THE CHALLENGES FOR GAS TURBINE OPERATORS OF CHANGING FUEL COMPOSITIONS AND THE AVAILABILITY OF ALTERNATIVE FUELS.

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What gases can gas turbines burn

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, Digester 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)
- and more...

BUT each individual gas turbine can only tolerate limited changes in gas composition and properties, depending on the gas turbine design and set-up ***and*** some gases may have an adverse impact on component life.

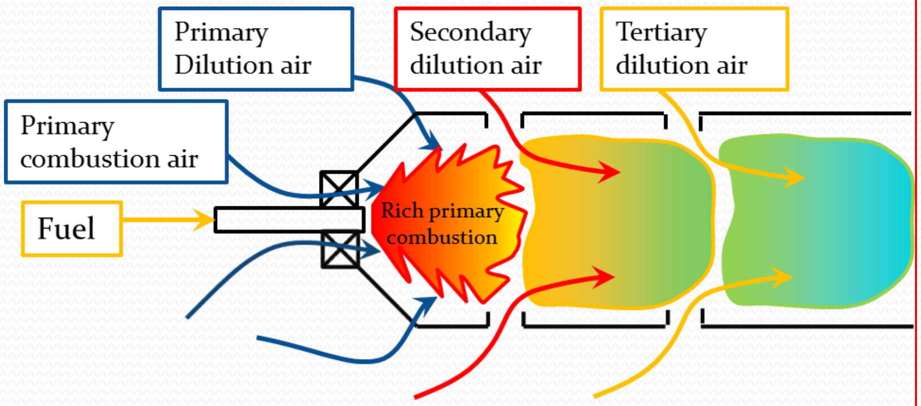
Typical GT Combustion Concepts

Diffusion Combustion:

- Air/fuel mixing in combustion zone
- Wide spread of fuel concentrations

Gives:

- Stable, efficient combustion
- Wide operating envelope
- Flashback resistant
- High NO_X emissions

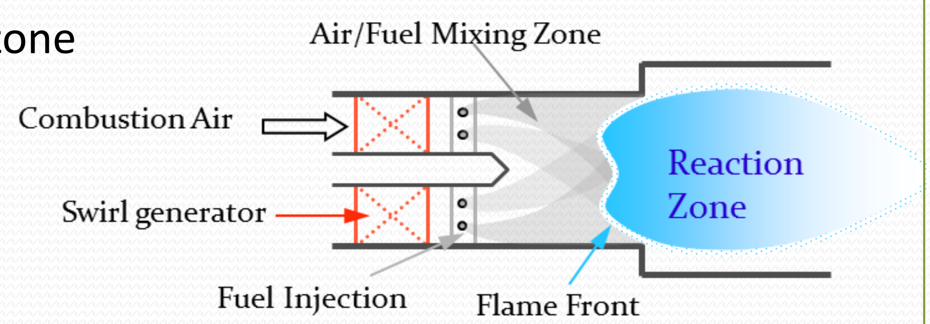


Lean Premix Combustion:

- Air/fuel mixing before combustion zone
- Lean Combustion

Gives:

- Low NO_X emissions
- Potential for flashback
- Issues with stability and dynamics
- Need for careful combustion tuning



Changing Conditions

Changing conditions for Power Generators

- Gas Grid Connected
  - Changing fuel composition (within current delivery specifications)
  - Widening delivery specifications
  - Power to Gas (P2G)
  - Opportunity fuels
    - Waste gases: refinery gases, process gases, gasification gases
    - Waste liquids
  - Emissions legislation
  - Life and interval extension
  - Operational flexibility

Changes in UK Gas Supply

- Based on *Future Energy Scenarios, GB gas and electricity transmission, National Grid, 2016*

- Significant changes over the last 10 to 15 years

  - Reducing UK Continental shelf supply
  - Increasing Norwegian and Continental imports
  - Increasing LNG imports

- Future scenarios similar and relatively stable

  - Continued slow decline in UK Continental shelf supply
  - Dependence on Norwegian imports, LNG and other imports.
  - Shale gas significant in *No Progression* scenario
  - Some influence of green gas in *Gone Green* scenario

Changing conditions for Oil and Gas

- Normally stable fuel composition
  - Interval and life extension
    - Impact of contaminants
  - Marginal fields with high inerts
  - Composition variability due to
    - Connection of new reservoirs
    - Gas re-injection
    - Connection to multiple reservoirs
  - Emissions requirements
  - Opportunity fuels
    - Gas condensates

Issues

Variation of Wobbe Index and Fuel Composition

Variation of Wobbe Index and Fuel Composition

- Increasing NO_X with increasing Wobbe Index
- Flame stability issues with reducing Wobbe Index (leading to dynamics and part load CO problems)
- Increases in dynamics with increasing C2+ or changes in Wobbe Index

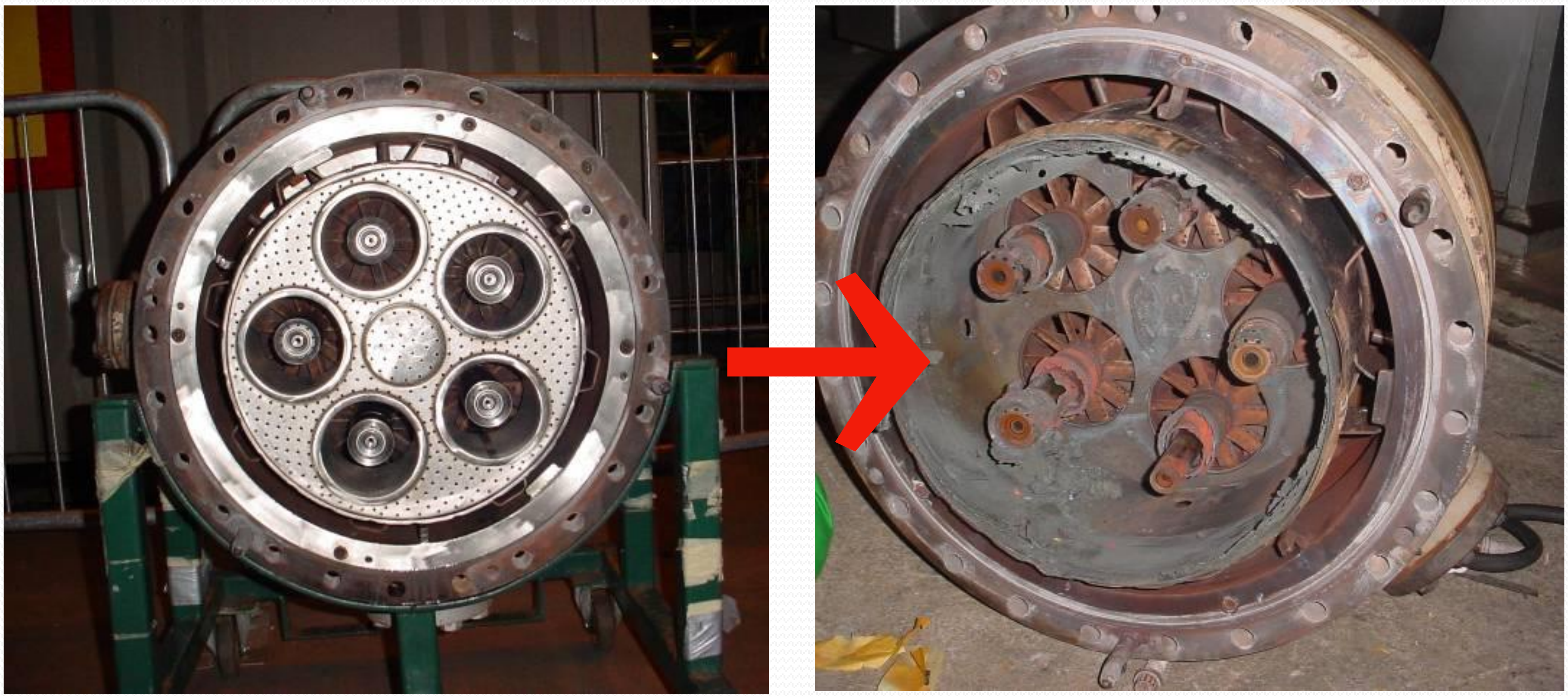
$$WI = \frac{\text{Calorific Value (volumetric)}}{\text{relative density}^{0.5}}$$

- High part load CO with low C2+
- Gas Turbine de-loads and trips
- Flashback

Flashback damage to burners has been linked to high levels of C2+

Damage due to high dynamics

(Not in this case caused by fuel composition changes)



From: David Abbott, Practical examples of the impact of variations in gas composition on gas turbine operation and performance, Gas to Power Europe Forum, January 2012

Mitigation Measures

- Combustion system redesign
  - Has effectively eliminated most flashback issues
  - Improvements in stability, emissions and dynamics
- Measurement of fuel composition and compensation through GT control
  - Issues with speed of composition measurement
  - Effective in controlling high C2+ in sequential combustion systems
- Measurement of Wobbe Index and compensation through fuel heating (see following)
- Control system response to changes in gas turbine behaviour without fuel composition or property measurement (see following)

Fuel Heating for Wobbe Index Control

Increasing fuel temperature decreases the effective Wobbe Index of the fuel

$$WI = \frac{\text{Calorific Value (volumetric)}}{\text{relative density}^{0.5}}$$

- Calculate WI from measured fuel composition (slow) or use fast WI meter
- Change fuel pre-heat to compensate
  - Very effective in controlling many emissions and dynamics issues
  - Does not help with part load CO issues caused by low C2+ content
  - Relatively low cost (especially if fuel pre-heat already implemented for efficiency improvement)

Control system response to changes in GT behaviour

Example 1: **Siemens Advanced Stability Margin Controller (aSMC)**

Used on Siemens SGT5-400oF (V94.3A) and SGT6-4000F (V84.3A)

The most significant issue is high combustion chamber acceleration caused by humming (combustion dynamics). aSMC is configured to control this

- Uses closed loop control of the combustion acoustics to change the pilot gas amount or the turbine outlet temperature according to a fixed set of set rules which depend of the load range and the frequency of humming
- System operates successfully to control humming
- Siemens claim (Eberhard Deuker, Siemens presentation at Power Gen Europe, Vienna, June 2013):
  - aSMC detects the actual margins and can transform them into
    - performance benefit
    - emissions benefit

Control system response to changes in GT behaviour

Example 2: **GE OpFlex AutoTune**

- Part of GE's "Combustion Versatility solution suite"
  - Automates combustion tuning
  - Uses measured combustion dynamics and NO_X emissions (may be calculated) fed into a model based control system to optimise dynamics and emissions.
  - Self teaching algorithms are used and require extensive initial set-up and tuning to generate robust models
- If using calculated NO_X, it is not clear how the system will deal with system degradation
- In principle could include CO emissions, but such implementation not known
- Works well to deal with fuel variations
- GE Claim (https://powergen.gepower.com/software-and-analytics/controls/opflex/opflex-autotune.html):
  - OpFlex AutoTune enables uninterrupted operation over a wide range of fuel variation, and during transient conditions to provide operators with improved reliability and confidence

Control system response to changes in GT behaviour

Experience and issues

- For normal fuel variations seen at UK and European sites:
  - Good experience with aSMC and AutoTune controlling:
    - NO_X (AutoTune)
    - Dynamics/humming (both)
  - Reduced periodic tuning (AutoTune)
- BUT
  - Operational experience of the extremes of capability is limited
  - Effects of system degradation uncertain
  - Currently no control of CO

Issues

Combustion of Sulphur-Containing Gases

Combustion of Sulphur-Containing Gases

Hot Corrosion

Accelerated corrosion due to salt contaminants such as Na_2SO_4, NaCl and V_2O_5 that combine to form molten deposits that damage the protective surface oxides

- **Type 1 (High Temperature) Hot Corrosion**
  - Typically in range 850-1050°C depending on alloy
  - Condensation of fused alkali metal salts on component surface
  - Attack of protective oxide film then depletion of chromium from substrate
  - Oxidation of substrate accelerates to give porous scale formation
- **Type 2 (Low Temperature) Hot Corrosion**
  - Typically 650 to 850°C
  - Pitting resulting from formation of low MP mixtures of Na_2SO_4 and $CoSO_4$

From: Salehnasab B, et al, Hot corrosion failure in the first stage nozzle of a gas turbine engine, Engineering Failure Analysis 60, pp 316–325, 2016

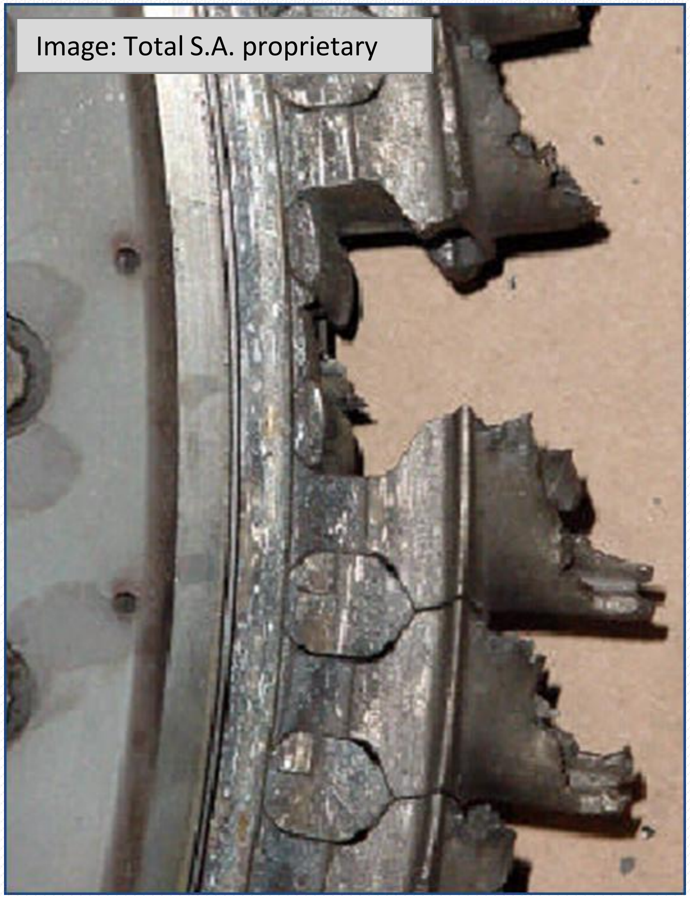
Combustion of Sulphur-Containing Gases

Hot Corrosion

- Damage due to hot Corrosion
  - First Stage Blade of HP Turbine
  - Offshore Application in Oil & Gas Industry
  - Fuel gas contained 0.4% H_2S

Mitigation:

- Local removal of sulphur from the fuel is often not economic (especially offshore)
- Air filtration to reduce salt content only partly effective
- Careful selection of blade material and coating
- Further development and application of coatings specifically designed to reduce hot corrosion



Combustion of Sulphur-Containing Gases

Acid dew point

- Even with pipeline gas sulphur levels, sulphur can have a significant effect on the acid dew point of the exhaust gases.
- Sulphur trioxide combined with moisture and other reactions form sulphuric acid (H_2SO_4)
- If the flue gas is cooled below the dew-point, acidic liquid will condense
- Dew point increases significantly with increasing sulphur content
  - Leading to condensation in downstream components (e.g. HRSGs)
  - Resulting in acid corrosion and fouling particularly of HRSG boiler tubes
    - Loss in boiler efficiency
    - Increased maintenance requirements

HRSG deposition due to acid dew point (Uniper Technologies)

Combustion of Sulphur-Containing Gases

Mitigation:

- Sulphur removal: not usually economic at pipeline sulphur levels
- Maintain component temperature high enough to prevent acid condensation
  - Significant impact on combined cycle efficiency
  - Difficult under part load operating conditions

HRSG deposition due to acid dew point (Uniper Technologies)

Issues

High Inerts

High Inerts

Potential issue for Oil & Gas Sector

- Large previously exploited fields with up to 40% CO_2 (e.g. Indonesia, Libya, Brazil)
  - Typically GTs can tolerate up to about 15% CO_2
  - With significantly higher levels of inerts GTs experience:
    - Issues maintaining stable operation over full operating range
    - Starting problems

Mitigation:

- Alternative fuel for starting (rich gas or liquid fuel)
- Restricted operating range
- Design Change

Issues

New Fuel Sources: Unexpected Contaminants

New Fuel Sources: Unexpected Contaminants

- New fuel sources can create new and unexpected issues due to trace components

Example:

- The use of landfill and anaerobic digester gas would not at first sight present particular issues

- Siloxanes (volatile silicon compounds) are present in landfill gas and wastewater treatment plant sludge digester gas in concentrations of 10 ppmv

New Fuel Sources: Unexpected Contaminants

Siloxanes are converted to silica (SiO_2) in the flame. This may:

- Erode parts exposed to high velocity gas streams,
- Accumulate on turbine blades and vanes either as a powdery substance or as a hard glass-like coating
  - leading to a reduction in turbine efficiency
  - possible blockage of blade and vane cooling holes
  - Adverse effect on refurbishability of the blades and vanes
- Possible fouling of downstream components
  - Loss of effectiveness of emissions control catalysts (e.g. Selective Catalytic Reduction of NO_X)
  - Reduction in heat transfer efficiency in HRSGs

Issues

Combustion of Hydrogen-Containing Gases

Combustion of Hydrogen-Containing Gases

Potential for firing natural gas—hydrogen mixtures:

- Power to Gas (P2G)
  - Use of excess renewable electricity to produce hydrogen as an energy storage medium
    - 40+ projects in Europe
    - many injecting into gas network
    - Up to 20vol% H_2 have been proposed
    - 5-10% more likely
- Co-firing of H_2 containing waste gases

Combustion of Hydrogen-Containing Gases

- Diffusion systems tolerate high levels of : up to 100vol%

- Lean premix specifications range from “trace” to 20vol%+
  - Typically expect 1-5vol% to be feasible

- Wide range of operational, integrity and safety concerns if H_2 added to gas network
  - HIPS-NET: network monitoring developments and understanding of H_2 addition to natural gas systems

Combustion of Hydrogen-Containing Gases

- GTs firing high H_2 fuels (>5vol%) typically start on alternative fuel
  - Increased flammability giving exhaust explosion risk and possibly flashback
- Affects emissions, dynamics and flame stability
  - Impact on operability, reliability, availability, component life, costs
- Impact on Hazardous area classification?
- Most current gas detectors do not recognise H_2
- Increased leakage potential (internal and external)
- Increased risk of exhaust explosion potential

Combustion of Hydrogen-Containing Gases

Mitigation

- Manufacturers to re-validate the GTs for higher levels of hydrogen
- Some issues may be mitigated by automatic tuning systems (see previously)
- More work needed...

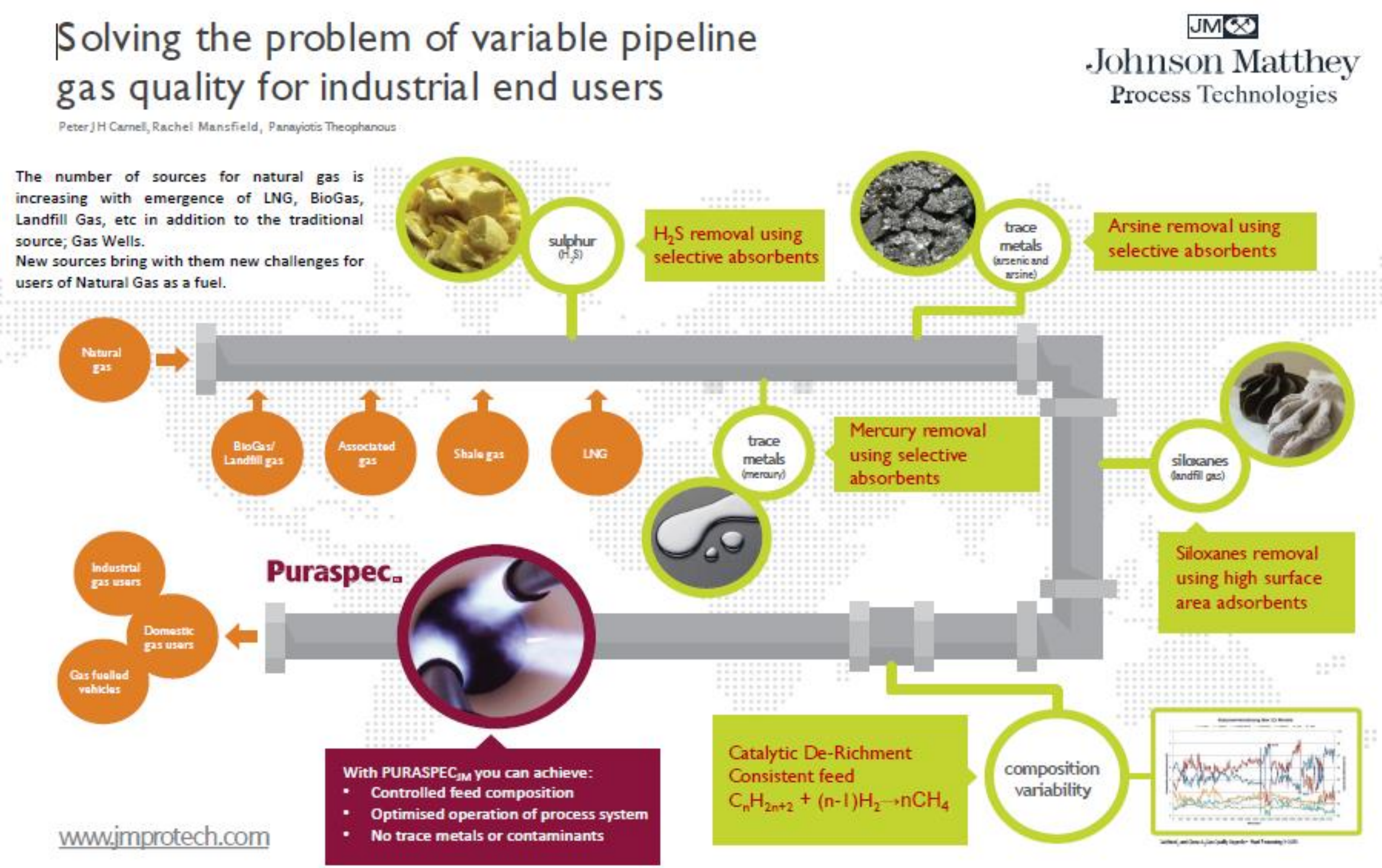
Fuel supply treatment

Fuel supply treatment

- Modification of Wobbe Index (see previous)

- Chemical or physical modification or removal of fuel components
  - Currently only used in special circumstances
  - May be appropriate to consider in future as technologies develop

- Examples:
  - Sulphur removal
  - Contaminant removal (e.g. Siloxanes)
  - Removal of higher hydrocarbons (C2+)
    - May cause issues if remaining fuel has too low level of C2+



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Conclusions

Conclusions

- The past decade has seen significant increases in grid fuel variability
- OEMS have developed more robust systems, automatic tuning systems and other mitigation measures.
- Cost of upgrades and implementation of mitigation measures remains an issue in the competitive power generation market
- Sulphur remains an issue for many operators
- Future challenges
  - Hydrogen addition to the gas network
  - New fuel sources
  - Exploitation of gas fields with high inerts

Development needs and possibilities

- Robust fuel flexible combustion systems
- Improved automatic tuning (dynamics, NO_X, CO)
- Improved hot corrosion resistance
- Practical sulphur removal and other fuel treatments
- Full range operation on high inert fuels
- Hydrogen tolerant GTs

Development needs to:

- **Be responsive to issues of new fuel sources and operating needs**
- **Generate low cost retrofits of new solutions**

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Thank you for your attention

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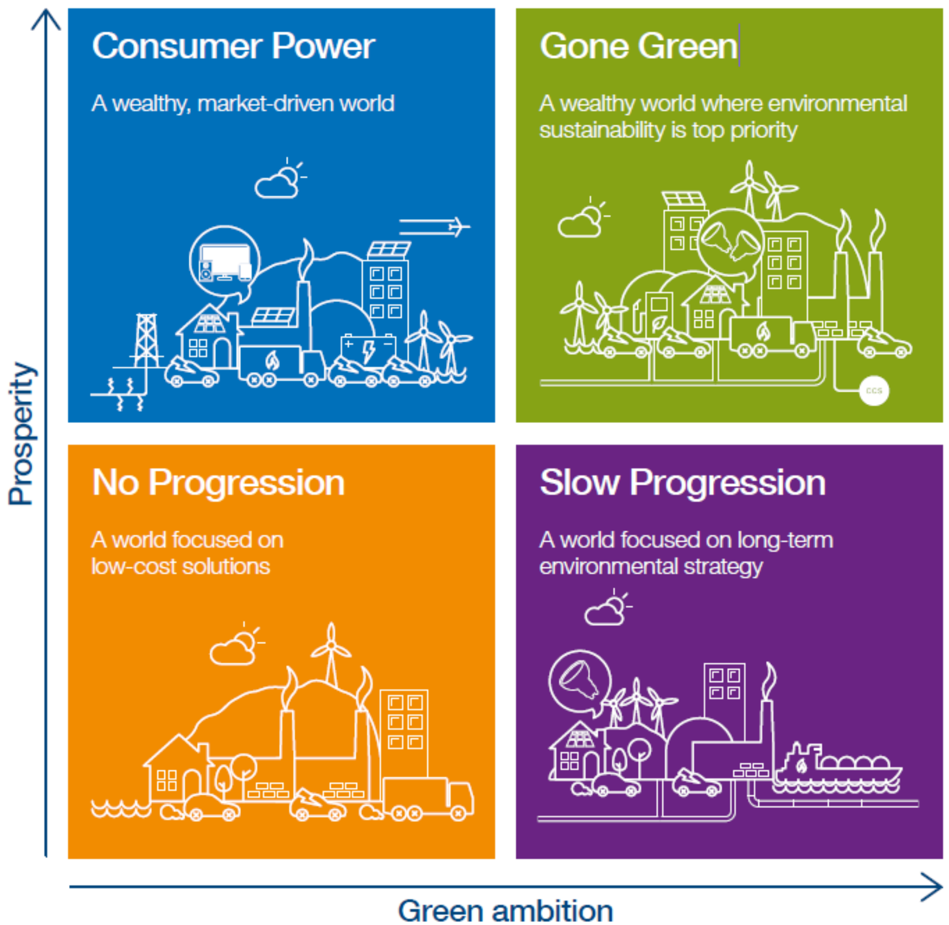
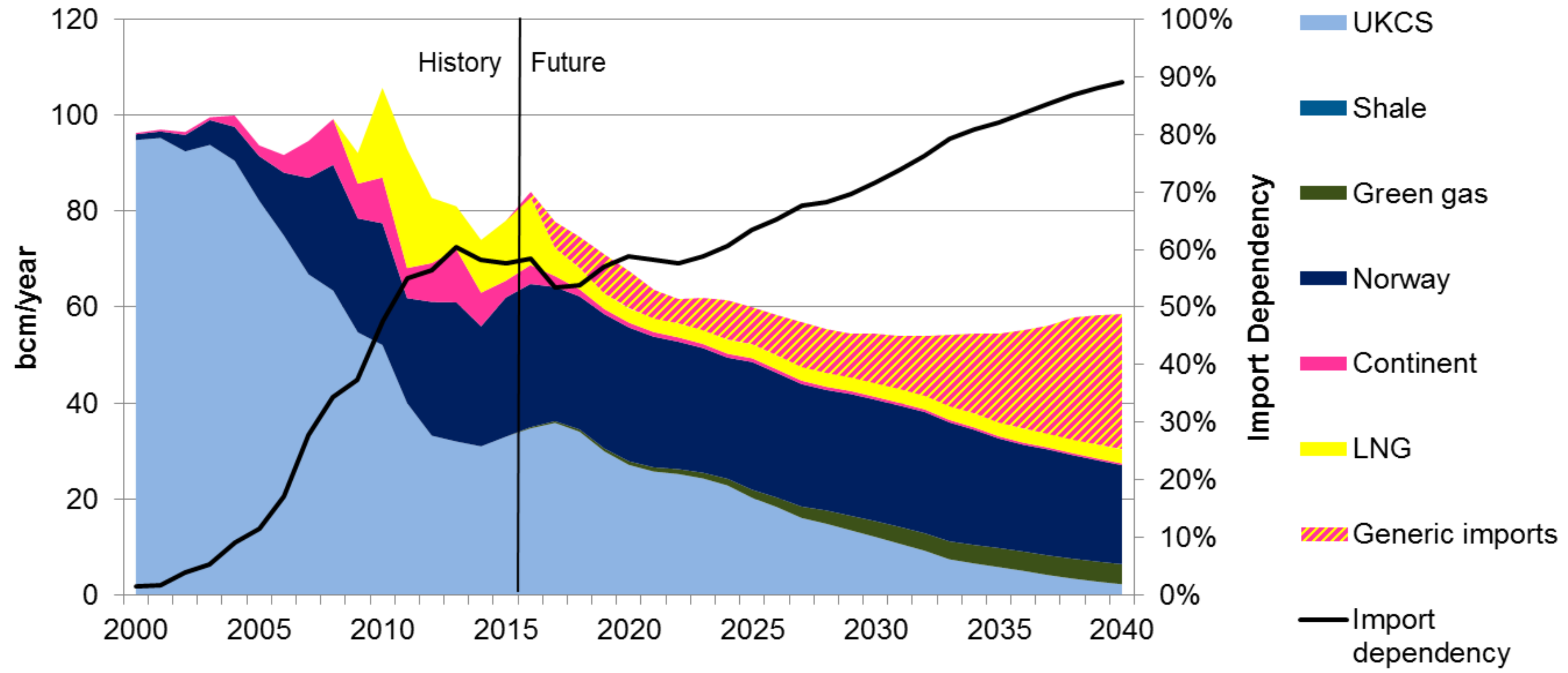
Back-up

Future changes in UK gas supply



From: Future Energy Scenarios, GB gas and electricity transmission, National Grid, 2016
From: http://fes.nationalgrid.com/

UK Fuel Supply: Gone Green Scenario



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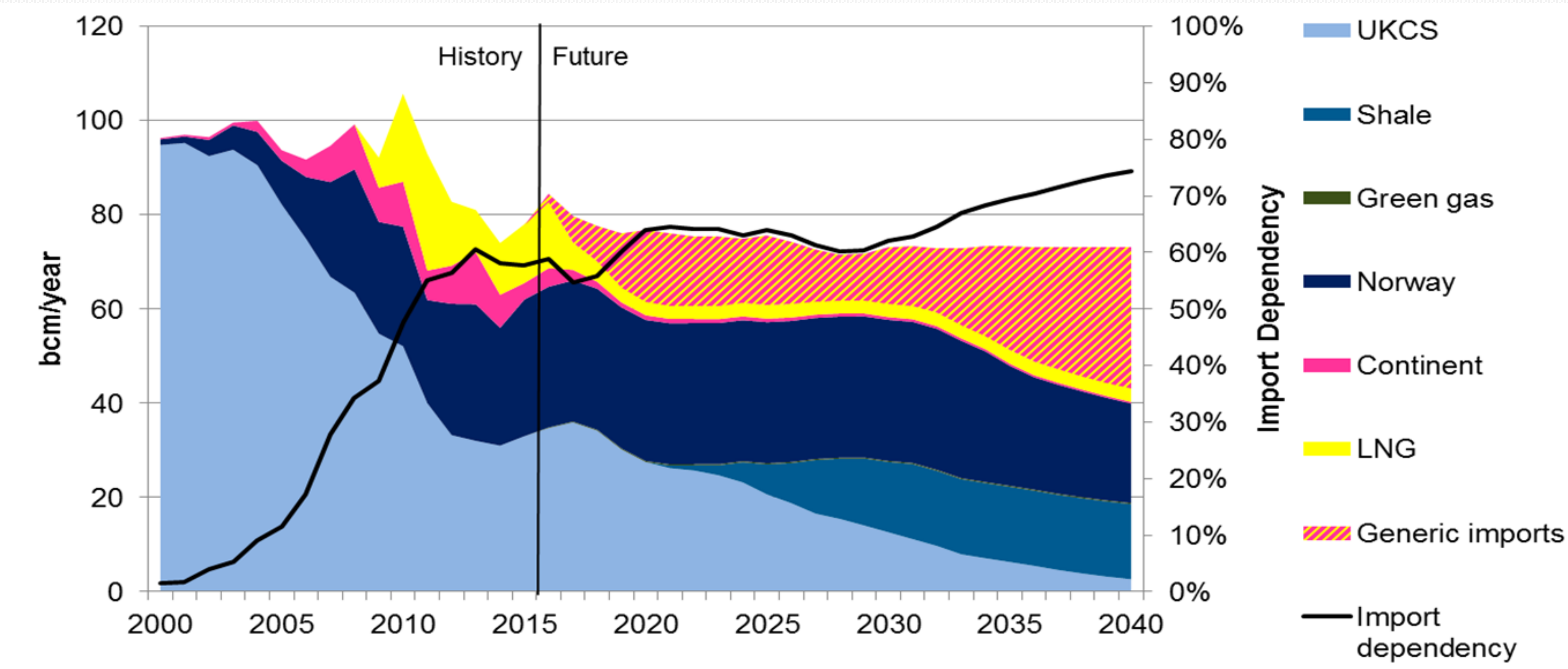
UK Fuel Supply: No Progression Scenario



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