



GTEN 2019 Symposium

October 21-23, 2019 | Banff, Alberta

Retrofit Solutions for Operational Flexibility

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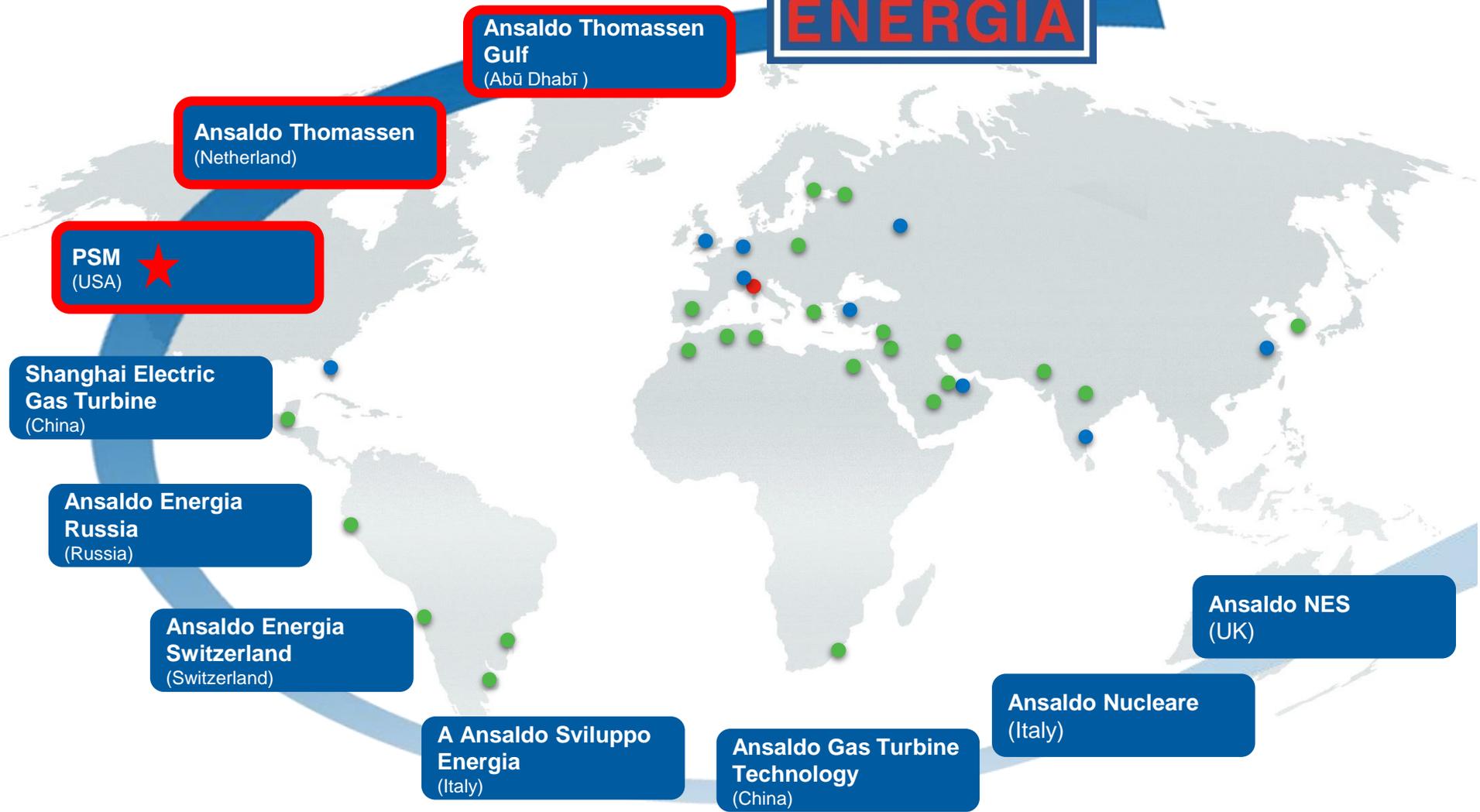
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October 21st, 2019

Presented at the Gas Turbines Energy Network (GTEN) 2019 Symposium
Banff, Alberta, Canada - October 2019

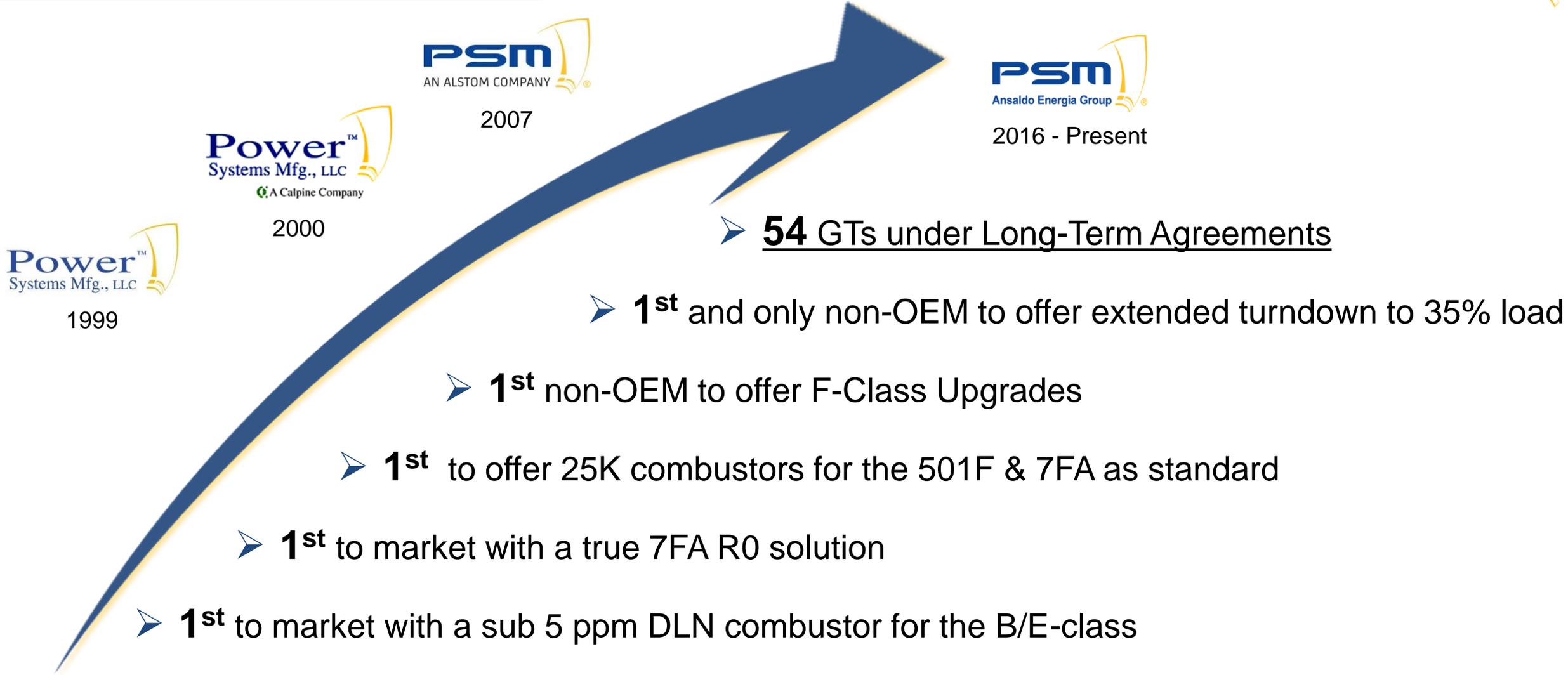
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ANSALDO ENERGIA



● Company Headquarters ● Controlled Companies and JVs ● Branches and Offices

Who is PSM?



➤ 54 GTs under Long-Term Agreements

➤ **1st** and only non-OEM to offer extended turndown to 35% load

➤ **1st** non-OEM to offer F-Class Upgrades

➤ **1st** to offer 25K combustors for the 501F & 7FA as standard

➤ **1st** to market with a true 7FA R0 solution

➤ **1st** to market with a sub 5 ppm DLN combustor for the B/E-class

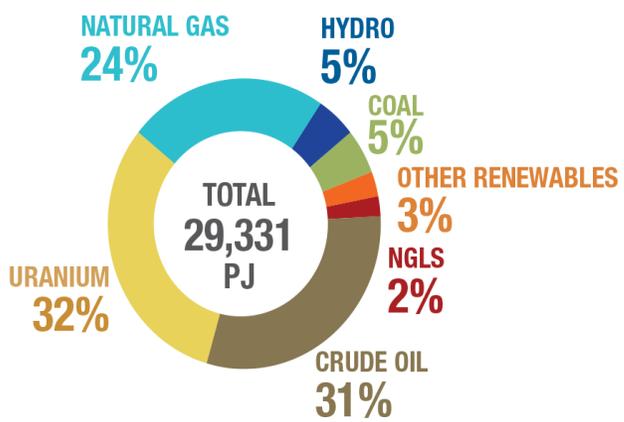
Flexible, Reliable & Multi-Platform Portfolio Improves Plant Profitability

Fuel Flexibility

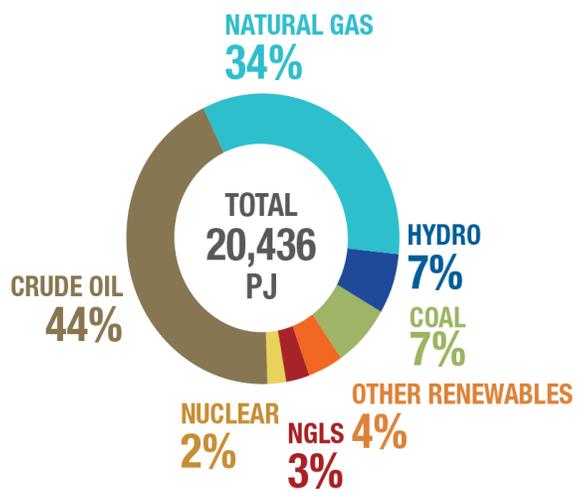
Current and Future Landscape of Gas Turbines



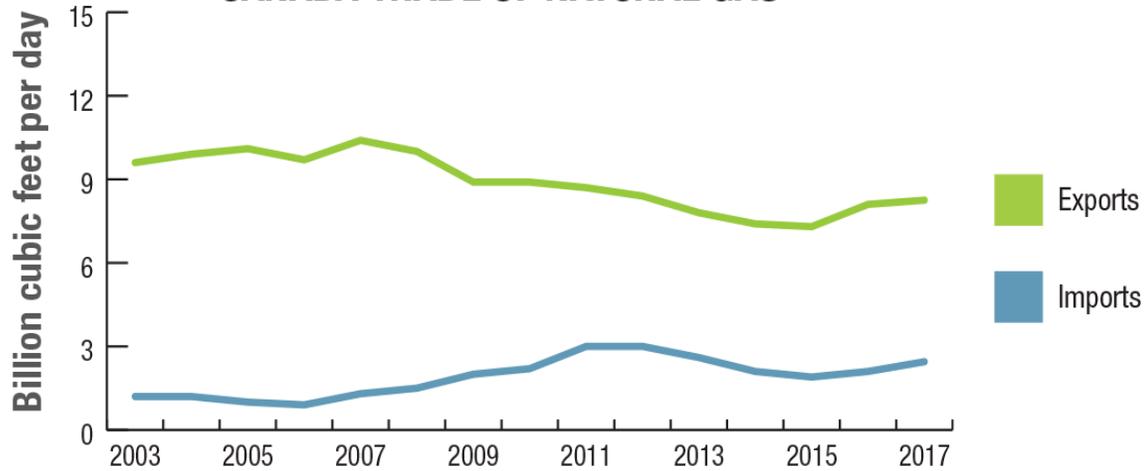
PRIMARY ENERGY PRODUCTION, INCLUDING URANIUM



PRIMARY ENERGY PRODUCTION, EXCLUDING URANIUM



CANADA TRADE OF NATURAL GAS



- Canada, relies on Natural gas to provide 24% of its energy production
- Canada is 4th largest NG producer
- Canada imports ~ 2.5-3 Bcf per day of Natural gas from the US

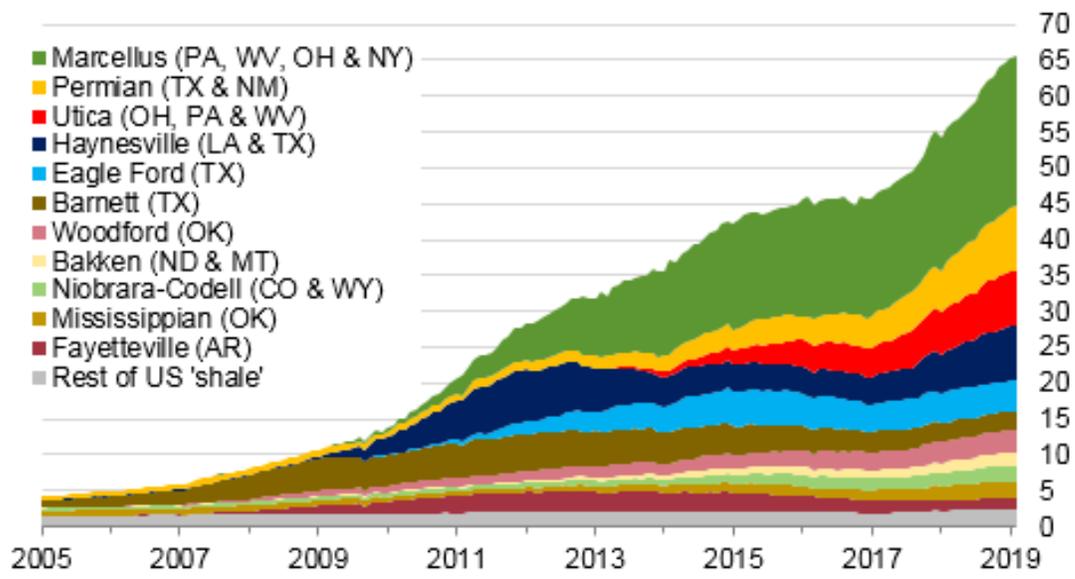
Fuel Flexibility

Current and Future Landscape of Gas Turbines



Typical Shale Gas Constituent Ranges (% Volume)						
	C1	C2	C3	CO ₂	N ₂	MWI Variation %
Barnett	80-95	2-12	0-6	0-3	1-8	-8%
Marcellus	79-86	3-17	1-4	0-1	0-1	-1%
Fayetteville	97	1	0	1	1	3%
New Albany	87-93	0-2	0-3	5-11	-	-21%
Antrim	27-86	3-5	0-2	0-9	0-65	-78%

Monthly dry shale gas production
billion cubic feet per day



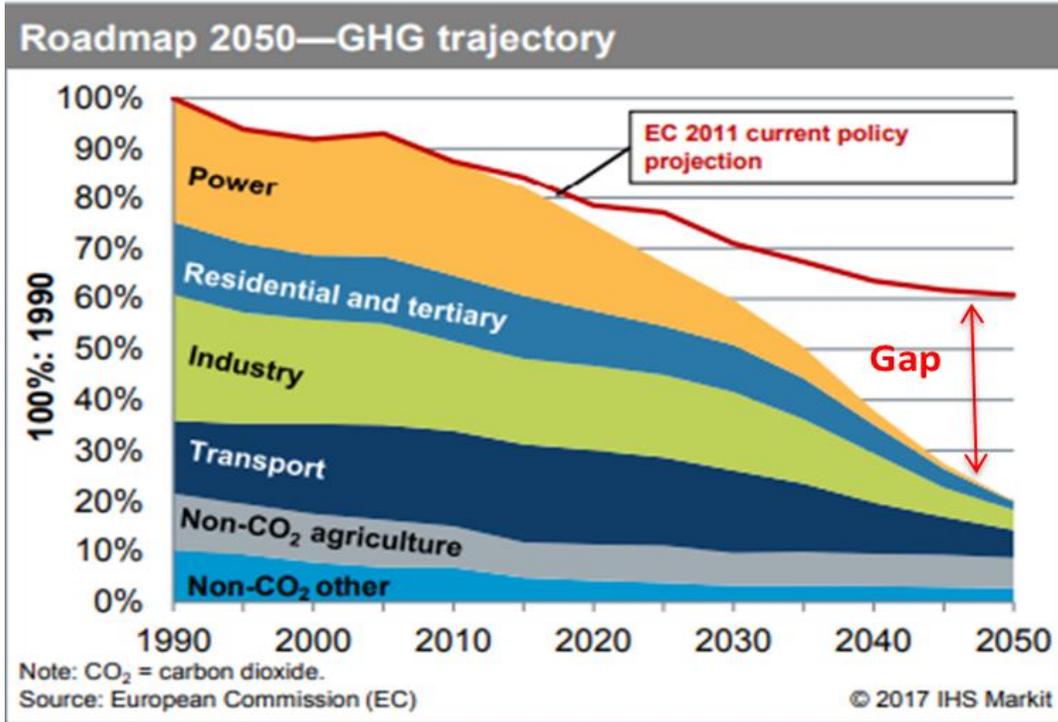
Sources: EIA derived from state administrative data collected by DrillingInfo Inc. Data are through February 2019 and represent EIA's official tight gas estimates, but are not survey data. State abbreviations indicate primary state(s).

$$\text{Modified Wobbe Index} = \frac{LHV}{\sqrt{SG_{gas} \times T_{gas}}}$$

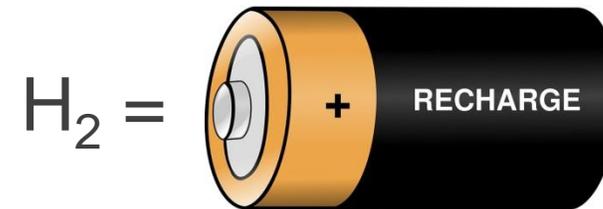
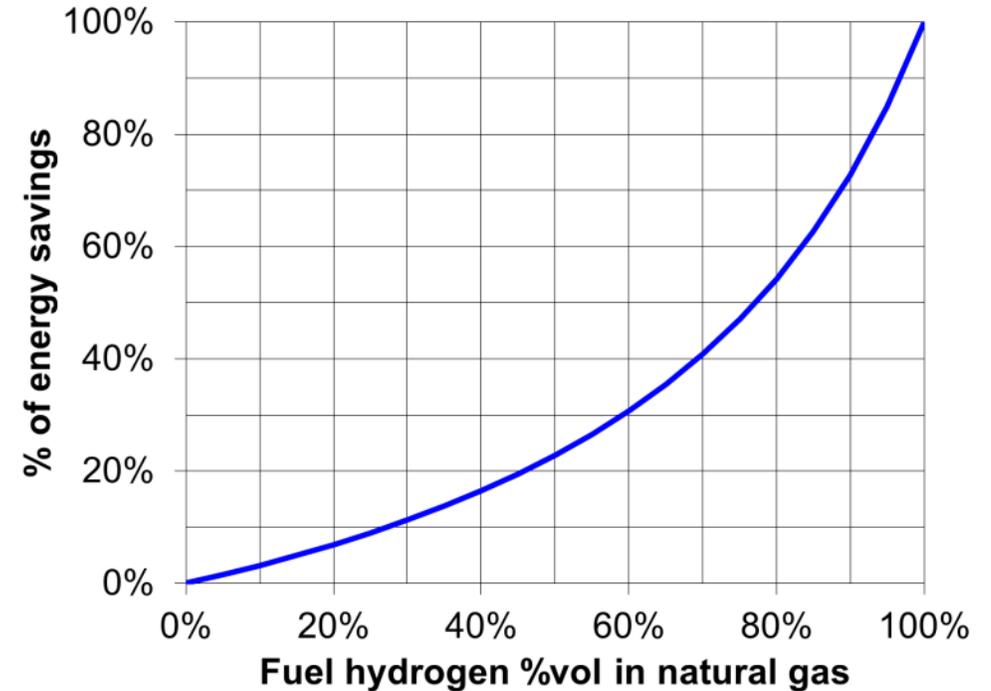
Higher MWI Capability Required to Handle Shale Gas Properties

Fuel Flexibility

Current and Future Landscape of Gas Turbines



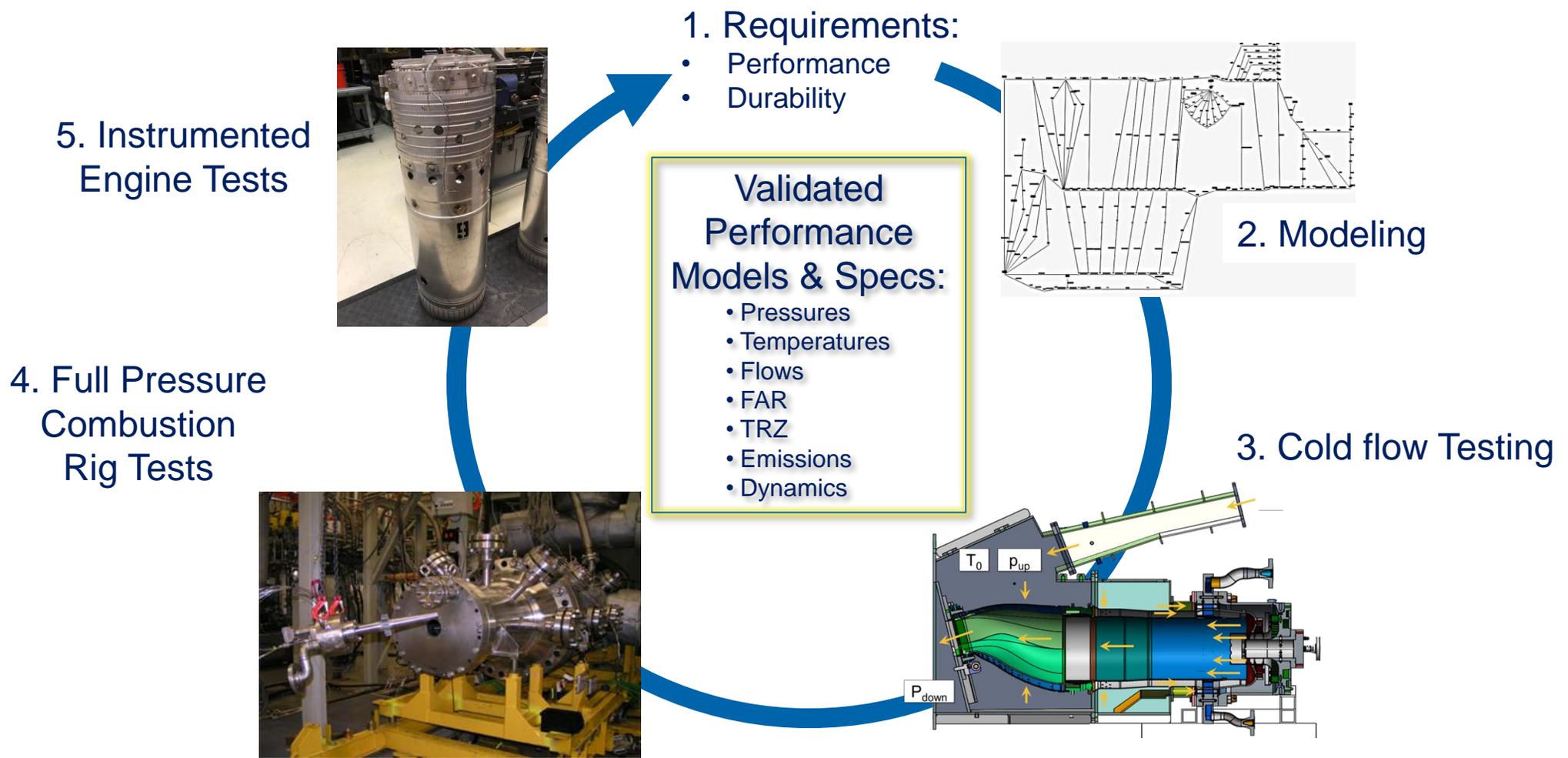
- Hydrogen initiative in the energy production making large strides from a decarbonisation and green house gas reduction standpoint.
- H₂ usage problematic for NG fired - Low Emissions Assets



De-carbonization Putting H₂ in Focus, Driving H₂ Technology Growth

Combustor Development Process

How does PSM design and implement new combustor systems?



Engineering Discipline – Key to Combustor Development

LEC™ Technology Evolution



LEC I

- 2000-2001
- Sub 25ppm NOx
- Gas Only
- 8K hr/400 start CI

LEC III™

- 2001 - Present
- Sub 5 ppm NOx
- Gas Only
- 55% Turndown with IBH
- 24K hr/900 start CI
- Off-Gas Fuel Flexibility



LEC NextGen

- 2015 - Present
- Sub 9ppm NOx
- Gas Only & Dual Fuel
- 50-55% Turndown with IBH
- Up to 32K hr/1200 start CI

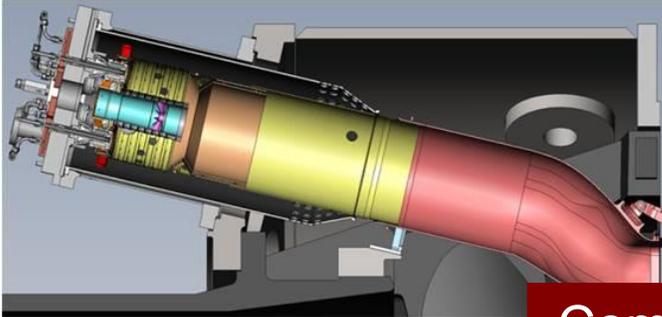
2018 and Beyond
Turndown Options →

- H2 Fuel Flex Addition – sub-40% Turndown
- AutoTune = Additional 5% Turndown
- Exhaust Bleed = Additional 10% Turndown
- FlameSheet™ = as low as 25-30% Turndown

Strategically Expanding Portfolio and Capabilities

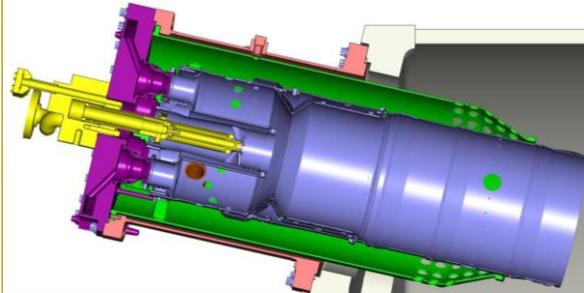
Multiple Advanced Combustor Solutions

T-DLN1



- Drop-In Compatible with OEM DLN System
- Gas Only and Dual Fuel Application with sub-9ppm Emissions
- Enhanced Coating, Sealing, and Bracket Configuration
- Wide Variety of Applications

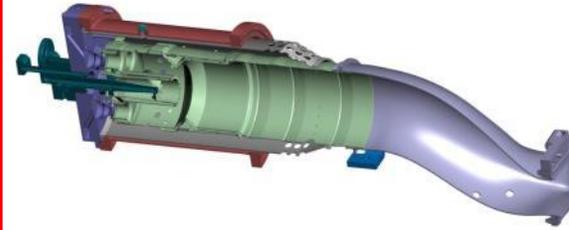
LEC III™ Ultra Low Emissions System



- Reverse Flow Venturi & Low Flowing Cap for Ultra Low Emissions
- Gas Only Application with sub-5ppm emissions
- Robust Transition Piece to Handle Increased Dynamics without Excessive Wear
- Pilot-less “Fin Mixer” Secondary Fuel Nozzle

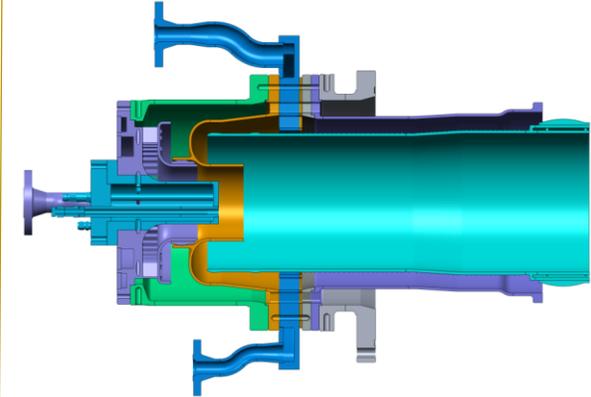
Combined Combustor Solution

LEC NextGen



- Drop-In Compatible with OEM DLN System
- Gas Only and Dual Fuel Application with sub-9ppm Emissions
 - Demonstrated sub-5ppm!
- 32k hours / 1300 Starts Capable System
- Enhanced Cooling and Durability
- Fuel Flexibility Options

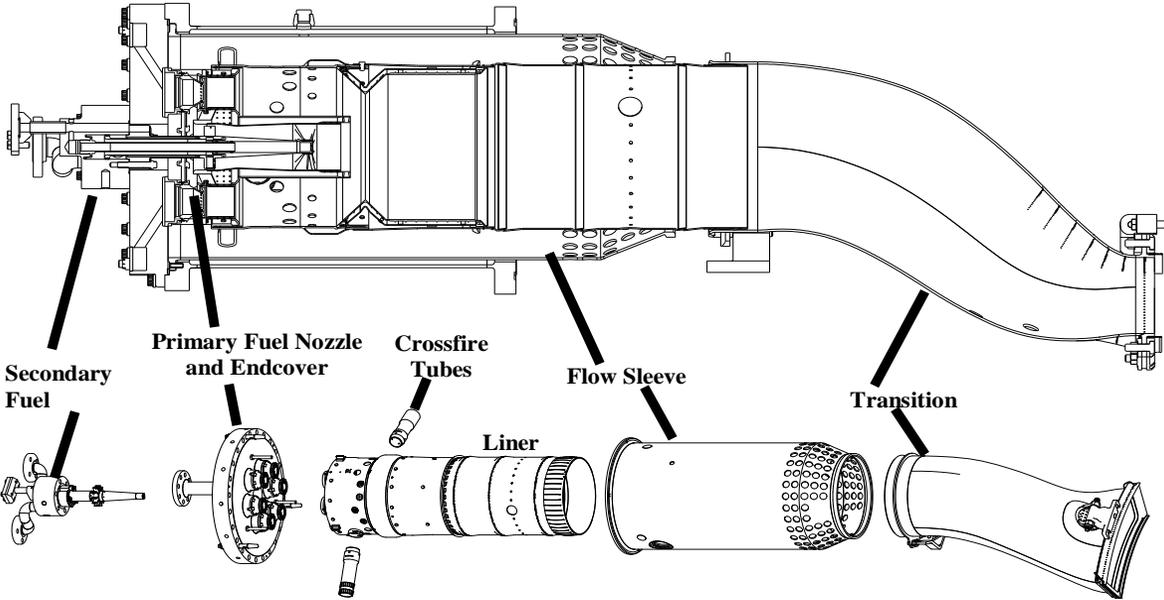
FlameSheet™



- Flame Isolation – Combustor Within Combustor For Advanced Flame Staging
- Aerodynamic Trapped Vortex Provides Wide Stability Margin
- High Premixer Exit Velocities For Tolerance To Highly Reactive Fuels
- Robust Mixing Techniques For Improved Fuel Flexibility & Tolerance To Fuel Wobbe Index Variation

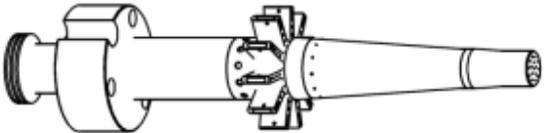
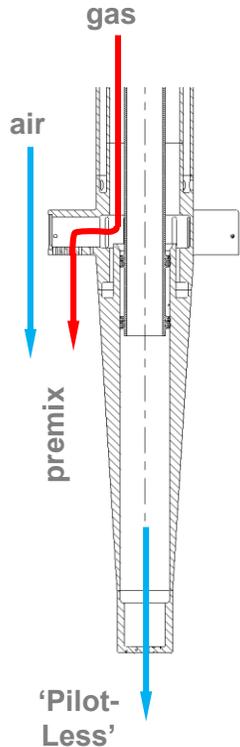
Wide Range of Options For Varying Unit Applications

Canadian Installation – LEC NextGen

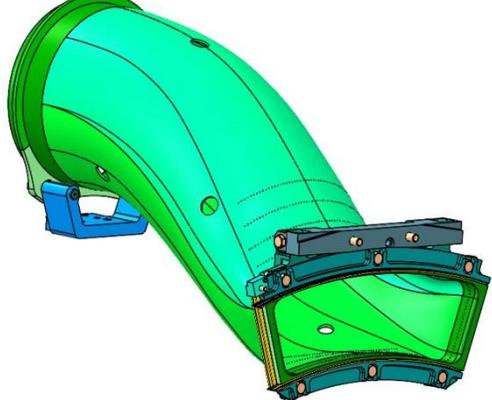
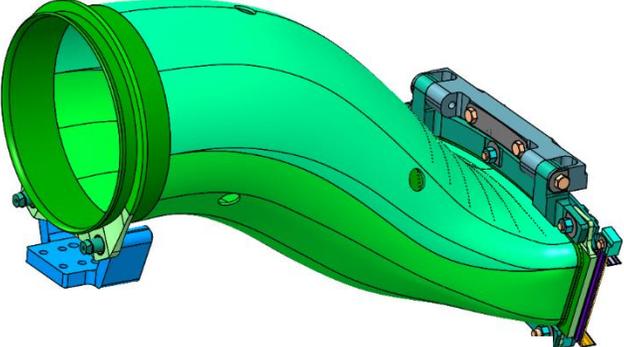


LEC NextGen Liner
 Improved Venturi Cooling and Materials
 Louvre Cooled and TBC Coated Pre-Mixer
 Extended Contact Wear Surfaces
 Thick Lower Liner

LEC "Fin Mixer"
 < 5ppm NOx

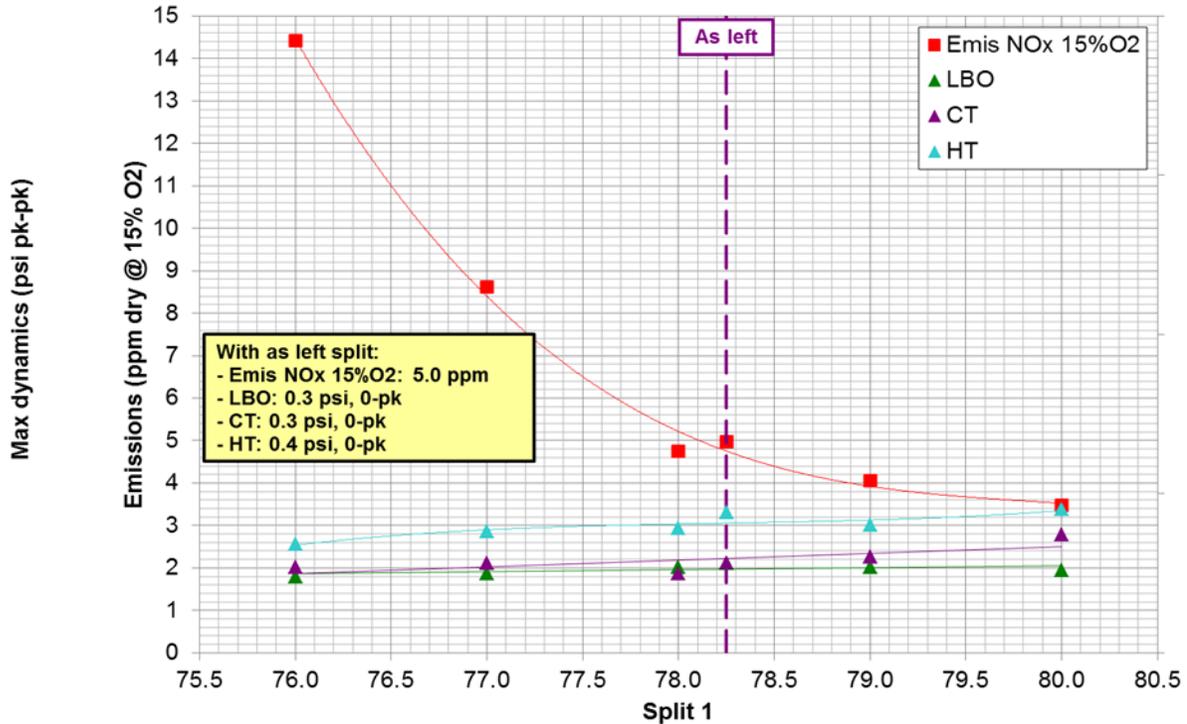
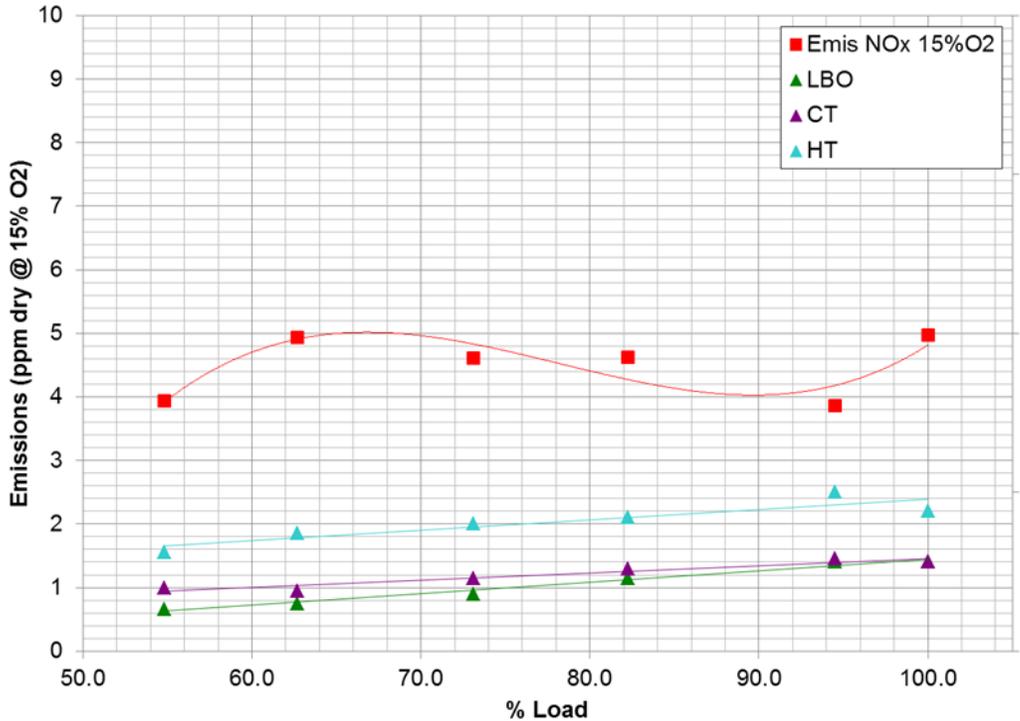


LEC Fin Mixer
 11 Fin Injectors with 8 holes each



LEC Transition Piece
 Thermally Free Aft Mount Integrated into Picture Frame
 "Twin Pin" Bullhorn Bracket
 Effusion Cooling
 Extended Contact Wear Surfaces
 Thick Inlet Support Ring
 Patented Flexible "Dog Bone" Seals

Canadian Installation – LEC NextGen



- LEC NexGen Installed on 2X Baseload 7EA Heavy Duty Gas Turbines in 2017 and 2019.
- Achieved <5ppm NOx operation across load range.

LEC III™ Combustion System

Combustor Design for Fuel Flexibility

- LEC introduced in 1998
- In 2017, First Commercial Operation of 35% H₂ Blending

Site Configuration

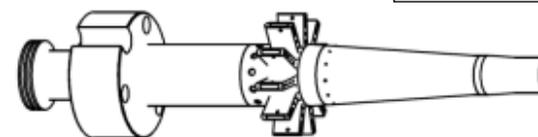
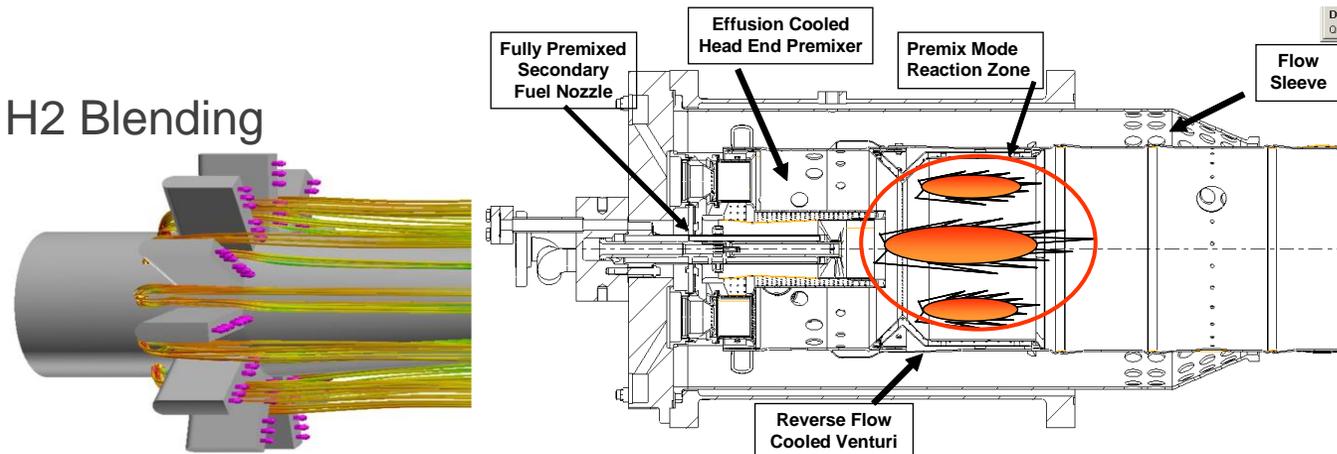
- 3 on 1 combined cycle units
- 3 9E LEC III™, 50Hz
- Ring manifold SFN
- 1 Steam Turbine

Off-gas (Hydrogen) fuel usage

- Nearby chemical plant produces H₂ gas and provides to the site
- Up to 10% H₂ by vol is consumed in the 3 GTs
- H₂ is combined with Nat. Gas via Mixing Station

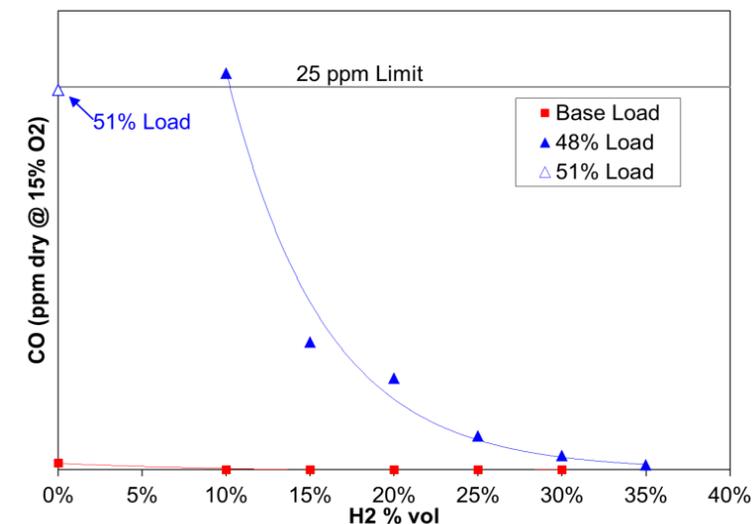
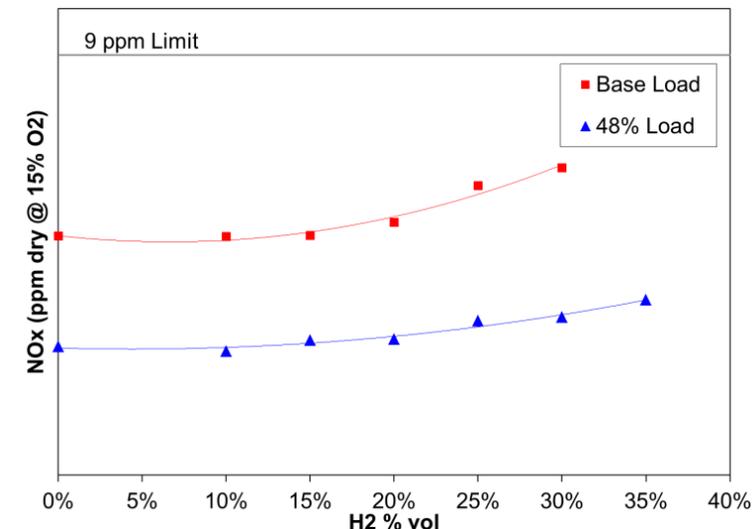
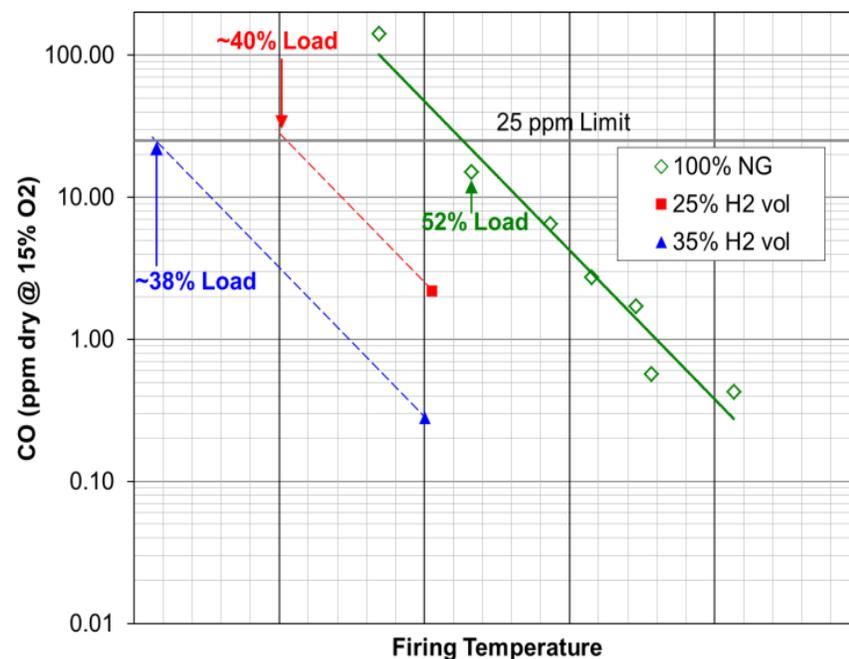
Conversion Scope

- Retrofitted combustion system with PSM Fin Mixer Technology for additional H₂ capability
- Implemented AutoTune System with Fuel Flex.



Industry-Leading Flexibility with High Hydrogen Capability

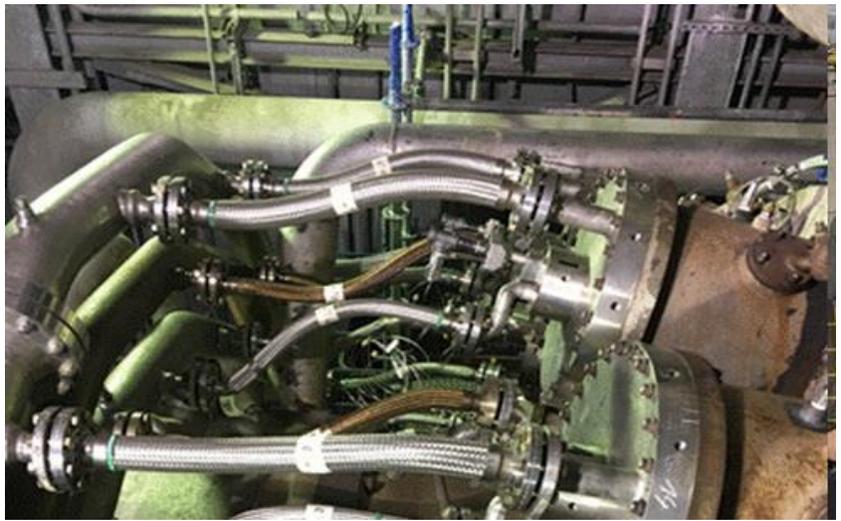
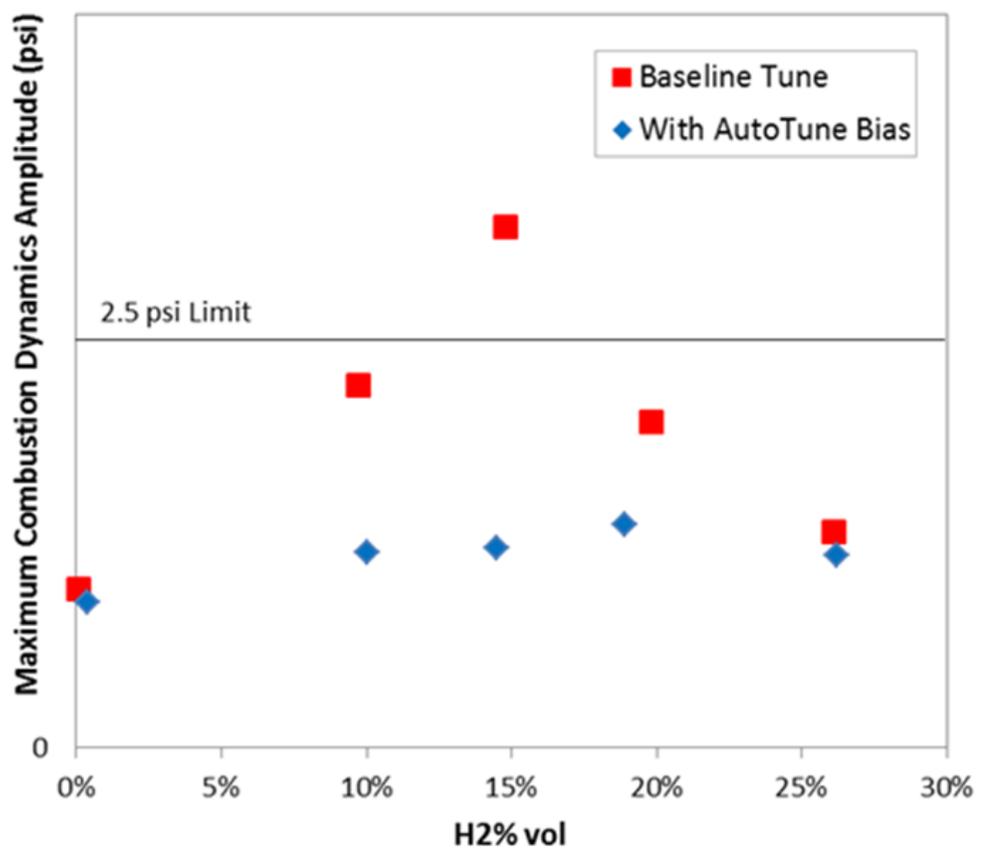
- Hydrogen is key for future GHG initiatives
- Ability to burn Hydrogen in Low NOx Combustion system is limited due to flashback
- Hydrogen content improves turndown due to higher local flame temperature (stability margin) and lower CO emissions.
- LEC III™ technology able to safely burn up to 35% H2 by Volume



LEC Combustion Systems Offering Low Emissions B/E Class Retrofit Solutions

LEC III™ 9E Engine Results – Netherlands

9E Commercial Engine H2 Operation with AutoTune



$$\text{Slope}_{\text{NG}} = \frac{\Delta P_{\text{NGCOR}}}{\dot{m}^2_{\text{NG}}} \quad \text{FPP} \equiv \frac{\text{Slope}_{\text{NG}}}{\text{Slope}_{\text{NGref}}}$$

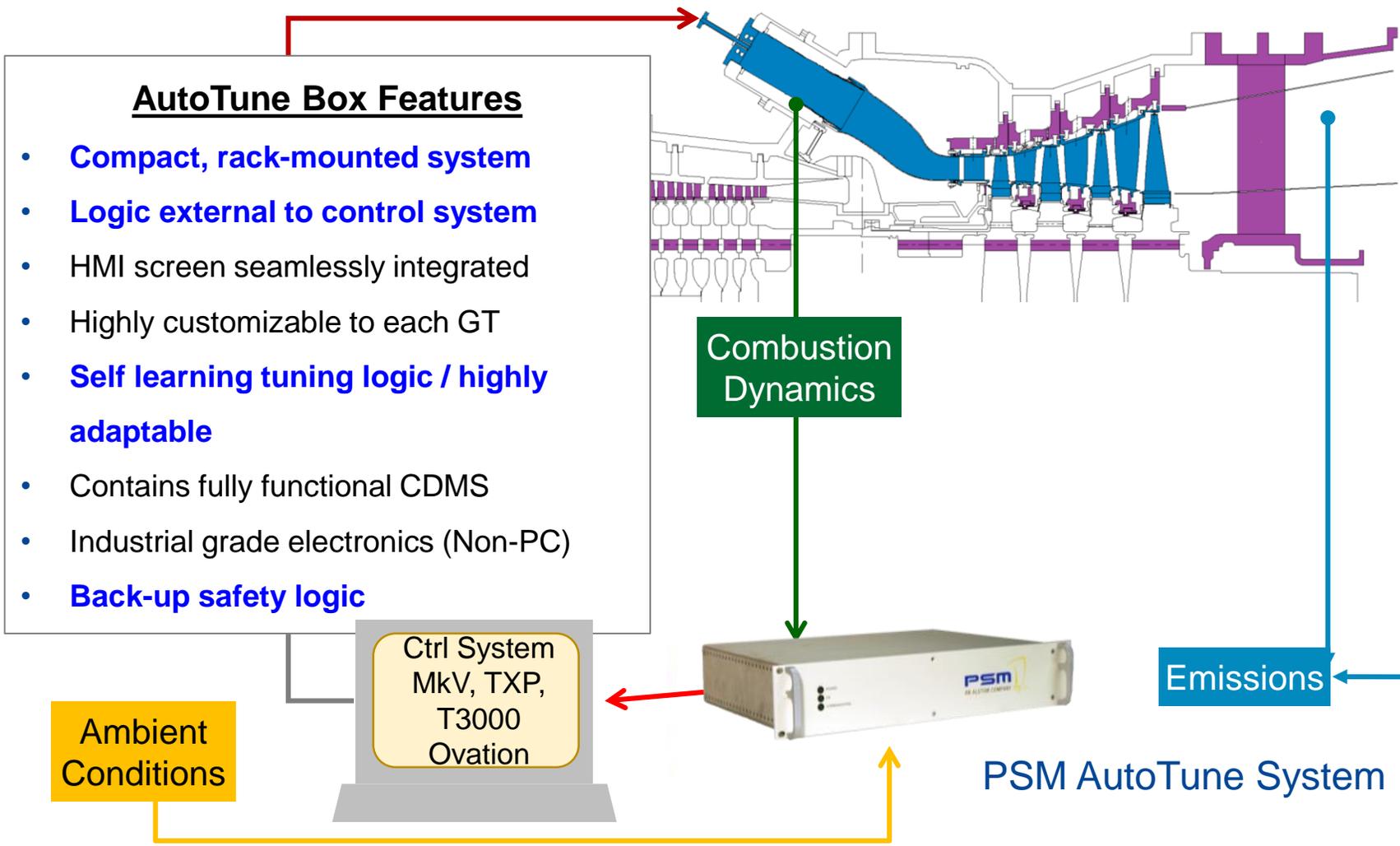


Novel “Fuel-Flex” AutoTune algorithm, allows fast acting gas constituency detection, and enables Tuning with varying H₂ content without need for gas chromatography.

Automated Tuning Function For Varying H2 Content Improves Reliability

FlexSuite: AutoTune

AutoTune System Overview



AutoTune Offers a 365.25/24/7 Onsite Tuning Capability

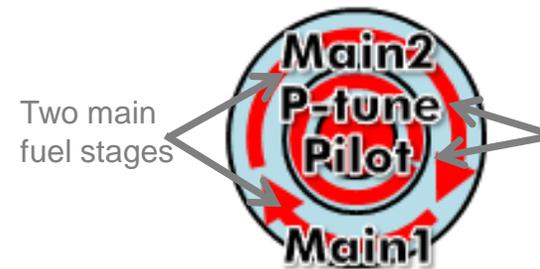
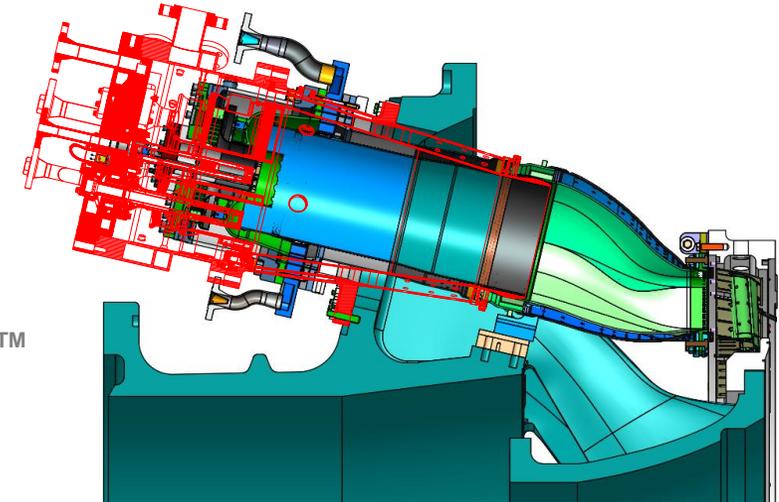
FlameSheet™ Combustion System

How It Works

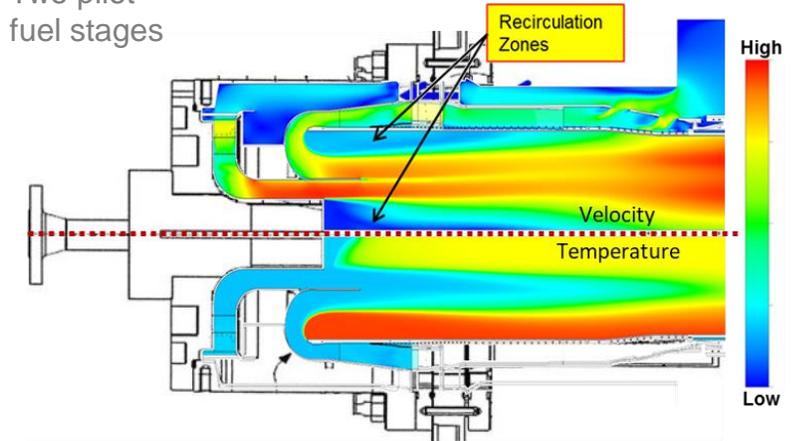
FlameSheet™ Attributes

- **Turndown to 35% Load** On Standard Firing Curve
 - Extended Turndown Also Realized On Reduced Low Load Firing Curve To Protect Unit HRSG
- Extended Fuel Flexibility
 - **30% Modified Wobbe Index (MWI) Variation**
 - Dual Fuel Capable
- Maintain Emissions Compliance Across Entire Load Range, Including Turndown and +50°F TIT
 - **NOx Below 9ppm**, As Low As 5ppm With AutoTune
 - CO Below 9ppm
 - No Diluents
- **32K hours / 1250 Starts** Inspection Interval

DLN2.6
FlameSheet™



Two pilot fuel stages



TWO Combustors in One; Turndown, Fuel Flexibility, & Emissions Capability

Results From Recent FlameSheet™ Installs

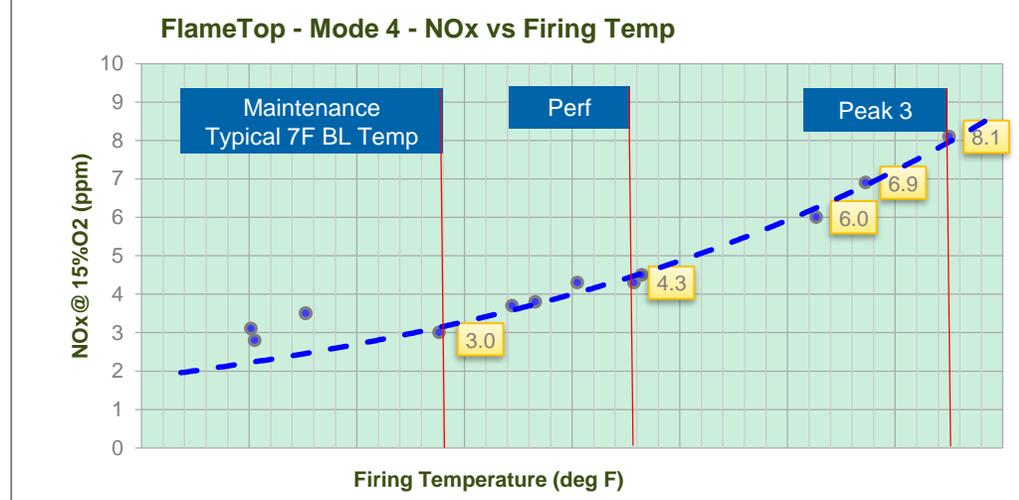
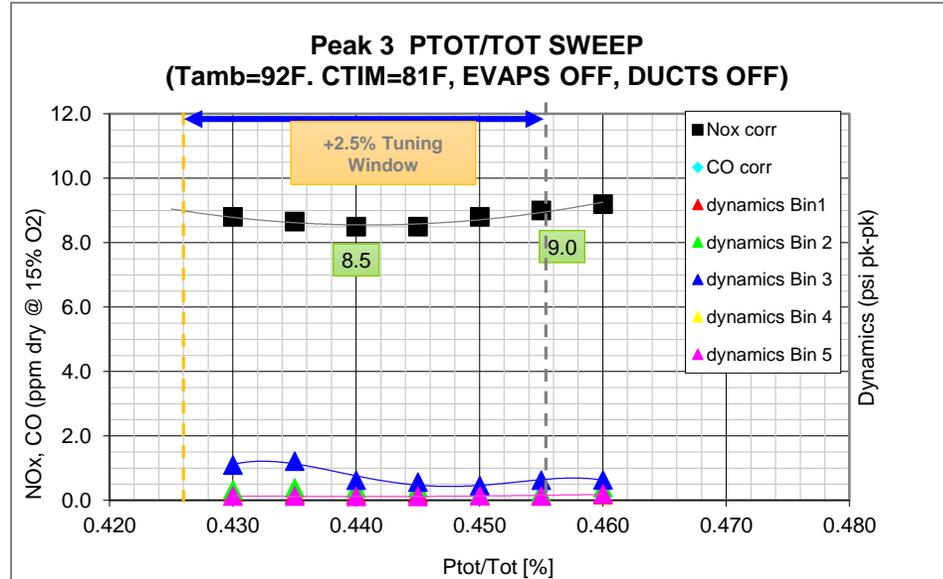
Low ΔP FlameSheet™

Customer Need:

- Improved Capacity, Improved HR
- Shale Gas Operation (up to 10-12% C₂'s)
- Improved Turndown for HRSG

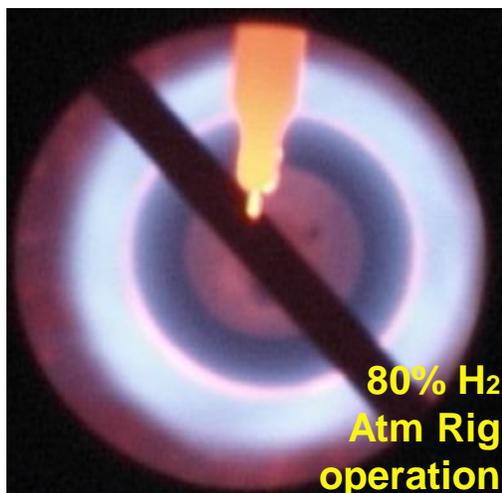
Achievements:

- +10% output and 2.2% HR improvement with Low DP FlameSheet™
- Turndown to 40% load (CO in compliance) on reduced exhaust temp Isotherm
- Reduced NOx (sub-9ppm) at BL +50F Firing
- Reduced start time by 30 minutes



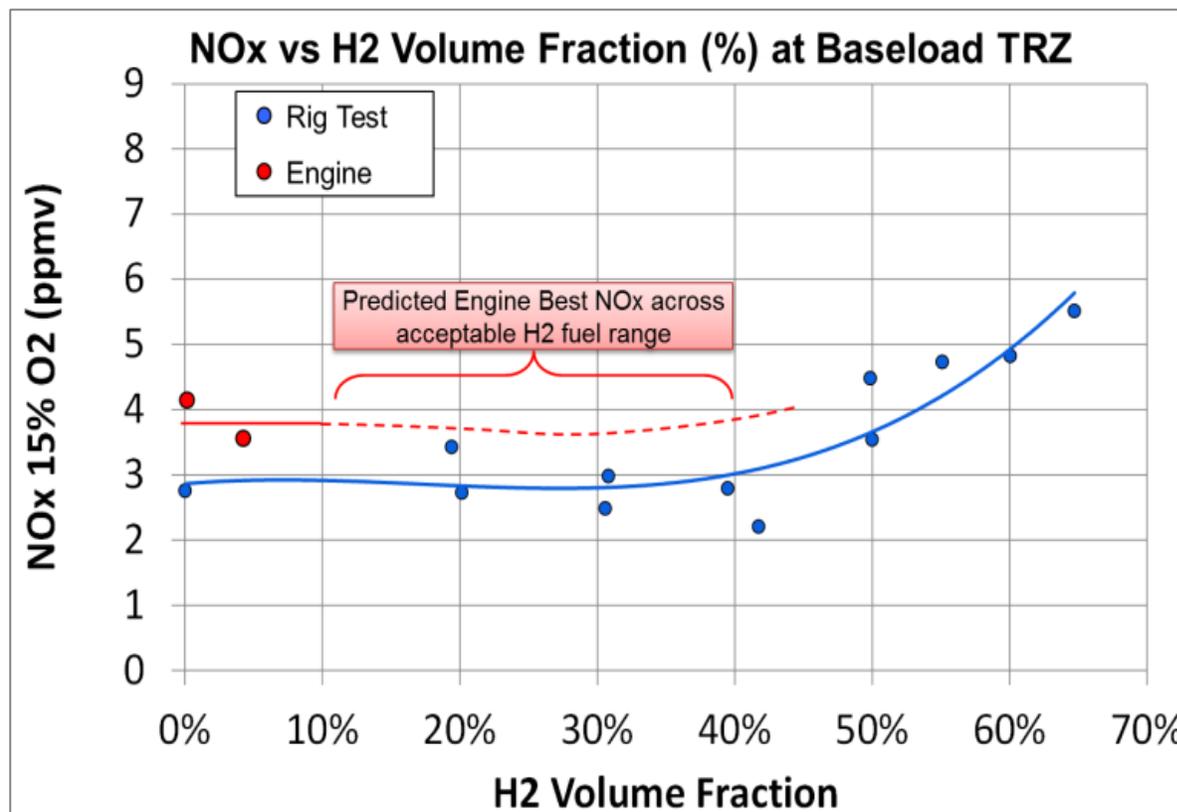
Sub 9ppm NOx @ Peak Fire (+50F) Output & Reduced HR on Shale Gas

- Engine emissions match High Pressure Rig Emissions within ~1 ppm of NOx
- Further validation of H₂ capability is to come in the future with upgrades of hydrogen capability at site



Hydrogen Blending At Baseload Conditions

- Demonstrated 65% H₂ By Volume In High Pressure Test Rig
- Maintained sub 6ppm NOx at 65% H₂ By Volume



Up to 65% H₂ (Vol) Validation at F-Class Engine Conditions

2018/19 Event Highlights

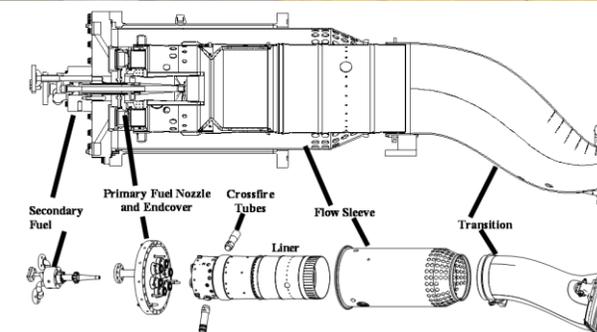
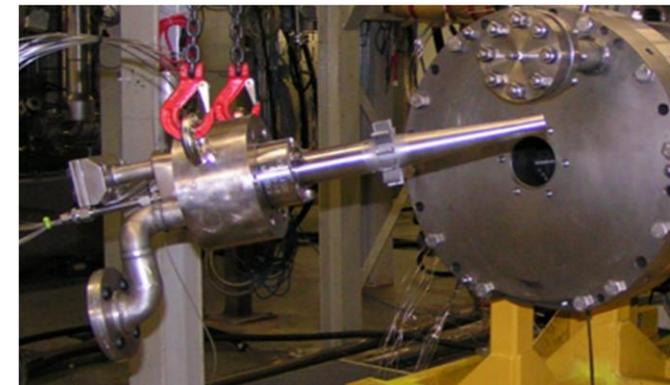
B/E/F-Class Combustor Conversions, Upgrades, and Installations

Total Projects

- (2) 7EA LEC-NextGen Upgrades – Canada
- Proposal to Dutch Government to Grow H2 Combustor Technology Across Multi-Platform
- 6B LEC-III® Combustor Conversion
- Final of (3) 9E LEC-III® H2 Upgrade – The Netherlands
- 6B DLN1 24k Upgrade
- 7EA LEC-III® Combustor Conversion
- 6B LEC-III® Virtual Flame Scanner Installation
- (5) 7FA FlameSheet™ Installations

Highlights

- Validated Increased H2 Fuel Flex – FlameSheet™ (7FA)
- 100% H2 Initiative Kick-Off – FlameSheet™
- 9E Combustor Upgrade to PSM Fin Mixer with PSM AutoTune/CDMS
 - Demonstrated ability to burn up to 35% hydrogen
- LEC-NextGen lowered NOx emissions less than 9ppm / 24k
 - Prior performance sub-14ppm / 12k



Market Driven GT Asset Renewal Initiative

- American and Canadian energy market driving need for flexibility
- Natural gas fired power assets poised to benefit from available technologies to enable operational flexibility and features to improve availability, service life and overall lowered life cycle cost.
- LEC III™, LEC NextGen, and FlameSheet™ easily retrofittable on existing F-Class and E-Class gas turbines.
- Automated tuning, can offer enhanced fuel flexibility to enable operations with shale gas, increased hydrogen gas content, improved turndown and low emissions.



Economical Flexibility Options – *The Future is NOW*