Alternative Fuels / Fuel Quality

Ivan Bach
Program Manager
Aero Derivative Gas Turbines

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1. Introduction

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Welcome

1. Standard Fuels
2. Non-standard Fuels
   a) Gas Fuels
   b) Liquid Fuels
3. Fuel Quality

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1. Standard Fuels

Basic fuel requirements for LMs

✓ Can burn Gas Fuels

- Ample heating value
- Kept as gas
- Clean

✓ Can burn Liquid Fuels

- Ample heating value
- Atomized
- Clean

– Can't burn Solid Fuels

✓ Unless gases or liquids synthesized from solids like coal

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Fuels for GE's LM Aero Derivative Gas Turbines

Well defined Fuel Specifications for both Fuel Gases and Liquid Fuels are already established:

- MID-TD-0000-1, rev.2009 for Gas Fuels
- MID-TD-0000-2, rev.2010 for Liquid Fuels


GE Energy

Process Specification
Fuel Gases For Combustion in AeroDerivative Gas Turbines

GE Aviation
GE Energy

Liquid Fuel Requirements for
GE Aero Derivative Gas Turbines

Non-standard Fuels can be used in your LM Gas Turbine

GE can support your efforts to start using a Non-standard Fuel

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2. Non-standard Fuels

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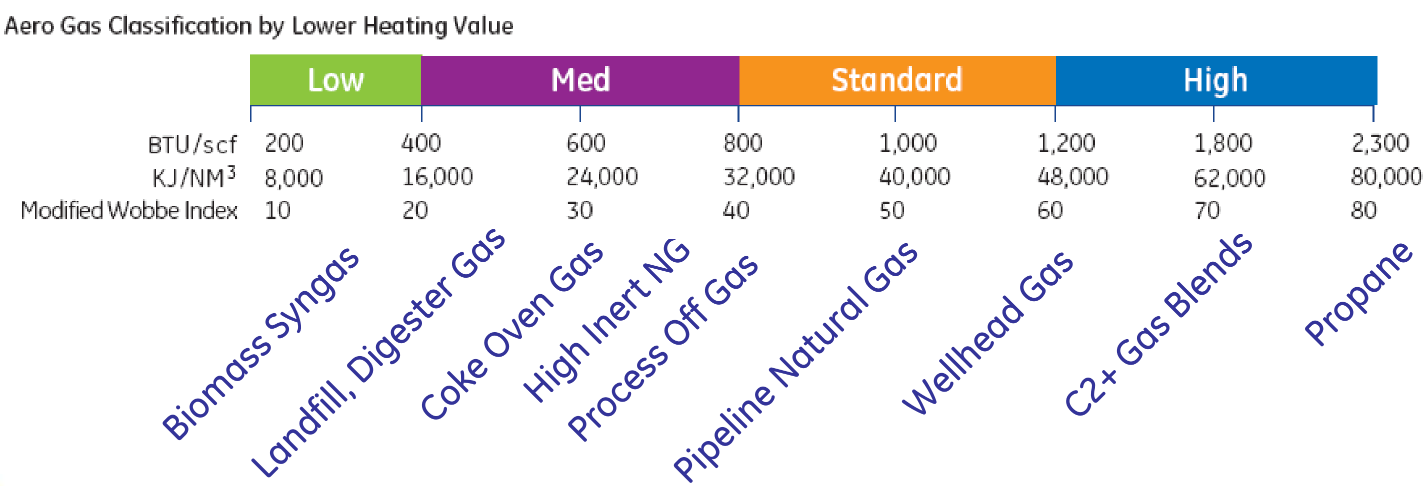
GE Aero non-standard fuel capabilities

Model**	Gas fuels: High-BTU	Standard	Medium-BTU	Low-BTU	Liquid fuels: Diesel, Kerosene, Jet	Naphtha	Biodiesel +blends	Ethanol	Methanol, DME
LM2500	● (SAC quote)	✓ (DLE and SAC)	✓ (DLE and SAC)	✓ (SAC)	✓ (DLE and SAC)	✓ (SAC)	✓ (SAC)	● (SAC quote)	● (SAC quote)
LM6000	✓ (SAC)	✓ (DLE and SAC)	✓ (DLE and SAC)		✓ (DLE and SAC)	✓ (SAC)	✓ (SAC)	✓ (SAC)	● (SAC quote)
LMS100	● (SAC quote)	✓ (DLE and SAC)	● (SAC quote)		✓ (SAC)	● (SAC quote)	● (SAC quote)	● (SAC quote)	● (SAC quote)

- ✓ (blue) Design or experience DLE and SAC
- ✓ (green) Design or experience SAC
- ● (blue) Would quote for DLE, may require requisition custom fuel system
- ● (green) Would quote for SAC, may require requisition custom fuel system

**Contact GE for specific engine options and package configurations



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What is the argument for biofuel greenhouse gas reductions?

Fossil fuel	Biofuel

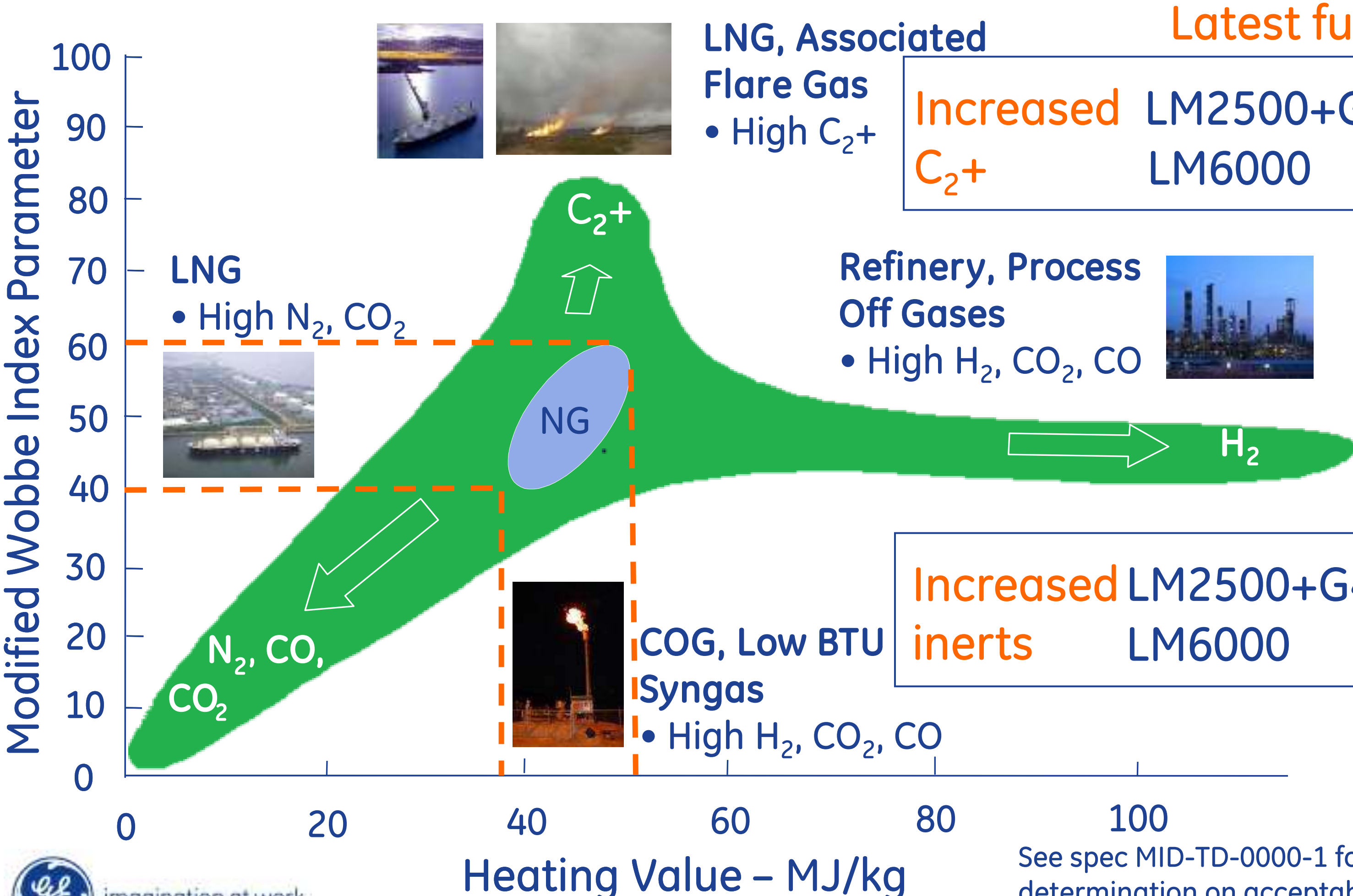
Carbon in fossil fuel released to atmosphere as CO2	On average, the atmospheric CO2 stays constant due to the sustainable cycle

2a. Non-standard Gas Fuel

What are non-standard gas fuels?

Fuels characterized by the following LHV and constituents:

- Modified Wobbe Index < 40 or > 60
- Low to med BTU fuels, LHV < ~29.8 MJ/m^3
- High BTU fuels, LHV > ~44.7 MJ/m^3
- High H_2 fuels > 5% by volume
- High CO, CO_2, N_2, C_2+



Latest fuel spec Sept '09

Increased C_2+	LM2500+G4	15 %	30 %
	LM6000	15 %	24 %

Increased inerts	LM2500+G4	MWI 40	35.8
	LM6000	MWI 40	

See spec MID-TD-0000-1 for final determination on acceptable fuel usage

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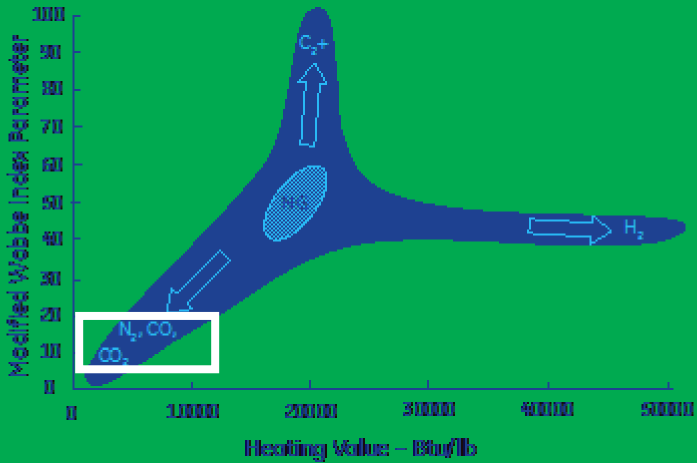
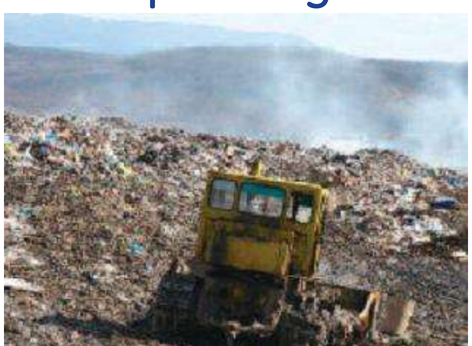
Applications of non-standard fuels
Low BTU syngas (landfill, biogas)



Low energy content gas solution

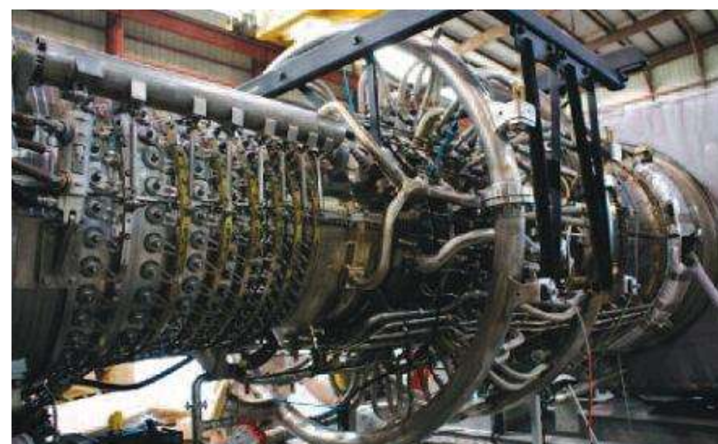
The Challenge

- Plant is designed to convert waste to obtain syngas
- One ton of the combustible waste derived syngas equals:
  - 560 m^3 of methane
  - 499 kg of fuel oil
  - 750 kg of coal
- How to utilize this low energy (~9,3 MJ/kg, MWI ~13), high H_2 syngas for power generation?



The Solution

- LM2500+G4 gas turbine selected
- Design modifications include
  - Fuel system
  - Increased nozzle capacity
  - High fuel flow rate
  - N_2 purge system (high H_2 syngas)
  - Associated control system changes



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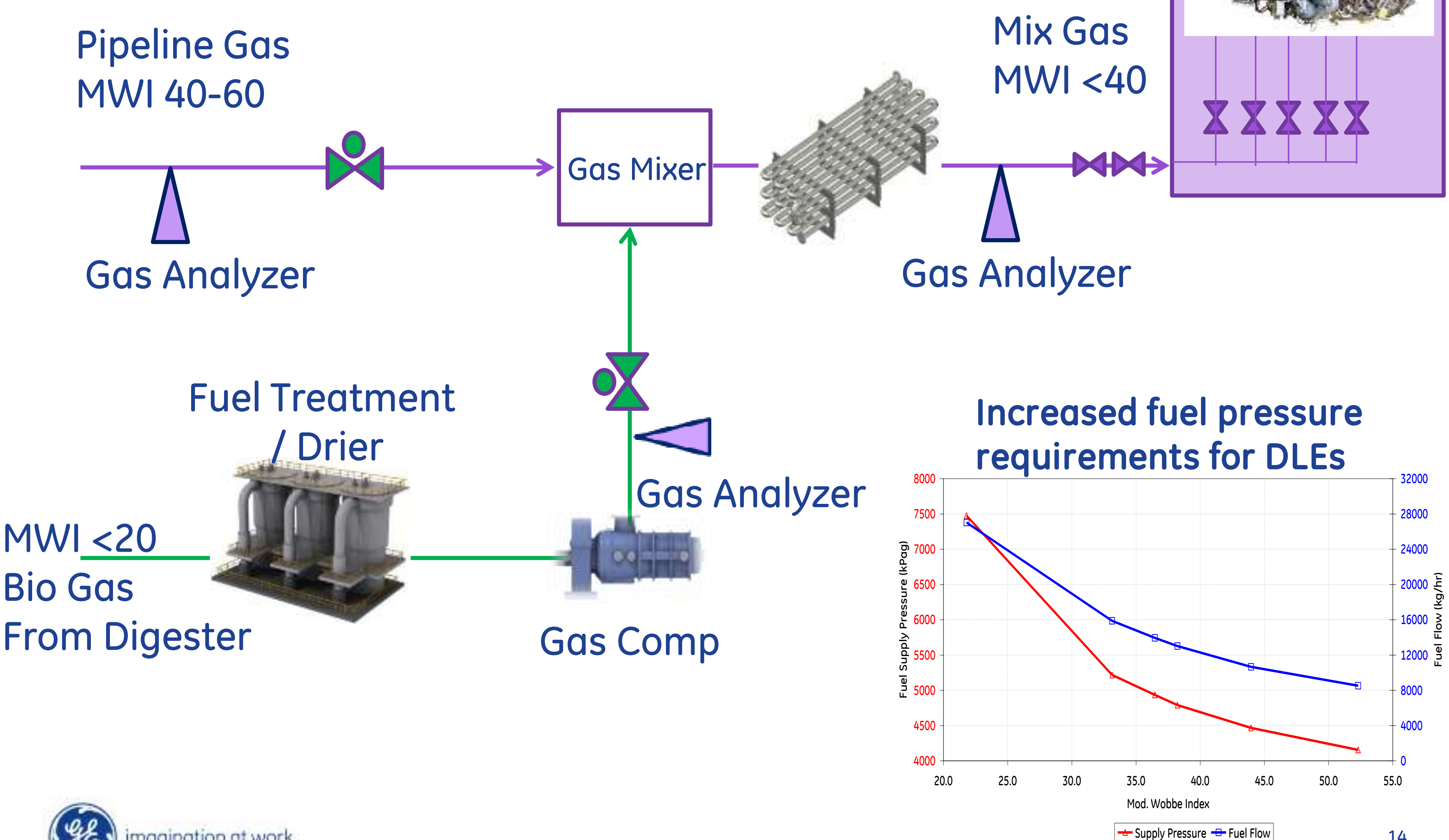
Biogas case example



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Aero related high-H_2 experience

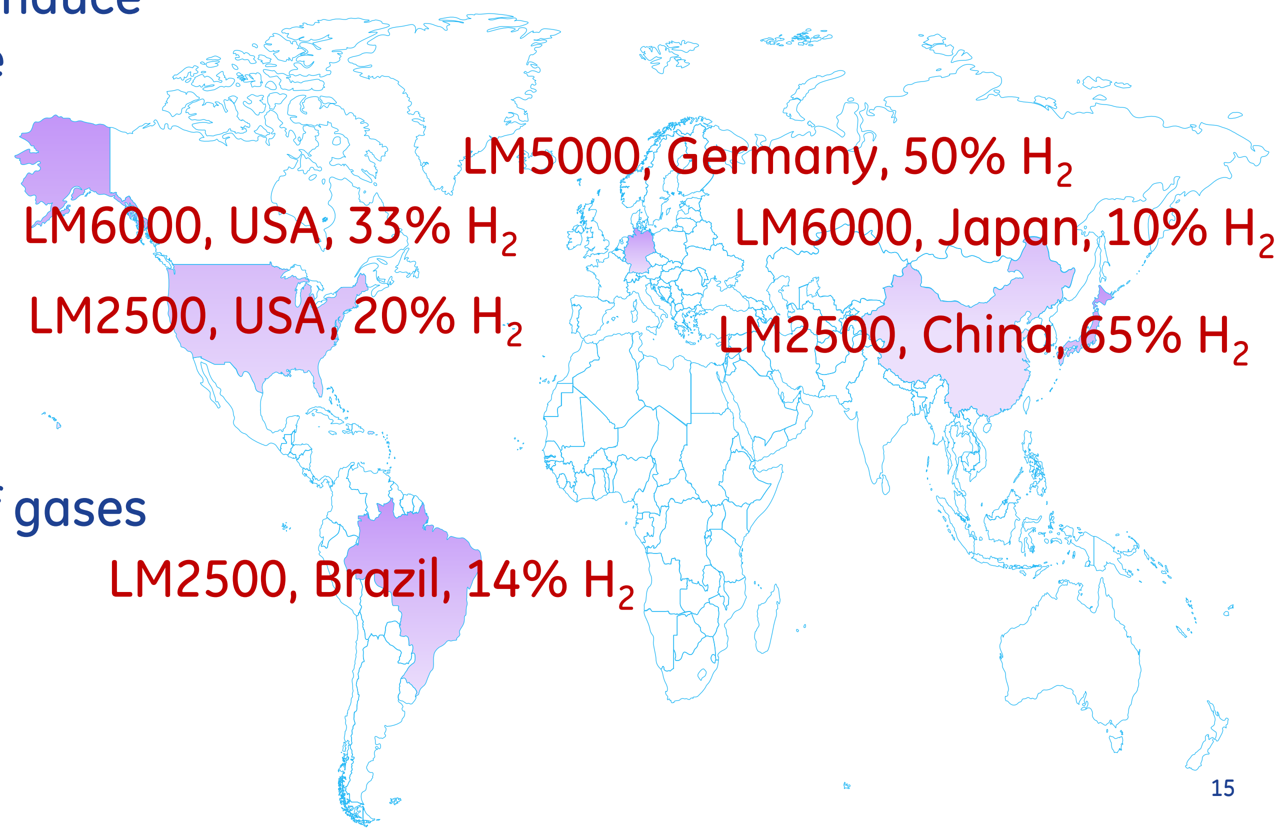


Experience:

- Aero has experience in burning high-H_2 fuels
- Gas composition and site specific needs may induce engine and package changes

Applications:

- Synthetic gases
- 'Steel' gases
- Refinery/process off gases
- Blends



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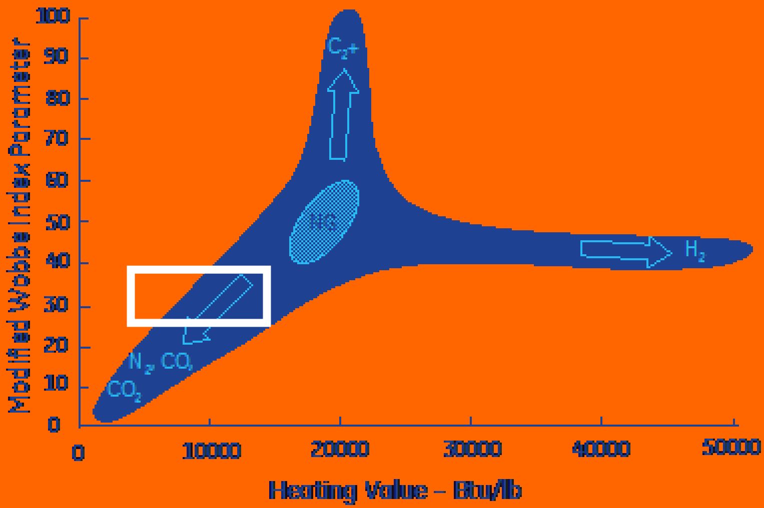
Applications of non-standard fuels
Coke oven gas



Coke oven gas

Medium BTU - Coking

- Coking temp: 900-1100°C
- Material: Bituminous coal
- Main product: coke
- Application: steel production, power generation

COG composition (vol%):

H_2	(55-65)
CH_4	(24-28)
CO	(6-8)
N_2	(4-7)
CO_2	(2-4)
C2+	(2-4)

MWI 31-34

LHV ~15-18 MJ/m^3

Henan LiYuan Coal & Coking Group Co., Ltd

1 ton coke → ~220 m^3 surplus COG

> 1 MT/ yr to power LM2500+

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Coke oven gas – risks & solutions

Risk	Concern	Solution
Fuel LHV	Constant flow & large volume of fuel required	Fuel delivery sized to handle added gas flow requirement
%Vol H_2	COG often has high levels (>50%vol) of hydrogen; risk of ignition in a confined volume	Inert purge system, which removes possibility of a premature ignition Class III certified electrical equipment
Contaminants	Potential contaminants (Tar, H_2S, NH_3, Benzene & Naphthalene) affect the engine, engine performance, emission, and lowers maintenance intervals	Gas purification system, removes contaminants from COG; allows for power generation w/ performance & maintenance intervals
Water and air	Heavy industrial environment with particulates and other air contaminants; alkalis in water	Proper design for air filtration and water sampling regimen and cleaning

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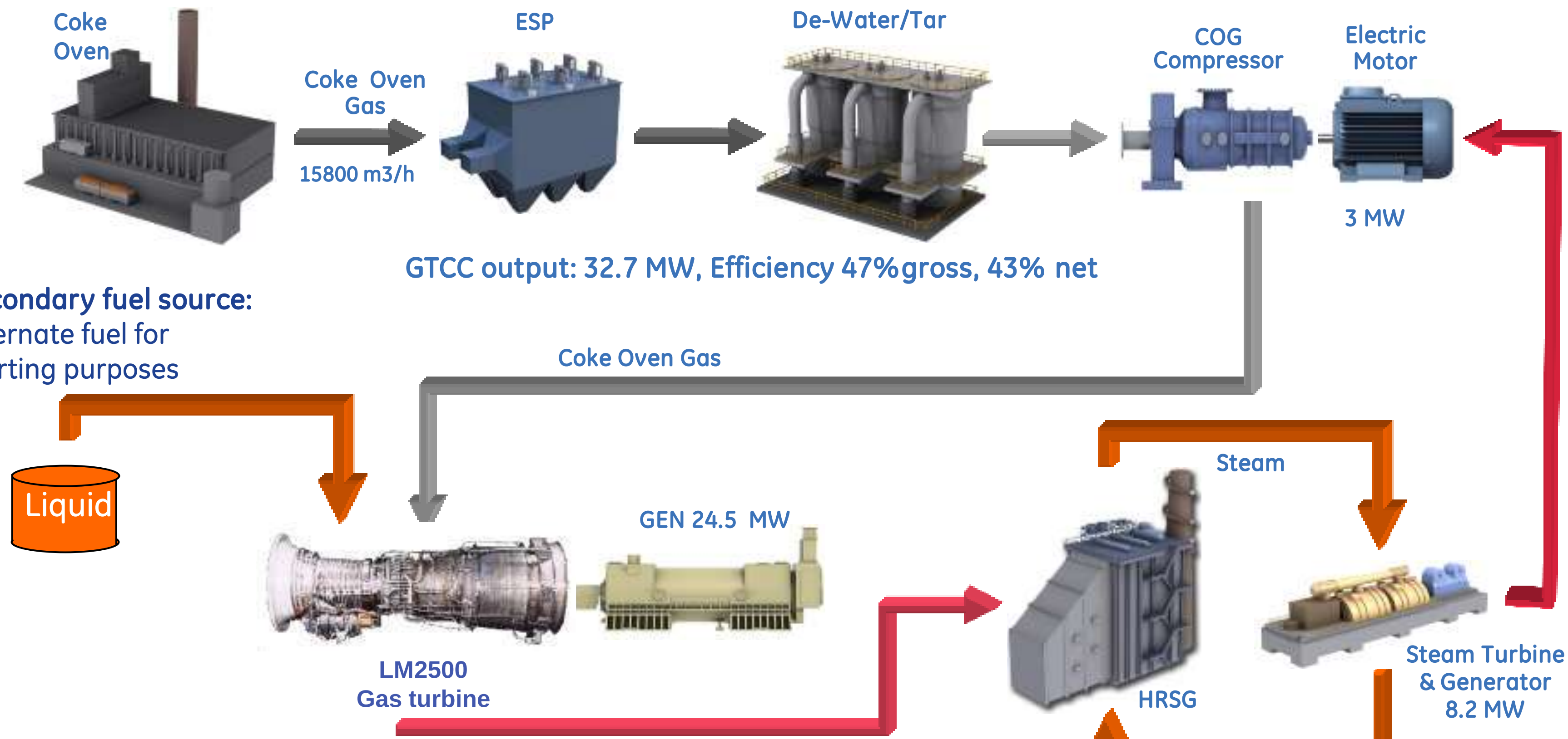
COG power generation

LM2500+ / +G4 CombCycle

Fuel treatment system:
Cleans contaminants and brings fuel within spec

Specialized delivery:
Updated fuel pumps, motors, valves and other hardware

Secondary fuel source:
Alternate fuel for starting purposes



Exhaust Gas

Water

Specialized gas turbine:
LM2500+ & +G4 capable of burning COG, Med BTU gas fuel w/ high H_2

Inert purge system: Purge piping & manifold; mitigate risk of self-ignition (high H_2)

NOx abatement: Water injection should be available when required to meet reduced emissions (39ppm)

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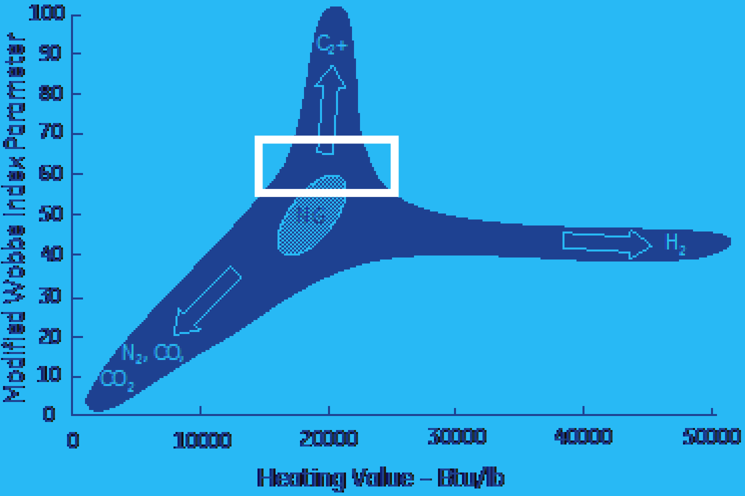
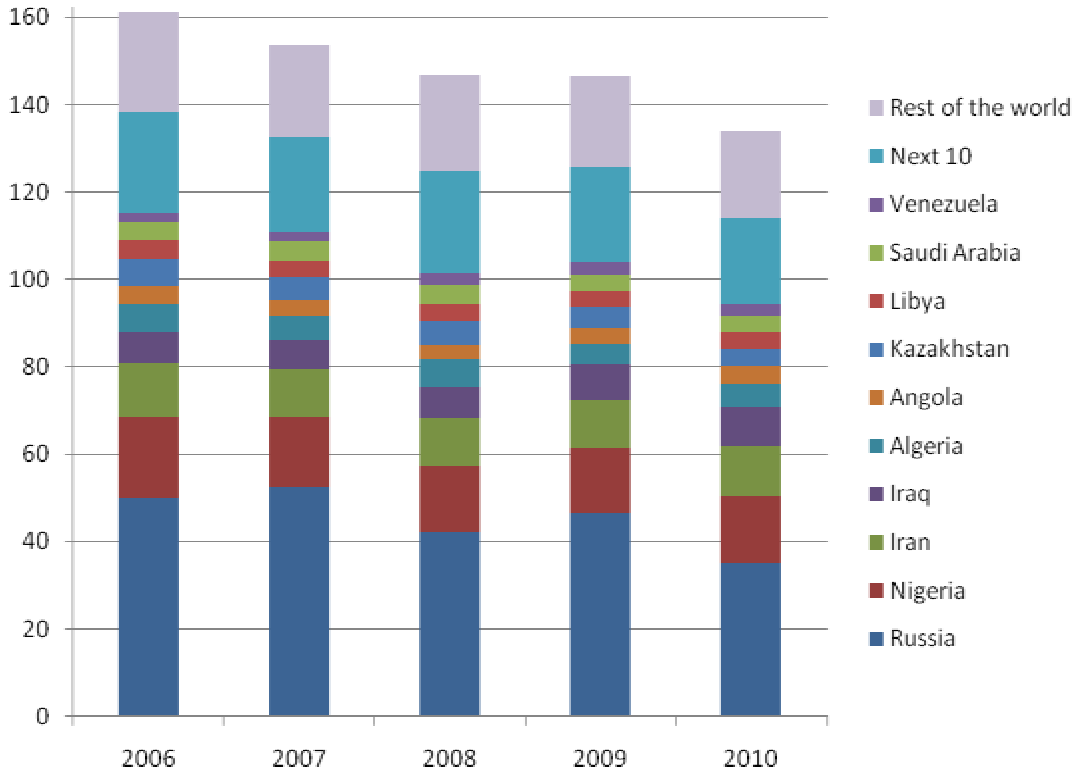
Applications of non-standard fuels
Flare gases



Flare gas - a global concern

140-150 bcm flared gas annually



150 bcm equivalent to:

Annual gas use of France and Germany combined

5% of global gas production

7-15 billion Euro per year in lost value

Annual emission from 77 million cars (1/3 of US fleet)

Source: World Bank - GGFR, NOAA (2006 - 2010), GE Energy Flare Gas Reduction white paper (2011)

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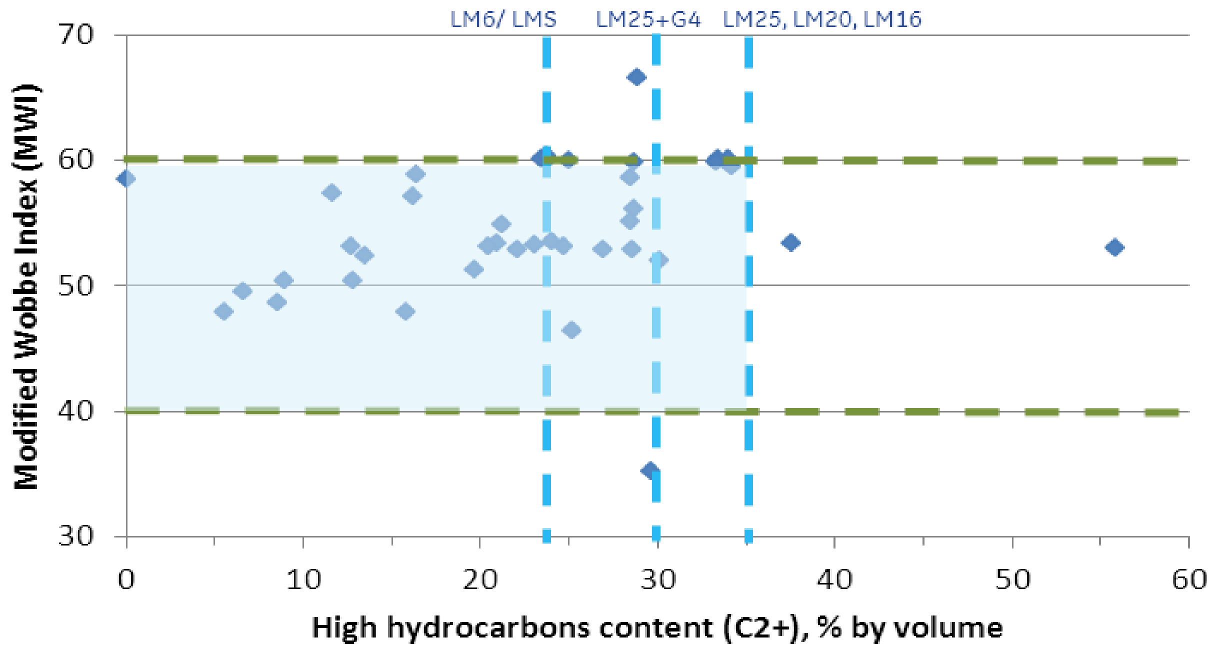
Flare gas properties survey



- ~60 flare gas samples analyzed, 90% within Aero fuel specification
- Most outside of spec could be approved after engineering review
- Standard Modified Wobbe Index (MWI) range is 40-60 (avg LHV value 42.5 MJ/m^3)
- Additional consideration for DLE: high hydrocarbon (C_2+) limits
- 95% flare gas samples meet DLE configuration limit for higher hydrocarbons, others could be approved pending specific C_2+ components and volumes

Aero turbines can burn majority of flare gases without engine modifications

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Aero applications for flare gas today

Experience growing ...

- LM2500 power plant in S. America
  - 16M ft^3/day flare generates >40MW
  - Operates with low BTU fuel
  - >50K Hours reliable operations
- PGT16 in Nigeria
  - Associated gas gathering (AGG) system
  - FG converted to LNG

- TM2500 in Nigeria
  - Compression station and power generation
  - FG converted to LNG via distributed power
  - Installed end 2009

GE Aero is ready to help put out flares

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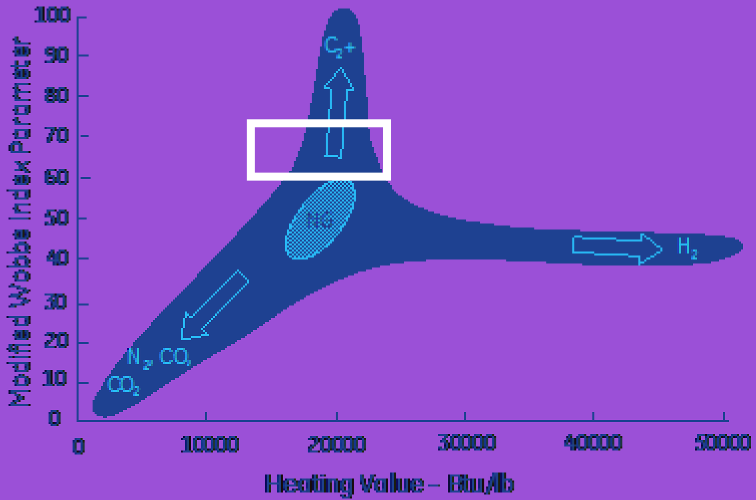
Applications of non-standard fuels LNG



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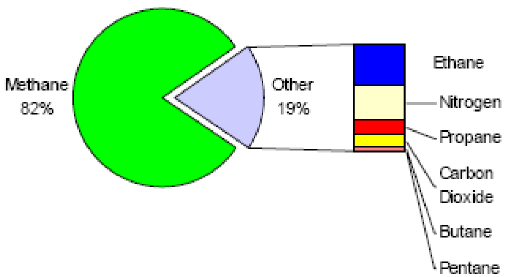
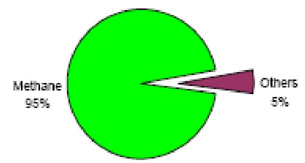
LNG fuel gases

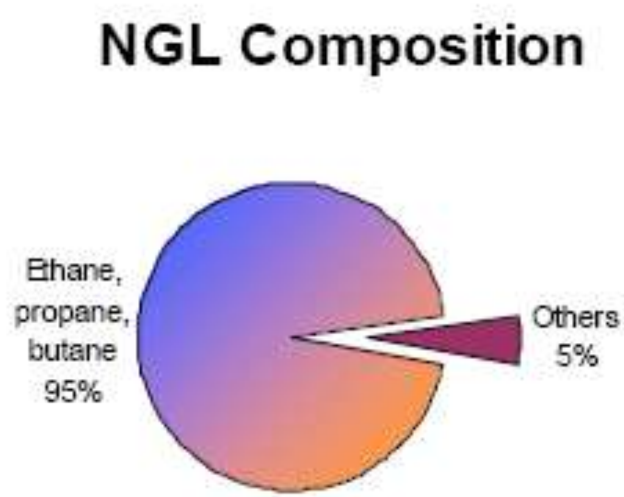
Typical Natural Gas Composition



Typical LNG Composition



- LNG production facilities required to maintain tight control of LNG composition.
  - Separate Natural Gas liquids (primarily C2+, N_2, CO_2) from liquefaction stream.
- LNG plants need gas turbines to be able to handle high C2+, N_2, CO_2.
- Aeroderivatives with SAC combustors can burn NGL blends maximizing investment recovery from the feed gas



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LM2500+G4 SAC FPSO
Med BTU GT + 538 Package

For offshore facilities, topside equipment and construction costs are extremely sensitive to weight and space. GE's compact marine configuration provides the lowest weight and smallest footprint of any standard gas turbine package in the 20 to 34 MW power segment.

Challenge:

- LNG and offshore facility gas may contain high inert (un-processed gas)
- Design a new fuel system capable of running medium BTU fuel with constraints on max supply pressure

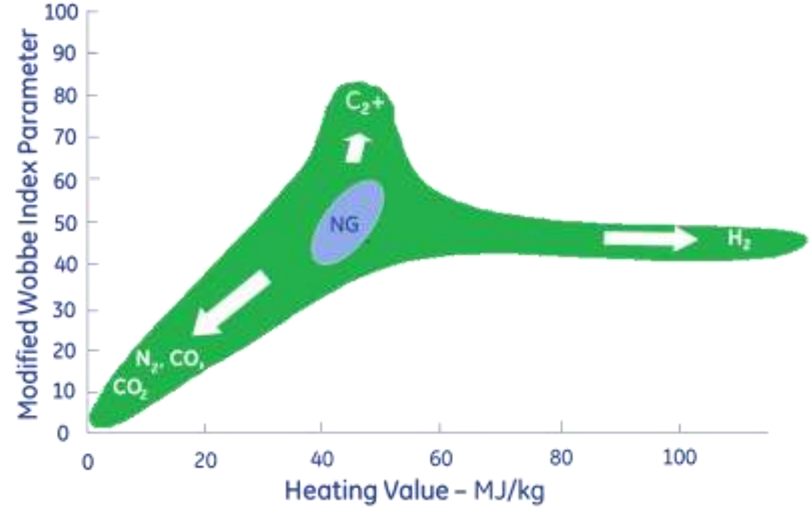
Solution:

- LM2500+G4 538 dual fuel package
- New nozzles, fuel delivery systems and control modifications to meet modified Wobbe index 37 – 45
- Diesel back up fuel

Expanding fuel flex

Why fuel flex?

- lower cost fuel alternatives = Customer OPEX savings
- step changes in capabilities enabled through:
  - ✓ technical innovations
  - ✓ extensive testing
- Result - in the last two years our customers have ordered **25 gas turbines** with some form of fuel flexibility features
- Expanding capabilities for
  - ✓ medium BTU fuels
  - ✓ high BTU fuels
  - ✓ gas variability



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Fuel Flex Testing to Date

High propane testing completed

- ✓ LM2500+ Q4'09

High N_2 testing completed

- ✓ LM2500+ Q4'09
- ✓ LM6000PD/PF Q3'10
- ✓ LM6000PH Q1'11

High CO_2 testing completed

- ✓ LM2500+G4 Q4'11

Gas mixing skid

CO_2 tank and vaporizer

Wobbe Index Meter and enclosure

Gas flare system

Test objectives

- Establish DLE capability limits
  - Combustion mode window sizes
  - emissions
  - acoustics
  - starting
- Demonstrate SAC reliable start and operation on low-BTU fuel

2012 Fuel Flex Engine tests

2012 fuel-flex engine tests

- LM2500+G4 DLE & LM6000PD validation tests in Q4 2012
- Enhanced dynamic response to change in fuel properties tested
- Performance entitlement tests for low-BTU fuels :
  - Low MWI limits down to MWI 28
  - True High MWI Rate of Change limits with new solution, up to 48MWI/min. change
  - Low MWI starts, load transients, drops & accepts

Schedule for 2012 Fuel-flex engine tests

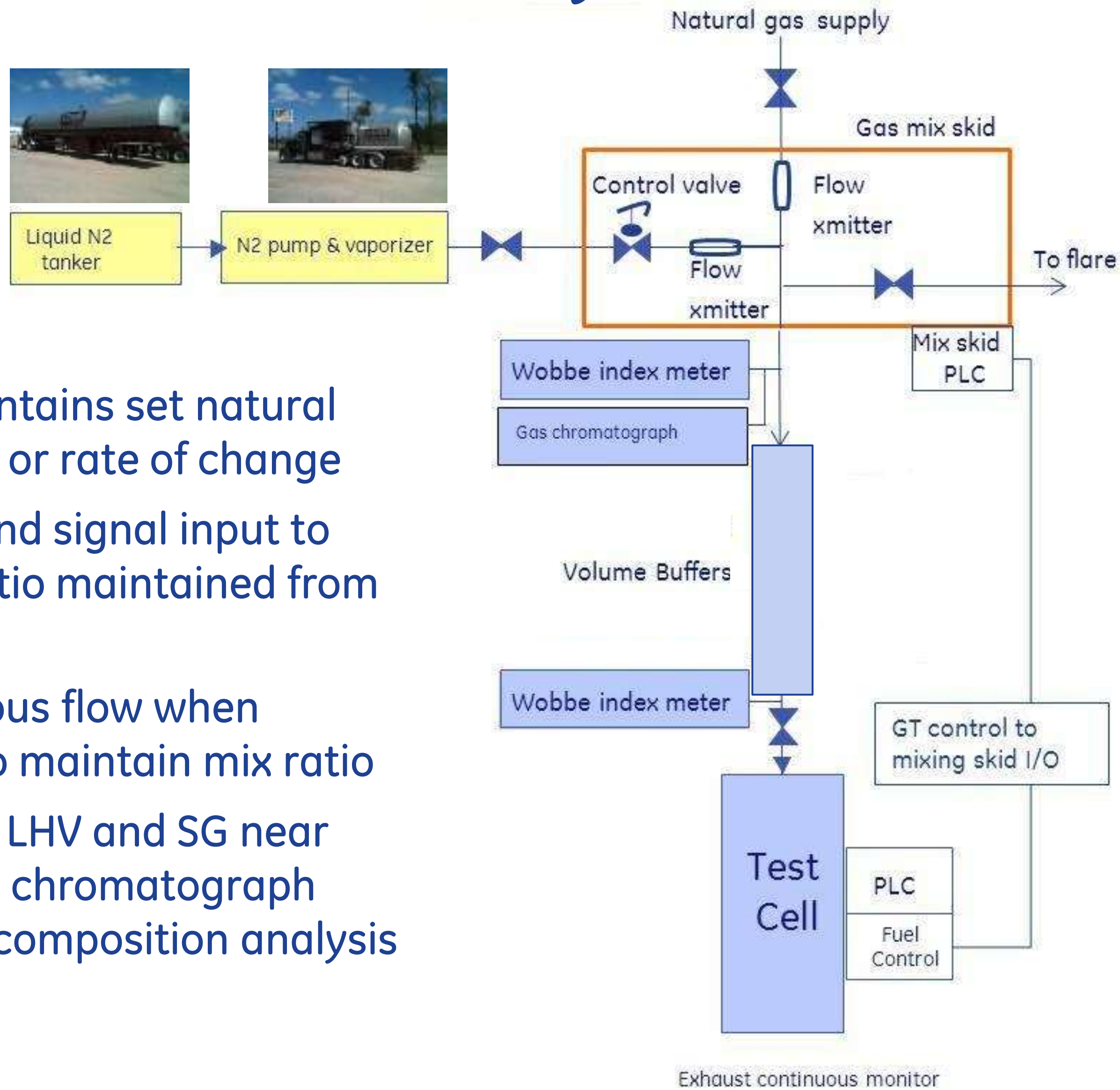
• Critical equipment ready	August
• Mixer system and SW tests	August
• LM6000PD Test	October
• Implement lessons learned	
• LM2500+G4 Test	November

Features of mixing system

- Permanent infrastructure for Natural Bas blending with N_2 vol. fraction of max. 57.3% (MWI 20)
- Dynamic control of selectable fraction of added gas or selectable rate of change
- Sized for LM2500 Base through LM6000PH fuel flow rates & pressures
- WIM and GC integrated for fast fuel properties measurement

Out with the old in with the new…

Test Setup Schematic N2 System



- Mixing system PLC maintains set natural gas : nitrogen mix ratio or rate of change
- Turbine fuel flow demand signal input to mix system PLC; mix ratio maintained from start up to base load
- Flare provides continuous flow when engine not operating to maintain mix ratio
- Wobbe index meter for LHV and SG near real time response; gas chromatograph provides accurate gas composition analysis

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2b. Non-standard Liquid Fuels

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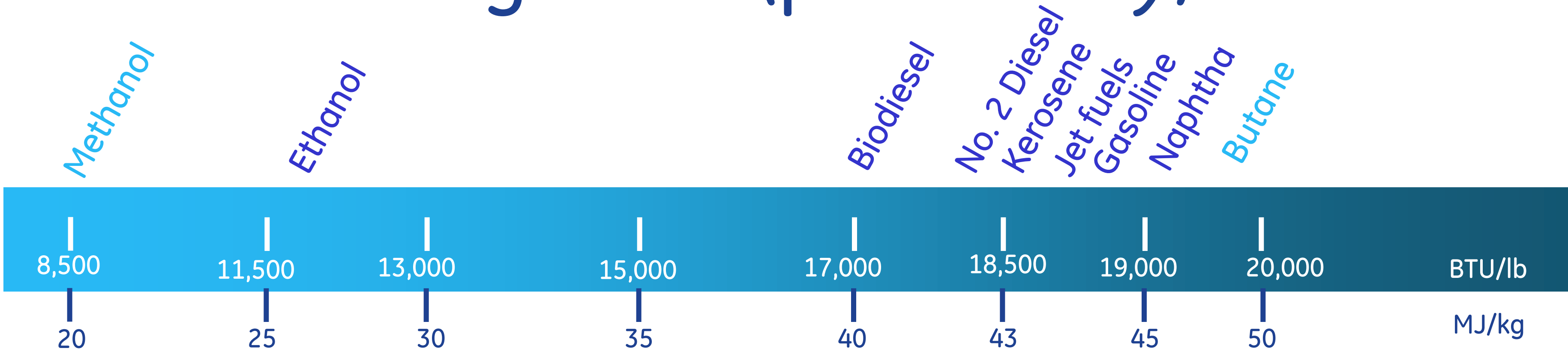
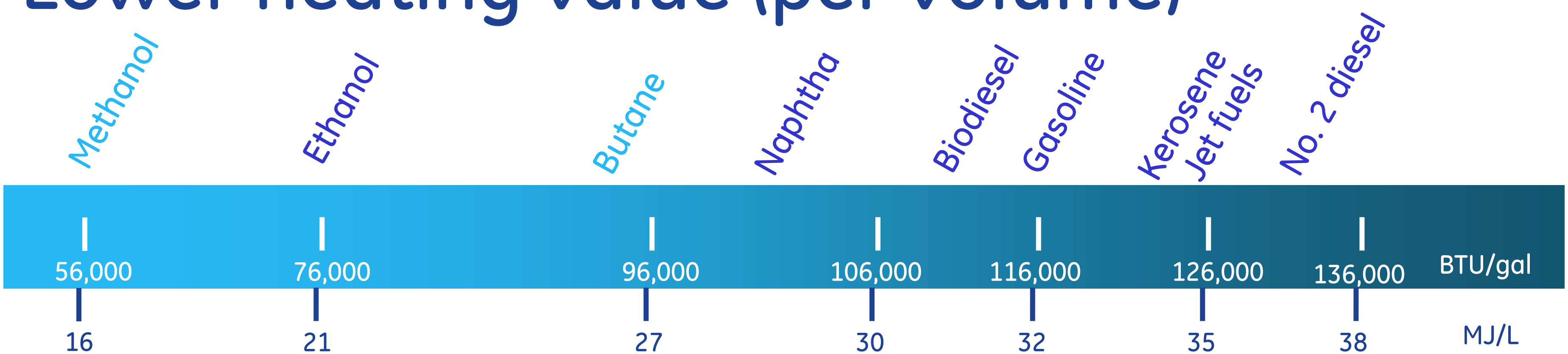
What are the liquid fuel capabilities?

Lower heating value (per density)

Demonstrated



Lower heating value (per volume)



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See spec MID-TD-0000-2 for final determination on acceptable fuel usage

LM biofuel applications

	Biodiesel	Ethanol
Is it really a GT fuel? Yes	Biodiesel blends up to 100% allowed per ASTM D6751 and EN14214 specs	ASTM D4806 for gasoline blends

Fuel characteristics vs. #2 diesel…

	Biodiesel	Ethanol
LHV	Lower (10% higher flow)	Lower (60% higher flow)
Flash point	Higher (start/ignition)	Lower (start fuel req'd)
Lubricity	Higher	Lower (pump)
Solvent	Higher (material compatibility)	Little change
Stability	Lower (logistics)	No change
Contaminants	Phosphorous, particulates	Sodium

Biodiesel and ethanol are GE Aero approved fuels

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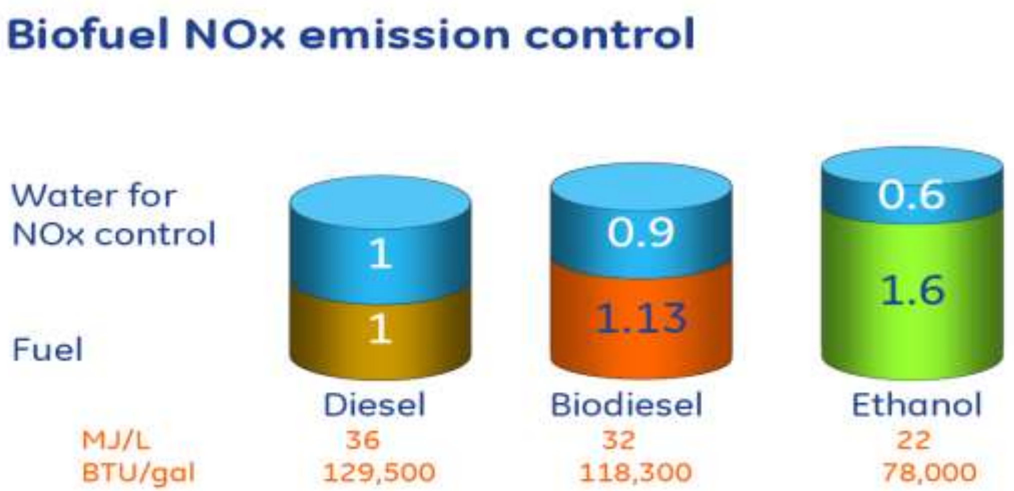
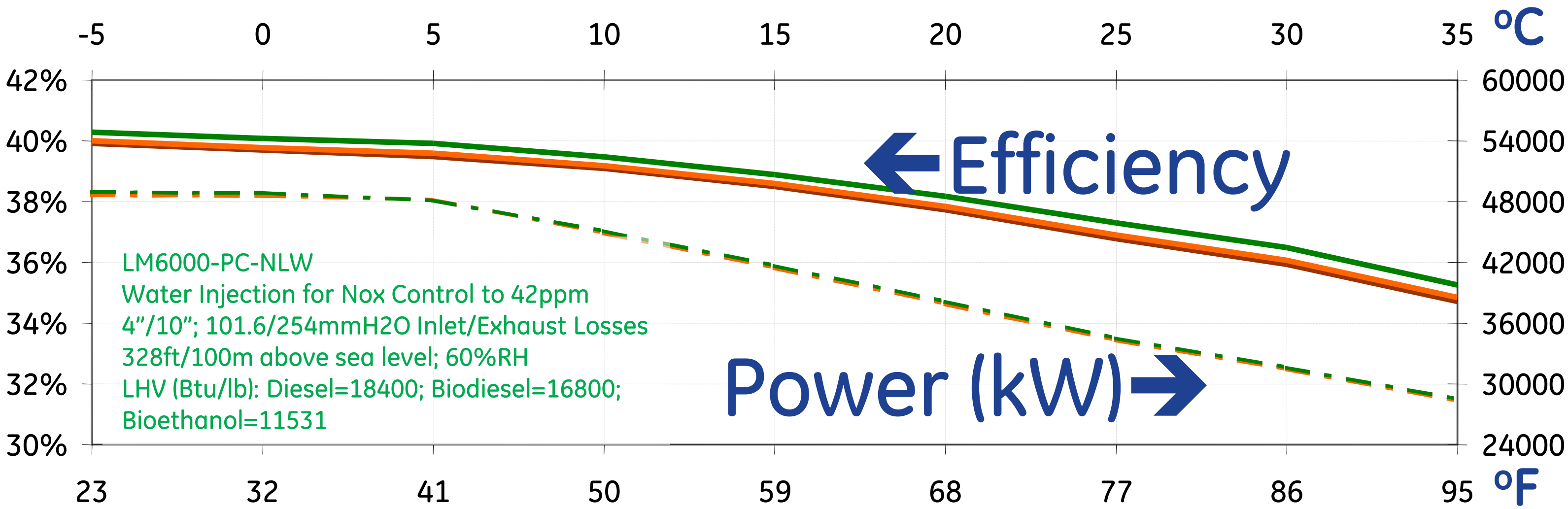
Power, Efficiency and Emissions





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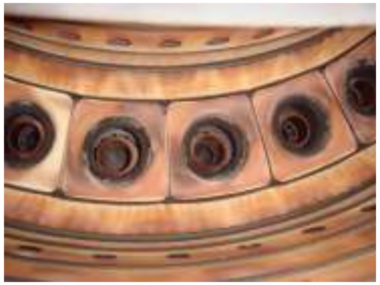
Diesel Biodiesel Ethanol

Petrobras ethanol demonstration

- LM6000PC conversion from gas only to dual fuel
- 1,000 hour demo, Q1 2010
- May operate on hydrous or anhydrous (hydrous for demo)
- Less water to control NOx than NG (~25% less) or distillate (~50% less)
- Liquid fuel valve design accommodates higher flow
- Alternate fuel recommended for starting and low power ops
- Estimate operation life equivalent to diesel

UTE-JUIZ DE FORA AFTER THE CONVERSION



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- +12 x LM2500+ on cruise ships have ran on biodiesel
- 2 x LM6000 have run on biodiesel at a New York site
- 2 x LM1600 successfully tested on biodiesel
- 2 x LM6000 are now ethanol capable at Brazilian plant

Results – cleaner engine and lower emissions

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3. Fuel Quality

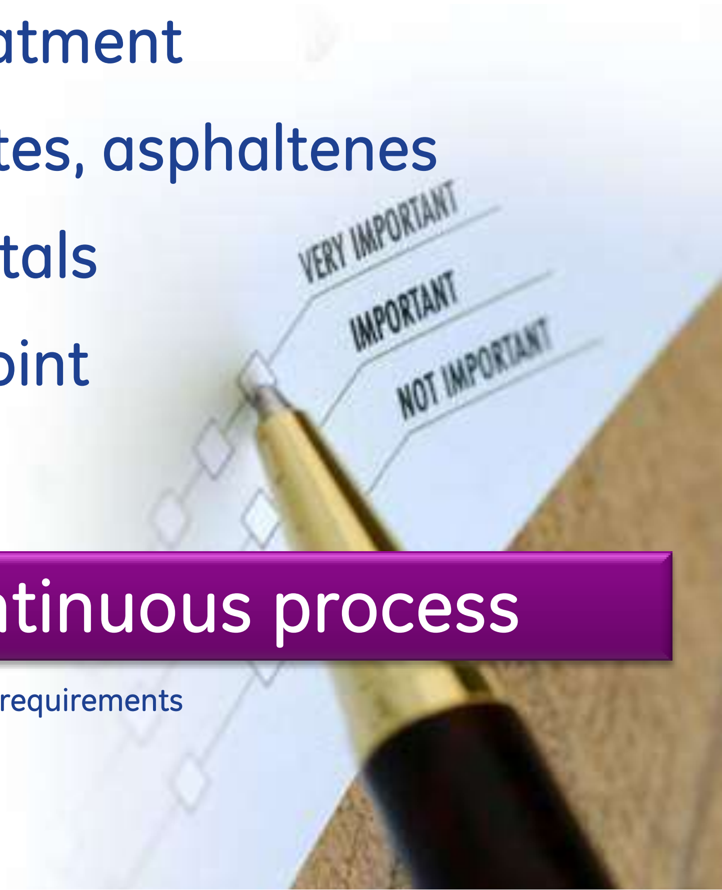
Fuel Quality is important for all fuels

Gas Fuels

- ☑ Proper analysis
- ☑ Basic conditioning
- ☑ Dew point
- ☑ Particulates
- ☑ Siloxanes
- ☑ Other

Liquid Fuels

- ☑ Proper analysis
- ☑ Basic treatment
- ☑ Particulates, asphaltenes
- ☑ Trace metals
- ☑ Bubble point
- ☑ Other



Fuel quality monitoring is a continuous process

See spec MID-TD-0000-1 and MID-TD-0000-2 for detailed guidelines and requirements


Thanks!
Q&A