Considerations for Hydraulic System Design and Compression Equipment on Pipelines Feeding LNG Plants in BC

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Agenda

- System Design
- Hydraulic Design Process Overview
- Design Considerations
- Hydraulic Simulation
- Reliability Assessment
- Fuel Estimates
- J-Curves
- Economic Model

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System Design



We are responsible for the long term planning and hydraulic analysis of TransCanada’s operated gas pipeline systems

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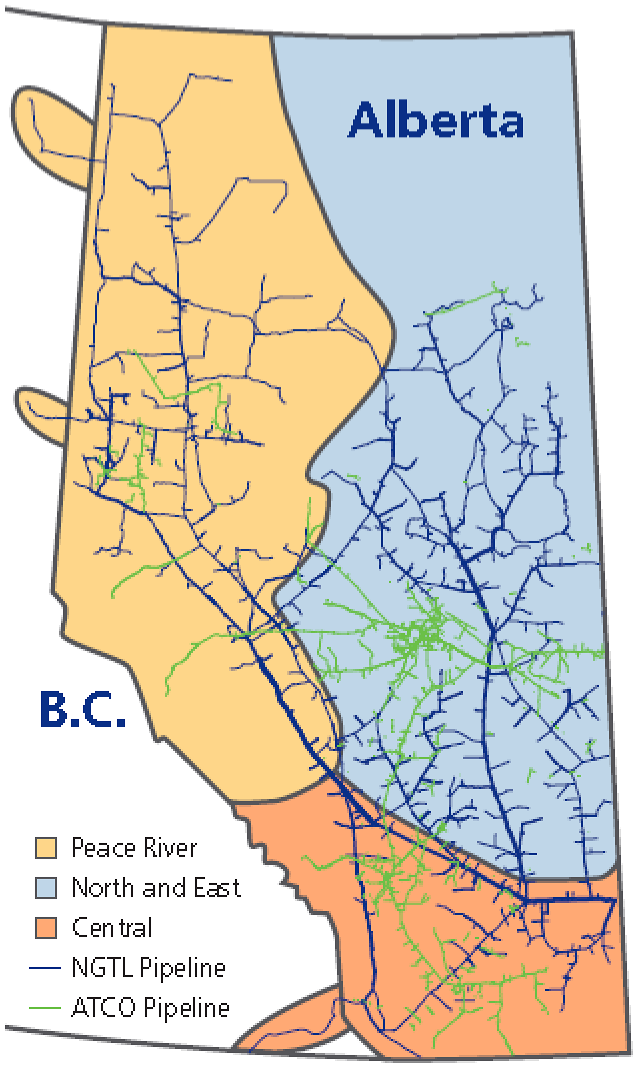
Mainline Planning West



Mainline Facility Planning for Western Canada

- Build-up strategy
- Design criteria/design flow
- Life cycle cost
- Facility requirements, approvals, retirements & alternatives

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System Design Process for BC LNG Facilities



1) **Proponent issues a Request For Proposal (RFP)**
2) **Develop hydraulic simulation models**
3) **Complete hydraulic simulation of facility options**
4) **Complete reliability assessment**
5) **Create J-curves**
6) **Select optimal platform using Cost of Service analysis**
7) **Refine**

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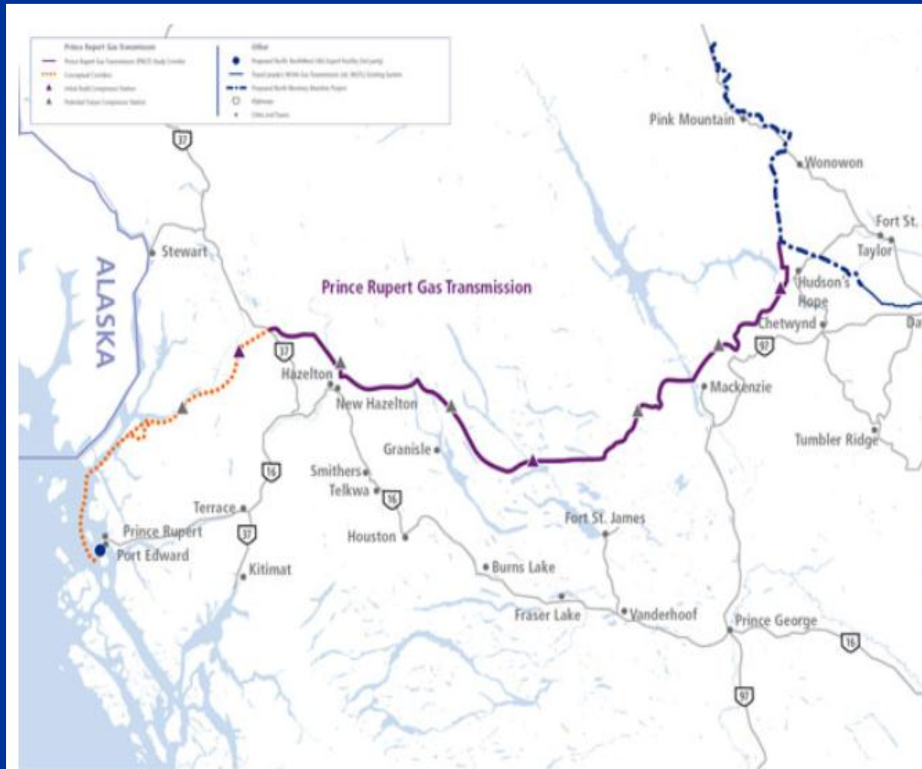
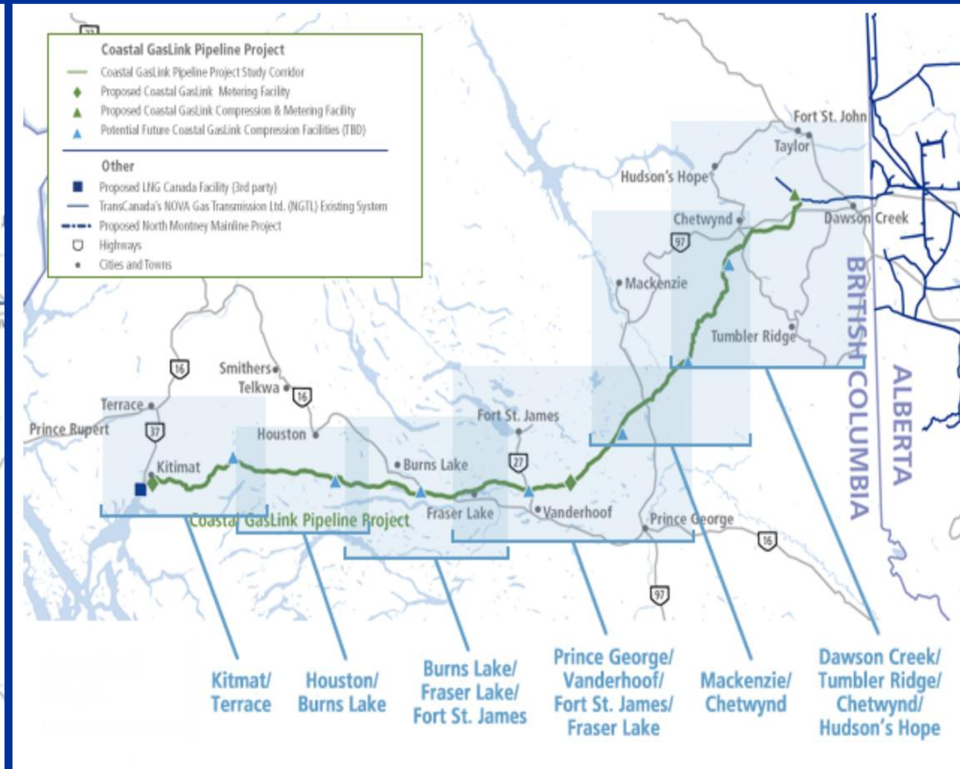
Conceptual Pipeline Corridor





Preliminary route assessment

- Desktop review to identify a conceptual corridor
- Defined by the primary routing control points and routing considerations

Conceptual corridor identification allows

- Initial engagement with Aboriginal groups, landowners, stakeholders and regulatory agencies
- Required to initiate hydraulic system design process

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Developing Simulation Models

Collect the data required to develop the model

- Based on the Conceptual Corridor
    - Preliminary elevation profile, ambient temperatures (daily peak and averages), ground temperatures, heat transfer coefficients
- Flow rates
- Receipt Conditions
    - Pressure, gas composition, inlet gas temperature
- Delivery Conditions
    - Minimum delivery pressure and design delivery pressure
- Pipe Option Details
    - Maximum operating pressure options, wall thickness, pipe size, internal pipe surface roughness
- Compressor Package Options

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Platform Options

What is a pipe platform?

Pipe diameter - at a given pressure rating

NPS 36 – 9 930 kPa (1440 psi)

NPS 42 – 17 240 kPa (2500 psi)

NPS 48 – 13 375 kPa (1940 psi)

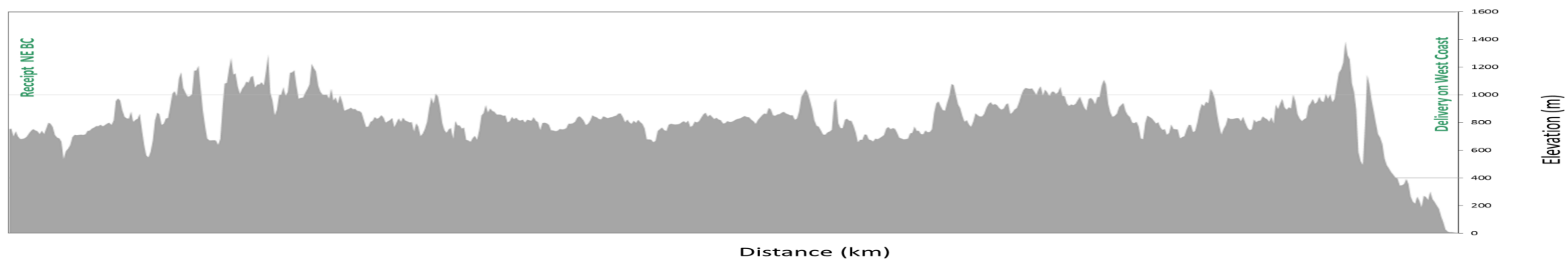
First step is to reduce pipeline platform options

- Using a rule of thumb platform capacity & engineering judgment remove platforms that could not meet highest flow requirements

The remaining platform options are evaluated

- Determine the hydraulically optimal compressor locations for each pipeline platform
  - Determine the compressor spacing required to meet highest RFP flow requirement with the least amount of facilities under peak design conditions
  - Determine the optimal compressor build for the staged flow ramp up utilizing the maximum flow compressor locations

Optimal Compressor Locations



Preliminary Compressor Spacing Determination

- Discharge from compressor stations at close to MAOP
  - Higher efficiency, reduced pressure losses, reduced fuel, reduced emissions, reduced facilities
- ~1.4 compression ratio for single stage compressors
- Assumed 80% compressor efficiency
- Route profile considerations
  - Avoid elevation peaks and valleys

Pipe

- Reasonable flow ranges for a given pipe size based on a rule of thumb pressure drop per km as a starting point
  - 35 kPa/km gives a good balance between the cost of pipe compared to compression fuel and O&M costs
  - 21 m/s maximum mainline pipe velocity

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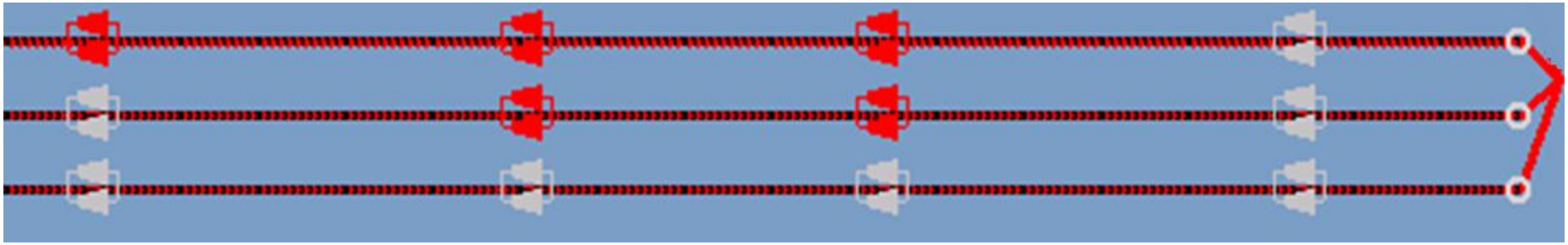
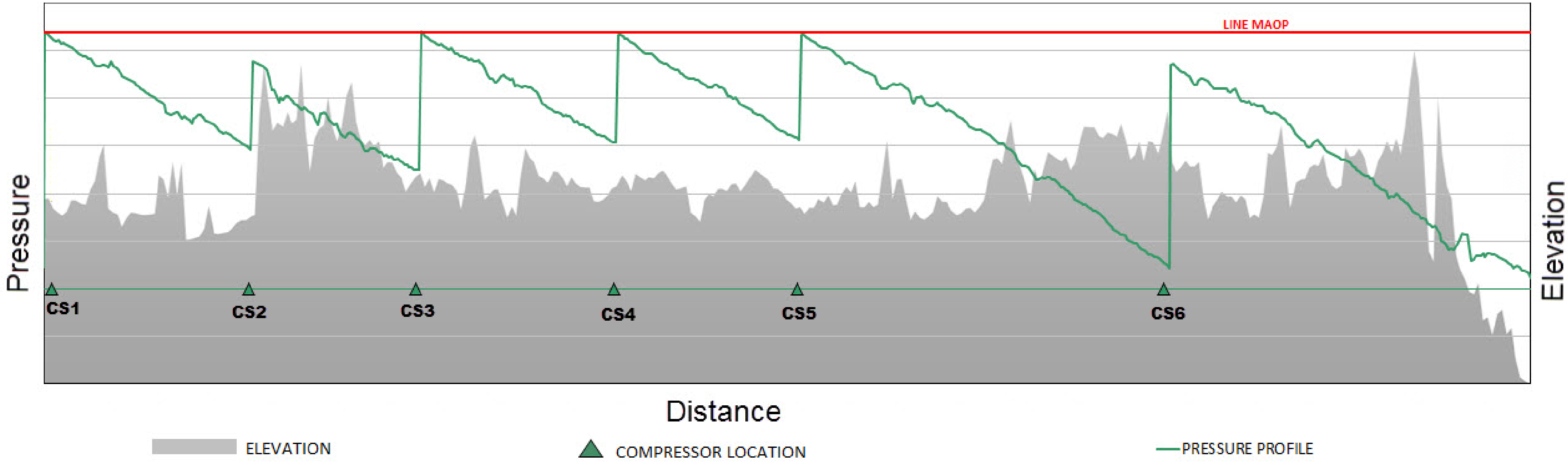
Compressor Spacing



Once the ultimate spacing for the platform has been determined utilize that spacing to determine the facilities required in the build up phases of the project

Hydraulic Profile:
Highest Design Flow Requirement



Compressor stations discharging close to MAOP

Typical compressor spacing

- 35 kPa/km, 21 m/s and ~1.4 compression ration

Compressors not located at peak elevations

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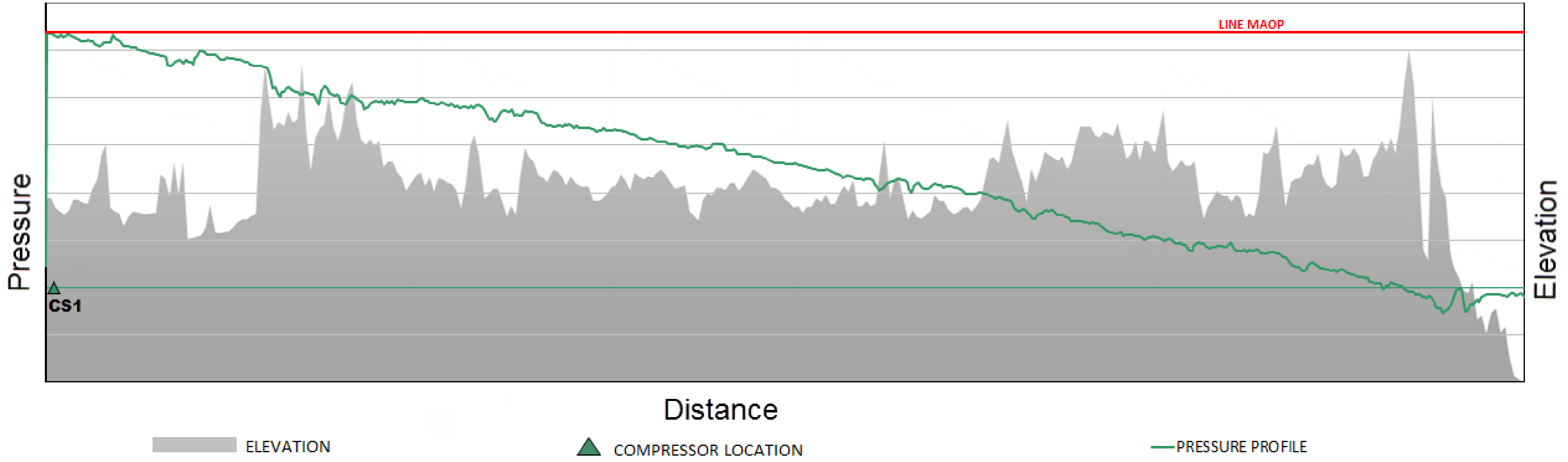
Hydraulic Profile:
Initial Design Flow Requirement



Based on the same pipe platform the initial flow requirement can be met with one compressor station

Compressor station discharging at MAOP

Note the reduced pressure drop

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Reliability

We have the base facility requirements but what about the reliability that was requested?

LNG Plant Proponents very concerned with reliability of supply

Reliability Assessment

Reliability target requires a RAM analysis to be performed on the base design

(RAM – Reliability, Availability & Maintainability)

Based on a Discrete Event Monte Carlo simulation

- MAROS developed by Det Norske Veritas (DNV) Inc.,
- Probability-based reliability model for process-based systems

Determines asset availability by assigning random failures and repairs to equipment based on statistical distributions

- MTTR – Mean Time To Repair a failure
- MTBF – Mean Time Between Failures

Hydraulic Simulation

- Base facility requirements (every platform at every flow rate)
- Outage impacts for RAM model

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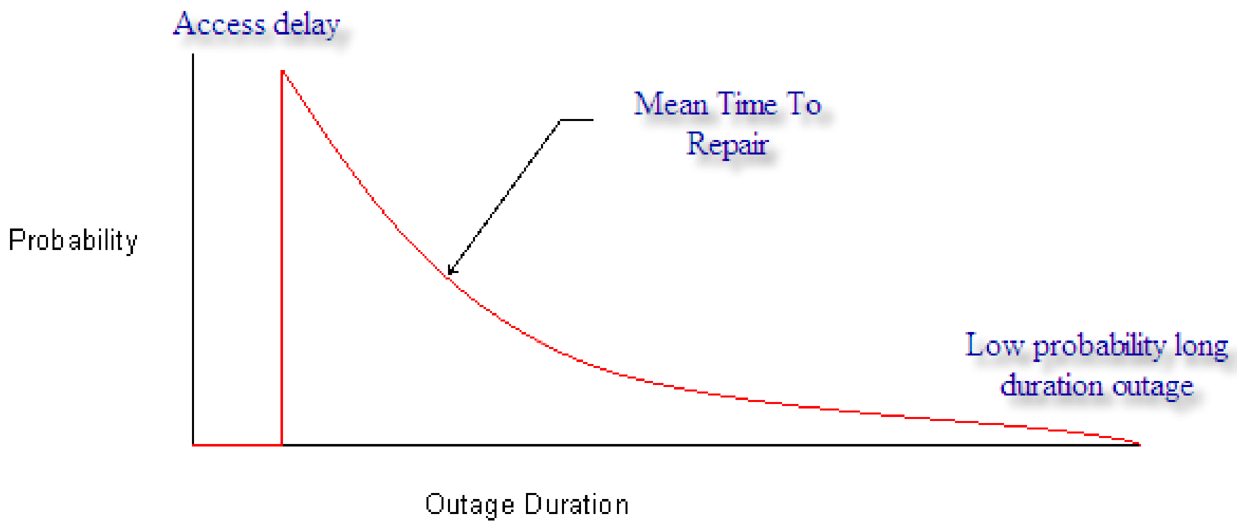
RAM Model Key Inputs

MTTR – Mean Time To Repair



MTBF – Mean Time Between Failures

- Failure rates for compressor units
- Balance Of Plant failure rates (Electrical, Controls, Mechanical, etc)
  - Based on historical high utilization stations on the TransCanada pipeline systems

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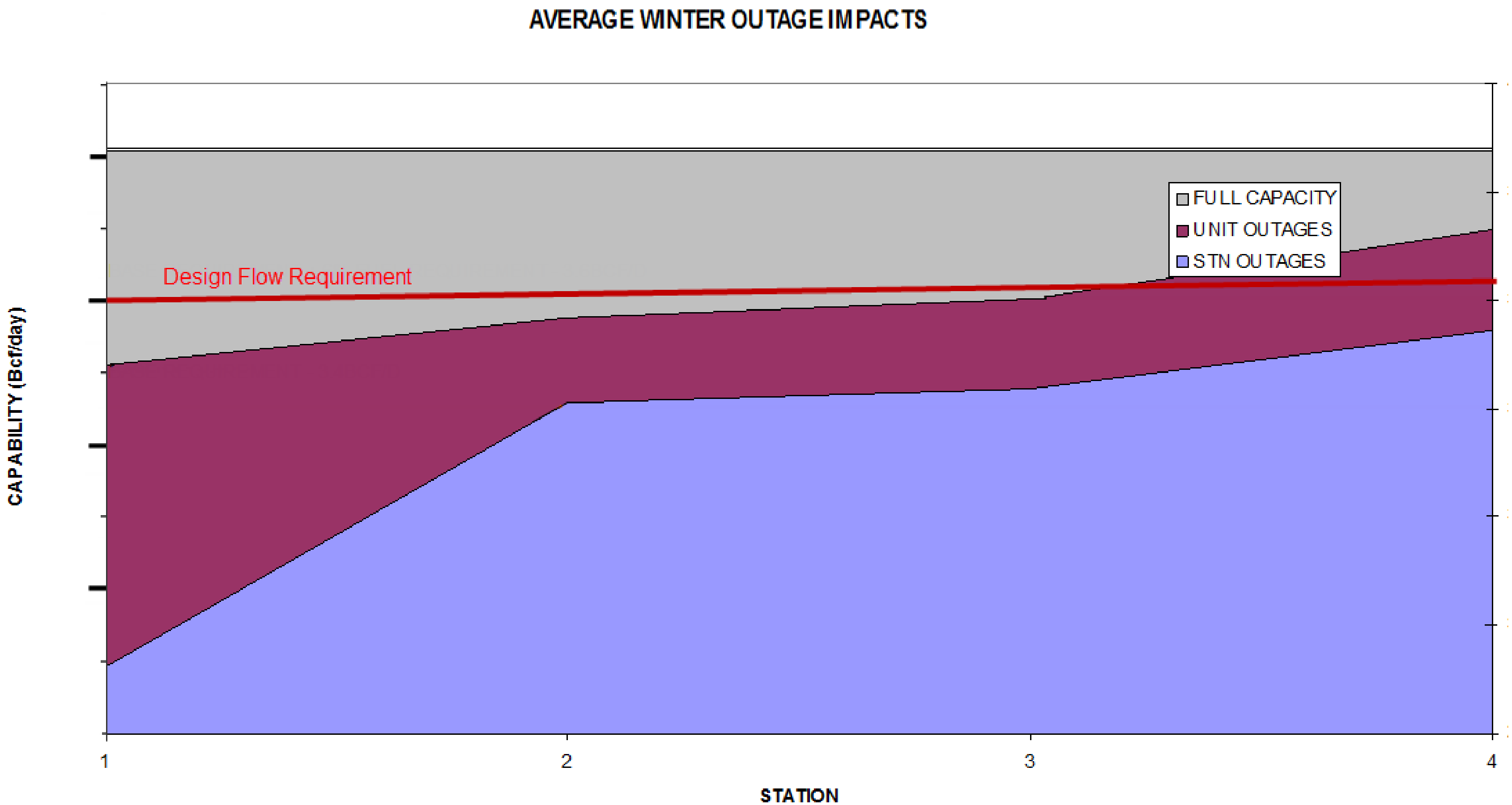
RAM Model Key Inputs

Hydraulic impacts of unit failures and station failures



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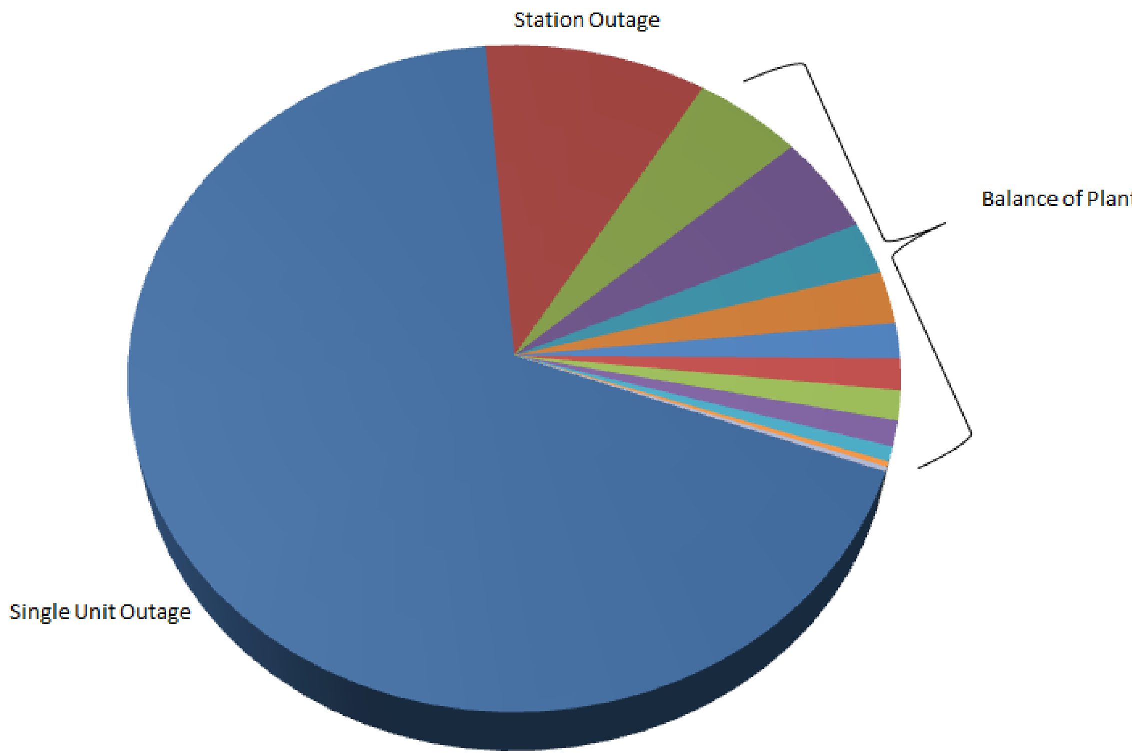
RAM Model Output

System Reliability

- System availability based on a percentage of annual flow

Failure modes impact on reliability

- Breakdown of the cause of the outage that resulted in missing the required flow



RAM Results

Typical bullet line base design reliability

- 96 – 98.5%

Major contributors to reduced availability:

- Station outages
- Unit outages
- Balance of plant outages

Facility additions to increase availability

- Additional spare compressor units at existing sites
- Additional spare balance of plant

Resulting reliability

- 98 – 99.5%

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J-Curves

J-curve analysis is used to further narrow the platform options to a smaller number of viable alternatives for more detailed analysis

- Cost of Service versus Capacity for each pipe platform
- Each point on the curve is based on the hydraulically simulated facility requirement for the flow rate

Current Present Value Cost Of Service (CPVCOS) calculation

NPV based on :

Capital Cost estimate

Operating & Maintenance cost estimates

Financial Parameters

- Interest on debt, Depreciation, Return on Equity

Taxes

Fuel (Calculated based on average day flow conditions)

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Fuel Determination

Design facilities are based on peak compression requirements to ensure the pipeline system can meet the flow requirements on all days of the year

- Maximum flow
- Highest ambient temperatures

Operationally we are not at these peak design conditions the majority of the year

- Ambient temperatures are lower the majority of the year

Lower temperature results in more Gas Generator power available

Results in lower utilization of compressor units and lower fuel utilization compared to design requirements

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Fuel Determination

Temperature Condition	<u>Station A</u> % Power Available Utilization	<u>Station B</u> % Power Available Utilization	<u>Station C</u> % Power Available Utilization	<u>Station D</u> % Power Available Utilization	System Fuel ($10^3 m^3/d$)
Peak Summer (~20 °C)	87%	87%	81%	78%	2,070
Average Summer (~5 °C)	83%	82%	77%	74%	2,020
Average Winter (-4 °C)	79%	78%	73%	71%	2,010

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J-Curve Creation

Current Present Value Cost Of Service calculation

- Capital Cost estimate (base & reliability facilities)
- Operating & Maintenance cost estimates (from historical & forecast information)
  - Estimated on a $/km of pipe basis
  - Estimated on a $/unit/yr for compressor units and drivers
- Fuel (Calculated based on average day flow conditions)
- Financial Factors
  - Interest on debt, Depreciation, Return on Equity
- Taxes (Municipal, Emissions and BC motor fuel tax)

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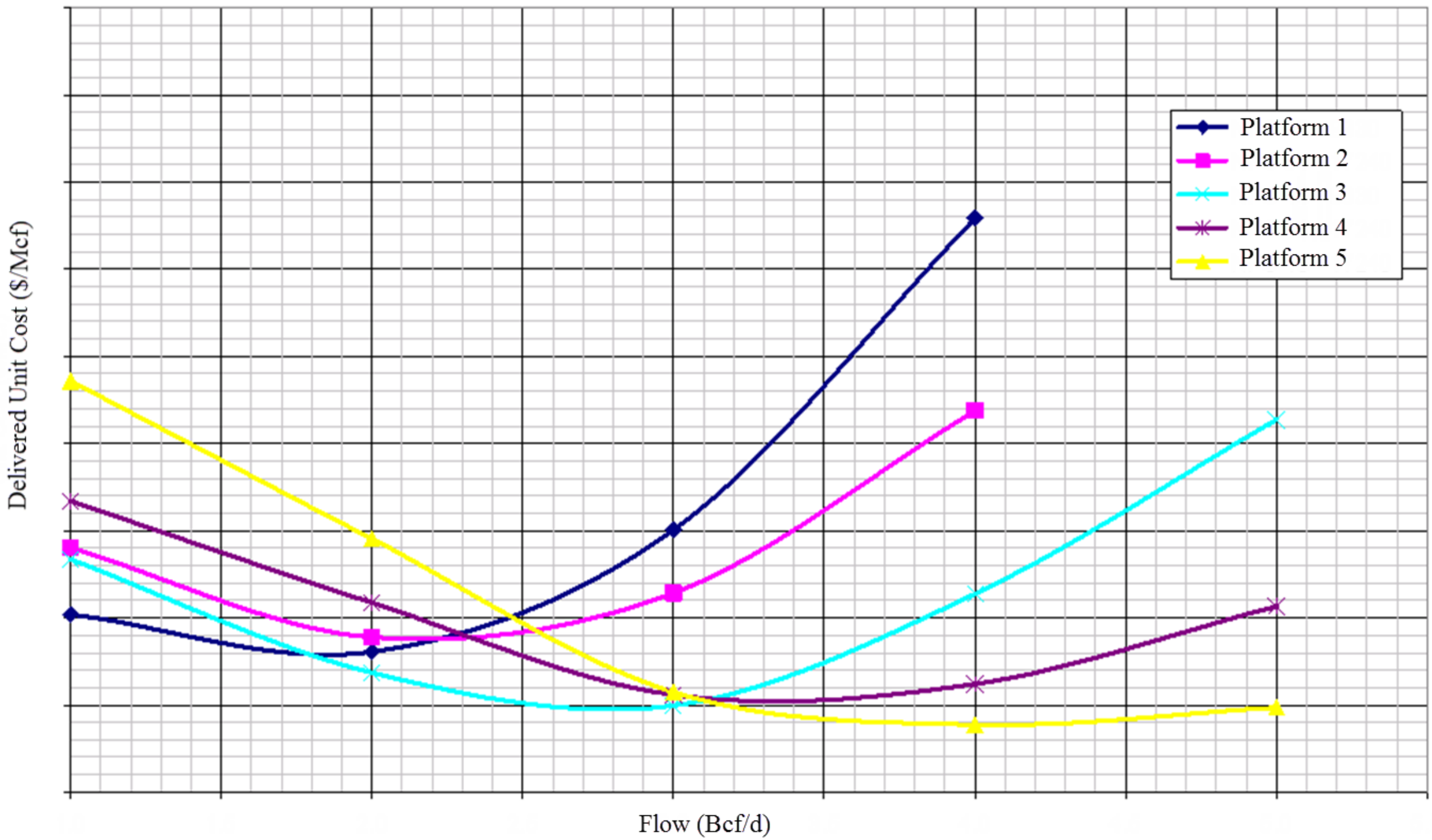
J-curves


Delivered Unit Cost ($/Mcf)
Flow (Bcf/d)
Platform 1
Platform 2
Platform 3
Platform 4
Platform 5

Cost of Service Model

Based on the J-curves comparison select the lowest cost solutions

- Utilize the cost of service model to determine the lowest NPV solution based on the requested flow and expansion stages

Determined by performing a 25 year Cumulative Present Value Cost of Service calculation on optimal alternatives capable of providing the required level of service

Key inputs are the same as J-curves

- Capital Cost estimate (including base, reliability and future facilities)
- Operating & Maintenance cost estimates (from historical & forecast information)
  - Estimated on a $/km of pipe basis
  - Estimated on a $/station/yr for compressor stations
- Fuel (Calculated based on average day flow conditions)
- Financial Factors
  - Interest on debt, Depreciation, Return on Equity
- Taxes (Municipal, Emissions and BC motor fuel tax)

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Pipeline Route and Compressor Location Refinement

Concurrent to the hydraulic and economic analysis, there is continued refinement of the pipeline route and compressor locations

Results in route revs and compressor location changes due to

- Field studies
- Input
    - Aboriginal Groups
    - Landowners
    - Stakeholders
    - Provincial and Federal Regulators

Additional technical details are also received

- Detailed compressor impeller design
- Ground composition
- More accurate temperature data for pipeline corridor

Updates hydraulic model to ensure feasibility with selected platform

If facility changes are significant re-evaluate J-curves and economic model to ensure optimal design has not changed

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Summary

Design Process

- Collect as much information as available to most accurately hydraulically simulate possible alternatives to determine Capital, O&M and fuel
- Apply CPVCOS calculations to produce J-curves to compare and reduce alternatives for the given flow ranges
- Select the optimal solution considering the Cost of Service Model
- Refine/Re-assess as more information is received.

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Questions?