The Impact of Fuel Gas Composition on Gas Turbine Operation:
Future Challenges

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British – French Flame Joint Meeting,
Lille , 9th to 10th March 2009

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Can gas turbines burn any gas?

It is often said that gas turbines can burn (almost) any combustible gas.

There are gas turbines capable of firing:

- Natural gas (including NG with high inerts and high non-methane hydrocarbons)
- Landfill gas
- Sewage gas
- Wellhead gases
- Syngas from coal, biomass and wastes
- Steelworks gases: Coke oven gas, Blast furnace gas
- Very high hydrogen gases (such as refinery gases)
- LPG and more...

Can gas turbines burn any gas?

BUT each gas turbine can only tolerate limited changes in gas composition and properties, depending on the gas turbine design and set-up.

Different combustion technologies are also appropriate for different gases

E.ON UK Gas Turbine Fleet

Gas Turbines from major suppliers:

- GE Energy (Heavy Duty and Aeroderivative)
- Siemens
- ALSTOM
- Rolls-Royce

Wide Range of Sizes:

- ~5MW to ~280MW

Range of combustion technologies:

- Lean Premix
- Staged combustion
- Sequential combustion
- Conventional (diffusion flame) with and without water or steam injection for NO_X control

- Fuel From National Transmission System (NTS) and non-NTS sources

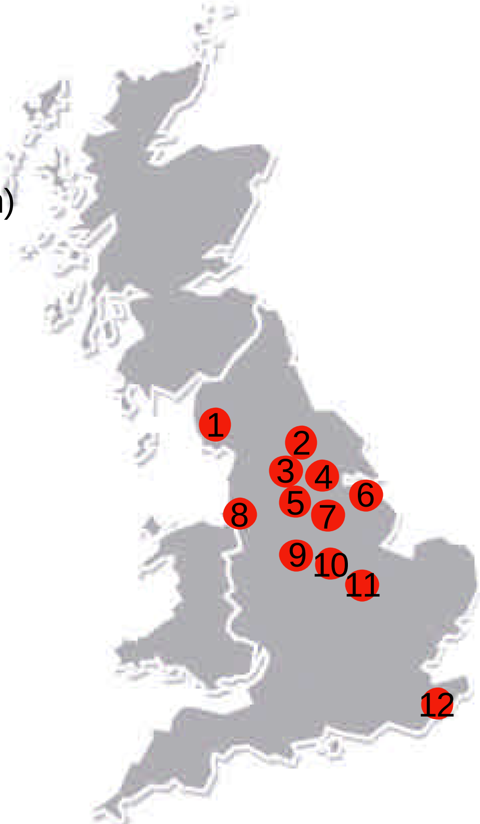
E.ON UK Gas Turbine Fleet
Combined Cycle Gas Turbine Power Generation

- 1. Connah's Quay (1420MW):
  4 off GE Frame 9FA
- 2. Killingholme (900MW):
  4 off Siemens V94.2A (SGT5-3000)
- 3. Cottam Development Centre (400MW):
  1 off Siemens V94.3A2 (SGT5-4000F)
- 4. Corby (JV) (350MW):
  2 off GE Frame 9E
- 5. Enfield (390MW):
  1 off ALSTOM GT26B
- 6. Grain (1275 MW)
  3 off ALSTOM GT26
  (export up to 340 MW of heat)
  Under Construction

E.ON UK Gas Turbine Fleet

Combined Heat and Power & Small Combined Cycle Plant

- 1. Workington:
  1 off GE LM6000PA
- 2. Bradford:
  1 off SGT-100 (Typhoon)
- 3. Castleford:
  1 off GE LM6000PD
- 4. Thornhill:
  1 off GE LM6000PB
- 5. Leeds:
  1 off Siemens SGT-100 (Typhoon)
- 6. Humber:
  4 off Siemens SGT-200 (Tornado)

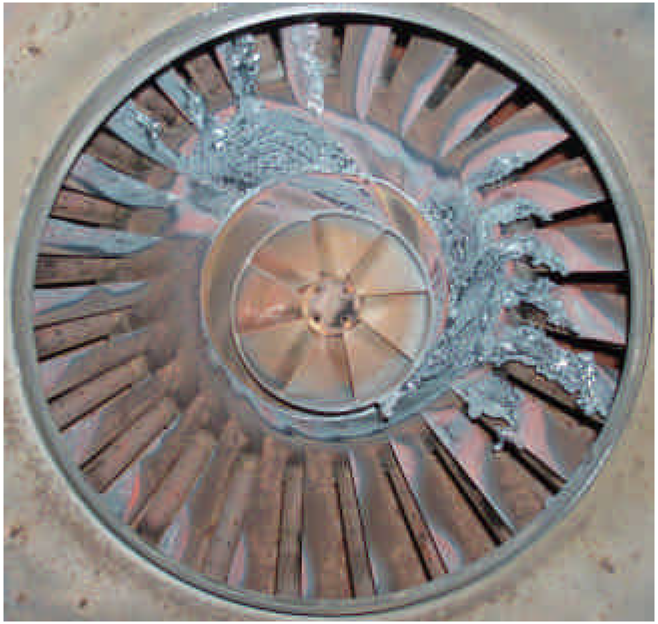


- 7. Winnington:
  2 off GE Frame 6B (DLN1)
- 8. Liverpool:
  1 off Rolls-Royce RB211
- 9. Sandbach:
  1 off GE LM6000PD
- 10. Stoke:
  1 off Siemens SGT-800 (GTX100)
- 11. Nottingham:
  1 off Siemens SGT-100 (Typhoon)
- 12. Kemsley:
  1 off GE Frame 6B (conventional)

Flashback damage to a gas turbine burner

- Flashback can be an issue particularly with modern low NO_X emission designs

- Changes in fuel composition can result in changes in flame speed or autoignition behaviour resulting in the flame position moving upstream. This can cause severe burner damage of the type show in the photograph



- **Changing fuel quality is a real issue for gas turbines**

Drivers for changing fuels

Pipeline Natural Gas

European Natural Gas Transmission System

- Depletion of traditional fields
- Exploitation of marginal fields
- Increased cross border trading
- Increased pipeline imports (Russia, Eastern Europe and Middle East)
- Increased import of Liquefied Natural Gas (LNG)
- Potential for injection of non-fossil gases into the system

  Bio-gas (Anaerobic Digestion)

  Bio-SNG (Thermal gasification with subsequent shift and methanation stages)

  Hydrogen

Drivers for changing fuels

Other gases

Direct use of alternative fuels either on their own or mixed with Natural Gas

Low Carbon Fuels

- Bio-gas (Anaerobic digestion)
- Bio-syngas (Thermal gasification of biomass)
- Coal gasification with carbon capture to produce hydrogen
- Hydrogen

Lower Cost Fuels: Process and other by-products or waste gases

- Refinery gases
- Blast furnace gas
- Coke oven gas
- Mines gas
- Natural gas liquids

European Turbine Network Position Paper

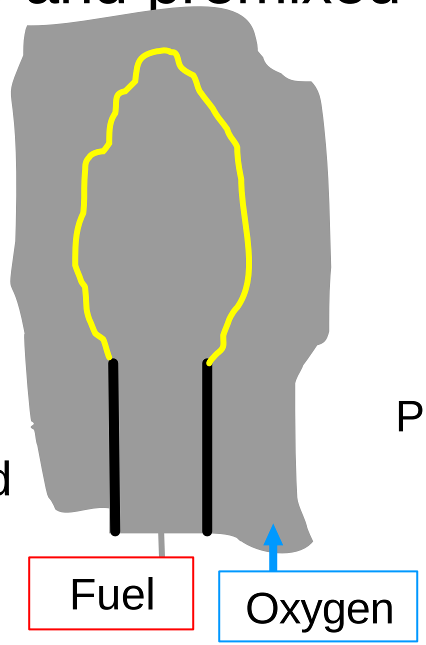
The ETN represents gas turbine technology community for power generation, mechanical drive and marine applications.
It is a collaboration across the whole value chain including manufacturers, operators, research and academic institutions.

Working Group 2 – Fuel Flexibility and Emissions has produced a position paper on the impact of fuel quality:

ETN Position Paper on the Impact of Natural Gas Quality on Gas Turbine Performance, February 2009

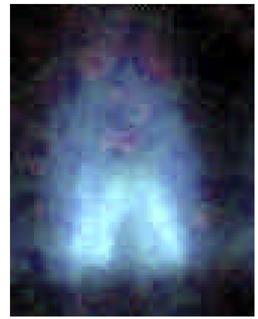
Available for download on:
http://www.eu-gasturbine.org/positionpapers.aspx

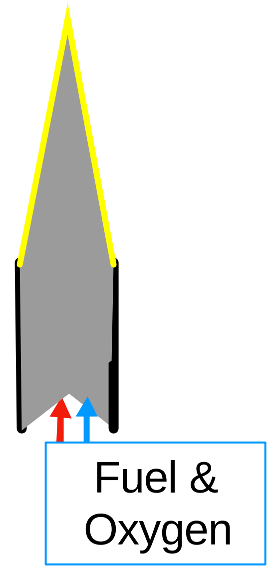
Diffusion flame and premixed combustion



Diffusion Flame

Flame front governed by the mixing of air and fuel to produce combustible mixture.



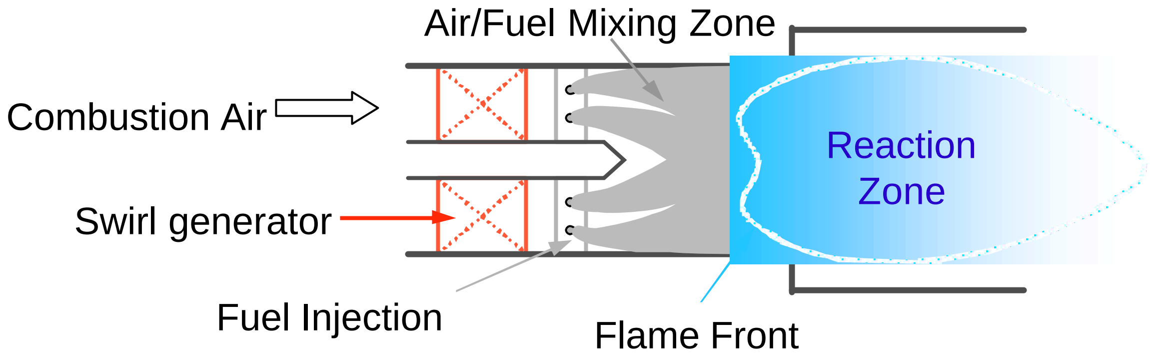


Premixed Flame

Flame front governed by balance between flame speed and rate of supply of fuel.

The existing gas turbine fleet contains both diffusion and premixed combustion systems, but the majority of the gas turbine capacity installed since 1995 has some form of premixed combustion.

Typical elements of a gas turbine Lean Premix burner



Key Combustion Parameters

Heat content and release rate
Flame speed
Autoignition temperature
Autoignition delay time
Flammability limits
Flame temperature

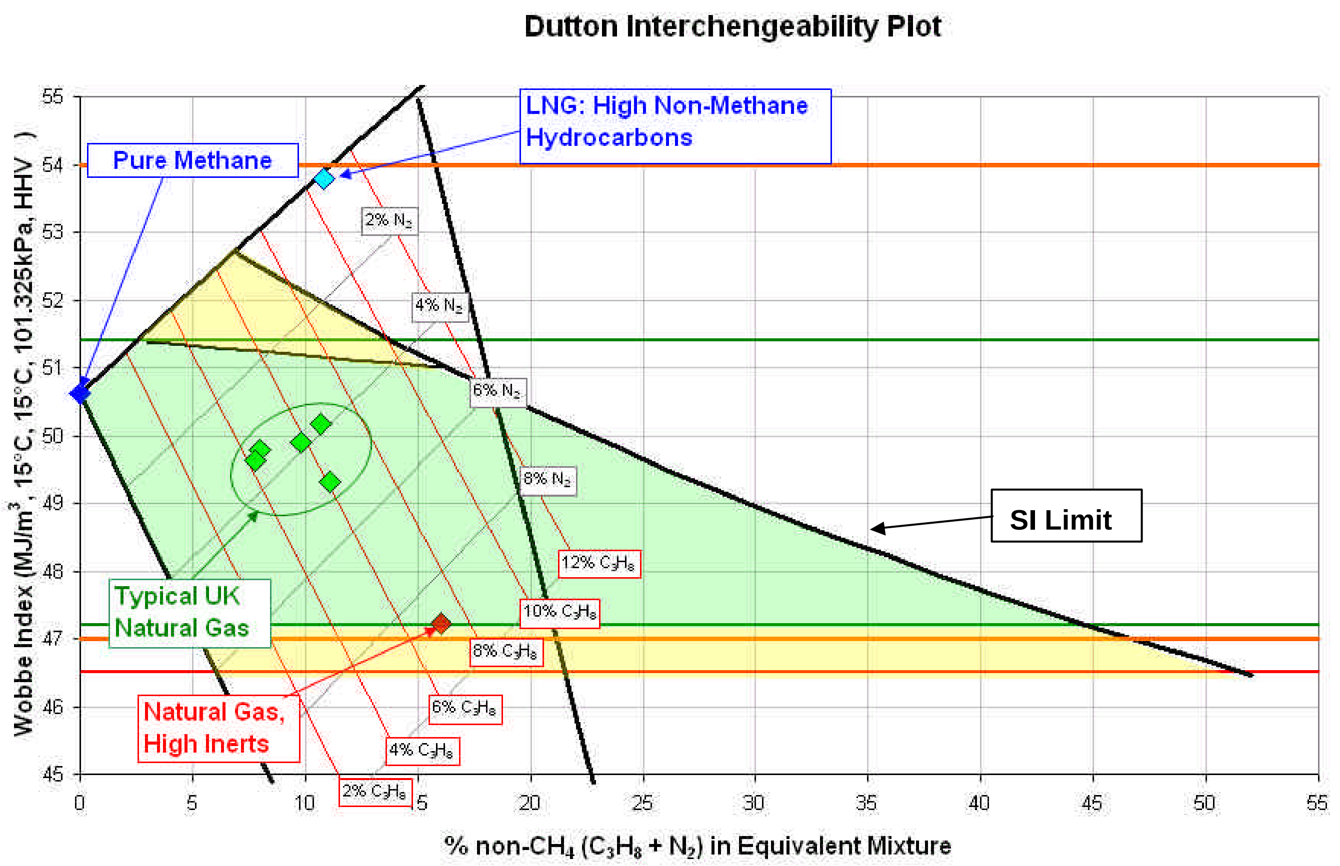
Air/Fuel Ratio
Fuel placement & air/fuel mixing

All are affected by fuel composition and affect flame behaviour such as flash-back, blow out, emissions and combustion dynamics

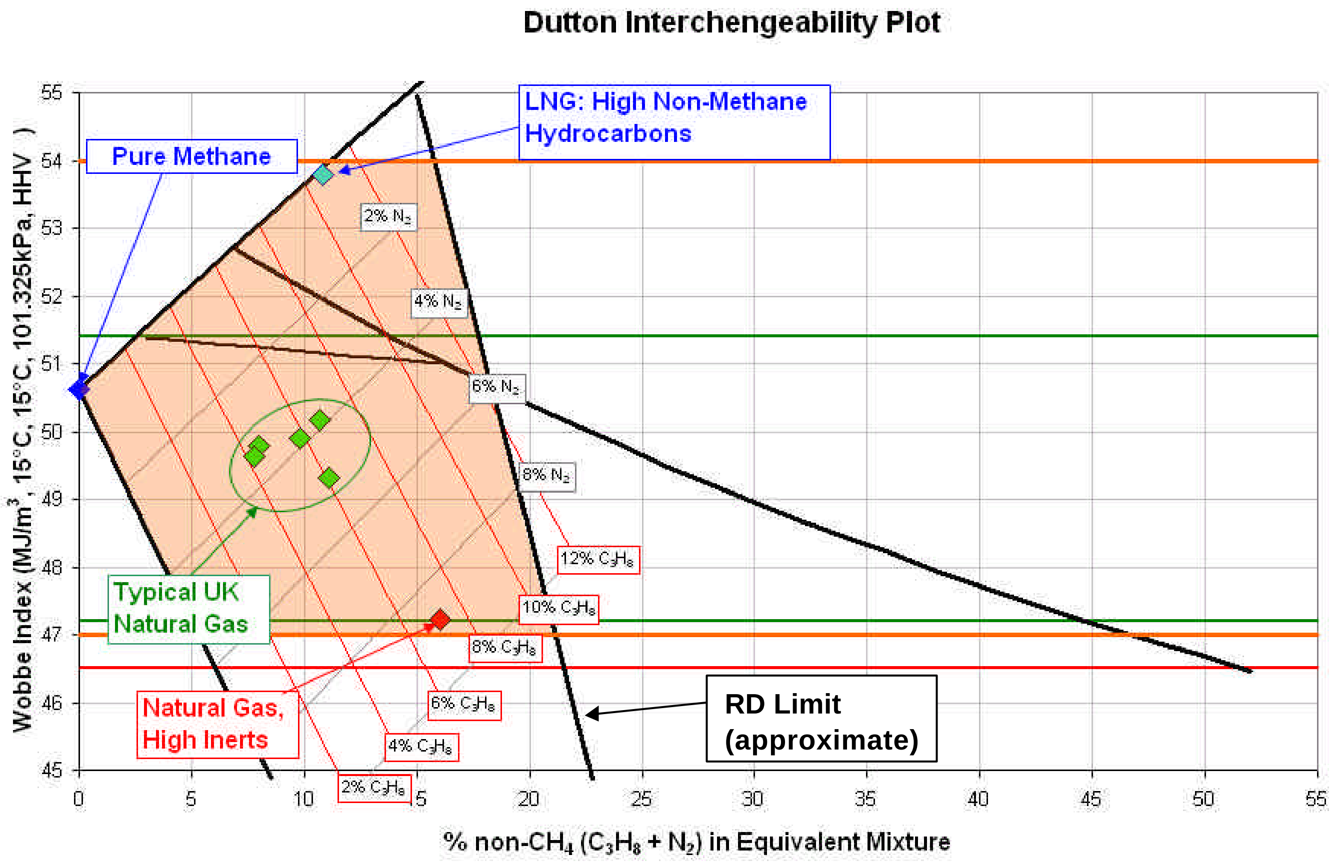
Key pipeline gas quality specifications

Parameter	The UK GS(M)R	EASEE-gas
Wobbe Index (MJ/Sm^3)	47.2-51.41	47.0-54.0
CO_2	**Not specified**	**=2.5 mol %**
Oxygen	**=0.2 mol%**	**=0.01 mol%**
Hydrogen	**=0.1 mol%**	**Insignificant**
H_2S	**=5 mg/m^3**	**=5 mg/m^3 (including COS)**
Total Sulphur	**=50 mg/m^3**	**=30 mg/m^3**
Water Dewpoint	**Shall not interfere with pipes or appliances**	**=-8°C at 70 bar (a)**
Hydrocarbon Dewpoint		**=-2°C at 1 to 70 bar (a)**
Relative Density (RD)	**Not specified**	0.555-0.70
Incomplete Combustion Factor) (ICF)	Less than 0.48	**Not specified**
Soot Index (SI)	Less than 0.60	**Not specified**

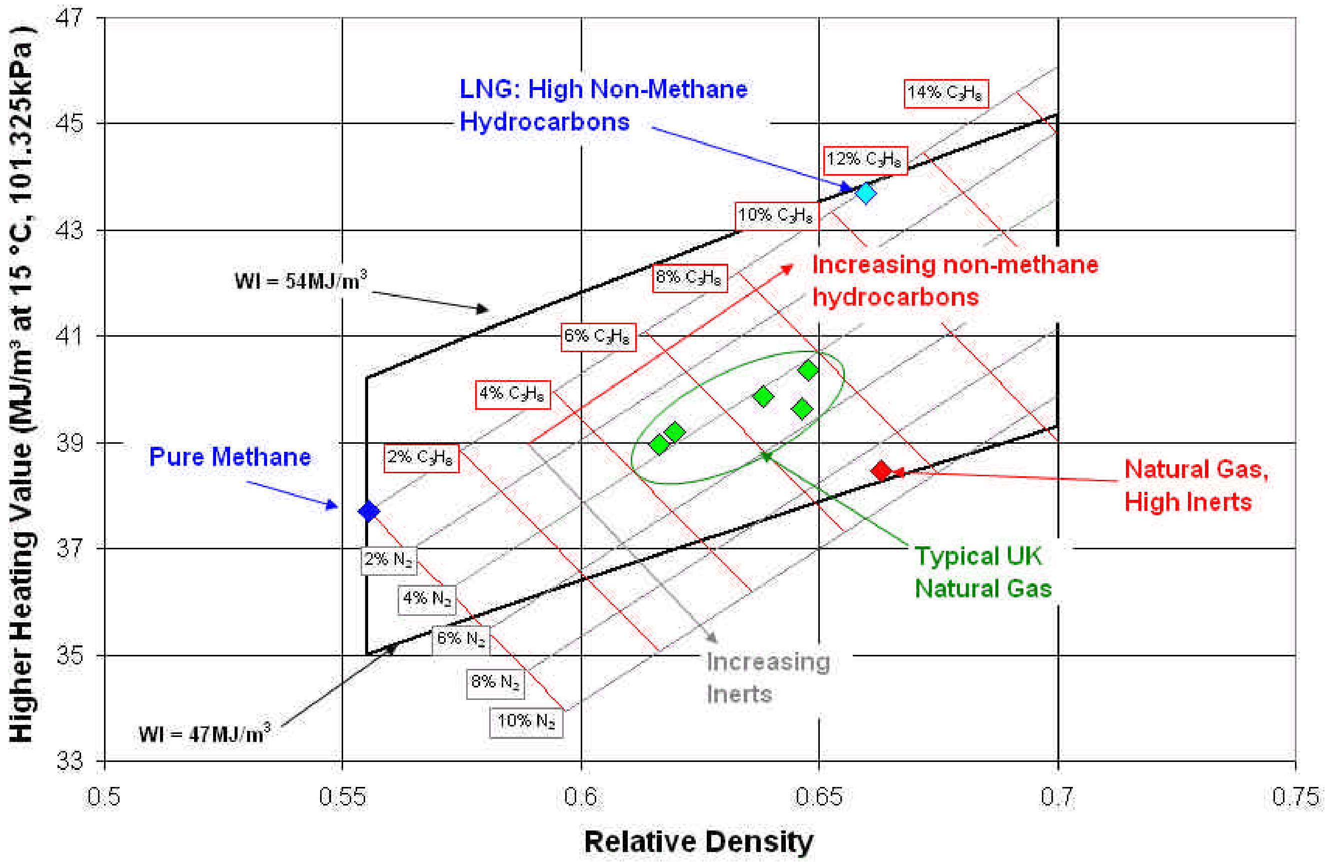
Dutton Plot: GS(M)R



Dutton Plot: EASEE-gas



HHV-RD Plot: EASEE-gas



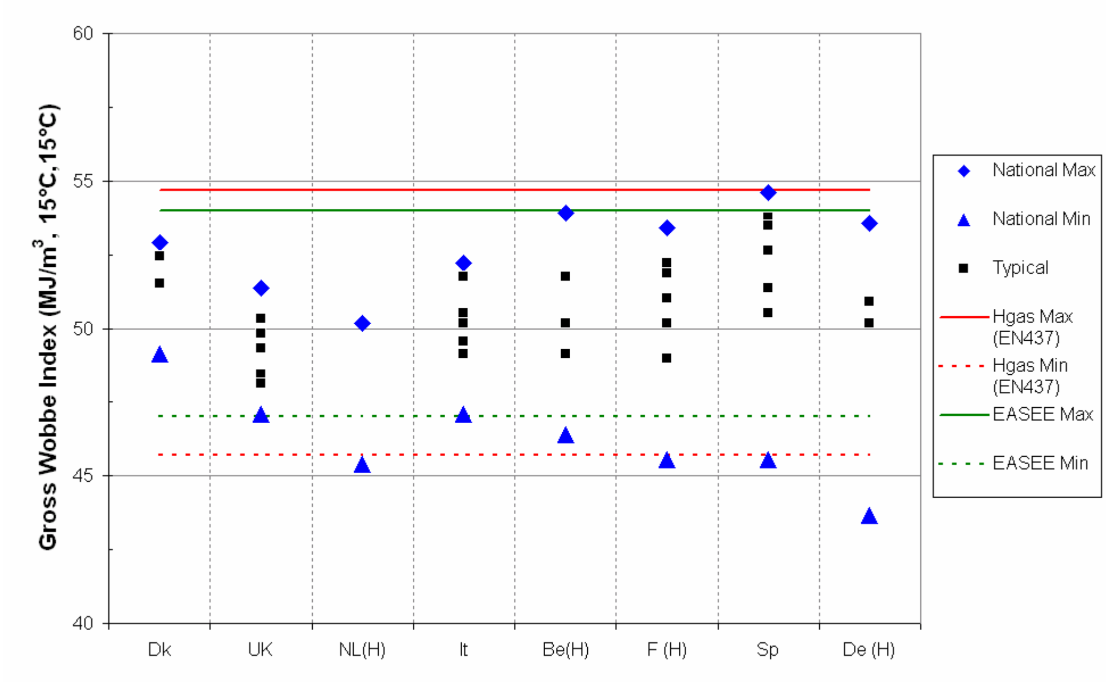
Gas turbine manufacturers’ fuel specifications

Wobbe Index
This is typically given by:

$$WI = \frac{\text{Fuel Volumetric Heating Value}}{(\text{Fuel Relative Density})^{0.5}}$$

Typically required to remain within ±5% of the commissioned/tuned value, with some gas turbines requiring ranges as low as ±2%.

European and national pipeline natural gas specifications and typical compositions



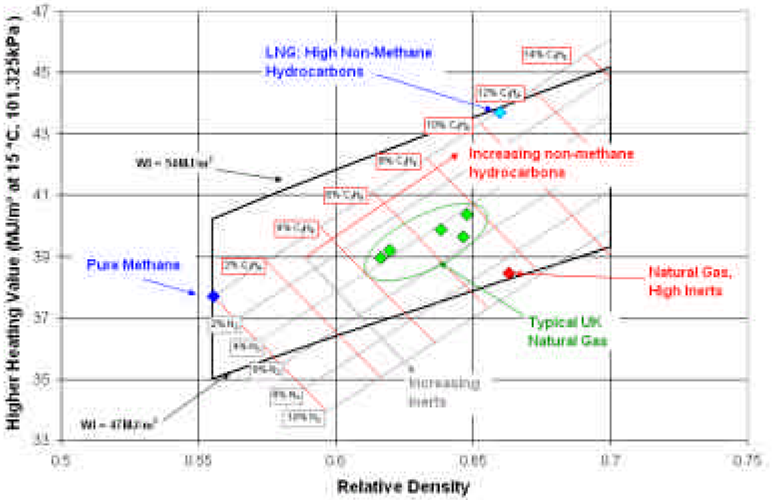
	Allowable Wobbe Range ±	Typical Wobbe Range ±
Dk	3.7%	0.9%
UK	4.3%	2.3%
NL(H)	5.0%	
It	5.2%	2.6%
Be(H)	7.5%	2.6%
F (H)	7.9%	3.2%
Sp	9.0%	3.1%
De (H)	10.2%	0.7%
EASEE	6.9%	

Implications of out-of-range Wobbe Index

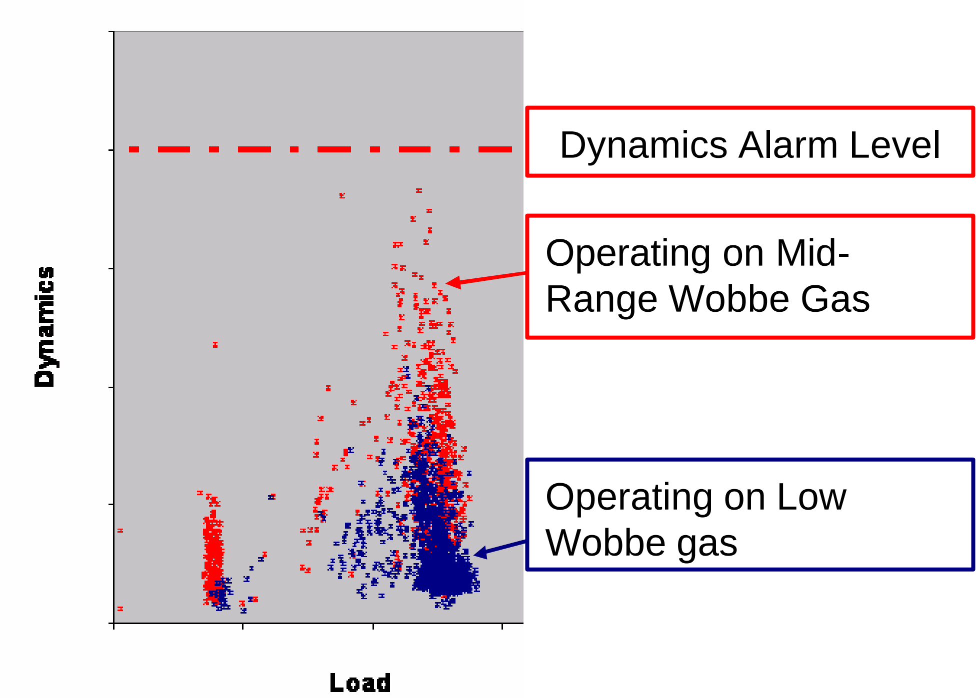
High Dynamics
- Reduced life
- Potential for catastrophic failure

Increased emissions
- Reduced operational flexibility
- Permit issues

Flame position
- Flashback
- Component overheating
  - ➔ Reduced life
  - ➔ Component failure



Implications of out-of-range Wobbe Index: high



Dynamics data for a gas turbine tuned on a Low Wobbe Gas and operated on both Low and Mid-Range Wobbe Gases

Damage due to high dynamics

Gas turbine manufacturers' specifications

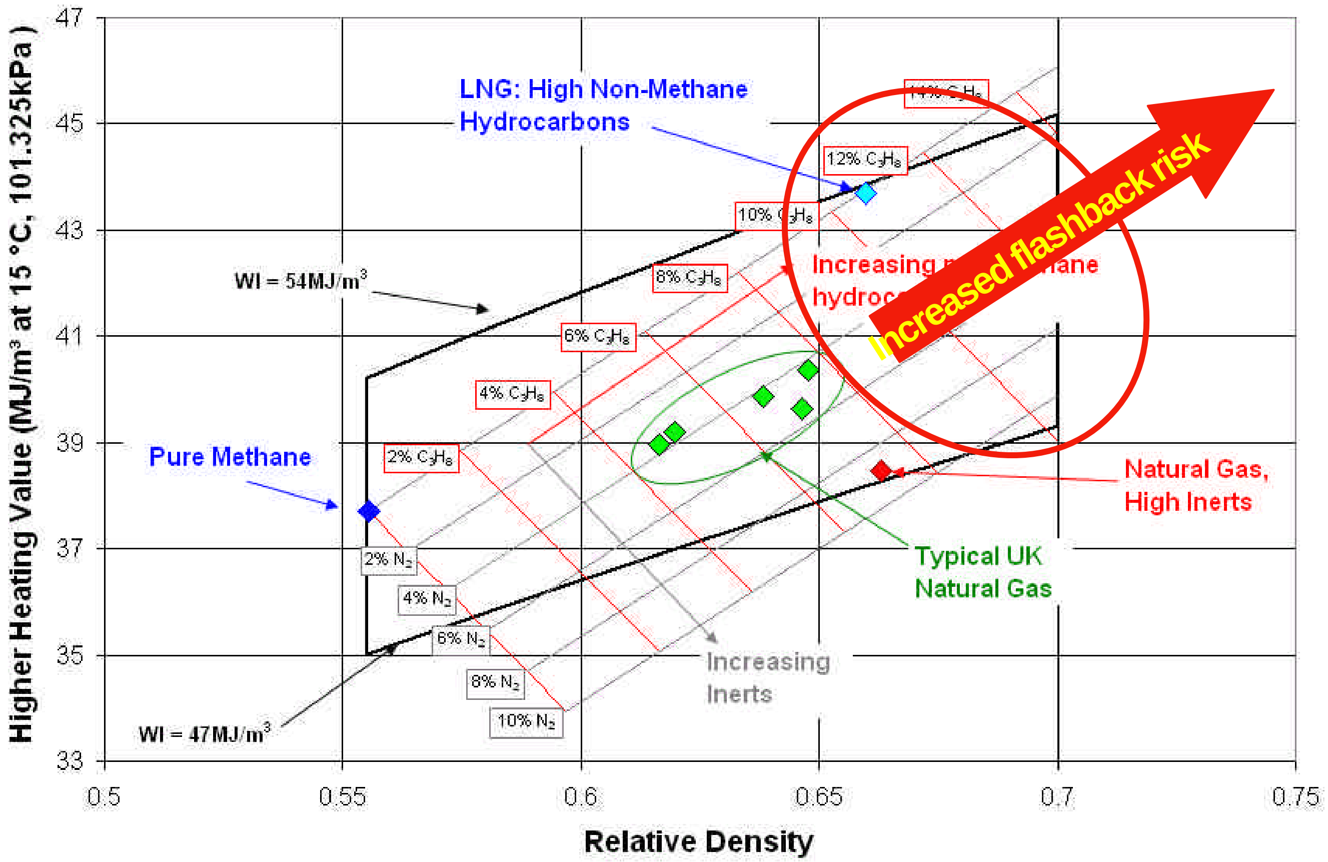
- Composition Criteria:

  In addition to the Wobbe Index alone, the composition affects flame speed, autoignition properties and the chemical kinetics of the flame, affecting in particular:

  - emissions
  - flashback
  - ignition properties

  There are a wide range of manufacturers' specification for composition, but typically specify maximum levels of higher hydrocarbons (individually or as C2+, C4+ etc), minimum methane and/or maximum inerts.

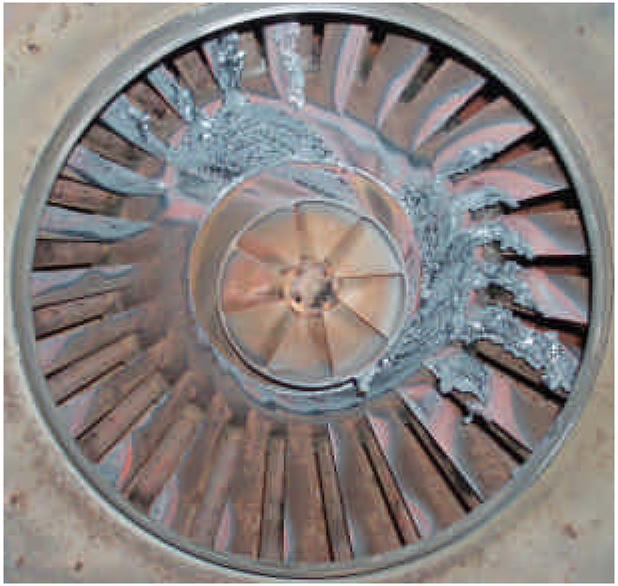
Implications of out-of-range composition: flashback



Implications of out-of-range composition

Increased emissions
- Reduced operational flexibility
- Permit issues

Autoignition and flashback
- Potential for catastrophic failure
- Component overheating
- ➔ Reduced life
- ➔ Component failure



Potential Solutions (1)

Combustion System Redesign

In some cases combustion systems have identifiable design weaknesses and the manufacturer can improve combustion performance through modified burner design. This has been successful in increasing the flashback resistance of a number of burners

On-line measurement of fuel composition and compensation through control or fuel heating

In some cases it is possible to effectively change control settings to adequately compensate for measured changes in fuel composition

In some systems, where the effective Wobbe Index is the critical feature, controlled fuel heating can be used to modify the effective Wobbe Index in response to fuel composition changes

Potential Solutions (2)

Control system response to changes in gas turbine behaviour without fuel composition or property measurement

In some cases this may be as simple as a change in load in response to a problem such as high combustion dynamics or emissions

In the most complex cases full model based control is used to effectively continuously optimise system behaviour.

Conclusions (1)

The risks for gas turbine operators associated with variation in pipeline gas composition are likely to increase in the future

Risks include the potential for:
Excessive emissions,
Reduced component life
Component failure

Further fuel composition variation may be driven by:
- Economic factors such as co-firing of low cost fuels with pipeline gas
- Alternative low carbon and future fuels e.g. bio-syngas or hydrogen

National and European gas specifications do not ensure that pipeline gas will be acceptable to all currently operating gas turbines

Conclusions (2)

Gas turbine manufacturers are addressing the issue in a number of ways (predominantly by control strategies)

Gas turbine operators must be aware of the risks and ensure that adequate mitigation strategies are in place.