Siemens Industrial Gas Turbines
Fuel flexibility and alternative fuels for gas turbines

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Opening Question

What do you, the audience, think are alternative fuels;

Is there room for alternatives to NG or distillate, noting the quantity of fuel necessary to sustain the current gas turbine fleet …

... or is the role of alternative fuels just going to provide a "niche" market

What about the "other players for alternative fuels"; the transport sector for example requires large quantities of non-fossil fuels to supplement the fossil fuel demands

And …
…let's not forget the other factors such as fuel quality required by GT OEM's

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Agenda

- Where are we located
- What products do we offer
- What capabilities
  - Fuels experience
  - Fuel flexibility
- How Achieved
  - Combustion Rigs
- Alternative fuels
  - Gasification / Pyrolysis
  - Examples / opportunities
  - High inert content fuels
  - Hydrogen
- Fuel Quality
- Summary and Questions

Lincoln, UK

A Cathedral city and major industrial and cultural centre for 2000 years

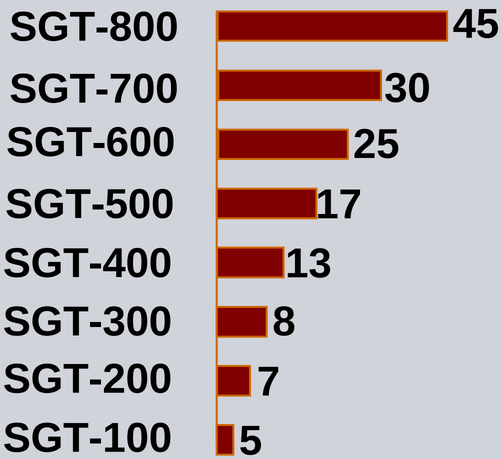
Location: 200km from London

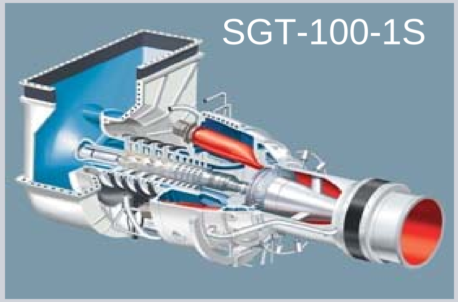
Population: 87,000

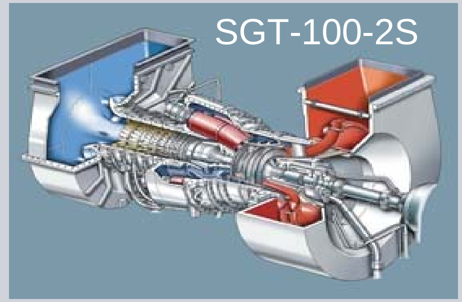
Gas Turbine Evolution

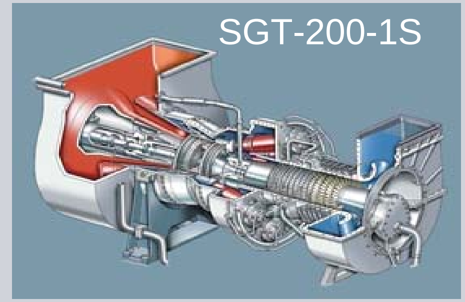
1946	-	Ruston & Hornsby developed prototype GT
1952	-	R & H delivered first production unit to Kuwait
1968	-	R & H acquired by GEC
1969	-	Ruston Gas Turbines Ltd formed
1989	-	GEC ALSTHOM formed
1990	-	European Gas Turbines created by GEC ALSTHOM and GE (USA)
1998	-	ALSTOM Gas Turbines formed as part of ALSTOM
1999	-	ABB ALSTOM POWER formed (GE agreement terminated)
2000	-	ALSTOM acquired ABB's 50% to form ALSTOM Power
2003	-	Siemens aquire SGT/MGT from Alstom

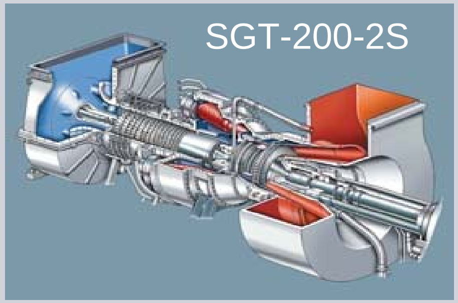
Industrial Gas Turbine Product Range

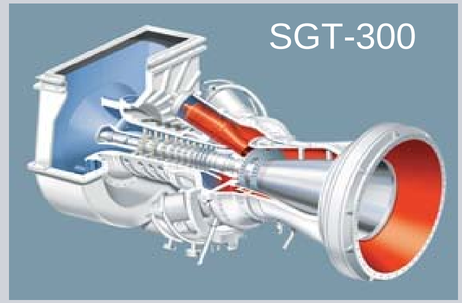


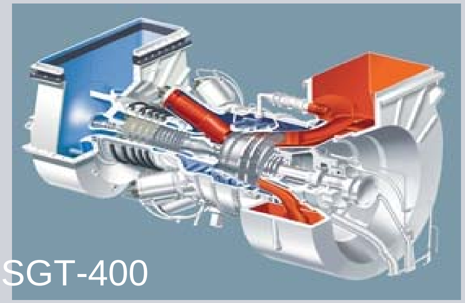


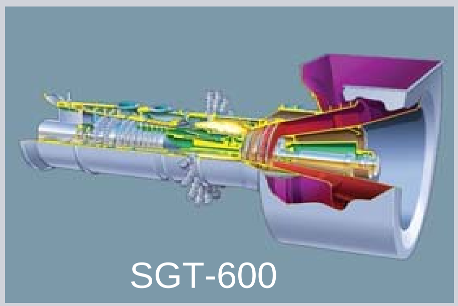


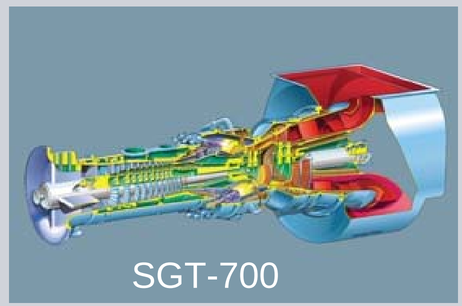


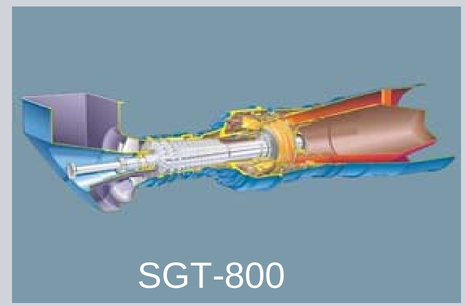












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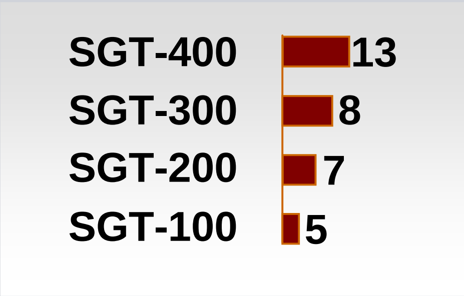
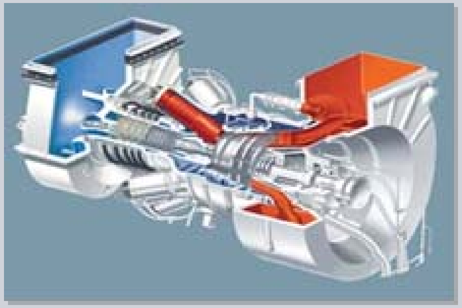
Industrial gas turbine range <15MW

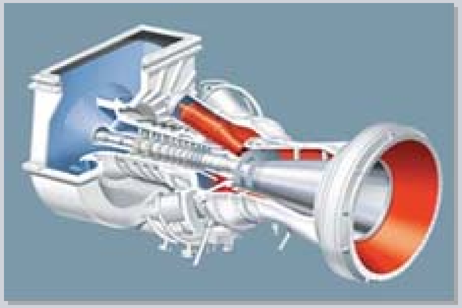


SGT-400 / 13MW



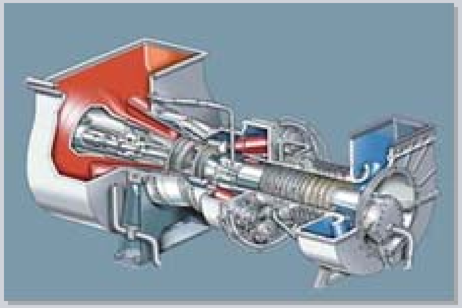
Entered Service 2000

SGT-300 / 8MW



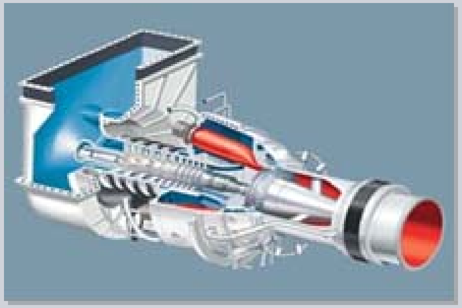
Entered Service 1997

SGT-200 / 7MW



Entered Service1981

SGT-100 / 4-5 MW



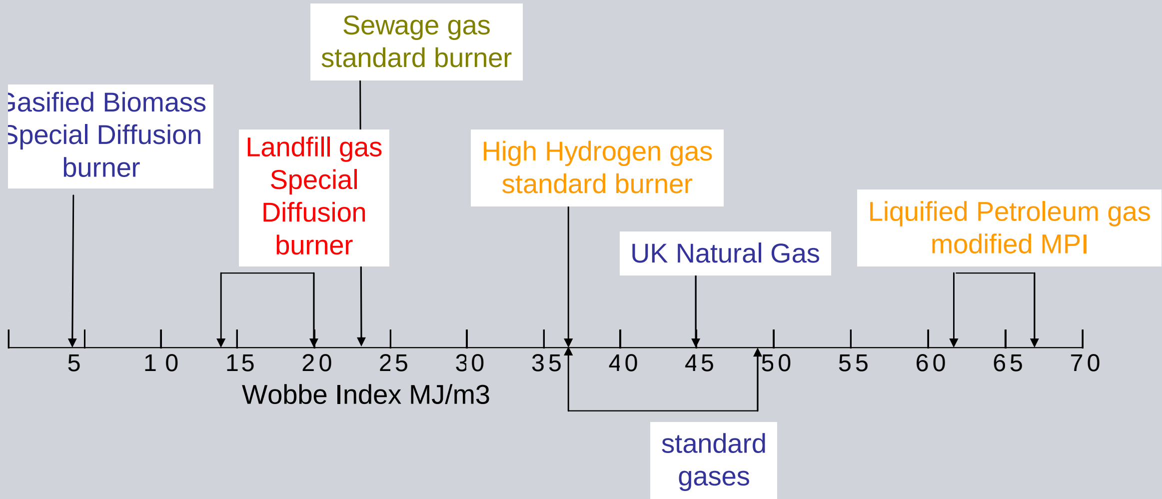
Entered Service 1989

- Family of Engines
- Commonality of Parts
- Proven Technology

Examples of Siemens SGT Fuels Experience

NON DLE Combustion

- Natural Gas
- Wellhead Gases
- Landfill Gas
- Sewage Gas
- High Hydrogen Gases
- Diesel
- Kerosene
- LPG (liquid and gaseous)
- Naphtha
- ‘Wood’ or Synthetic Gas
- Gasified Lignite

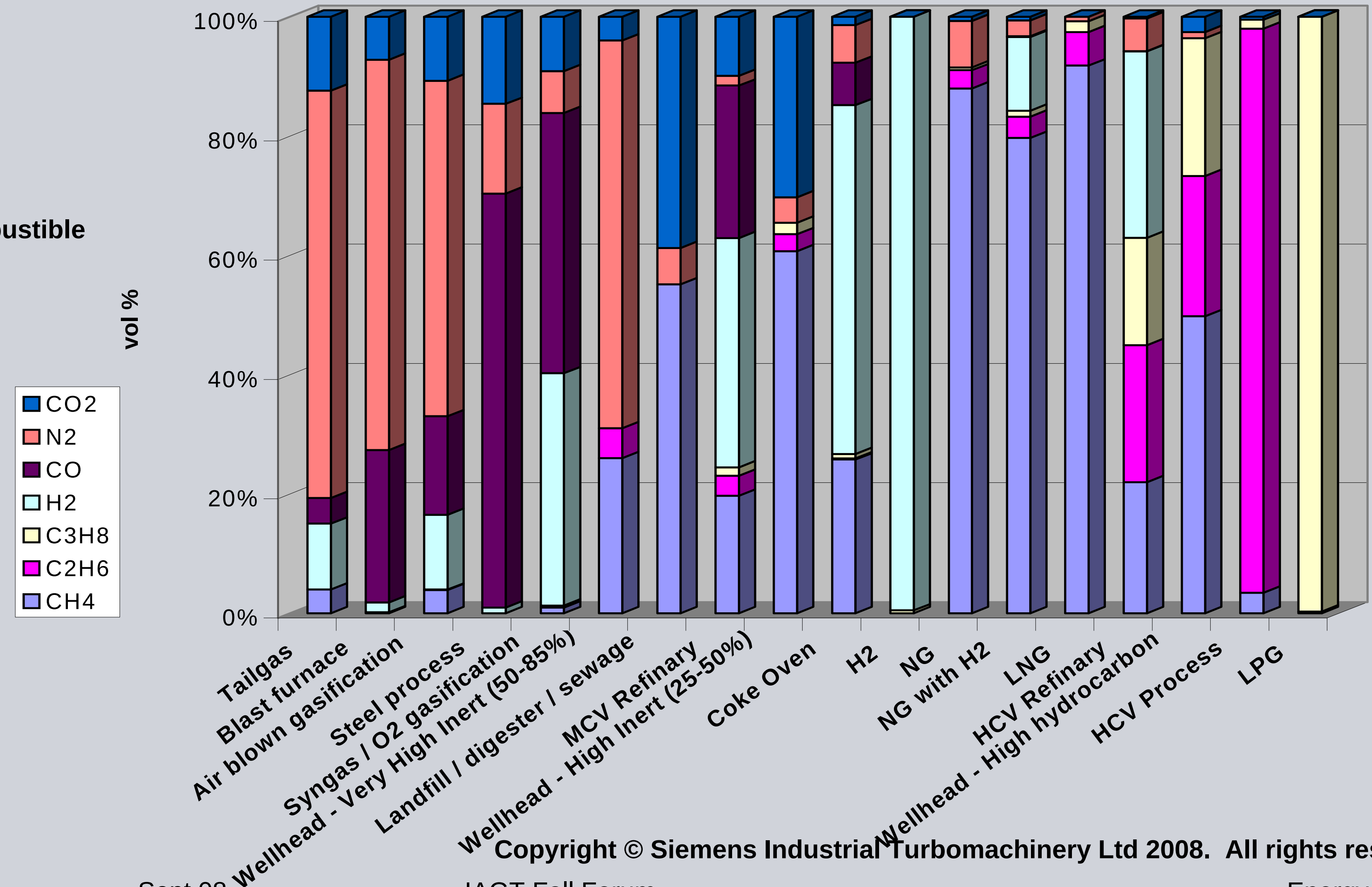


Gaseous Fuel Range of Operation

- DLE experience on Natural Gas, Kerosene and Diesel
- DLE on Associated or Wellhead Gases from depleted sources

Fuel categories by content

CH4-CO combustible
N2,CO2 inert



Fuel Categories by description

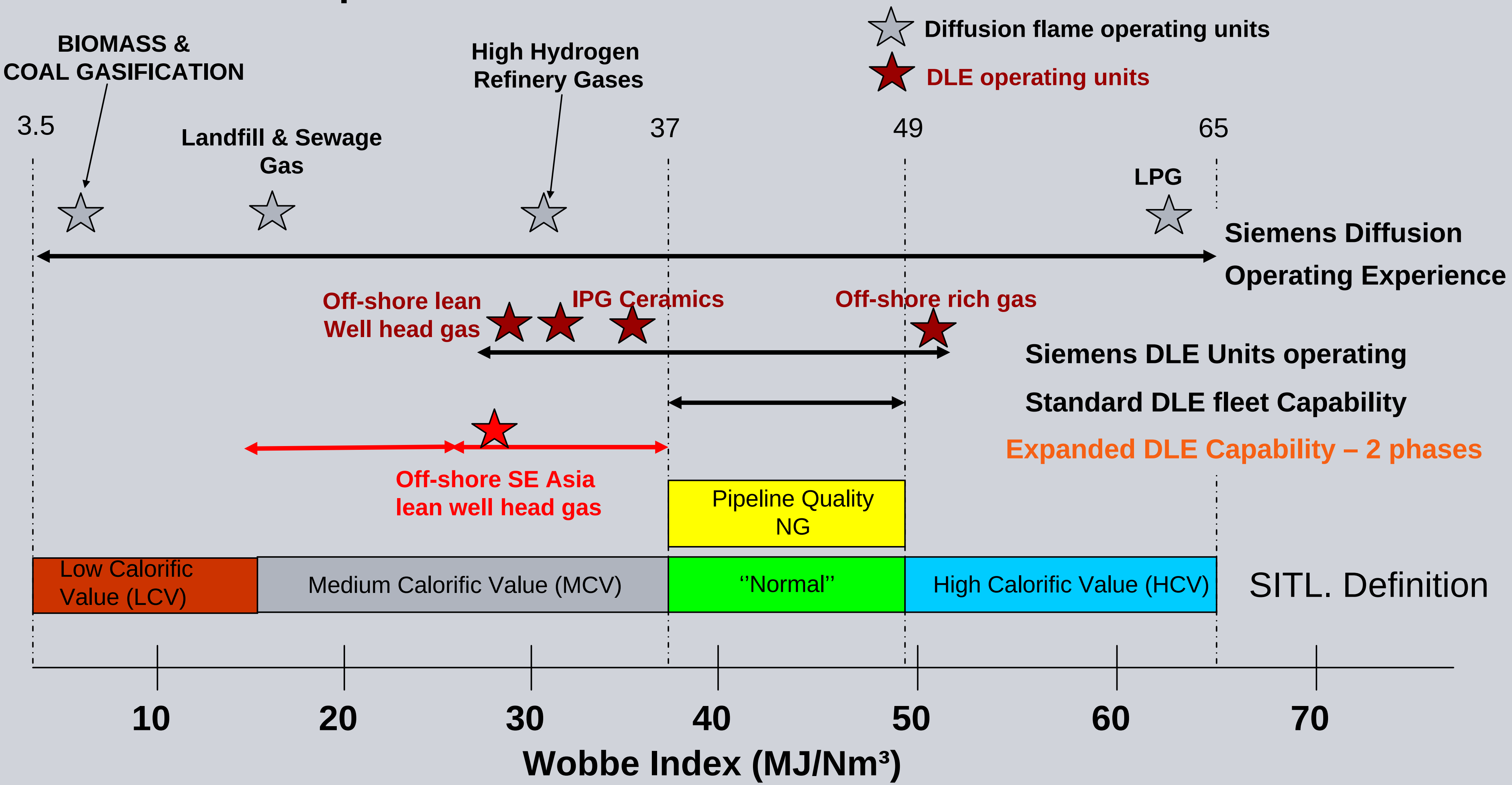
Fuel Types

- Hydrocarbon fuels derived from fossil sources
  - Methane Rich Gas fuels
  - Little or no Carbon Monoxide or Hydrogen

- Hydrocarbon fuels from, for example, waste
  - High levels of inert species
  - Methane based

- Syngas produced from fossil (IGCC), non-fossil sources or waste (BIGCC)
  - High in Carbon monoxide and Hydrogen
  - Little Hydrocarbon species
  - Balance usually Nitrogen and or Carbon Dioxide

Gas Fuel Flexibility
SITL Product experience



Fuels Test Capability

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Gas Mixing Plant, Lincoln, UK

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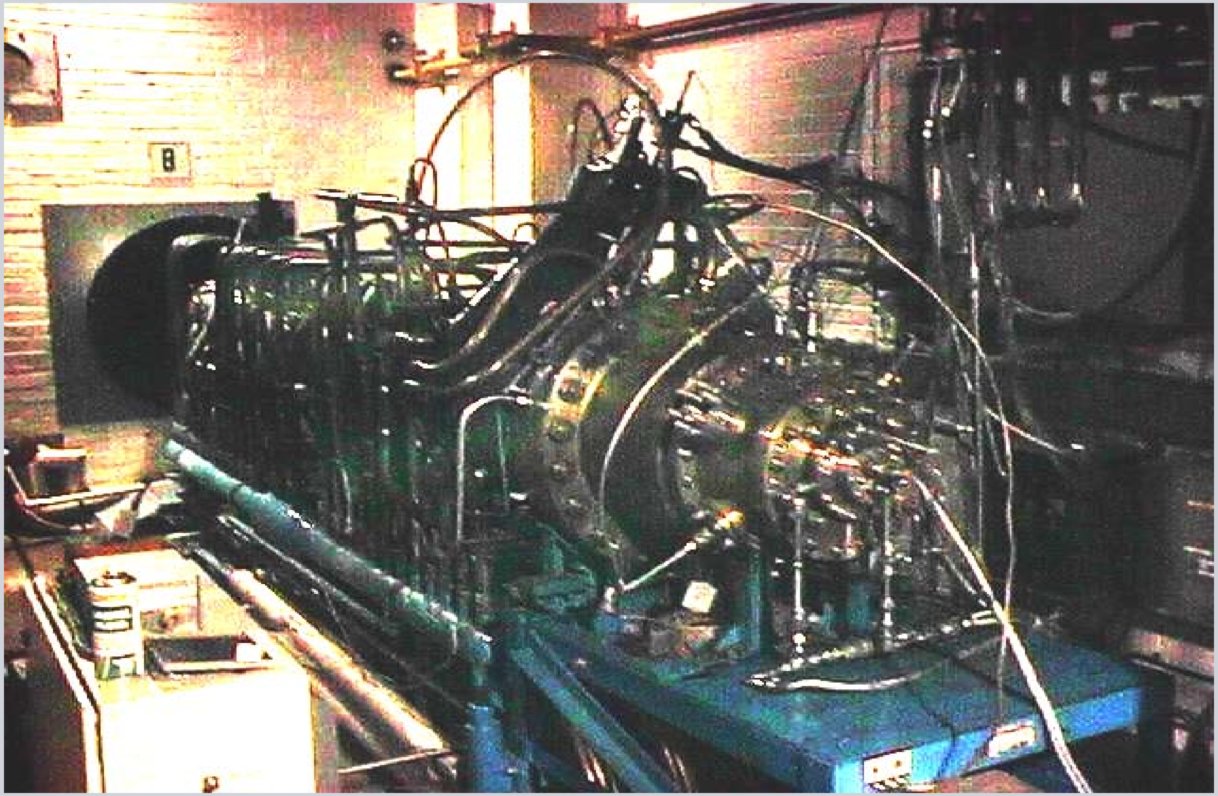
HP Combustion Rig Facility



- HP Combustion Facility
- Linked to gas mixing plant
- Separate rigs cover:
    - SGT100/200
    - SGT300/400
- Fuel Flexible
- Steam / Water Injection

Gasification

Challenges & opportunities associated with alternative fuels

Gasification and Pyrolysis are not new technology, but biomass and waste are new applications.

Many different techniques employed depending on feedstock, i.e.

- Atmospheric Circulating Fluidised Bed
- Pressurised Circulating Fluidised Bed
- Indirectly Heated
- Fixed Bed (Updraft and Downdraft)
- Bubbling bed
- Pyrolysis
- Entrained Flow

Gasification

Different processes produce gases of differing calorific values

▪ Medium CV	15 - 37 MJ/Nm3	(pyrolysis and indirectly heated gasifiers)
▪ Low CV	7 - 15 MJ/Nm3	(oxygen blown and indirectly heated gasifiers)
▪ Very low CV	3 - 7 MJ/Nm3	(air blown gasification)

This affects turbine combustor configuration, turbine performance and overall plant efficiencies (and unit availability)
Choice of gasification system depends on feedstock and application
Choice between atmospheric and pressurized systems can affect plant NOx emissions

Gasification - Medium CV Atmospheric Processes

Typically :

- Indirectly Heated Gasifier (e.g. FERCO)
- Pyrolysis Kiln (e.g. Techtrade, JND, GEM)

Advantages

- Simplicity of concept
- Removal of ammonia etc. pre-turbine, so low NOx and ‘clean’ gas to GT
- Reduced gas compression power compared to low CV processes

Disadvantages

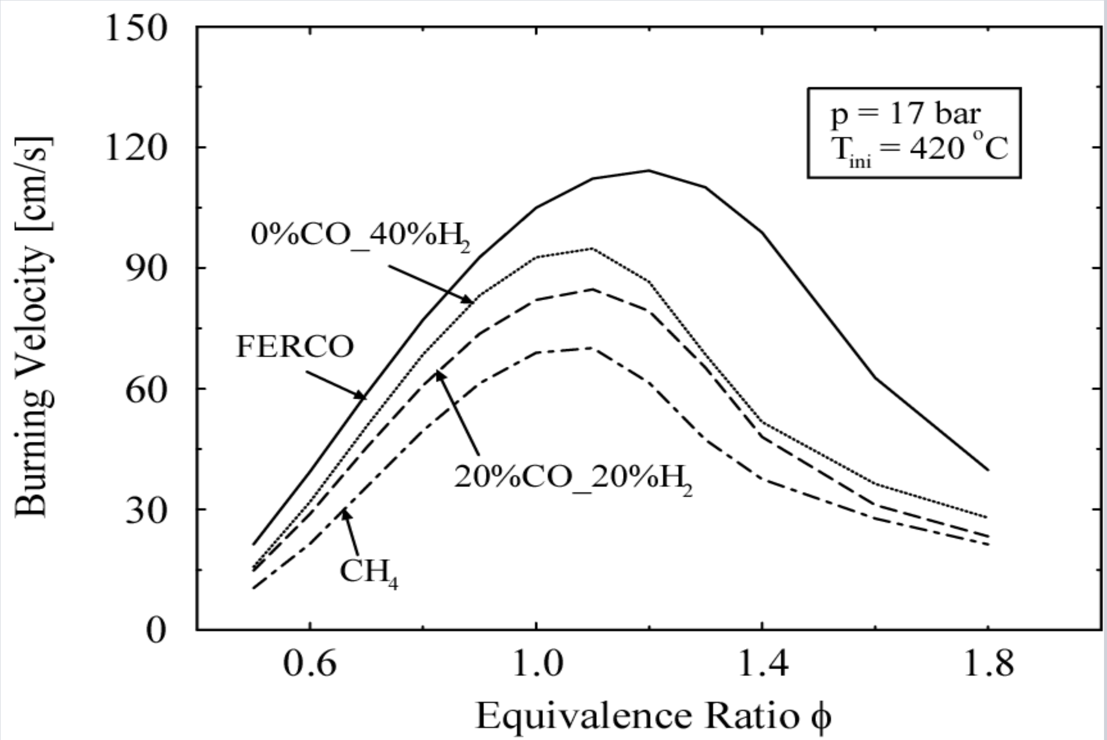
- High tars from pyrolysis
- Lower tars from indirect gasification, but still requirement for cracking
- Complex gas cleaning systems, waste water disposal
- Parasitic load of gas compressor, slightly reduced GT output & efficiency

Technical Challenge

Flame Velocity of various fuel mixtures

DLE Challenge

- The introduction of CO with H2 fuels exacerbates flame velocity
- Result is flashback and component damage
- Component design changes increase H2 content at constant CO from 12%(v) to in excess of 30%(v)



Technical Challenge

BIGCC

Biomass **I**ntegrated **G**asification **C**ombined **C**ycle

Funded programme by UK Dept Trade & Industry (DTI)

Commenced in 2003 and just recently completed.

Major activity:

- Gas Turbine:
  - Combustion changes
  - Compressor modifications
  - Turbine modifications
  - Fuel System upgrades
- Challenges:
  - Additional mass flow associated with fuel
  - Increased turbine loading
  - Flame speed of gas (H2/CO content)
  - Fuel system size increase

Technical Challenge

Progress
- Combustion difficulties
- Market survey identified little appetite for such capability
- However, MCV fuels from gasification in absence of air/O2 appeared to be gaining ground in terms of technology
- BIGCC programme modified to accommodate MCV instead of LCV fuels

- Status
  - Combustion programme confirmed issues and concerns with DLE and flashback
  - Non DLE (diffusion flame) demonstrated superior capability
  - Compressor improvements addressing potential surge limit issues completed
  - Market study completed
    - All potential gasification/pyrolysis process covered
    - Potential for IGCC or BIGCC plant still very limited
    - Lower technology solutions still preferred.

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Varnamo

World's first Biomass Integrated Gasification Combined Cycle (BIGCC) scheme

- ca. 4000 hours operational experience on BIGCC

- 4MW SGT-100 (Typhoon) gas turbine, with 2MW steam turbine, producing 6MWe and 9MWth for district heating scheme

- Feedstocks tested include wood, forestry wastes, wood/bark mixtures, straw, Refuse Derived Fuel (RDF)/Wood chip

- Measured electrical efficiency 32%.   Scheme built today with current technology would achieve c.40%

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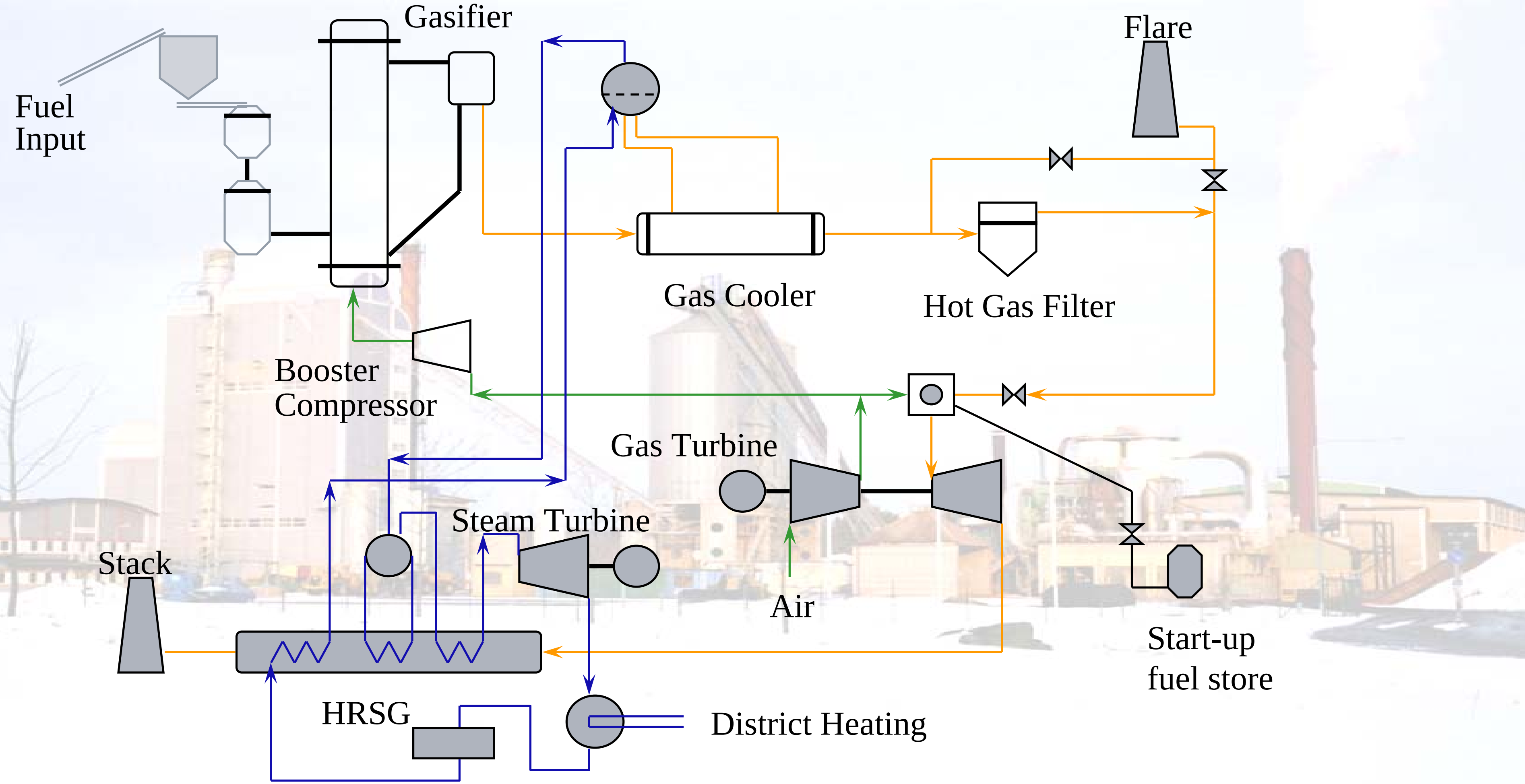
Varnamo

Varnamo B-IGCC Scheme



Project ARBRE

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ARBRE - Low Cv Biogas

Atmospheric Gasification System using:

- SGT-100 (Typhoon) GT
- configured with bespoke combustion hardware (cf Sydkraft)
- Project mothballed

MCV Gasification process

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FERCO 'SilvaGas' Process
300 Tons per day
40MWth output
Catalytic Tar Cracker

Linked to SGT-400

- 40%+ overall efficiency

McNeil Plant, Burlington,Vermont

IDP Devon UK

BIG CC Application – MSW plus Forest Waste
Application for SGT400 with FERCO gasifier

Location: Winkleigh, Devon

Design: 23MW, net output @ 36% Th Eff
part funded with DTI capital grant (£11m+)

Status: Planning application submitted, October 04

Project Stopped 2006 due to failure of planning consent

Artist model picture courtesy of Peninsula Power

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Experience - inert content

Challenges & opportunities associated with depleted fuels

MCv Fuel derived from waste (sewage/water treatment ..)

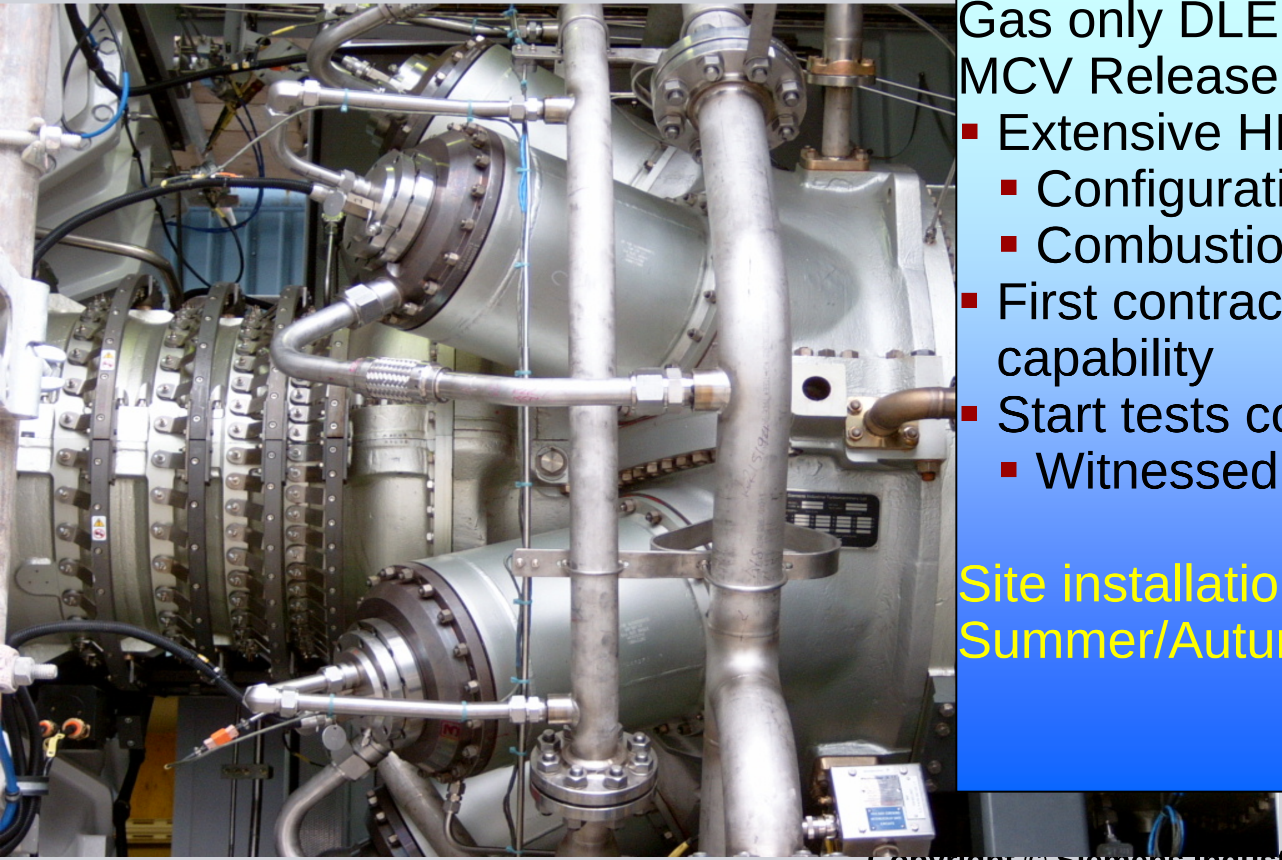
- Purfleet Board Mills TB5000
- Thames Water, Beckton 2 x SGT-100
  - Typhoon burner adapted for this application, but then adopted as engine standard

Landfill Gas

- Arbor Hills, USA 3 x SGT-100
- Pinebend, USA 2 x SGT-100
- Mallard Lake, USA 3 x SGT-100
- Typhoon configured with be-spoke diffusion flame combustor
- Typically 45% methane 55% Inert
- Clean-up of gas required especially for Siloxane and H2S
- Depleted Well (associated gas)
  - Approx 35% inert content 2 x SGT-400

Widened Fuels range using DLE

MCV gas only DLE combustion installation



Contract awarded for fuel WI = 28MJ/m3
Gas only DLE configuration
MCV Release completed:

- Extensive HP rig testing completed
  - Configuration definition released
  - Combustion hardware confirmed and procured
- First contract engine converted to MCV capability
- Start tests completed
  - Witnessed and approved by Client

Site installation (SE Asia) completed
Summer/Autumn 2008, 2 units operational

Experience Other Fuels

Harworth Colliery,UK Mines Gas TB5000

- Colliery has gas mixing facility to raise methane content to 41 or 42% if insufficient mines gas available.
- Typical supply pressures
  - LCV dependant
    - 40% methane @ 17.4 bara
    - 50% methane @ 14.3 bara
    - 60% methane @ 12.3 bara

Cwm Colliery, UK	Coke Oven Gas	TB5000
HRL, Australia	Gasified Lignite	SGT-100
Several	Hydrogen	SGT-200

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Experience: Hydrogen

High Hydrogen Fuel Applications

SGT-200-1S (Tornado)

Issue 2
Date: 15 September 2008

Total Running Hours > 600,000

With H2 > 50%

Customer	Location Site	Country	CHP	Combustion Comb Config	Water / Steam Injection	TCM Log (actual at date) Hours	No Starts	Date
Petromed (BP Refinery)	Castellon de la Plano	Spain	n/a	Conventional Gas		122271	1309	0.3/04/2008
Gulf Oil	Milford Haven	UK	Yes	Conventional Dual	PSI	41500	464	Estimated Dec-2000
						41500	486	
						36500	480	
Whitegate Refinery (Irish Refinery)	Middleton Cork	Eire	Yes	Conventional Dual		80833	1157	12/07/2008
Eon Conoco Refinery	Humberside	UK	Yes	Conventional Gas		87237	543	01/08/2008
						91955	394	31/10/2007
						92960	537	16/04/2008
						87397	365	15/05/2008

Fuel Quality

- Fuel quality must be recognised when sourcing fuels
- Equally applicable to pipeline fuels as well as to these alternative fuels
- The following notes provide some of the issues and concerns associated with various aspects of fuel quality. This subject is a major one in its own right and should be treated as such when reviewing alternative fuels
- Fuel is not the only source of contamination, and all fluids entering the gas turbine must be equally assessed. Aspects of air, fuel, lube oil, water … must be equally be considered.

Gas Fuels

❑ The quality and composition of gaseous fuels can impact gas turbine operation, including combustor and hot gas path life.

❑ Changes in quality of gas fuels can lead to operational difficulties such as stability or combustion dynamics under both steady state and transient conditions.

❑ For example a moving from pipeline quality gas fuels to these 'alternative' may require additional processing and pre-treatment to make them suitable for use in a gas turbine application. Also, combustion control parameter settings will have to change along with changes to the combustion hardware.

❑ Recognition of fuel species is necessary in terms of additional monitoring equipment, such as that associated with Hydrogen fuels.

Gas Fuels
Contamination Issues

Operational concern	Effect
Solids in gas fuel ➢ Scale, rust, sand, dirt, weld splatter, grit blast ➢ From old poorly maintained pipe system ➢ From new or modified fuel system	➢ Wear of fuel system component ➢ Valve failure to seat increased leakage ➢ Corrosion and wear of fuel injector ➢ Erosion of fuel/combustion components ➢ Build up of debris in gas passageways - impaired operation
Heavy Hydrocarbons as liquids ➢ Incorrect process control ➢ Not present in pipeline quality gases ➢ Incorrect temperature for fuel dew point ➢ Over fuelling (uncontrolled)	➢ Can drop out in fuel system, resulting in poor fuel control ➢ Carried in combustion resulting in uncontrolled combustion - explosions, flashback ➢ Abnormal distribution and localised hot gas path component damage ➢ Coking of fuel burner passages and mal distribution ➢ Abnormal temperature spread, as seen in exhaust / interduct thermocouples ➢ Adverse impact on performance and emission targets
Water in gas fuel ➢ Affinity of other contaminant - eg sodium, calcium etc ➢ Acid formation ➢ Formation of Hydrates ➢ At low temperature can freeze resulting in pipe blockage and reduced gas flow ➢ ingestion of liquids into combustion with consequential damage	➢ Ice & Hydrates can cause valve failure ➢ Corrosion of pipe system and valve ➢ Corrosion of hot turbine components ➢ Poor combustion operation, including loss of flame ➢ Unstable operation

Gas Fuels
Contamination Issues

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Operational concern	Effect
Gas Fuels containing Hydrogen Sulphide H_2S ➢ Poisonous even in small quantities ➢ Flammable ➢ Acidic when water present ➢ Corrosive	➢ Harmful to personnel ➢ Can result in hot gas component erosion ➢ Sulphidation attack on some materials ➢ Increased component attack in the presence of other contaminants, such as Sodium
Gas Fuels containing Carbon Dioxide, CO_2 ➢ Acidic when water present ➢ Lowers effective heating value of fuel	➢ Reduced output for same volume input (lower heating value) ➢ Increased supply pressure ➢ Combustor passage size increase
Gas fuels containing Hydrogen, H_2 ➢ Increased flammability ➢ Explosive	➢ Leakage of pipe work - consider regulations - eg Group 2C approval ➢ Explosive ➢ System design - flange joints and seals - embrittlement
Gas fuels containing Carbon Monoxide, CO ➢ Poisonous ➢ Exacerbates flame velocity, especially if H_2 present ➢ Flash back	➢ Harmful to personnel ➢ Flashback results in damage to combustion components

Issues and concerns 1
Hydrocarbon Carry over

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DLE Combustion Pre-Chamber Failure

- Attributed to hydrocarbon carry-over
- And Poor control of dew point

DLE Pilot / Main burner with carbon formation

- Attributed to hydrocarbon carry-over
- And Poor control of dew point

Issues and concerns 2
Poor fuel and air issues

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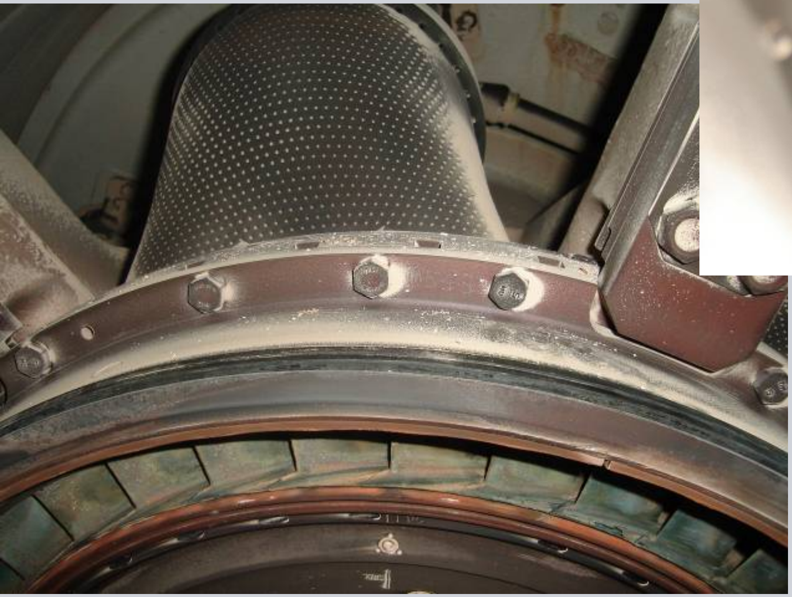
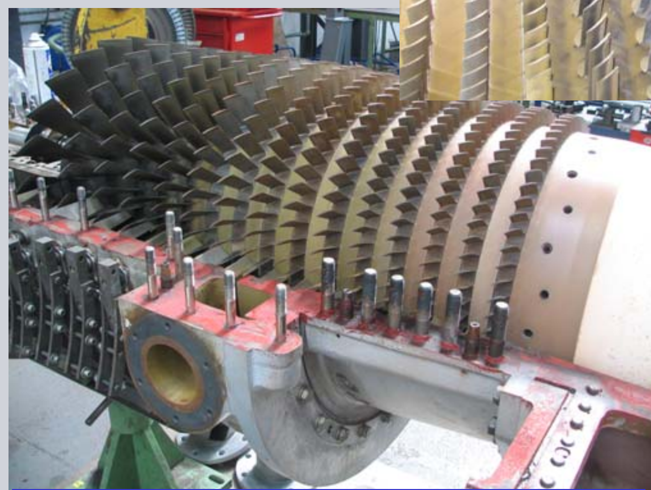
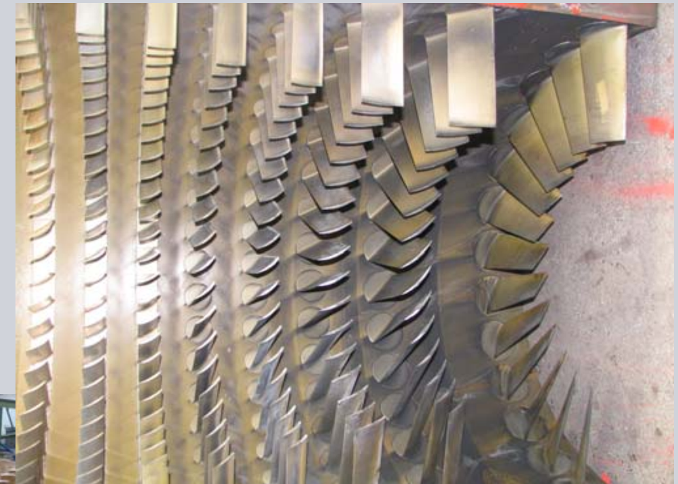
Sulphidation attack and debris build up
Fuel containing high Sulphur
Air contamination with Calcium (extensive local building work)



Local environment





48,000 hours operation with high efficiency air filtration

Fuels Experience - Overview

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Liquid Fuels Normally Standby operation	Gaseous Fuels Continuous operation

Distillate II

Kerosene

Naphtha

LPG

Natural Gas

Well Head Gas

Gasified LPG

High H_2 Refinery Gas

Depleted Well Gas

Sewage Gas

Landfill Gas

Gasified Coal

Gasified Forest Waste

A Significant Player in Fuel Diversification

Summary

Siemens (and as part of Alstom beforehand) have developed alternative fuels capabilities.
Access made to UK government funding, and with several external bodies/agencies in collaborative projects
Many of the technical challenges have been met and overcome, however, there are still many more to be met. (Some associated with clean-up to achieve GT specifications for fuel quality have yet to be met)
One fundamental problem still exists and that is market acceptance for a GT based BIGCC solution. Market study completed serves to demonstrate this.

This leaves the other types of opportunities to be considered, such as using waste gases – high inert content and process gases such as COG and H_2. Many such projects have shown to offer both environmental as well as economic benefits.

New opportunities / projects using high inert containing methane fuels such as Landfill gas or gas derived from anaerobic digestion seem to be a growing trend.

Questions to consider - SynGas

Does the audience think the generation of syngas through gasification or pyrolysis processes is sufficiently mature and free of operational problems to make a BIGCC solution a viable or tenable application.

Should such projects be aimed at the gas turbine market, or should such processes as “fast pyrolisis” be used to provide liquid fuels suitable for transportation use

Should the uses of gases such as landfill gas be classed as renewable fuels, or should more effort be made in re-cycling thus minimising the amount of rubbish sent to landfill. As a supplementary question if recycling is maximised and there is still waste left should this go to landfill or should it be offered as a feedstock for incineration (either simple burning via Fluidised Bed process or via pyrolysis)

Our values

Our Values – for a global business	
Responsible	Committed to ethical and responsible actions
Excellent	Achieving high performance and excellent results
Innovative	Being innovative to create sustainable value

Highest performance meets highest ethical standards

Compliance is the top priority

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Prevent…	Detect…	Act…
… through clear rules, training programs, communication and clear responsibilities	… compliance violations through audits, reviews and monitoring	… with rigorous and appropriate measures in cases of compliance violations

- Uniform, seamless and mutually complementary legal, compliance and audit processes worldwide
- Compliance must be part of our company culture and firmly anchored in all business processes
- Unlimited commitment to integrity and responsible action

A business based on the highest ethical principles – at all times and everywhere in the world

" I have made the topic of compliance one of my top priorities. There will be no compromises here: Illegal and improper behavior will not be tolerated under any circumstances."

(Peter Löscher, President and CEO of Siemens AG)

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