Shale Plays Start Production**
- **Recession**
- **Gas Reestablishes Cost Advantage**
- **Oil Drops**

Years:
- 1996
- 1998
- 2000
- 2002
- 2004
- 2006
- 2008
- 2010
- 2012
- 2014

Graph shows the fluctuation of energy cost from 1996 to 2014, highlighting key events and trends in both oil and gas markets.
Conventional Production

\[
\begin{align*}
\text{C}_2\text{H}_4 + \text{Cl}_2 & \rightarrow \begin{array}{c}
\text{C}_2\text{H}_4 \\
\begin{array}{c}
\text{Cl} \\
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& \rightarrow \begin{array}{c}
\text{Cl} \\
\text{C}_2\text{H}_4 \\
\text{Cl}
\end{array} + \text{HCl}
\end{align*}
\]

\[
\begin{align*}
\text{C}_2\text{H}_4 + 2\text{HCl} + \frac{1}{2}\text{O}_2 & \rightarrow \begin{array}{c}
\text{C}_2\text{H}_4 \\
\begin{array}{c}
\text{Cl} \\
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\begin{array}{c}
\text{Cl} \\
\text{Cl}
\end{array}
\end{array} + \text{H}_2\text{O}
\end{align*}
\]

\[
\begin{align*}
\text{C}_2\text{H}_4 + \frac{1}{2}\text{Cl}_2 + \frac{1}{2}\text{O}_2 & \rightarrow \begin{array}{c}
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\begin{array}{c}
\text{Cl} \\
\text{Cl}
\end{array}
\end{array} + \text{H}_2\text{O}
\end{align*}
\]
Conventional VCM

- C₂H₆ (Ethylene)
- C₂H₄ (Ethylene)
- Cl₂ (Chlorine)
- NaCl (Salt)
- C₂H₃Cl (Vinyl Chloride)

**Processes:**
- Ethylene Plant
- Chlor-Alkali Plant
- Vinyl Chloride Plant
- Vinyl Chloride Product
Breakthrough

Cu performance

dilute ethylene conditions
Lab Results

84% selectivity to VCM + EDC + EtCl

Ethylene in = Ethylene out

400°C

C₂H₆

C₂H₄

HCl

C₂H₄

HCl

VCM

75 3% sel

COx

Arrow width is proportional to mass flux.

1/21/99 R1
Lanthanide Catalyst

not a redox metal!
Options for Olefins

Syngas / MeOH

Avoid syngas

Avoid intermediates
(methane coupling)
Experience From 2004

ignition quench

![Graph showing mass spec units over time with different markers for methane, oxygen, water, m/z 28, m/z 29, m/z 30, m/z 44. The graph includes a time axis ranging from 0 to 8000 seconds and a mass spec units axis ranging from 0 to 100.](image-url)
The Dow Methane Challenge
1991 Top 50 U.S. Chemical Companies Today

Updated from version shown in on 10 Sept 2015
Chemical Industry Key Concepts

• Capital - don’t want to spend it
• Risk - won’t tolerate it
• Scale - economics demand it
• Purity - markets demand it
• Commoditization - avoid it