Pipeline Construction Drivers, Corrosion Costs and Engineering Issues

Presented by
David Webster, P. Eng.
Vice President/General Manager
Pipeline Systems Business Unit
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Pipeline Construction Drivers, Corrosion Costs and Engineering Issues
Macro Energy Sector Trends

Source: Energy Sector Review, 22nd January 2010, Douglas-Westwood
Onshore and offshore driver for activity is global demand

Global demand has tripled over last 50 years
  - Driven by developing economies

2008 saw energy consumption decrease in some countries due to financial crisis
Global Energy Demand 1966 - 2008

Source: BP Review of World Energy 2009

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Global Oil Supply 1930 - 2050

- Developing countries will keep upward pressure on demand
- The International Energy Agency forecasts peak demand of 106 million BPD by 2030
  - Current daily consumption is 84 million barrels
- 100 countries produce oil and gas liquids
- 66 countries are 5 years past their production peak
  - Includes US
  - Remainder will have peak production within 25 years
- Forecast is for Global oil production to peak by 2016 at 100 million BPD
Global Oil Supply 1930 - 2050

Source: Douglas-Westwood
Global Onshore Heavy Oil Production
2005 - 2014 (API < 22)

Source: Energyfiles
Global Onshore Extra Heavy Oil Production
2005 - 2014 (API < 10)

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Source: Energyfiles
Global Oil Price – Supply Drivers

- Production decline
- Geopolitics
  - Tensions create price volatility
- Accidents/Force Majeure
  - Earthquakes, floods, hurricanes, human error
Global Oil Price – Demand Drivers

- Weak US dollar
  - Hedging against inflation
- Historical demand growth
  - Driven by China and India
- Long-term Global GDP growth
- Supply cannot keep up with demand
North American Energy Situation

- Major onshore oil & gas reserves have been exploited
- Remaining recoverable reserves
  - Offshore deep waters
  - Remote arctic locations
  - Unconsolidated reservoir sands
- High cost production
U.S. 2010 (est.) oil production – 3.1 billion barrels
  - Flat production

Increasing reliance on cheaper imports

US 2010 (est.) imports – 4.9 billion barrels
  - Increasing year over year

Top US supplier – Canada (0.9 billion barrels in 2008)
  - Delivery increasing year-over-year
Canada exports more than 60% of crude production to US

Conventional production is declining

Oil sands production increasing
  - Mining
  - SAGD
  - Fire floods
Canada Oil Sands Production 2005 - 2025

- Oil Sands Mining
- Oil Sands In-Situ
- Potential Growth Given Higher Oil Prices

Source: CAPP
North American Natural Gas Production

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Source: Energyfiles
The US consumes more natural gas than it produces
Canada produces natural gas exceeding domestic consumption
Canada exports between 50 and 60 per cent of its gas production
- Largest gas supplier to the US
August 2009 YTD exports to the US were down 1%.
Major new gas supplies required for US and Canada

**Conventional sources**
- Remote locations
  - US - Alaska
  - Canada - North West Territories
  - Offshore development

**Unconventional sources**
- Shale gas
- Coal bed methane
- Sour gas
Pipeline Construction
Pipeline construction related to infrastructure capacity
  ▪ Controlled by supply and demand

Supply and demand impacts oil and gas price
  ▪ High prices spur production development

Oil and gas development/expansion will require pipelines
### Expenditure Summary - Global

**Pipeline Systems Business Unit**

<table>
<thead>
<tr>
<th>HC Market</th>
<th>Spend Type</th>
<th>2009 ($B)</th>
<th>2010 ($B)</th>
<th>% Change</th>
<th>Forecast ($B)</th>
<th>Forecast Period ($B)</th>
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<tbody>
<tr>
<td>Global Upstream Offshore</td>
<td>Capex</td>
<td>137.4</td>
<td>137.0</td>
<td>-0.3%</td>
<td>874.3</td>
<td>2010-2014</td>
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<td>Global Upstream Offshore</td>
<td>Opex</td>
<td>102.1</td>
<td>111.4</td>
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<td>Deepwater</td>
<td>Capex</td>
<td>24.4</td>
<td>27.2</td>
<td>11.5%</td>
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<td>Fixed Production Platform</td>
<td>Capex</td>
<td>42.4</td>
<td>44.7</td>
<td>5.4%</td>
<td>241.0</td>
<td>2010-2014</td>
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<tr>
<td>Floating Production</td>
<td>Capex</td>
<td>7.1</td>
<td>5.7</td>
<td>-19.7%</td>
<td>39.8</td>
<td>2010-2014</td>
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<td>Global Upstream Onshore</td>
<td>Capex</td>
<td>67.0</td>
<td>74.4</td>
<td>11.0%</td>
<td>409.5</td>
<td>2009-2013</td>
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<tr>
<td>Oil Sands</td>
<td>Capex</td>
<td>5.1</td>
<td>8.5</td>
<td>66.7%</td>
<td>55.9</td>
<td>2010-2014</td>
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<tr>
<td>Refining</td>
<td>Capex</td>
<td>19.5</td>
<td>23.5</td>
<td>20.5%</td>
<td>151.3</td>
<td>2010-2014</td>
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<td>Gas Processing</td>
<td>Capex</td>
<td>7.4</td>
<td>7.8</td>
<td>5.4%</td>
<td>43.1</td>
<td>2010-2014</td>
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<td>Petrochemicals</td>
<td>Capex</td>
<td>16.7</td>
<td>15.8</td>
<td>-5.4%</td>
<td>80.0</td>
<td>2010-2014</td>
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<tr>
<td>Onshore Pipelines</td>
<td>Capex</td>
<td>31.9</td>
<td>31.0</td>
<td>-2.8%</td>
<td>144.0</td>
<td>2009-2013</td>
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<td>Offshore Pipelines</td>
<td>Capex</td>
<td>17.9</td>
<td>15.1</td>
<td>-15.6%</td>
<td>62.5</td>
<td>2009-2013</td>
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<td>LNG Liquefaction</td>
<td>Capex</td>
<td>13.0</td>
<td>9.7</td>
<td>-25.4%</td>
<td>57.4</td>
<td>2010-2014</td>
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<td>LNG Regasification</td>
<td>Capex</td>
<td>7.2</td>
<td>7.0</td>
<td>-2.7%</td>
<td>40.6</td>
<td>2010-2014</td>
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<td>FLNG Liquefaction</td>
<td>Capex</td>
<td>0.0</td>
<td>0.1</td>
<td></td>
<td>18.1</td>
<td>2010-2016</td>
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<tr>
<td>FLNG Import</td>
<td>Capex</td>
<td>0.3</td>
<td>0.3</td>
<td>22.4%</td>
<td>5.0</td>
<td>2010-2018</td>
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<tr>
<td>GTL &amp; CTL</td>
<td>Capex</td>
<td>5.3</td>
<td>7.0</td>
<td>32.2%</td>
<td>18.2</td>
<td>2010-2014</td>
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<tr>
<td>Offshore Wind</td>
<td>Capex</td>
<td>2.2</td>
<td>2.7</td>
<td>25.0%</td>
<td>38.2</td>
<td>2010-2014</td>
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<tr>
<td>Decommissioning (Offshore)</td>
<td>Capex</td>
<td>0.7</td>
<td>1.2</td>
<td>78.2%</td>
<td>5.7</td>
<td>2010-2014</td>
</tr>
</tbody>
</table>
## Expenditure Summary - North America

**HC Market** | **Spend Type** | **2009 ($B)** | **2010 ($B)** | **% Change** | **Forecast ($B)** | **Forecast Period ($B)**
--- | --- | --- | --- | --- | --- | ---
Upstream Offshore | Capex | 21.0 | 21.9 | 4.3% | 143.1 | 2010-2014
Upstream Offshore | Opex | 13.0 | 13.6 | 4.6% | 82.4 | 2010-2014
Deepwater | Capex | 1.1 | 1.5 | 36.4% | 4.0 | 2010-2014
Fixed Production Platform | Capex | 22.0 | 19.0 | -13.6% | 93.2 | 2010-2014
Floating Production | Capex | 0.8 | 1.0 | 25.0% | 3.1 | 2010-2014
Upstream Onshore (Canada) | Capex | 22.9 | 25.9 | 13.1% | 144.4 | 2009-2013
Oil Sands | Capex | 5.1 | 8.5 | 66.7% | 55.9 | 2010-2014
Refining | Capex | 4.1 | 5.6 | 36.6% | 26.9 | 2010-2014
Gas Processing | Capex | 1.0 | 0.4 | -60.0% | 1.7 | 2010-2014
Petrochemicals | Capex | 2.6 | 2.4 | -7.7% | 12.4 | 2010-2014
Onshore Pipelines | Capex | 6.7 | 6.7 | 0.2% | 31.1 | 2009-2013
Offshore Pipelines | Capex | 1.1 | 0.8 | -27.3% | 2.7 | 2009-2013
LNG Liquefaction | Capex | 0.0 | 0.0 | 3.3 | 2010-2014
LNG Regasification | Capex | 2.5 | 2.6 | 4.1% | 8.5 | 2010-2014
FLNG Liquefaction | Capex | 0.0 | 0.0 | 0.4 | 2010-2016
FLNG Import | Capex | 0.0 | 0.0 | 29.7% | 1.2 | 2010-2016
GTL & CTL | Capex | 0.0 | 0.0 | 0.0% | 0.0 | 2010-2014
Decommissioning (Offshore) | | 0.2 | 0.4 | 68.7% | 1.9 | 2010-2014
Projected U.S. and Canadian Pipeline Additions in the Base Case (Miles)

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1 Includes pipeline mileage of downstream expansions on existing corridors in the U.S. and Canada in addition to the pipeline associated with the arctic Canada and Alaska frontier projects.

2 Lateral is defined as a spur off the main transmission line, normally used to connect production, storage, power plants, LNG terminals or isolated demand centers.
WorleyParsons
resources & energy
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Pipeline Repairs/Replacements

- **Wear-out (corrosion)**
  - 70% of all releases
    - 58% related to internal corrosion

- **Third party damage**
  - 5% of releases

- **Construction**
  - 8% of releases

- **Operations and other**
  - 17% of releases
1990 – 2005 Alberta Pipeline Releases

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- Internal corrosion 57.7%
- External corrosion 12.0%
- Damage by others 5.0%
- Weld 3.5%
- Construction damage 4.5%
- Overpressure 1.6%
- Pipe 2.8%
- Joint 3.5%
- Earth movement 1.7%
- Valve/fitting 2.2%
- Other 5.5%
Oil Sands extraction processes introduce new corrosion issues

- Corrosion problems pushed downstream to the shipper

Pipelines used to move waste heat

- Heat required in the production processes
  - Reduces natural gas consumption
- Results in increased pipeline operating temperatures
  - Up to 150°C and considering 170°C
Thin film pipeline coatings only recently developed for temperatures up to 150°C

Need exists for thermal insulation to limit heat transfer

- High temperature polyurethane (PUR) foams exist for 150°C operation
  - Driven by EN 253 – District Heating Pipes

Thermal aging of foams

- Thermal properties and life decreases as temperatures increases
- Work being done with polyisocyanurate (PIR) foams to reduced aging effects
Cost of Corrosion

Source: Corrosion Costs and Preventive Strategies in the United States, FHWA-RD-01-156
Natural Disaster
- A hazard event that results in widespread destruction of property or causes injury and/or death

Corrosion
- A natural deterioration phenomenon
Natural disasters and corrosion both contribute to
- Dangerous situations that can impact safety of persons
- Expensive damage
Corrosion can be controlled
“Facility owners often under estimate the importance and value of corrosion control, which is neglected in favor of more tangible, short-term issues”
$276 Billion

The United States Cost of Corrosion Study

NACE INTERNATIONAL

Leaders in Corrosion Control Technology
Industry Sectors Examined

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Highway Bridges
Gas & Liquid Transmission Pipelines
Waterways & Ports
Airports
Motor Vehicles
Tele Communication
Chemical, Petrochemical, Pharmaceutical
Pulp & Paper
Petroleum Refining
Storage Tanks
Home Appliances
Gas Distribution
Nuclear Waste Storage
Oil & Gas Exploration & Production
Aircraft
Railroads
Electronics
Agricultural
Food Processing
Mining
Defense

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Gross Domestic Product (GDP) Defined
- Market value of all the output produced in a nation in one year

US GDP in 1999 was $9 trillion

Perspective on $276 B annual corrosion cost
- ~ 4 times the insurers cost for all US natural disasters in 2007
- ~$900 for each man, woman and child in the US
US GDP Summary

- Services: 20.9%
- Finance, Insurance, and Real Estate: 19.2%
- Manufacturing: 16.3%
- Retail Trade: 9.1%
- State and Local Government: 8.5%
- Transportation and Utilities: 8.3%
- Wholesale Trade: 7.0%
- Construction: 4.3%
- Federal Government: 4.1%
- Agriculture: 1.5%
- Mining: 1.2%

Extrapolated Corrosion Costs: $276 billion, 3.1%
### Other Cost of Corrosion Studies

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>TOTAL ANNUAL CORROSION COST</th>
<th>PERCENT OF GNP</th>
<th>YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.A.</td>
<td>$5.5 billion</td>
<td>2.1</td>
<td>1949</td>
</tr>
<tr>
<td>India</td>
<td>$320 million</td>
<td>–</td>
<td>1960</td>
</tr>
<tr>
<td>Finland</td>
<td>$54 million</td>
<td>–</td>
<td>1965</td>
</tr>
<tr>
<td>W. Germany</td>
<td>$6 billion</td>
<td>3.0</td>
<td>1967</td>
</tr>
<tr>
<td>UK</td>
<td>£1.365 billion *</td>
<td>3.5</td>
<td>1970</td>
</tr>
<tr>
<td>Japan</td>
<td>$9.2 billion</td>
<td>1.8</td>
<td>1974</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>$70 billion</td>
<td>4.2</td>
<td>1975</td>
</tr>
<tr>
<td>Australia</td>
<td>$2 billion</td>
<td>1.5</td>
<td>1982</td>
</tr>
<tr>
<td>Kuwait</td>
<td>$1 billion</td>
<td>5.2</td>
<td>1987</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>$276 billion</td>
<td>3.1</td>
<td>2002</td>
</tr>
</tbody>
</table>
All studies indicate that the cost of corrosion is 2 – 4% of GDP

Estimated worldwide cost is $2.5 – $3.5 trillion annually

Equivalent to the GDP of 4th largest country in the world
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Cost of Corrosion Per Analyzed Economic Sector, ($ x billion)
<table>
<thead>
<tr>
<th>Service</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protective Coatings</td>
<td>B$ 108.6</td>
</tr>
<tr>
<td>Corrosion Resistant Alloys</td>
<td>B$ 7.7</td>
</tr>
<tr>
<td>Corrosion Inhibitors</td>
<td>B$ 1.1</td>
</tr>
<tr>
<td>Engineering Plastics/Polymers</td>
<td>B$ 1.8</td>
</tr>
<tr>
<td>Cathodic &amp; Anodic Protection</td>
<td>B$ 1.0</td>
</tr>
<tr>
<td>Corrosion Control Services</td>
<td>B$ 1.2</td>
</tr>
<tr>
<td>Research &amp; Development</td>
<td>B$ -</td>
</tr>
<tr>
<td>Education &amp; Training</td>
<td>B$ -</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>B$ 121.41</strong></td>
</tr>
</tbody>
</table>
Indirect corrosion costs not included

- Labor cost for corrosion management
- Cost of equipment
- Loss of revenue from product supply disruption
- Loss of reliability cost
- Legal costs and failure compensation

Indirect costs estimated to double the annual cost of corrosion to US$552 B
Corrosion Engineer’s Dilemma

- Corrosion control is not core to any industry
- Cost of Corrosion study shows that corrosion control is critical to many industries
- Owner’s demand improved performance and reduced maintenance costs

Don’t interfere with core business
Gas & Liquid Transmission Pipelines
$7.0 Billion - Annually
Summary: Transmission Pipelines

- **Operations & Maintenance**: 52%
- **Cost of Capital**: 38%
- **Failures**: 10%

80% of this cost is related to corrosion.
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Gas & Liquid Transmission
Pipelines

- Oil & Gas
  - Natural Gas
    - Transmission 300K miles
    - Distribution 1,700K miles
    - Gathering 28K miles
  - Hazardous Liquids
    - Transmission 135K miles
    - Gathering 21K miles

- Production
  - Crude Oil
    - 53K miles
  - Liquid Products
    - 82K miles

- Facilities
  - Production Facilities
  - Oil & Gas

- Pipelines
  - 1,700K miles
  - 28K miles
  - 2,000K miles
  - 156K miles
  - 53K miles
  - 82K miles
  - 21K miles
  - 200K miles

Hazardous Liquids
156K miles

Production

Facilities

Oil & Gas

Pipelines

2,000K miles

Crude Oil
53K miles

Liquid Products
82K miles

Gathering
21K miles

Gathering
28K miles

Distribution
1,700K miles

Transmission
300K miles

Natural Gas
2,000K miles
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Primary Cost Contributor - Age

- Over 768,000 km of gas and liquid transmission pipelines in U.S.
- Over 350,000 km of gas and liquid transmission pipelines in Canada
- Typical design life was 20 – 25 years
- 60% of pipelines are over 40 years old
“Even when corrosion control is on the agenda, overcoming the owner’s emphasis on initial cost is often a limiting factor in providing the most effective solutions”
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- Owner push-back relating to costs
- Corrosion problems are not always addressed and resolved during design
- Problem solving typically shifted to operations
  - OPEX increases related to more stringent maintenance practices

Increased CAPEX
Advanced design practices for better corrosion management

Advanced life-prediction and performance-assessment methods

Improve corrosion technology through research, development, and implementation
• Increase awareness of the large corrosion costs and potential savings
  ▪ Public Affairs/Government Relations
    • Liaison with industry and regulators
  ▪ Periodicals
  ▪ Videos
  ▪ Corrosion Books
Change the misconception that nothing can be done about corrosion

- Improve education and training of staff
- Technical standards
- Identify trends/issues so objectives meet the needs of industry and the public
  - NACE Pipeline and Coatings Councils
  - World Corrosion Organization (WCO)
Change policies, regulations, standards, and management practices to increase corrosion savings

- Link corrosion monitoring and inspection to maintenance
- Establish inspection and evaluation program
  - Identify, assess and classify problems early

Training
- Identify, inspect, assess, implement

Apply lessons learned
- Design, construction, specifications
Improve education and training of staff

- NACE International certification and training programs in 20+ countries
- NACE Foundation
  - K – 12 educational support
  - Post secondary scholarships
- Industry seminars
- Corporate internships
Looking Forward
Best-Practice Engineering

- Incorporating Colt Engineering
- Pipeline Systems Business Unit

Flowchart:
- Repair & Replace
- Maintenance
- Prevention

Comparison:
- Current Practice
- Best Practice

Net Savings:
- 2015: 30%
- 2030: 50%

Stages:
- Stage 0
- Stage 1
- Stage 2
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- 33% of total cost of corrosion can be saved utilizing current technology
- 30% net savings is possible
  - 10% of the total cost savings required to implement better practices
- U.S. economy could save $83 annually
Corrosion can be controlled

Corrosion control incurs costs

Industry and owners must identify problems and articulate their needs

Trained personnel can determine the solutions and reduce cost

Controlling corrosion costs less than doing nothing
Existing pipelines

- Commodity changes
  - Management of Change process is critical
- Commodity source may cause unexpected problems
- High temperature
  - Effects on coatings
  - Increased pipe stresses
  - Aggressive flow streams
- Problems must be solved as they are identified
  - Cost implications
Canada
- Oil sands development
- High Arctic development
- Offshore development

United States
- Offshore development

Expect different problems when compared to transporting *conventional* oil
- High temperature operation
- Aggressive flow streams contributing to internal corrosion
- Special engineering challenges
- Work in remote locations
Remote locations
- High Arctic
  - Alaska
  - North West Territories
- Offshore

Extreme environments
- Aggressive sea water
- Severe low temperatures

Material supply
- High strength steels
- Specialty coatings

Engineering issues
- Strain based design
Design challenges
- Additional design costs
  - Strain base versus stress base design
  - Route selection

Additional construction costs
- Welding high strength steels
- Inspection
  - Mainline and girth weld coatings
  - Welding
- Coating repairs
- Select backfill
Improved materials and testing
- Higher grade pipe steels
- High temperature coatings
- Thermal insulation
- More durable coatings for handling

Better construction practices
- Coating protection during handling and installation
- Improved field and plant inspection
Northern Pipelines – Design
Strain based design

- A design method that places a limit on the strains rather than the stresses at the design condition

Strain based design typically used for

- Offshore pipelines
- Arctic pipelines
- Design and assessment of pipelines in areas with significant expected ground movement
- High-temperature and high-pressure pipeline designs

Results in cost savings for pipe

- High strength but thin wall
Coating Needs

- Compatible with pipeline operation
  - Chilled operation (-10°C to -20°C)
- Resistance to handling, transport and installation damage
- Compatible with cathodic protection (CP)
- Coating of girth welds in extreme cold
  - Minimize manpower
  - Use of standardized equipment
  - Coating effectiveness
Coating Technical Requirements

Minimize costs for coating and transportation
  ▪ Portable plants

Minimize construction concerns
  ▪ Decrease need for import backfill
    • Field and/or laboratory cold temperature tests required for impact and abrasion
  ▪ Automated girth weld coating equipment
  ▪ Factory trained application/repair personnel

Constructability
  ▪ Impact resistance in cold climate (-40°C)
  ▪ Bendability
  ▪ Handling
Various coatings were tested for use on northern pipelines
  - ASTM tests
  - Backfilling impact tests

The best test results were provided by a polyethylene (PE) and fusion bond epoxy (FBE) coating system
  - PE outer sheath for mechanical protection
  - FBE corrosion barrier
  - Defined as system B2 in CSA Z245.21
    - Bredero-Shaw HPCC with side extruded PE overwrap (3mm)
The preheating cycle contributed to the onset of discontinuous stress-strain curves

High temperature caused thermal aging of the pipe

The heating cycle increased the yield strength
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Stress-Strain Curves

Helical Engineering $\sigma - \epsilon$ Curves (FBE Heat Cycled 200C) - Mean YS
Longitudinal Tensile (LT), Compression (LC) and Hoop Tension (HT)
The maximum application temperature for three-layer coating is 240°C ± 5°C for 4 ± 1 minutes.

An aging study determined:
- The stress-strain discontinuity could be controlled if the pipe coated at a lower temperature:
  - A temperature of up to 210°C for 6-8 minutes was acceptable.
- Lower preheat temperature allowed the stress-strain curves to remain continuous.
Stress-strain curves are specific to pipe grade and manufacturing method

Thermal aging effect is more pronounced with increasing pipe grade
  - High strength steels

A discontinuous stress-strain curve is one of the effects of aging the pipe at temperatures ranging from 150°C to 300°C
  - Temperature depends on pipe grade
Bredero-Shaw undertook a research program to identify thermoset powders that would provide similar performance to their standard powders.

Final selected products could be applied at temperatures below 200°C:
- Performance met or exceeded project parameters
- Performance exceeded all required coating tests
Offshore and Arctic pipelines can be expected to present unexpected design problems
- Problems may be new and not well understood

Engineering must be more stringent to ensure identification of any problems

All pipeline design problems have solutions
- Cooperation and assistance of suppliers can be key to finding solutions

There will be cost implications to doing it right
The End