Pipelines & Tankers

Outline

- LNG Supply Chain: Transportation & Storage
  - Transportation: Pipelines & Tankers
  - Storage
- Government Involvement
- Pipeline Capacity Pricing

Based on
Pipeline Types

◆ Classification by cargo
  – Gas
  – Oil
  – Refined products: Such as dedicated jet fuel pipelines to airports. In total, about 95 K miles in the US.

◆ Classification of oil/gas pipelines by location in the energy supply chain
  – Collection (Root) Pipelines: 2-6 inch diameter
    » 30-40 K miles of oil collection pipelines in oil fields
    » 20 K miles of gas collection in gas fields
  – Transmission (Trunk) Pipelines: 16-48 inch diameter, most interstate pipelines are 24-36 inch diameter.
    » 55 K miles of oil trunk pipelines
    » 278 K miles of gas trunk pipelines.
  – Distribution (Branch) Pipelines all the way to homes
    » 1,800 K miles of gas branch lines in the US.
Granite Wash Tight Sand - NGL & Gas Infrastructure


Pipeline Blue NGL
Rest are Natural Gas
Hexagons are gas processing plants
Circles are refineries
Triangles are storage facilities
Interstate Transmission Pipelines
Gas, Oil and Refined Product


Pipelines
Red for Gas
Green for Oil
Blue for Products (gasoline, propane)

C23 from Denver to Salt Lake City. C7 from Edmonton to Detroit; 20, 24, 34”. C41 from Bakersfield to San Francisco; 8,12, 14”.

Pipeline name and numbering are reminiscent of the interstate highways.
Natural Gas Transportation in USA

Natural Gas Distribution Pipelines

Consumers receive gas from a distribution company whose pipelines connect to transmission pipelines.

-**Atmos Energy**
  - *distributes* gas in Dallas,
  - *owns* pipelines underneath the streets,
  - *needs* to connect every home/business regardless of the cost,
  - *maintains* and *replaces* pipelines

  » **Steel Pipe Replacement Program**: “As part of our daily business, we routinely test and replace gas piping to ensure the safety and reliability of our system. In the months ahead, Atmos Energy will replace steel service lines with polyethylene pipe in neighborhoods throughout our service area.”

- Atmos buys natural gas at the “citygate” from producers and sells to consumers.

  “Commonly, local delivery charges make up about half the total retail cost of natural gas.”

  » **Source**: p.80 of *Energy Trading* (2010) by D. Edwards

- In Atmos bills, **Gas Cost Recovery** (GCR): “This charge recovers the actual gas cost paid to suppliers and the transportation charges paid to deliver gas to the company's distribution system. There is no profit added to the gas cost. This amount is multiplied times your usage.”

  » **Source**: http://www.atmosenergy.com/home/cs/samplebill.html

- In 2011, my bill shows **GCR of $9.4/thousand cf or about $9.4/Million Btu**. Combining above findings: Atmos pays
  - **$4.7/MMBtu to purchase from suppliers**. But prices dropped below $3/MMBtu in 2012.
  - **$4.7/MMBtu to transport to the citygate**. But from where, more on this later.

- **How does Atmos pay for its own expenses?**
  - **Customer charge**: To cover a portion of the fixed costs that it incurs to serve each customer.
  - **Consumption charge**: To cover any remaining fixed costs and the variable costs incurred to serve customers.
  - **Rider fee**: To cover special expenses (replacement of service lines) to provide continued safe and reliable service.
Major ConocoPhillips Pipelines

1 Market share based on all ConocoPhillips stations as a percentage of total stations in region.
2 Terminals based on refined products and LPG terminals with truck racks.
Owner Examples:
BP, Exxon, Shell Crude Pipelines

Main Pass Oil Gathering
Capacity: 168 K bbl/day
Length 92 miles
62 miles 18” diameter
4 miles 20” diameter

BP
Exxon
Shell

LOUISIANA
Empire
Cypress
Delta
MP 60

MPOG
Commissioned
1996

MP 225
VK 823
Virgo

MP 281
CNG

VK 826
Neptune
Marlin
Batching Refined Product in Pipelines

- Same pipeline to simultaneously ship various products
  - Gasoline: 93 Octane, 90 Octane, 87 Octane
  - Ultra Low Sulfur Diesel (ULSD) fuel
  - Heating oil (Low quality diesel)
  - Jet fuel
- Try to ship without mixing the products
  See [http://www.refinerlink.com/blog/pipelines_ship_refinery_products_to_pump](http://www.refinerlink.com/blog/pipelines_ship_refinery_products_to_pump)

- Sequence liquids according to properties: gasoline, sulfur level, etc.
  - Gasoline Similarity: Different octane gasoline products
  - Low sulfur similarity: Diesel fuel and 87 octane gasoline
  - Sulfur similarity: Heating oil (high sulfur diesel) and diesel fuel
- Liquids can mix
  - If similar liquids, sell the mixture as lower grade product.
    » Ex: Mixture of Octane 87 and 90 Gasoline sells as 87 Octane.
  - If dissimilar liquids, the mixture is called transmix & trucked back to a refinery.
- Pigs, plastic spheres or cylinders, inserted into pipelines to avoid mixing.
  - IoT: Robotic pigs move along the pipeline & clean the inner surface of the pipe by scrubbing it, or detect faults & cracks in the pipe.
Pumping Station and Compressors (Pumps)

- As the liquid flows, it slows down due to friction. To speed up the liquid, pumping stations are used
  - **Scrubber** to separate NGL, water, vapor, dirt from gas
  - **Compressor** to re-pressurize
  - **Cooler** to decrease the temperature

Illustration of a gas pumping station

Pipeline Transportation Pumps by Flowserve, Irving, TX (Often Fortune 500)
https://www.flowserve.com/files_FILES/Literature/ProductLiterature/Pumps/fpd-8-e.pdf
Laying Down Pipelines

Source: Photo taken by Luis Carlos Reyna in Mexico in July 2015.
Pipeline Challenge 1: Keystone
2018 Keystone Project - Skipped

Keystone XL to bring oil to Houston refineries.

- 875 miles: Morgan, MT to Steele City, NE.
  - 285 miles in MT, 316 miles in SD, 274 miles in NE.
- Pump station (PS) 9 in Morgan and PS 26 in Steele City, a total of 18 PSs spread over MT, SD, NE.
- Pump stations are electric-powered.
  - A new 230 kV transmission line from Big Bend Dam in SD to Witten Substation between SP 20 and 21 in southern SD.
  - Power will also be provided by local providers.
- PS 14 is in Baker, MT and to be connected to the Bakken field in MT and ND.
- Proposed route avoids environmentally sensitive Sand Hills Region in NE
- Proposed route as of 2014 does not include the segment extending from Cushing, OK to Gulf of Mexico. This segment is being built separately.

Concerns

- greenhouse gas and climate change effects of the extraction, processing, and the crude oil project carries
- potential releases from the project (i.e., spills) could pollute major groundwater resources such as the Ogallala Aquifer
- the impacts of bitumen extraction in Canada
- the crude oil transportation market not adequately analyzed
- the accuracy of job creation estimates for construction and operation of the proposed project

Engineering (failure frequency, risk, leak detection and prevention) Review Report by Battelle
Environmental Review Report by Exponent

Alternative: Bring oil to Kitimat to ship to China.

Pipelines in Europe

Yamal Peninsula 55 Tcm = 2000 Tcf
Russia’s largest energy project

Urengoy 10 Tcm

Shtokman 3.8 Tcm

Yamburg 8.2 Tcm

Yuzhno-Russkoye 0.8 Tcm

1 m = 3.28 ft
3.28³ = 35.3 ft³
1 m³ ≈ 35.3 ft³

Tcm: 10¹² cubic metre
Tcf: 10¹² cubic feet
Bcf: 10⁹ cubic feet
Mmcf: 10⁶ cubic feet
Mcf: 10³ cubic feet

Source: allrussias.com.
China is reaching out for Russian energy

**Pipeline Challenges 2 and 3:**
Central European and Baltic States Depend on Russian Gas

China wants more Russian Gas

Baltic States (Estonia, Latvia, Lithuania) and Central European States (Czech R., Poland, Hungary) receive a significant amount of gas from Russia. For Baltic states, Russian gas constitutes 100% of total gas consumption.

The ratios are lower for Czech R., Poland, and Hungary but significant:

- Russian gas for Hungary meets 30% of total energy consumption.
- Similar numbers for Czech Republic and Poland are 10%.

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**Ties That Bind**

Countries in Central and Eastern Europe, including the Baltic states, have extensive trade and energy ties to Russia. This would likely suffer if relations worsen between Russia and the European Union over Ukraine.

- **GDP growth**: Actual and estimates
- **Share of total exports**: To Russia and To Ukraine
- **Natural-gas imports from Russia**: 80% of total consumption
- **Population**: Ethnics
  - Russians

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**Source for above:** M. Karnitschnig and P. Wasilewski. “Central and Eastern Europe Face Economic Threat From Ukraine Crisis”, WSJ Mar 14, 2014.

**Source for below:** European Energy Security – Conscious Uncoupling. The Economist, Apr 4, 2014.
Pipeline Challenge 4: Indian Gas Market and Pipelines

PNG (Petroleum & Natural Gas) Regulatory Board of India established in 2006, www.pngrb.gov.in

- It regulates the hydrocarbon markets
- Aims for more certainty to investors
- Defends consumer rights

The issue ~ 2012 is extension of Indian natural gas inter-province pipelines

India buys LNG from Qatar and receives it at gasification facilities on its western shores.

- Some gas discovered offshore on the eastern seaboard.

Gujarat is the gas hub but the market is small and regulated with respect to the USA.

Downstream gas market has limited residential customers, the bigger part is industrial, commercial and automobile fuel (CNG).

PNG Regulator wants pipelines to cover the country, especially rural areas. Investors are more interested in urban areas. Regulator licenses rural areas along with urban ones. Investor has exclusive right to deliver in the area for 5 years.

$18 billion pipeline investment needed in the next 5 years

Fractured ownership of the path: Each province can object / stop a pipeline over its land.
Tankers

Source: Photo taken by Sebastiaan (a tanker jetty operator) in Rotterdam in July 2015. Crude tanker is Stena Alexita (263 meters long) built in 1998 and registered in Bahamas.
Oil Tankers: Size and Capacity

Weight capacity in Dead Weight (metric) Ton. DWT = Cargo + Fuel + Seamen + Food + Water + …

<table>
<thead>
<tr>
<th>Type</th>
<th>DWT in 1000s</th>
<th>Barrels in 1000s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refined product tanker</td>
<td>10-60</td>
<td>-</td>
</tr>
<tr>
<td>Medium range/coastal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panamax</td>
<td>60-80</td>
<td>400</td>
</tr>
<tr>
<td>Aframax</td>
<td>80-120</td>
<td>500</td>
</tr>
<tr>
<td>Suezmax</td>
<td>120-200</td>
<td>1,000</td>
</tr>
<tr>
<td>Very large crude carrier</td>
<td>200-315</td>
<td>2,000</td>
</tr>
<tr>
<td>Ultra large crude carrier</td>
<td>320-550</td>
<td>3,000</td>
</tr>
</tbody>
</table>

Air draft length: From water surface to the top. Under bridges
Draft length: From water surface to the keel (bottom). Shallow seas
Beam length: Maximum width of the ship. Through straits
Aframax, Suezmax and Hauls

- **Aframax** refers to large vessels that can be classified as a certain DWT or less. This had tax advantages for shippers in the 1970s. AFRA: Average freight rate assessment.
- **Suezmax**: 1,000,000 Barrel of light oil weighs 140,000 tons.
  - 1 Barrel of water is about 160 kg. 1 Barrel of light oil (density of 0.873 gr/cm³) is about 140 kg = 0.14 ton.
  - 6.3 barrels is 1 cubic metres. 1,000,000 Barrels fit into about 160,000 cubic metres. A cube with 55 meter sides or length 160 metre, width 50 metre, depth 10 metre.
- Because of their weight and size, tankers have high inertia:
  - They can take up to 5 miles to stop.
  - Their turning diameter can be over 1 mile.
  - Turning path is not a perfect circle.
    - Turning path can be constructed.
    - A tanker tuning to port (left) side initially veers off to starboard (right) side.
- **Longer haul**:
  - New routes such as Brazil-China route.
  - Larger tankers. E.g., Hellespont tanker company had several ultra large crude carriers (ULCC) built in 2002. ULCC business had been dormant before then.
- 45% of world crude oil production shipped in tankers in 2010: 1,800 Million ton of crude = 13 Million barrels/day.
- In 2011, 103,392 commercial cargo ships in service with 1,396 million DWT.
  - 475 million DWT oil tankers
  - 532 million DWT dry bulk (coal) carriers
  - 184 million DWT container carriers
  - 109 million DWT general cargo carriers
  - 43 million DWT LNG tankers
Oil Tankers: Prices and Rates

- Global demand for oil tankers is driven by oil demand. Demand ↓ 1.9% in 2009 and ↑ later 2.2% in 2010.
  - China’s oil demand ↑ 10.4% in 2010.
  - It imported 54% of its crude, surpassing self-imposed rule of not importing > 50%.
  - Its reliance on imported oil will increase: 66% in 2015 and 70% in 2020.

- Oil tanker shipping (origin-destination) rates can be found from
  - worldscale.co.uk known as W(orld)S(cale) rates; see example table below
  - www.asba.org : Association of Ship Brokers and Agents

<table>
<thead>
<tr>
<th>WS From * to Yokohoma</th>
<th>Distance in Miles</th>
<th>$/ton</th>
<th>$/barrel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide, Australia</td>
<td>10,574</td>
<td>10.60</td>
<td>1.4840</td>
</tr>
<tr>
<td>Aden, Yemen</td>
<td>13,038</td>
<td>12.39</td>
<td>1.7346</td>
</tr>
<tr>
<td>Chiba, Japan</td>
<td>50</td>
<td>2.90</td>
<td>0.4060</td>
</tr>
</tbody>
</table>

Shipping rates per unit

Unlike renting a car, you cannot drive your tanker. Rate / day is relevant more for the tanker owner.

Cost of the tanker

<table>
<thead>
<tr>
<th></th>
<th>Price million $</th>
<th>Average Rate $/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refined product tanker</td>
<td>$36</td>
<td>-</td>
</tr>
<tr>
<td>Aframax</td>
<td>-</td>
<td>16,800</td>
</tr>
<tr>
<td>Suezmax</td>
<td>$66</td>
<td>25,967</td>
</tr>
<tr>
<td>Very large crude carrier</td>
<td>$103</td>
<td>29,500</td>
</tr>
</tbody>
</table>

- Tanker owner and oil owner negotiate for prices
  - WS80 price refers to 80% of standard (book price) rate.

- They are standard rates as they are based on a tanker
  - Weight: 75,000 tons
  - Speed 14.5 knots = 27 km/hr
  - Fuel consumption
    - for propulsion: 55 ton fuel oil/day
    - for other purposes: 100 ton fuel oil/day
  - Crew and maintenance cost: $12,000/day.
Choke Points in Maritime Oil Transportation

- **sea mines** at Straits of Hormuz
- **heavy traffic** at Straits of Malaca
- **piracy** around Suez Canal, Bab el-Mandab and Straits of Malacca; watch the movie “Captain Phillips”.
- **navigation challenges** at Turkish Straits: The hourly traffic ... is ≈ 6 ships at İstanbul. The 30-kilometre İstanbul strait is not straight; its width drops to approximately 700 metres and it has strong undercurrents and blind turns. 12 million people live around the strait that is busy with local (ferry & fishing) boats. Ships are advised to use local captains as guides, but nearly half opt out. Combining these hazards with the heavy traffic of large ships, it is not surprising that transit and waiting times before entering the strait are respectively about 1.7 and 7 hours (higher for cargo ships), and about 200 accidents happened during the past decade. (Çakanyıldırım and Haksöz 2012).
Storage of Oil and Gas
Complexity of Pipeline Operations Require Storage

Storage is necessary because pipelines cannot be shut down and demand cannot be controlled.
- Turning them on later takes time: Pressure build up is the key.
- Demand ↓ ⇒ gas needs to be stored at the end of pipeline.
- Demand ↑ ⇒ stored gas is used.

Types of Underground Gas Storage

**Working gas** goes into a storage & comes out; **base gas always** remains there for sufficient pressure.

<table>
<thead>
<tr>
<th></th>
<th>Expansion</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depleted</td>
<td>4.9</td>
<td>6.6</td>
</tr>
<tr>
<td>Salt</td>
<td>6.7</td>
<td>8.4</td>
</tr>
<tr>
<td>Aquifer</td>
<td>10.9</td>
<td>13.6</td>
</tr>
</tbody>
</table>

Source: The Importance of Storage, Pipeline and Gas Technology, June 2010: 22-29

Salt domes are impermeable. Geologically sealed.
- Identify them
- Dissolve the center with water & pump it out to clear space.
- Pump gas at high pressure.

Aquifers are permeable. Geologically unknown.
- Explore and test an aquifer
- Gas is injected over the water in aquifer.
- Aquifer-stored gas may need dehydration.
- Leaks are likely.
- Requires relatively more base gas.

For short-term storage (as a real swing option), salt caverns are more appropriate than aquifers.

Source: Energy Information Agency.
Natural Gas Storage in USA and DFW

Underground Natural Gas Storage in the Lower 48 States.
327 Depleted; 29 Salt Cavern; 43 Aquifer in October 2008.

Worsham-Steed is a depleted reservoir
Source: NorTex.com

Aquifer storage least desirable most expensive

Source: Energy Information Agency.
Seasonality of Natural Gas Storage

- Natural gas storage is seasonal; Minimum in April and maximum in October.
  - Colder winter as in 2014-15 ⇒ April inventory ↓.
  - Warmer winter as in 2015-16 or 2017-18 ⇒ April inventory ↑.
- 2006-17 winter is relatively moderate, April inventory is moderate.
  - Projected to end April with 2.2 Tcf = 7.8% of (Yuzhno-Russkoye field 28.24 Tcf)

- First week of March in 2017 is relatively cold
  - Arctic cold temperatures covered the East of the USA.
  - Total demand for the week averages over 100 Bcf/d, only seen during a few winter weeks of 2016-17
  - The unseasonal cold ⇒ a withdrawal of >150 Bcf in the first week of March 2017, as opposed to an injection of 13 Bcf during the same week of 2016.
- 2,200 Bcf of storage lasts 22 days with the peak demand of 100 Bcf/d.
Liquefied Natural Gas Supply Chain
LNG Supply Chain

Liquefaction $2.15 per MMBtu
Shipping $1.25 per MMBtu
Gasification $0.70 per MMBtu

Total Cost of Shipping is $4.10 per MMBtu
LNG Processing

- Natural gas markets are local. Lack of infrastructure to liquefy and gasify.
- Cool down gas to -160 °C to reduce its volume by an order of 600:
  - From a beach ball down to a ping-pong ball: Reduction of radius by an order of 8.4 yields reduction of volume by \((8.4)^3=600\).
  - Liquefaction happens through multiple trains, each with a current capacity of ~ 11 B m³ as opposed to earlier capacities of 1.4 B m³.

Precooling cycle uses propane to cool the gas down to -40 °C. Propane also cools MR, see below.
Liquefaction cycle uses mixed refrigerant (MR, nitrogen, methane, ethane, propane) to cool the gas down to -160 °C.

This design is known as APCI or C3MR. It is used respectively in 90% and 56% of facilities before 2000 and after.

Gas Tankers: LNG and LPG

- Typical delivery leadtime is 2-3 years.
- Tankers can be spherical or membrane design. The latter has multiple tanks separated by membranes.

<table>
<thead>
<tr>
<th></th>
<th>Capacity m$^3$</th>
<th>Price $ million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average LNG carrier</td>
<td>160,000</td>
<td>208</td>
</tr>
<tr>
<td>Q-max</td>
<td>266,000</td>
<td></td>
</tr>
<tr>
<td>LPG carrier</td>
<td>15,000</td>
<td>41</td>
</tr>
</tbody>
</table>

Every day 0.15% of LNG boils and becomes natural gas.
- Some ships use this as fuel for propelling the ship.
- Some ships have re-liquefaction facilities.
- Offshore re-liquefaction is hard but being researched.

An LNG ship's hull and containment system, more than six feet thick, as shown in cross-section.
LNG Global Market

Suppliers by Target markets:
- Far East Asia: Qatar (Exxon), Malaysia, Indonesia, Australia
- USA: Trinidad & Tobago, Nigeria, Algeria
- Europe: Algeria, Nigeria, Libya.

Natural gas exports are increasing; Global LNG trade is to double from 2000 to 2020.
Increase in 2004 was 9%
Exports were 25% of consumption
¾ of exports by pipelines;
¼ by LNG tankers.
Benefit of Global Warming: LNG Arctic Route

Japan is a major importer
Global warming made arctic route navigable for ships.
This route to ship oil & gas Northern Europe → Far East, i.e., Hammerfest (LNG terminal), Norway → Japan.
The traditional route is through the Suez channel, but it is 40% longer than the arctic route.

Counterclockwise starting from top:
- Arctic route.
- On Arctic route escorting is by nuclear powered Russian ice breakers.
- Ob River is a strengthened hull tanker; 288 m long built by Hyundai Industries, South Korea.
Landed LNG Prices in February 2012

February 2012 landed LNG prices in $ per Million Btu (MMBtu)


Which country prefers to buy its energy in gasoline rather than LNG?

Recall gasoline cost of $35=4*(1,000,000/114,000) per MMBtu.

Why do not we buy at lake Charles and sell in Japan?
Landed LNG Prices in February 2017

Lake Charles price is almost the same as it was 5 years ago. Korea and Japan prices have dropped significantly. Argentina and Brazil pay more than Japan.

Government Involvement
LNG or Pipeline? Or CNG? Or GTL?

- **Why to ship?** Local oversupply and undersupply causes location based price spreads.
  - Local market around reserves (in Trinidad and Tobago, Nigeria, Siberia, Northern Australia, Carmisea in Peru) are not developed. If they develop, LNG or pipeline will not be necessary.
  - **LNG or Pipeline:**
    - Geography can dictate: Pipelines are often on the surface of the earth so a challenging option in the seas.
    - Pipelines ⇐ For shipments from Russia → Europe or Asia.
    - LNG ⇐ For shipments from and to islands and remote places.
  - **Cost** of LNG shipments have dropped to be competitive with pipelines
    - Long distance (more than 2000 km) favors LNG. This is because gas pressure must be increased in pipelines every 40-50 miles. Moreover, maritime shipping is relatively cheap.
  - **Continuity** of gas (energy security):
    - Pipelines cross multiple countries: Russia ships, Ukraine controls, Italy complains.
    - Security and integrity of pipelines
      - Pilferage by locals in Nigeria.
      - Access to control rooms. El Paso Corporation.’s control room for Eastern Pipeline Group is in Houston. Western pipeline group is controlled from Colorado Springs.
      - Access to transmission data. Special attention to non-transmission (marketing, consultant) personnel’s access to transmission data. See Independent Functioning Rule in FERC’s Standards of Conduct for Transmission Providers Order 717-A. FERC (Federal Energy Regulatory Commission)
    - Ships are subject to weather calamities and piracy. How to go from Qatar to Mediterranean ports?
  - **Flexibility:** LNG does not have a fixed route unlike pipelines. If not from Libya, UK gets LNG from Algeria.

- **Compress Natural Gas** up to 2,000-4,000 pounds per square inch (psi). CNG ships costs similar to LNG ships but LNG ships can carry more volume for the same energy content. CNG shipping is relatively expensive.

- **Convert Natural Gas To Liquids** (GTL): Methane + Oxygen + Water ⇒ Longer chain hydrocarbons. Send these hydrocarbons to regular refineries to obtain diesel and gasoline.
  - Capital cost for GTL: $25-35 K/barrel. Comparable to refinery capital cost of $15 K/barrel. In the environment of too-cheap gas and expensive oil, keep your eyes on GTL industry, especially in Qatar, Iran, Russia, Nigeria, Australia, Algeria, and USA.
If LNG is chosen, Liquefaction Plant Ownership

- Three primary models:
  - Facility is owned by the gas producer
    - A: Facility profit is integrated with the gas producer’s profit
      - Free on board (FOB): Seller owns LNG until the tanker: RasGas of Qatar.
    - B: Facility is a separate company but a subsidiary of gas producer.
      - Free on board (FOB): Oman LNG.
      - Cost, Insurance, Freight (CIF): Malaysia LNG and Atlantic LNG Train 1 of Trinidad and Tobago.
    - C: Facility owned by both gas producer and customers: Atlantic LNG Train 4 and Egyptian LNG.
    - D: Facility earns some toll for every ton of LNG produced: Operation on a toll-basis.

- Model A has consolidated ownership, it avoids negotiations, transfer prices.
- Models B, C have fragmented ownership through a subsidiary. Interests of liquefaction facility and its investors can be better/more directly represented.
- Models D allows facility to earn a toll regardless of natural gas and LNG prices and their fluctuations. Model D implies less profit risk and hence easier to finance.
- Models A, B, C, D are just simplifications. Reality is more complex:
  - Australian NWS gas is owned by two companies: A pipeline and an LNG company.
  - In Egypt, different trains have different shareholders.
  - In Trinidad and Tobago, different trains have different ownership models.
LNG Industry Development

An LNG project (liquefaction + tankers + gasification) or pipeline project costs billions of dollars.

Checklist before starting:

- **Supply**: Sufficient gas reserves for 20-30 years.
- **Demand**: A buyer who will sign a contract to commit to buy fixed amounts. These contracts are called take-or-pay contracts. If the buyer does not buy the committed quantity, he pays a penalty.

<table>
<thead>
<tr>
<th>Current take-or-pay contracts between Turkey and</th>
<th>Volume B m³/year</th>
<th>Signature date</th>
<th>Period in years</th>
<th>As of 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia (Westward)</td>
<td>6.0</td>
<td>14-02-1986</td>
<td>25</td>
<td>Expired</td>
</tr>
<tr>
<td>Algeria—LNG</td>
<td>4.0</td>
<td>14-04-1988</td>
<td>20</td>
<td>Expired</td>
</tr>
<tr>
<td>Nigeria—LNG</td>
<td>1.2</td>
<td>9-11-1995</td>
<td>22</td>
<td>Expired</td>
</tr>
<tr>
<td>Iran</td>
<td>10.0</td>
<td>8-08-1996</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Russia (Black Sea)</td>
<td>16.0</td>
<td>15-12-1997</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Russia (Westward)</td>
<td>8.0</td>
<td>18-02-1998</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Turkmenistan</td>
<td>16.0</td>
<td>21-05-1999</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>6.6</td>
<td>12-04-2001</td>
<td>15</td>
<td>Expired</td>
</tr>
</tbody>
</table>

- **Access to capital**: Equity, borrowing or World Bank / government backing.
- **Positive relationships**: Among seller, buyers, regulatory agencies. Problems are inevitable.
- **Technical details / plans**: Feasibility analysis, process analysis, bottleneck identification, engineering design, project execution, operational plans.
- **Commercial issues**: Contracts for prices and quantities, fall-back clauses. Defining roles of buyer and seller and the ownership of the LNG in the supply chain: FOB or CIF.
- **Safety and siting**: LNG is explosive. Facilities should be further from population centers from a safety perspective. From a profit perspective, gasification plants should be at the city gates. That is the source of a small conflict.
- **External advisers**: Management and technical consultants, lawyers.
- **Government regulations**: Security, safety, environmental regulations, assistance and taxes.
Government’s Share and Taxes

- Depreciation to recover capital costs
  - Some countries allow full expensing of upstream expenses against revenue before taxes are assessed.
  - Most use depreciation schedules
    - 10%-25% per year straight line depreciation
    - Brunei, Malaysia, Trinidad and Tobago allow accelerated depreciation. Deduct more now, less later.
  - Recoverable amount of expenditures
    - Uplift incentives in Nigeria and Norway in the form of 105-120% expenditure recovery.
    - Limitations: Malaysia and Egypt 30-60% expenditure recovery.
- Average corporate income tax rate 40%
  - Nigeria LNG has multiyear tax holiday.
  - Norway’s Snøhvit has tax rate of 78%.
  - Profit-sharing tax: Malaysian government’s share increases once a preset volume of gas is produced.
- Resource rent tax
  - Tax applies after cumulative revenue surpasses a portion of cumulative cost.
  - This delays the tax collection but incents the international investors.
- Production-sharing contracts
  - If there is production, foreign investor shares a percentage with the government. The investor assumes exploration and production risk.
  - Indonesia and Russia use these contracts.
Government Response to a Crisis
FERC’s Response to Propane Crisis of Feb 2014

Natural gas has low energy density and is commonly transported through pipelines. Pipelines are owned by companies which rent transportation capacity to others. These companies are regulated by Federal Energy Regulatory Commission (FERC) with the aim of keeping pipeline market, efficient, open and competitive. Regulations cover new construction, rate limits, nondiscriminatory access, unbundled services.

Background
As of 2012, households using Propane for heating:
36% of Midwest; 34% of South; 16% of West; 14% of Northeast
Propane is used for drying harvest
Propane is shipped with pipelines and trucks.
Not 1 but 3 factors happen in Feb 2014 and propane supply in Midwest drops significantly while prices spike up.
– 2013-2014 winter is colder than usual.
– Farmers used more propane to dry unusually wet harvest in 2013.
– A key pipeline is shut down for repairs.
State governors respond:
– In Minnesota, governor expanded the state's heating assistance program to more households.
– In Indiana, governor waived fees for overweight propane loads for suppliers.
– In Colorado, governor eased restrictions on the drivers’ working hours so they can deliver more fuel.
– A group of Midwestern governors sent a letter to President asking for help.
Resolution on Feb 7, 2014: Federal Energy Regulatory Commission (FERC) ordered a pipeline company, Enterprise TE Products Pipeline Co., to give priority to shipments going from Texas to the Midwest and the Northeast. That marked the first time FERC issued such an order.
"At the end of the day, this is really a transportation and distribution issue," and the problem isn't a lack of propane, but “getting that supply to those who need it the most”. Mollie O’Dell, National Propane Gas Association, underlining the role of Supply Chains.
Pipeline Capacity Pricing
Master Limited Partnership Ownership for Pipelines as well as Oil, Gas, Coal Fields

- Master Limited Partnership (MLP or PTP for publicly traded partnership) is a legal entity. Parts of it can be sold as units of ownership.

- MLP is managed by a general partner who is familiar with the business & executes the operations.
  - Consider El Paso Pipeline Partners (NYSE: EPB): EPB engages in the ownership and operation of natural gas transportation pipelines and storage assets in the US. It owns
    - Wyoming Interstate Co. (WIC) - NatGas pipeline.
    - Southern Natural Gas Co. (SNG) - NatGas pipeline.
    - Elba Express Pipeline.
    - Southern LNG Co. (SLNG) – LNG storage and regasification in Savannah.
  - In total, 12,900 miles pipeline and 97 Billion cubic feet storage capacity.

- El Paso Pipeline GP Company serves as the general partner of the MLP. The MLP was founded in 2007 and is based in Houston, Texas. It has about 205 million shares each is valued about $35.

- There are many other MLPs: www.alerian.com/list-of-mlps.
- MLPs are indexed by Alerian (1717 McKinney Av., Suite 1450, Dallas) MLP Infrastructure index focusing on liquid midstream MLPs.

- An investor buys ownership units to receive quarterly cash payments from the MLP. This is similar to dividends from a stock but could be more advantageous:
  - Tax rules motivate GP to distribute a large percent of earnings.
  - Investors have tax advantages.
  - MLPs should generate cash fast.
  - MLPs can be less correlated with the overall market.

- MLPs are only available for energy related investments: oil, gas, coal, pipeline, LNG facilities.
Tennessee Gas Pipeline (TGP)

TGP is owned by El Paso Corporation, which was being acquired by Kinder Morgan pipeline company circa 2013. This is the same El Paso Corporation that acts as General Partner in El Paso Pipeline Partners MLP.

Ownership of pipeline assets keep changing!
TGP has 7 zones: 0 for Texas, L for Louisiana, and Zones 1-6.

TGP has more than 100 interconnects with most major interstate and intrastate pipeline systems.
TGP’s assets receive natural gas from Nova Scotia, emerging LNG projects along the Gulf Coast and Eastern Seaboard, and emerging domestic supplies from several shale regions.

TGP – Zone 0 Texas

TGP receives gas at receipt points which are numerous in Texas.
TGP – Zone 6

TGP delivers gas at delivery points which are numerous in Northeast.
Contracting for Pipeline Capacity

A shipper wants to send natural gas to a small NGCC (Natural gas Combined Cycle) plant in Boston area. The plant generates 40 MW and consumes 277 MMBTU of natural gas per hour.

- The closest receipt meter to this plant is meter # 020808 in Massachusetts, Zone 6.
- The gas is received at Alamo point in Texas, Zone 0.

Every month, the shipper needs to buy 200,000 MMBTU pipeline capacity from Alamo to Boston. TGP sells monthly pipeline capacity in advance; buy now for the next month in two forms:

1) **Firm contracts**  
2) **Interruptible contracts**, base rates are cheaper than firm contract base rates.

According to pages 7 and 37 of TGP Gas Tariff Filed with FERC: Spot prices for firm contracts are slightly below base rates for interruptible contracts. Rates are per **dekatherm (=1 million BTU or 1000 cubic feet gas)**.
Location Spread Based Prices for Pipeline Capacity

- **FERC** regulates the conduct of pipeline companies:
  - Minimum and maximum rates for contracts. But, range is wide, and non-monopolistic pipeline companies can negotiate prices, which can be higher than maximum rate.
- **Nondiscriminatory sales**, usually through capacity auctions during certain time windows (open seasons).
- **Shippers** submit bids such as:
  - Bid 8; Path: Zone 0 to Zone 6; Receipt point: Alamo (A); Delivery point: Boston (B); Quantity=200,000 dekatherm.
  - Bid 11; Path: Zone 3 to Zone L; ……………………………………………………….; Quantity= 50,000 dekatherm.
- A **pipeline company** (e.g., TGP) has to determine the price for shipping 1 dekatherm of gas from point A to point B.
  - This pricing problem is similar to toll road pricing
    - Car (2-axle) toll charge is based on the distance traveled between entry and exit plazas.
    - One method to come up with prices is to set them high enough that the **pipeline company** collects all of the money the shipper can pay and the shipper is still willing to ship the gas.
- **How much can a pipeline company** charge to ship the gas from A to B?
  - The **shipper** has the gas at A bought (or produced) at the unit price $p_A$. The shipper can also buy the gas at the unit price $p_B$ at point B. The shipper would not do that as long as pipeline capacity is sold at
    \[ p_B < p_A \]
  - The **pipeline company** incurs cost of $c_{AB} >0$ to ship the gas (incl. energy cost of pumping) from point A to point B. The pipeline capacity will be sold at $> c_{AB}$.
  - If $p_B - p_A > c_{AB}$, there is room for negotiating prices. However, by introducing an auction mechanism, the **pipeline company** can force the shippers to pay as high as possible. That is
    \[ \text{Maximum}\{p_B - p_A, c_{AB}\} \].

This pipeline capacity price can be charged only if the location spread is $p_B - p_A$ known. Location prices $p_A, p_B$ are known for spot market (buy in April for April) transactions for capacity but not for forward (buy in April for May) contract purchases.
Location Spreads are Unknown

– The price of

\[ \text{Maximum}\{ p_B - p_A, c_{AB} \} \]

depends on the location spread, which in turn depends on prices \( p_A \) and \( p_B \) at time \( T \) of delivery.

– Currently we are in month \( t = \text{April} < \text{May} = T \) and do not know the prices that will materialize in May. Let \( p_A(t, T) \) be the gas price that will materialize at point A in month T as it is assessed from the current month \( t \). Similarly, \( p_B(t, T) \).

– Need to better understand \( p_A(t, T) \) and \( p_B(t, T) \).
A Probabilistic Model of Prices from the Pipeline Company Point of View

- Gas (commodity) prices are given by the market; so they are random for the pipeline company.
- The future price of gas at location A is the average (E expected value) $E(p_A(t, T))$.
- How does $E(p_A(t, T))$ differ from $p_A(t, T)$?

- Dependent price scenarios: Most of the gas at B is shipped from A and hence price at B is higher when price at A is higher.
- Independent price scenarios: A small portion of the gas at B is shipped from A and hence price at B can be lower/the same when price at A is higher.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$p_A(t, T)$</th>
<th>$p_B(t, T)$</th>
<th>Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.25</td>
<td>2.30</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>2.30</td>
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<tr>
<td>3</td>
<td>2.35</td>
<td>2.36</td>
<td>0.01</td>
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</table>

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<td>0</td>
</tr>
<tr>
<td>3</td>
<td>2.25</td>
<td>2.35</td>
<td>0.10</td>
</tr>
<tr>
<td>4</td>
<td>2.35</td>
<td>2.25</td>
<td>-0.10</td>
</tr>
</tbody>
</table>
Average (Expected) Pipeline Prices by Always Recovering Cost

Find the pipeline price supposing the shipping cost \( c_{AB} = 0.02 \) per dekatherm.

- Dependent price scenarios, charge to recover cost.

<table>
<thead>
<tr>
<th>Scen.</th>
<th>( p_A(t,T) )</th>
<th>( p_B(t,T) )</th>
<th>( \text{Max} { p_B - p_A, c_{AB} } )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.25</td>
<td>2.30</td>
<td>0.05</td>
</tr>
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<td>0.03</td>
</tr>
<tr>
<td>3</td>
<td>2.35</td>
<td>2.36</td>
<td>0.02</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>0.10/3</td>
</tr>
</tbody>
</table>

Charge less, lose revenue
Charge more, lose customer

- Independent price scenarios, charge to recover cost.

<table>
<thead>
<tr>
<th>Scen.</th>
<th>( p_A(t,T) )</th>
<th>( p_B(t,T) )</th>
<th>( \text{Max} { p_B - p_A, c_{AB} } )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.25</td>
<td>2.25</td>
<td>0.02</td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
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<td>2.35</td>
<td>0.10</td>
</tr>
<tr>
<td>4</td>
<td>2.35</td>
<td>2.25</td>
<td>0.02</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>0.04=0.16/4</td>
</tr>
</tbody>
</table>
Average Pipeline Prices by Recovering Cost on Average

- Dependent price scenarios

<table>
<thead>
<tr>
<th>Scen.</th>
<th>$p_A(t,T)$</th>
<th>$p_B(t,T)$</th>
<th>$\text{Max}{p_B - p_A, 0}$</th>
</tr>
</thead>
<tbody>
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<td>2.30</td>
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<td>2.36</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Average of positive parts of spreads $0.030 = 0.09/3$

- Independent price scenarios:

<table>
<thead>
<tr>
<th>Scen.</th>
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<th>$\text{Max}{p_B - p_A, 0}$</th>
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<td>2.25</td>
<td>0</td>
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</table>

Average of positive parts of spreads $0.025 = 0.10/4$

Charging a price of 0.03, recover the cost 0.02 on average. This price is less than 0.10/3.

Charging a price of 0.025, recover the cost 0.02 on average. This price is less than 0.04.

A pipeline company sets lower prices if it is recovering costs on average as opposed to under each scenario. Conservative companies would ensure costs are covered under each scenario. Appetite for Risk?
Summary

- Pipelines and Storage
- Oil Tankers
- LNG Supply Chain
- Government Involvement
- Pipeline Capacity Pricing