19th SYMPOSIUM ON INDUSTRIAL APPLICATIONS OF GAS TURBINES

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SATISFYING THE LNG INDUSTRY'S REQUIREMENTS FOR AGILE OPERATION ON HIGH C2+ AND INERT CONTENT GAS FUELS IN ROLLS-ROYCE AERODERIVATIVE INDUSTRIAL GAS TURBINES

by

Brian J Nolan / Rolls-Royce Canada

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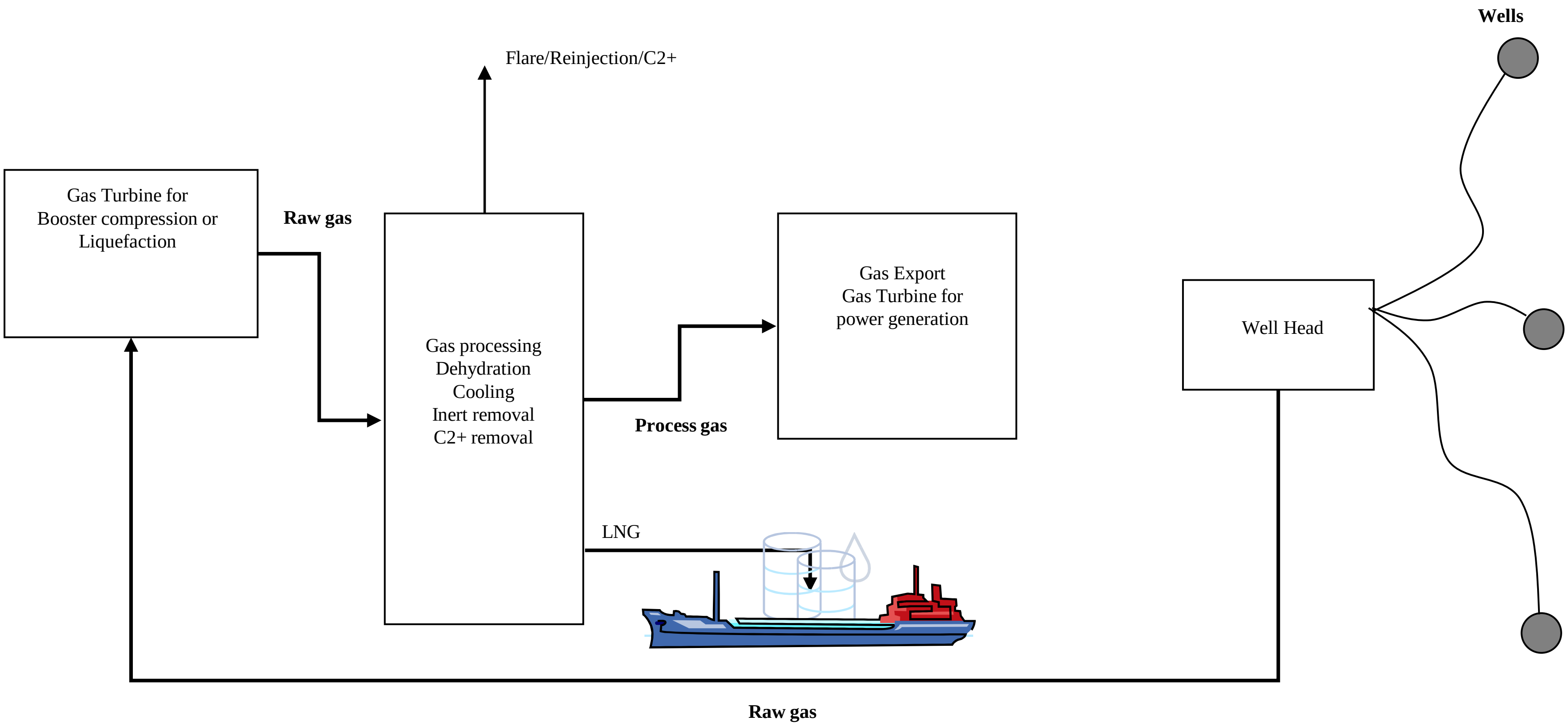
Background

- Steady growth in the LNG market since 1960's.
- 1/600th the volume of natural gas in the gaseous state.
- Production tends towards intermittent (e.g. by ship) rather than continuous
- Plant design frequently results in an envelope of high C2+ and high inert gas for use in the gas turbines.
- Rolls-Royce Energy launched analysis and testing to validate whole engine functionality for the envelope of gas mixtures

Key Drivers for Aero derivative Usage

- Power Density
- Availability and Reliability
- Rapid starting, loading and load changes
- On-line transfer between different fuel types
- Used in a variety of sub-systems:-
  - Electrical power generation
  - Compressor boosting of gas
  - Refrigerant compression for gas cooling
  - Waste gas compression of well re-injection

Simplified LNG plant schematic



Example Spectrum of Fuel Types

Description		Normal Operation	Normal Start	Fault Start 1	Fault Start 2	Fault Start 3	Compressor Trip	Booster Trip
Composition:								
CO_2	mol%	0.00	3.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	mol%	9.16	0.91	0.94	1.05	20.30	1.02	9.05
Methane	mol%	82.38	76.55	78.91	88.45	79.69	85.84	84.77
Ethane	mol%	8.32	9.83	10.13	10.26	0.01	12.91	6.04
Propane	mol%	0.13	6.65	6.86	0.23	0.00	0.22	0.13
i-Butane	mol%	0.00	0.89	0.92	0.00	0.00	0.00	0.00
n-Butane	mol%	0.00	1.45	1.49	0.00	0.00	0.00	0.00
i-Pentane	mol%	0.00	0.23	0.24	0.00	0.00	0.00	0.00
n-Pentane	mol%	0.00	0.39	0.40	0.00	0.00	0.00	0.00
n-Hexane	mol%	0.00	0.05	0.05	0.00	0.00	0.00	0.00
n-Heptane	mol%	0.00	0.04	0.04	0.00	0.00	0.00	0.00
n-Octane	mol%	0.00	0.01	0.01	0.00	0.00	0.00	0.00
H_2O	mol%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H_2S	mol%	0.00	Max 5 ppmv	Max 2ppmv	Max 2 ppmv	0.00	0.00	0.00
Total	mol%	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	C1	82.38	76.55	78.91	88.45	79.69	85.84	84.77
	C2+	8.45	19.54	20.14	10.50	0.01	13.14	6.18
	inerts	9.16	3.91	0.94	1.05	20.30	1.02	9.05

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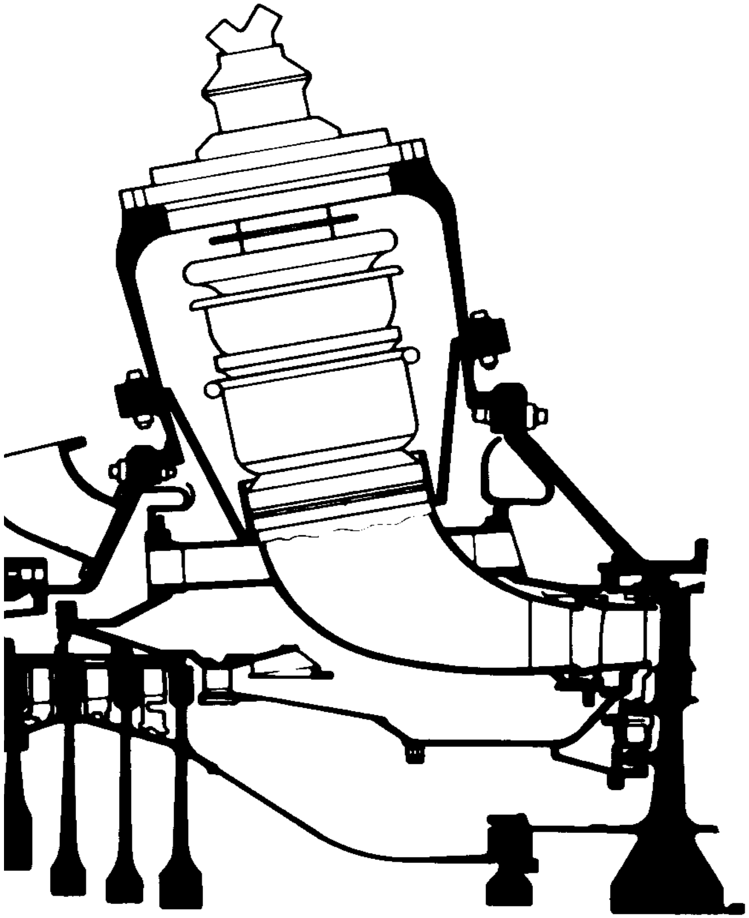
Key Operational Considerations

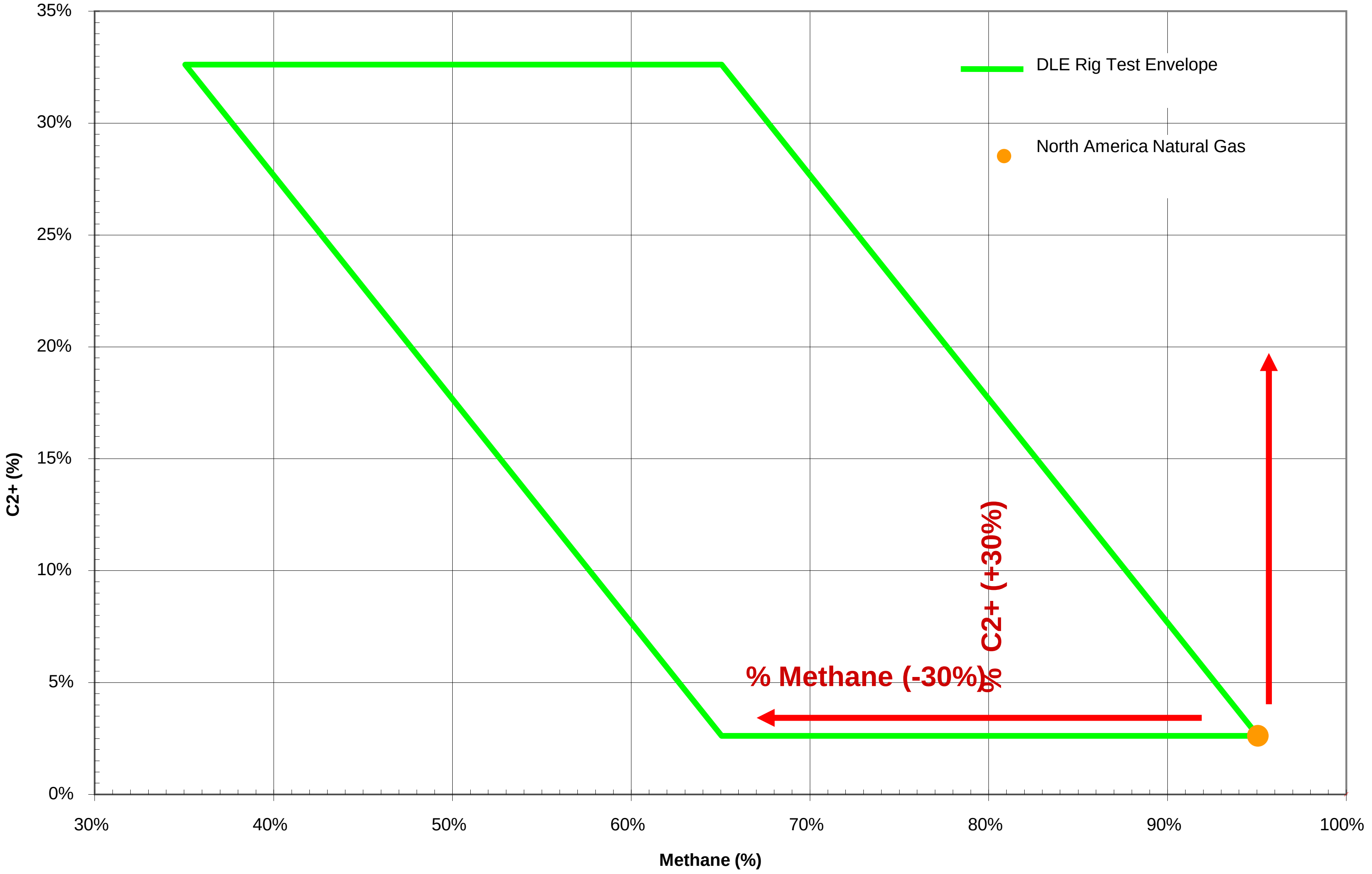
- Fuel ignition and flame stability
- Burner Injection Velocity
- Combustion Rumble
- Delivery System Pressure Limits
- Liquid Condensates
- Compressor Working Lines

DLE Operational Considerations

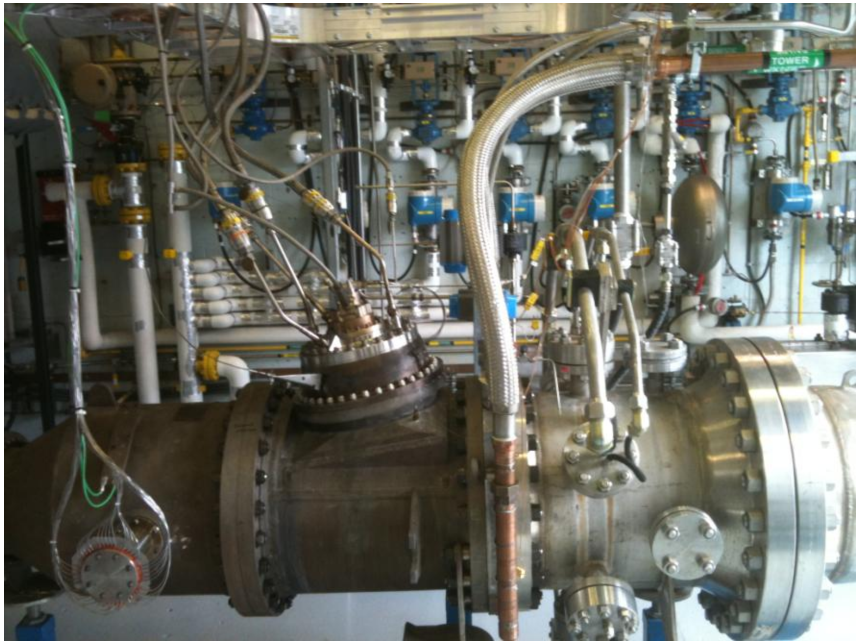
- Autoignition/flashback
- Emissions Control
- Combustion Noise
- In 2004, Rolls-Royce launched a rig initiative to understand the DLE effect with increasing C2+ and inert.

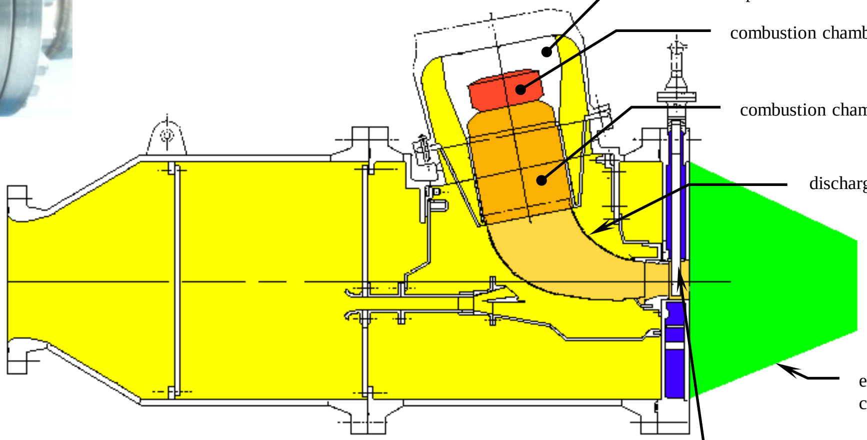


Test Methodology



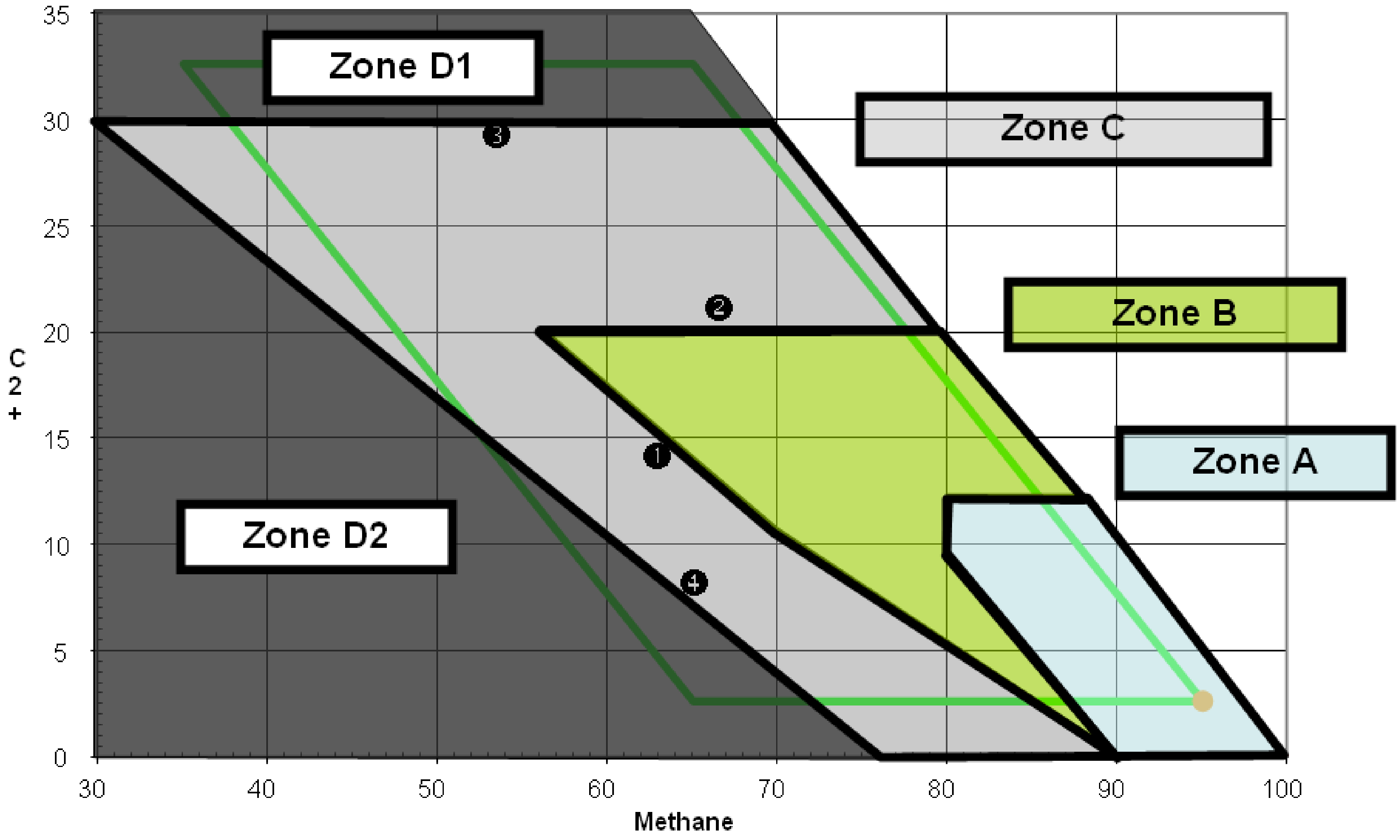
Test Set-up





combustor premixers
combustion chamber, primary zone
combustion chamber, secondary zone
discharge nozzle
exhaust pipe and exhaust cooling
Water cooled emissions sampling

Test Outcome



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Test Outcome

- Zone A - Universally acceptable
- Zone B - Highly likely acceptable for all operational & power requirements
- Zone C - Case-by-Case fuel and application assessment required.
- Zone D - Likely to only be acceptable for limited operational requirements

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Zone B Summary

- Highly likely acceptable for all operational & power requirements
- Some operational experience
- Approaching ❶ sees increasing fuel delivery pressures, particularly on high CO2 on higher power engine marks.
- Approaching ❷sees combustion noise signature beginning to change when high concentrations of butane are present, requiring adjustment in primary zone temperatures.

Zone C Summary

- Case-by-Case fuel and application assessment required.
- Limited operational experience
- Approaching ❸ sees combustion noise signature beginning to change even on lighter species of C2+ (propane and ethane)
- Approaching ❹sees increasing fuel delivery pressures, even on N2. In addition, fuel ignition repeatability during start-up begins to decline when C2+ elements are limited.

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Zone D Summary

- Likely to only be acceptable for limited operational requirements without some changes to hardware (e.g. fuel delivery pipe-work sizing)
- In Zone D1, on any C2+ fuel, the operational window between lean blow out and noise control becomes impractical without allowing emissions levels to begin to elevate.
- In zone D2, fuel manifold conditions begin to limit achievable power. Fuel ignition repeatability during start-up is poor in zone D2 when C2+ elements are limited.

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Conclusions

- Rig testing, analytical assessment and service experience read-across has shown that the RB211 DLE machine has the ability to satisfy the operational requirements of a significantly wider inert and C2+ envelope than originally standarised, without hardware change.
- Due to permutations of inert, C2+, site conditions and required operational maneuvers, the significant number of acceptability criteria a gas turbine manufacturer must consider make it difficult to draw lines of absolute unacceptability and case-by-case analysis is often required.

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