The Energy Infrastructure of the Future

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All figures courtesy of Elliott Group, Solar Turbines Inc., Southwest Research Institute, and General Electric
Elliott Group’s Global Manufacturing

Jeannette, PA (Pittsburgh USA)

- 110 Acre Campus
- 802,000 Sq. Ft Factory Area
- Organizational Center for 1000 Professional and Skilled Workers at Site

Sodegaura, Chiba (Tokyo, Japan)

- 41 Acre Campus
- 371,000 Sq. Ft Factory Area
- Organizational Center for 750 Professional and Skilled Employees
Turbomachinery Products

- Multistage centrifugal compressors
  - Axially split (M Series)
  - Vertically split (MB Series)
- Single stage centrifugal compressors
- Axial Compressors
- Hot gas expanders
- Special purpose steam turbines
- General purpose steam turbines
- Cryogenic Pumps
- Cryo Expanders
Connect the Energy Source with the Sink

- Sources of Energy
  - Fossil Fuel Production Sites (Coal, Natural Gas, and Liquids)
  - Alternative Energy Plants (Wind, Solar, and Hydro)
  - Nuclear Power Plants

- Intermediaries/Converters
  - Fossil Fuel Power Plants
  - Energy Storage

- Sinks
  - Industrial Electricity and Gas Users
  - Domestic Gas and Electricity Consumers
Energy Transportation and Storage Efficiency

Transport Losses per 100 miles:
• Electric Transmission Line: 1-10%
• Gas Pipeline: 0.1-0.3%
• Liquid Pipeline: 0.02-0.1%

Storage Losses (Roundtrip Efficiency Losses):
• Battery Storage: 5-10%
• Thermal-Mechanical Storage: 25-50%
• Gas Caverns/Tanks: 1-3%
• Liquid Tanks: 0%

Hydrocarbon Transport/Storage Is Far More Efficient Than Electricity Transport/Storage
Wind, Solar, Hydro Energy Transport

• Option A: Electric Transmission Lines with and without Storage
  • Advantage: No Carbon Footprint, No Energy Conversion Required
  • Disadvantage: High Transmission Losses

• Option B: Hydrogen Conversion And Gas Pipeline Gas Transport
  • Advantage: “Built-In Storage”, No Carbon Footprint, Some Existing Infrastructure
  • Disadvantage: High Conversion Losses (Electrolysis and Heat Engine)

• Option C: Liquid Conversion and Liquid Pipeline Transport
  • Advantage: “Built-In Storage”, Lowest Transportation Losses, Secondary Products
  • Disadvantage: High Conversion Losses, Not Necessarily Carbon Neutral, Lack of Existing Infrastructure

Balance Between Conversion Efficiency and Transportation Efficiency
Fossil Fuel Energy Transport

- **Option A: Pipeline or Rail Transport**
  - Advantages: Existing Infrastructure, No Storage Required, Low Transportation Losses
  - Disadvantage: High Conversion Losses, Not Carbon Neutral

- **Option B: Source De-Carbonization and Hydrogen Pipeline Transport**
  - Advantages: Carbon Sequestration, No Storage Required, Limited Infrastructure
  - Disadvantages: Hydrogen Transport Challenges, Conversion Losses

- **Option C: Pipeline or Rail Transport and Sink De-Carbonization**
  - Advantages: Carbon Sequestration, No Storage Required, Existing Infrastructure
  - Disadvantage: Conversion Losses

**Pre-Transport De-Carbonization Is Least Viable Option**
Gas or Power or Hydrogen to Liquids
Comparison of Reforming Processes

Reforming to produce syngas

\[ \text{CO}_2 + \text{CO} + \text{H}_2 + \text{heat} \]

Ammonia Path

Methanol Path

GTL Diesel Path

Typically use Steam Methane Reformer or Auto-thermal Reformer.

Natural Gas Feed

Steam {& \ O_2}

\[ \text{C}_n\text{H}_{2(n+2)}, \text{typ. Diesel and Naptha} \]

\[ \text{CO}_2 \text{ Removal} \]

\[ \text{Fischer-Tropsch Reaction} \]

\[ \text{ASU, Add } \text{N}_2 \]

\[ \text{Heat, } \text{H}_2\text{O} \]

\[ \text{Polypropylene, Ethylene, Propylene, or gasoline} \]

\[ \text{NH}_3 \]

\[ \text{Cyrogenic Clean-up} \]

\[ \text{NH}_3 + \text{impurities} \]

\[ \text{ Reforming and Shift} \]

\[ \text{CO}_2 \]

\[ \text{Carbon Removal and Conversion} \]

\[ \text{H}_2 \]

\[ \text{Methanation} \]

\[ \text{CH}_4 \text{O} \]

\[ \text{Polypropylene Plant} \]

\[ \text{Polypropylene, Ethylene, Propylene, or gasoline} \]

\[ \text{N}_2 + \text{H}_2\text{O} \]
US Natural Gas Production

Plenty of Gas for Growth...and then some for LNG Export
Energy Costs – What it means to an economy!

2015 USA:
75 bcf/d consumption at $4.5/MMBTU

= 335 million Dollars per day
= 122 billion Dollars per year

≈ The price of 80-100 new large NGCC (750MW Each) power plants per year

Sources: World Bank and Citi Research
- 2.3 million miles of pipelines
- 850-900 mainline compressor stations, 800-900 booster stations (+15,000 gas gathering machines)
- Average age of pipeline compressors: 25-30 years
- Consume/lose about 2.5-3.5% of US NG = 0.7 tcf/y = 3-4 billion US Dollars per year

Minimum of 5,000,000 hp of Compression must be replaced in next 15 years on US pipelines.
Pipeline Compression Equipment Most Commonly Used

**Gas Turbine Driven Centrifugal Compressor:**
- Simple cycle gas turbine driver
- Direct drive compressor (6,000-20,000 rpm)
- Centrifugal compressor with 1-2 impeller stages

**High Speed Separable Recip Compressor:**
- Gas Engine driver
- Direct drive compressor (1200-1600 rpm)
- 2-4 double acting cylinder stages

**Electric Motor Drive:**
- Centrifugal and recip compressors
- With or without gearbox
- Fixed speed or variable speed (VFD)

All figures courtesy of Elliott Group, Solar Turbines Inc., Southwest Research Institute, and General Electric
Pipeline Compression Basic Efficiency Problem

• Driver Efficiency (GT, Engine, Motor): 25-40%
• Driven Equipment (Centrifugal, Recip): 75-90%
• Plant Losses (Bottles, Scrubbers, Filters): 2-5% (Losses)
• Off-Design Operation, Recycle : 0-70% (Losses)
• Leakage and Blowdown: 0-50% (Equivalent Efficiency Losses)

Total Average Compressor Station Efficiency is Always Well Below 20%.

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## Making Pipeline Compression More Efficient

<table>
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<th>Approach</th>
<th>Possible Efficiency Gain</th>
<th>Funded R&amp;D</th>
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<tr>
<td>Improve Driver Efficiency</td>
<td>3-10%</td>
<td>OEM, DOE</td>
</tr>
<tr>
<td>Improve Driven Equipment Efficiency</td>
<td>2-5%</td>
<td>OEM</td>
</tr>
<tr>
<td>Add Recuperation</td>
<td>0-10%</td>
<td>OEM</td>
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<tr>
<td><strong>Add Waste Heat Recovery</strong></td>
<td><strong>15-35%</strong></td>
<td>DOE</td>
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<tr>
<td>Improve Balance of Plant Efficiency</td>
<td>1-5%</td>
<td>Users</td>
</tr>
<tr>
<td>Reduce Leakage</td>
<td>0-30%</td>
<td>OEM, DOE, Users</td>
</tr>
<tr>
<td>Avoid Blowdowns</td>
<td>0-10%</td>
<td>Users</td>
</tr>
<tr>
<td>Optimize Pipeline &amp; Station Operation</td>
<td>0-30%</td>
<td>Users</td>
</tr>
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**Total US R&D Budget WAG:**  
- OEMs: $100-300M  
- DOE: $50-150M  
- Users: $20-60M
Efficiency Standards for Compressors

• 1975 Energy Policy and Conservation Act (EPCA)
  • Gives DOE broad powers to regulate efficiency requirements of consumer products and certain industrial equipment
  • List 11 types of equipment and allows the secretary of energy to add other types of equipment
  • Rules must be documented to be technically feasible, economically justified, and result in significant conservation of energy

• 2012 DOE issues Proposed Determination of Coverage for commercial and industrial compressors

• 2014 DOE issues Request for Information for compressor efficiency standards (includes natural gas compressors)

• 2014 DOE issues Framework Document (air compressors only)

• 2016 DOE issues Minimum Efficiency standards (Final Rule) for air compressors only

• 2017 Administration delays implementation of Final Rule

DOE has Authority to Regulate Oil & Gas Compressor Efficiencies
Future: Natural Gas Compressors

• Unlikely current administration will pursue rulemaking for natural gas compressor minimum efficiency standards

• EPA (both federal and state) can enforce efficiency limits in air permitting process (CO₂ emissions reduction). This is in litigation in several states.

• Current administration’s focus for oil & gas appears to be:
  • Energy independence
  • Improved production and distribution infrastructure
  • Supply reliability
  • Less focus on greenhouse gas emission reductions

Oil & Gas Industry Needs to Address Machinery Efficiency Requirements:
- There will be DOE or EPA rules (eventually)
- Some state EPAs already enforce new station efficiency requirements
- Improves operations economics
Thank You Very Much!

Questions?

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