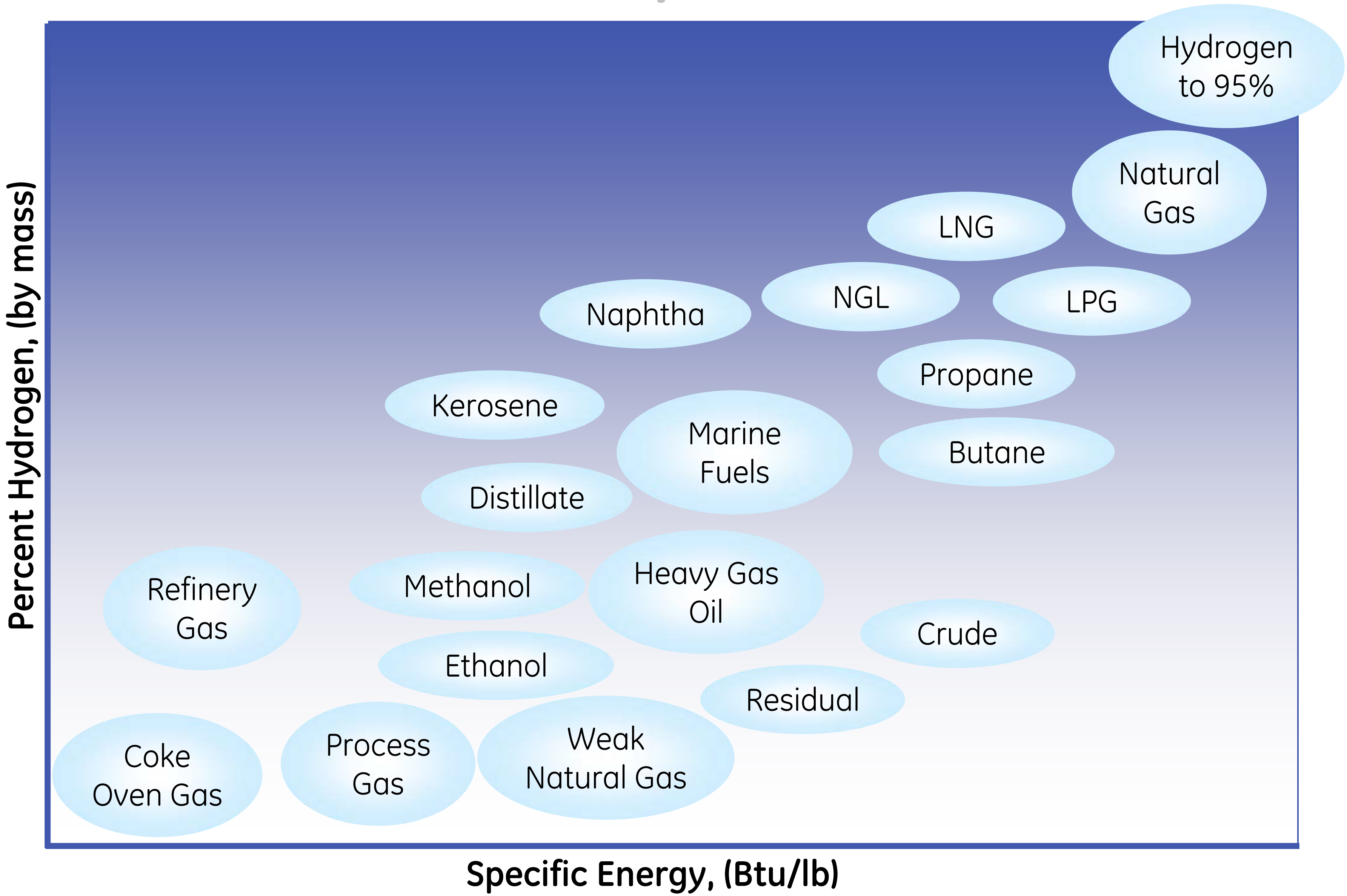
Gas Turbine Fuel Flexibility For A Carbon Constrained World

Bob Jones
Syngas Power Is. Products

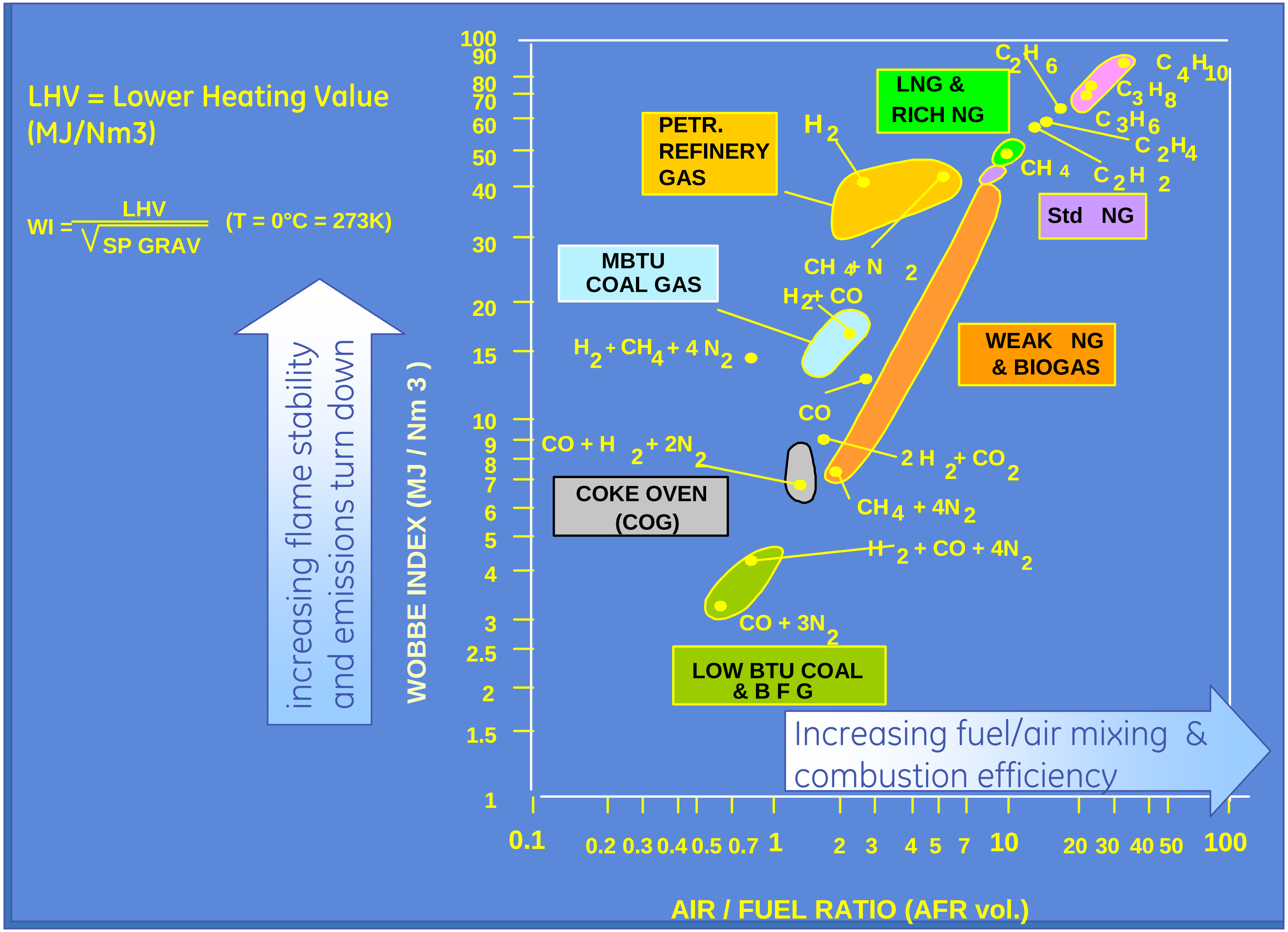
imagination at work

Workshop on Gasification Technologies
Bismarck, ND
June 28, 2006

Combustion Fuels Experience



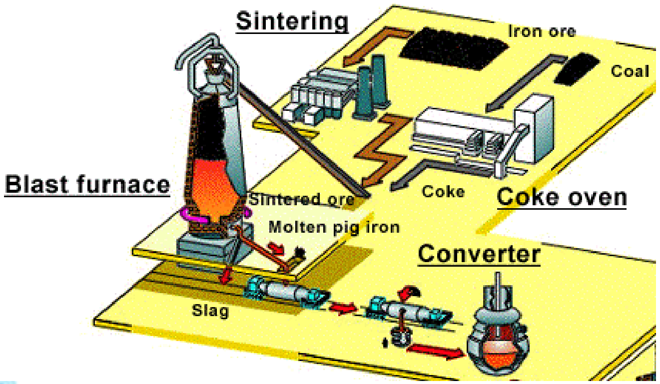
Gaseous Fuel Panorama



Fuel Flex Markets

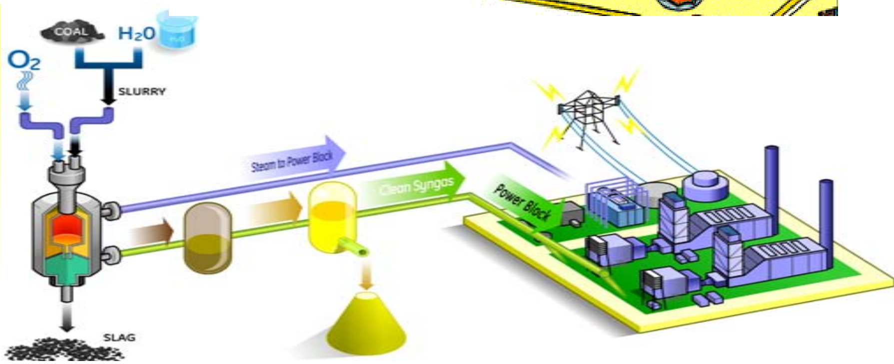
Metals Industry (Low H_2)

- **Ultra Low Btu Fuel** (80-200 Btu/scf)
- Steel mills- Asia, India, US
- 50 & 60 Hz gas turbine products



IGCC (Med H_2)

- **Medium Btu Fuel** (200-300 Btu/scf)
- Coal & Refinery IGCC – Europe, US
- 50 & 60 Hz gas turbine products



Carbon Capture (Hi H_2)

- **Hi H2/N2 Fuel blends** (150-275 Btu/scf)
- IRCC & IGCC- Pre-combustion Decarbonization: Europe & US (FutureGen)
- Carbon free combustion of H_2 EOR & CC&S
- 50 & 60 Hz gas turbine products

GE Syngas Experience by Application

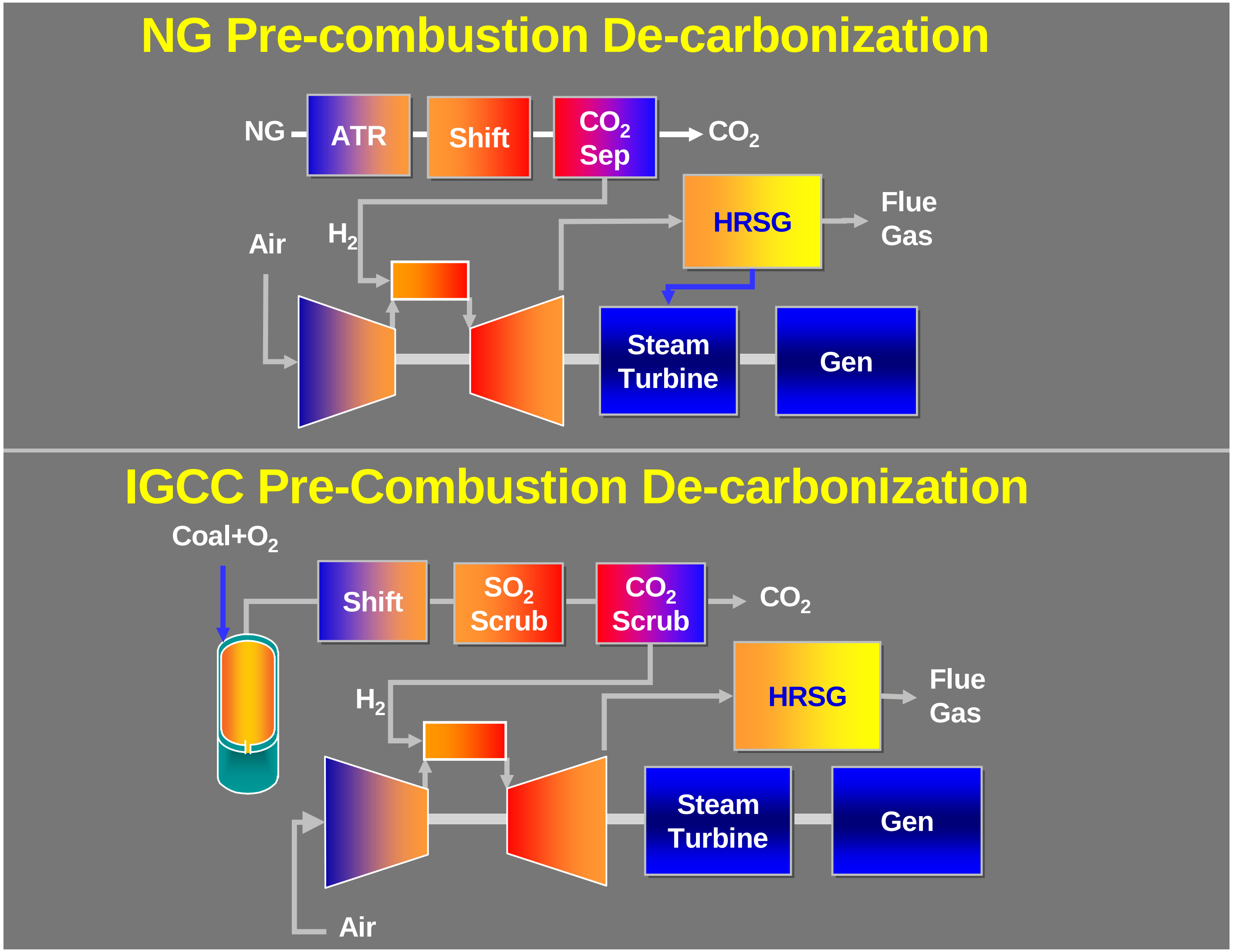
Plant	Type	COD	MW	Power Block	Application	Integration	Gasifier	Fuel
Coal IGCC Experience								
Coolwater	IGCC	1984	120	107E	Power	Steam	GE	Coal
SUV Vresova	IGCC	1996	350	209E	Cogen	Steam	ZVU	Coal
SVZ	IGCC	1996	70	6B	Cogen/ MeOH	Steam	GSP	Coal
Wabash	IGCC	1996	250	107FA	Power	N2	E-Gas	Coal/Pet Coke
Tampa Polk	IGCC	1996	250	107FA	Power	Steam/N2	GE	Coal
Refinery IGCC Experience								
Frontier	Refinery	1996	40	6B	Cogen	Steam/Air/N2	GE	Pet Coke
Shell Pernis	Refinery	1997	120	206B	Cogen/H2	Steam	Shell/Lurgi	Oil
Sarlux	Refinery	2000	550	3x109E	Cogen	Steam	GE	vis breaker tar
Motiva	Refinery	2000	180	2-6FA	Cogen	Steam/N2	GE	Pet Coke
Exxon Singapore	Refinery	2000	173	2-6FA	Cogen	None	GE	Oil
Nexen/Opti	Refinery	2006	160	2-7EA	Cogen	Steam	Shell	Asphaltene
Steel Experience								
ILVA ISE	Steel	1996	520	3x109E	Cogen	None	Steel Mill	BFG/COG/LDG
Piombino Edison	Steel	2001	180	1x109E	Cogen	None	Steel Mill	BFG/COG/LDG
Tonghua	Steel	2003	50	6B	Cogen	None	Steel Mill	BFG/COG
Jinan	Steel	2004	100	6B	Power	None	Steel Mill	BFG/COG

GE Syngas Experience by Composition

Syngas	Cinergy	Tampa	El Dorado	Pernis	Sierra Pacific	ILVA	Schwarze Pumpe	Sarlux	Opti Nexen	Exxon Singapore	Motiva Delaware	Vresova	Tonghua
H_2	24.8	37.2	35.4	34.4	14.5	8.6	61.9	22.7	31.8	44.5	32.0	46.8	10.3
CO	39.5	46.6	45.0	35.1	23.6	26.2	26.2	30.6	63.5	35.4	49.5	15	22.3
CH_4	1.5	0.1	0.0	0.3	1.3	8.2	6.9	0.2	0.4	0.5	0.1	11.6	3.8
CO_2	9.3	13.3	17.1	30.0	5.6	14.0	2.8	5.6	3.6	17.9	15.8	24.5	14.5
N_2 + AR	2.3	2.5	2.1	0.2	49.3	42.5	1.8	1.1	0.5	1.4	2.15	0.76	48.2
H_2O	22.7	0.3	0.4	--	5.7	--	--	39.8	0.2	0.1	0.44	--	0.9
LHV, - Btu/ft^3	209	253	242	210	128	183	317	163	295	241	248	300	134.6
- kJ/m^3	8224	9962	9528	8274	5024	7191	12,492	6403	11598	9,477	9,768	11,800	5304
T_{fuel} F/C	570/300	700/371	250/121	200/98	1000/538	400/204	100/38	392/200	171/77	350/177	570/299	300/149	-
H_2/CO Ratio	.63	.80	.79	.98	.61	.33	2.36	.74	0.5	1.26	.65	3.12	.46
Diluent	Steam	N_2	N_2/Steam	Steam	Steam	--	Steam	Moisture	Steam	Steam	H_2O/N_2	Steam	n/a
Equivalent LHV - Btu/ft^3	150	118	113*	198	110	--	200	--	162	116	150	247	134.6
- kJ/m^3	5910	4649	4452	7801	4334	--	7880	--	8006	4600	5910	9700	5304

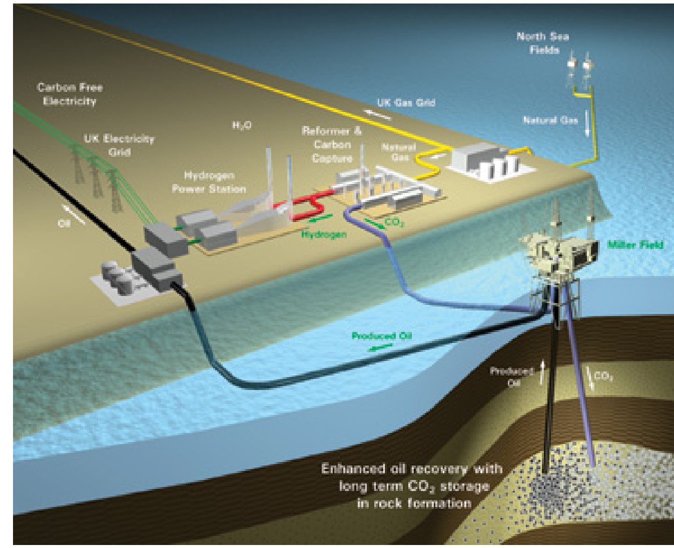
* Always co-fired with 50% natural gas

Pre-Combustion CO_2 Capture



alternativenergy
Powered by BP

Growing hydrogen power



Currently

We're planning the world's first hydrogen power plant with Carbon Capture and Sequestration in Scotland. Hydrogen will be made from natural gas with carbon dioxide being stored on a long-term basis in depleted oil reservoirs

Our commitment

We plan to build a second, even larger, hydrogen power plant in the US and show the technology works at scale.

BP and Edison Mission Group Plan Major Hydrogen Power Project for California

Release date: 10 February 2006

Carson CA, Febuary 10, 2006: BP and Edison Mission Group (EMG), a subsidiary of Edison International, today announced that they are planning a new $1 billion hydrogen-fueled power plant in California that would generate clean electricity with minimal carbon dioxide (CO_2) emissions.

The first-of-its-kind plant would be located alongside BPâ€™s Carson refinery, about 20 miles south of Los Angeles, and would be capable of producing 500 megawatts (MW) of low-carbon generation, enough power to serve 325,000 Southern California homes.

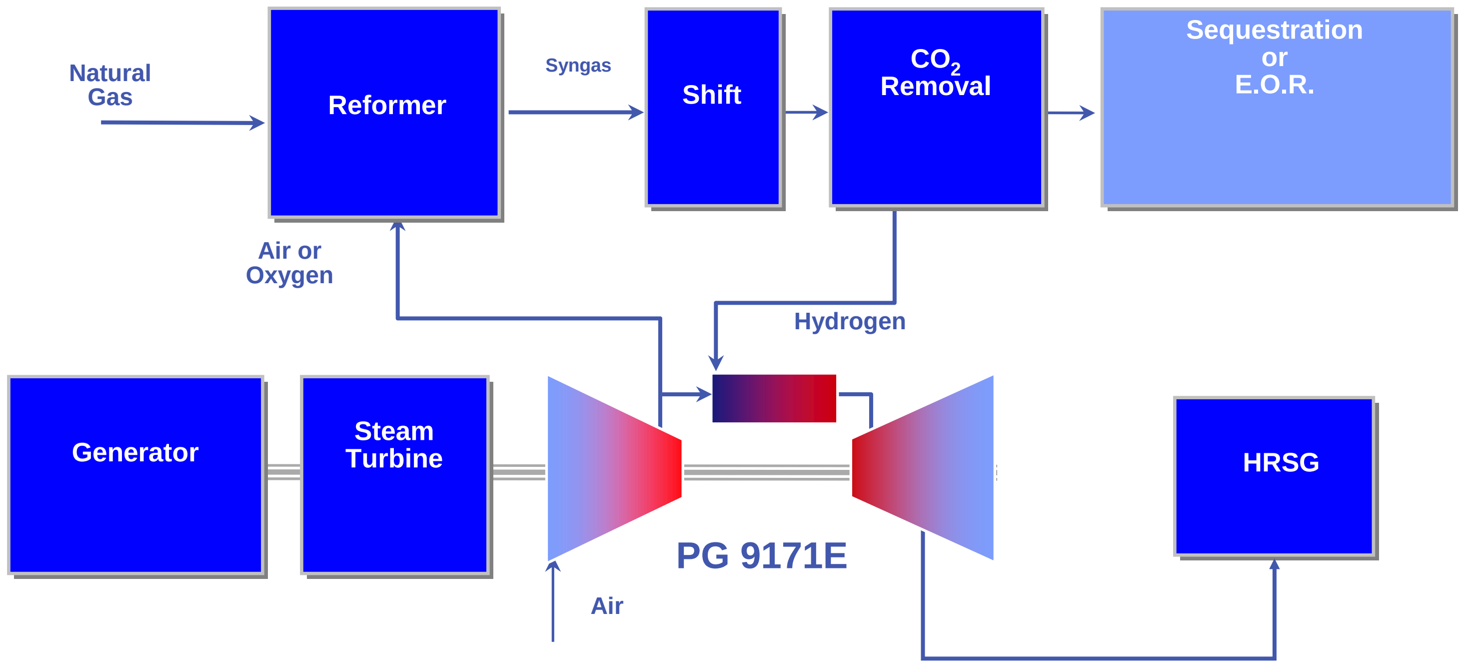
BP and EMG hope to complete detailed engineering and commercial studies in 2006, finalize project investment decisions in 2008 and bring the new power plant online by 2011.

In this section

- No more smelly hands after filling up your car
- **BP and Edison Mission Group Plan Major Hydrogen Power Project for California**
- BP Signs Agreement to Boost LNG Supplies to Atlantic Markets
- BP Replaces Reserves for 13th Year in a Row

Nat Gas Pre-Combustion De-Carbonization

Integrated Reformer Combined Cycle (IRCC) – BP Peterhead



CO2 Reduction

GE High Hydrogen Experience

Customer/ Site	Model	No.	Gas	Features
ExxonMobil Singapore	MS6241FA	2	IGCC	44.5% H_2
Georgia Gulf	MS7001EA	3	Blend	Methane+50% H_2
SUV Vresova	MS9001E	2	IGCC	46.8% H_2
BASF/ Geismer	MS6001B	1	PG	Up to 80% H_2
Koch Refinery	MS6001B	1	RFG	12% to 50% H_2
Daeson Korea	MS6001B	1	PG	up to 95% H_2
Shell Int'l	MS5001P	1	RFG	60% H_2, propane
Reutgerswerke	MS3002J	1	PG	60% H_2
Tenerife	MS6001B	1	RFG	~70% H_2
Cartagena	MS6000B	1	RFG	66% H_2
San Roque	MS6000B	2	RFG	70% H_2

IGCC=Syngas; RFG=Refinery Gas; PG=Process Gas; TG=Tail Gas

Customer/ Site	Model	No.	Gas	Features
Antwerpen	MS6000B	1	RFG	78% H_2
Puertollano	MS6000B	2	RFG	Up to 60% H_2
La Coruna	MS6000B	1	RFG	Up to 52% H_2
Rotterdam	MS6000B	1	RFG	59% H_2
AGIP/ Milazzo	MS5001P	1	RFG	30% to 50% H_2
Cochin Refineries	MS5001P	1	RFG	50% H_2
Mobil/ Paulsboro	MS5001P	2	RFG	20% to 60% H_2
Uhde NUP	MS3002J	1	TG	~60% H_2
Donges	GE10	1	RFG	76% H_2
Zarqa Refinery	PGT10	1	RFG	82% H_2

F-Class Hydrogen Experience

	PSI Wabash	Tampa Polk	Exxon Singapore	Motiva Delaware
Turbine	7FA	7FA	2x6FA	2x6FA
H_2 (% vol)	24.8	37.2	44.5	32.0
CO	39.5	46.6	35.4	49.5
CH_4	1.5	0.1	0.5	0.1
CO_2	9.3	13.3	17.9	15.8
N_2+Ar	2.3	2.5	1.4	2.2
H_2O	22.7	0.3	0.1	0.4
LHV BTU/ft^3	209	253	241	248
kJ/m^3	8,224	9,962	9,477	9,768
T_{fuel} F/C	570/ 300	700/ 371	350/ 177	570/ 299
H_2/CO Ratio	0.63	0.80	1.26	0.65
Diluent	Steam	N_2	Steam	H_2O/ N_2
Equiv LHV BU	150	118	116	150
kJ/m^3	5,910	4,649	4,600	5,910

Combustion Development

- State-of-the-art combustion development facility at Greenville, S.C.
- Combustor operating conditions duplicated at Full Flow/Press/Temp
- 200+ tests per yr with precision data acquisition systems
- Over 25 yrs. experience testing low Btu synthesis gas
- GE Global Research Synergy

Fuel LHV Range and Combustor Types

Fuel Lower Heating Value (LHV) Range MJ/Kg

5 10 20 40 50 60 120

Ultra Low LHV	Low LHV	Natural Gas	High LHV	High H2 Fuels
Furnace gases	Weak NG	Typically:	Re-injection, LNG plants	Refinery gas
Biomass Gasification	Landfill Gas	CH_4 90 %	CH_4 >60 %	CO_2 sequestration
CH_4 < 10%, H_2 <10%	CH_4 < 60 %	C_XH_Y 5 %	C_2H_6 up to 25%	H_2 = 50- 100 %
N_2 >40-60 %	N_2 +CO_2 = 40-50 %	CO_2/N_2 5 %	C_3H_8 up to 15%	C_XH_Y = 0- 40 %

Mid H_2 Fuels
Coke Gasification, Syngas (H_2 = 20 -50 %)

Gas Turbine Combustor Types

- Diffusion Flames
- Dual Fuel, Co-firing
- Fuel Doping

- Premixed Flames
- DLN Combustors
- H_2 < 5-10 %

- Diffusion Flames
- Diluent Injection
- Dual Fuel

MNQC Syngas Combustor

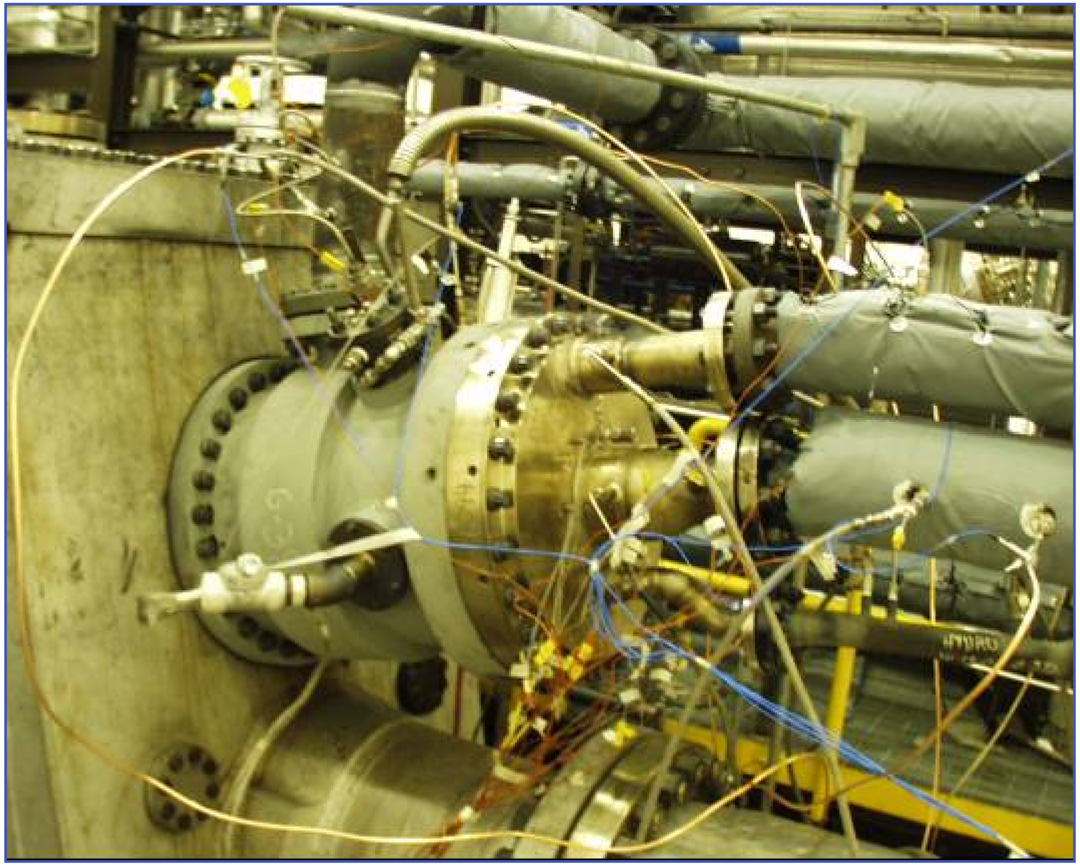
Liner Cap

Liner

Full-scale, Full Pressure Syngas Testing

- Full pressure, temperature, and flow
- Fuel blending capability for H2, N2, CO, CO2, and H2O
- Identical combustor hardware to engine
- Dynamics, emissions, ignition, full and part load characterization
- Full combustor characterization

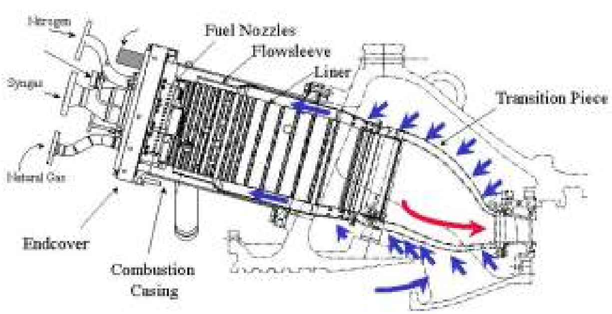
MNQC Syngas Test

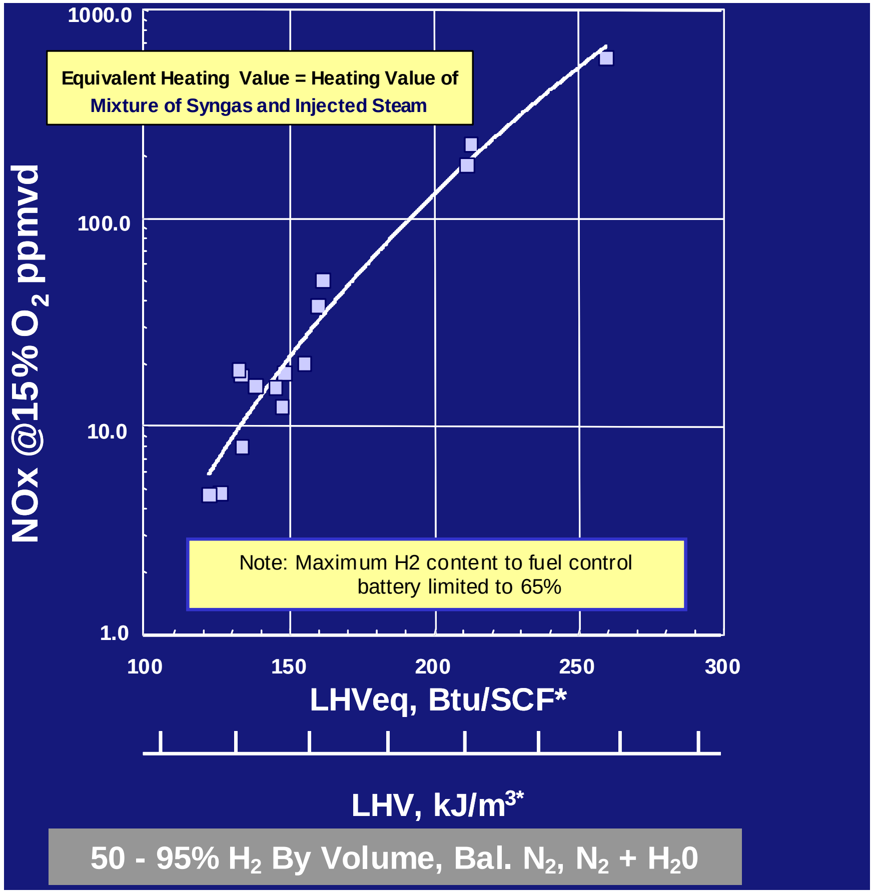


6FA MNQC H_2 Combustion Testing

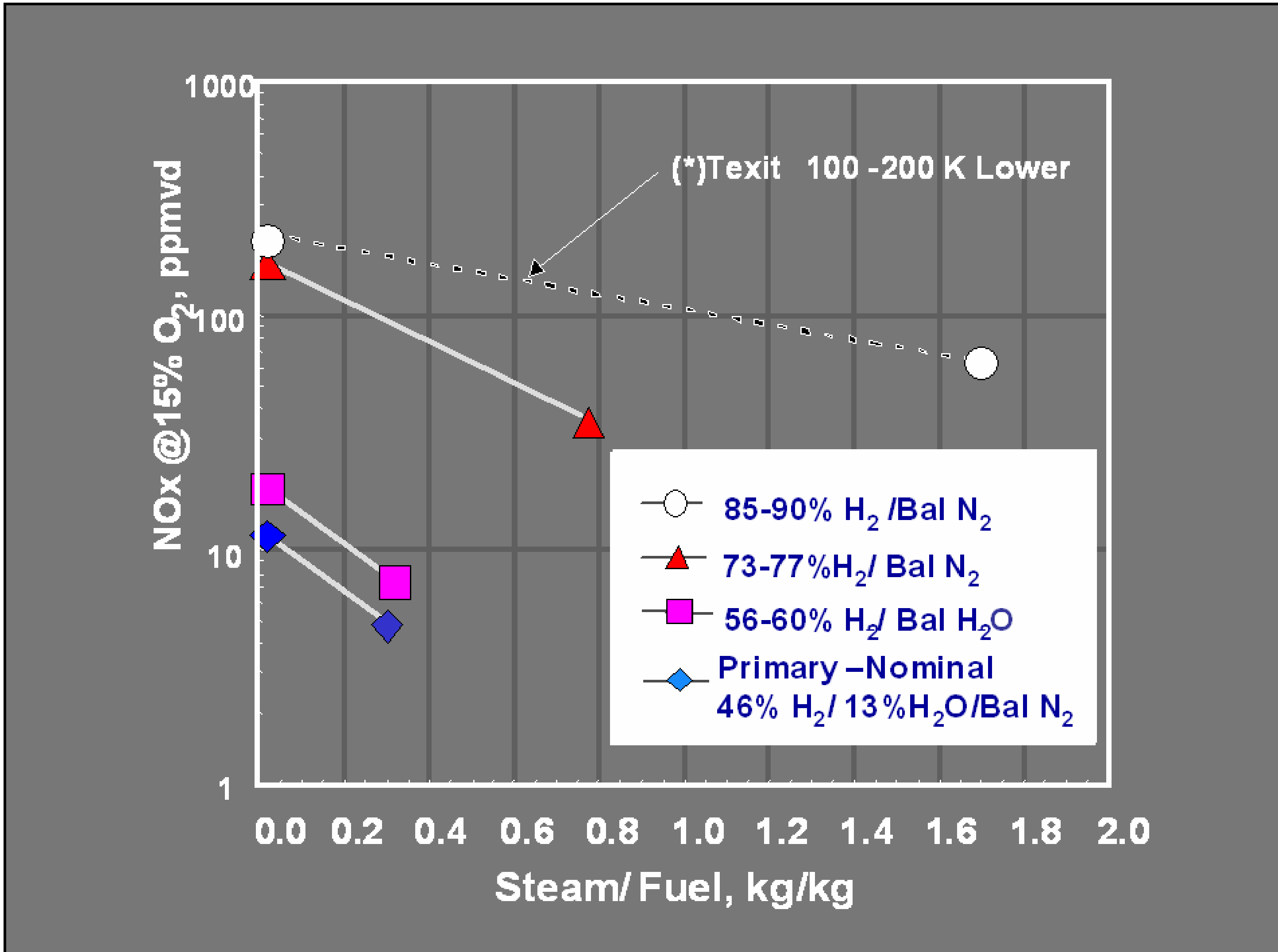
Video Capture of Flame Structure - 85-90% H_2

Reverse Flow Combustion System
(Typical)





H2- Syngas MNQC Emissions Mapping

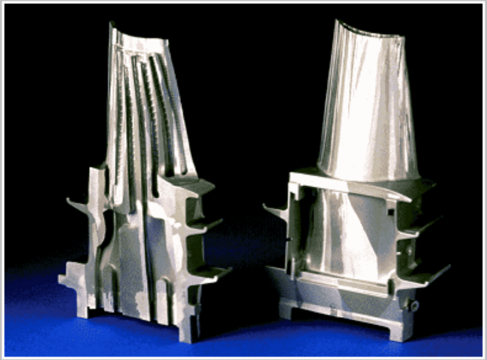


Fuel Properties

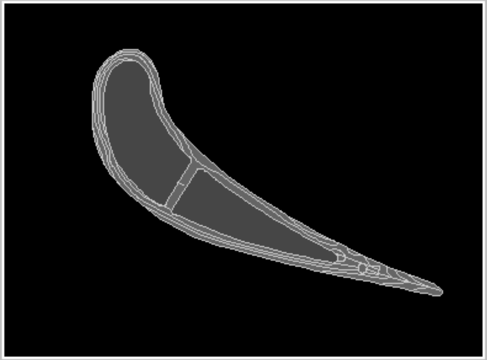
Fuel	Typical Fuel Properties					Combustion Products
	Btu/lb	Btu/scf	Density lb/scf	Specific Volume (scf/lb)	Mass Ratio N_2/ Fuel	H_2O % Vol
100% H_2 [1]	51,495	273.5	0.0053	188.68	---	16.94
H_2 Mix (50/50 H_2/N_2)	3,457	137.0	0.0396	25.25	13.90	12.30
Medium BTU Syngas (Coal)	4,671	249.3	0.0534	18.73	--	9.12
Diluted Medium BTU Syngas (Dry N_2 to 15ppm NOx)	1,776	114.6	0.0645	15.50	1.63	6.01
NG DLN	18,507	873.0	0.0472	21.19	--	8.30

[1] Hypothetical only-- would not be fired at 100% H_2

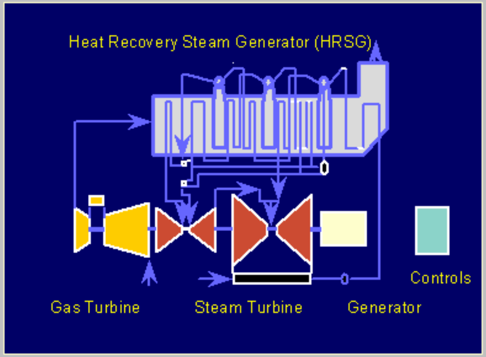
GT Dev. Needs for Next Gen H2 Plants



Advanced alloy & TBC interactions with high moisture/high temperature combustion gas



Aero-thermal studies and experimental validation to optimize tradeoffs between efficiency and RAM



Process evaluations for optimal gas turbine integration and demos to validate concepts

Fuel Impact On Premixed (DLN) Combustors

Fuel Lower Heating Value (LHV) Panorama MJ/Kg

5 10 20 40 50 60 120

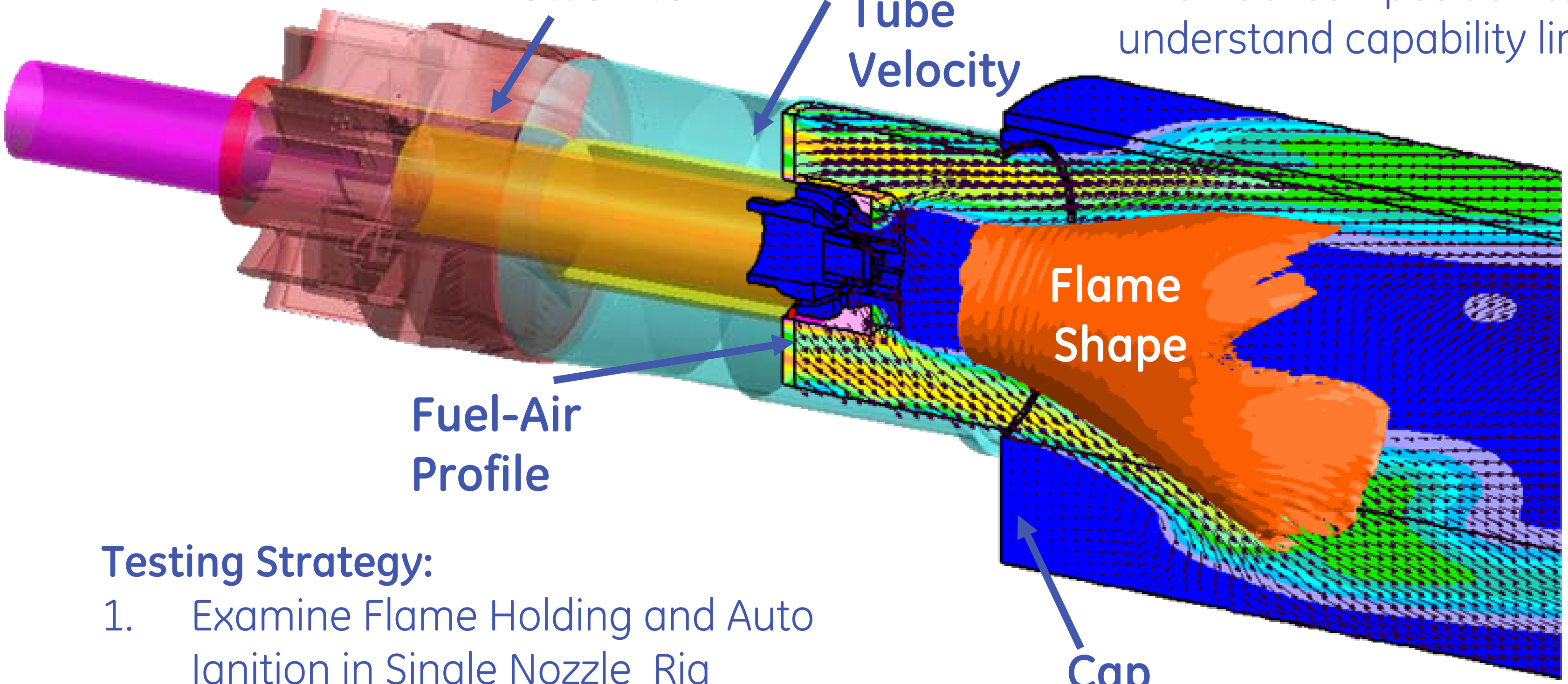
Low LHV (20–40) | High LHV (50–60)

Key Challenge: Flame holding

	Low LHV	High LHV
Design Challenges	• LBO at ignition and part load • Flame stabilization • CO emission • Engine operability limitations	• Flame holding • NOx emission • Safe ignition - Multi fuel system • Pilots overheating
Design Features	• Increased fuel nozzle passages • Continuous dynamics monitoring • Dual gas option	• Aero design of premixers • Flame holding margin • In line Wobbe Index meter

Flame-Holding Tests to Determine Applicability to High-H_2 Fuels

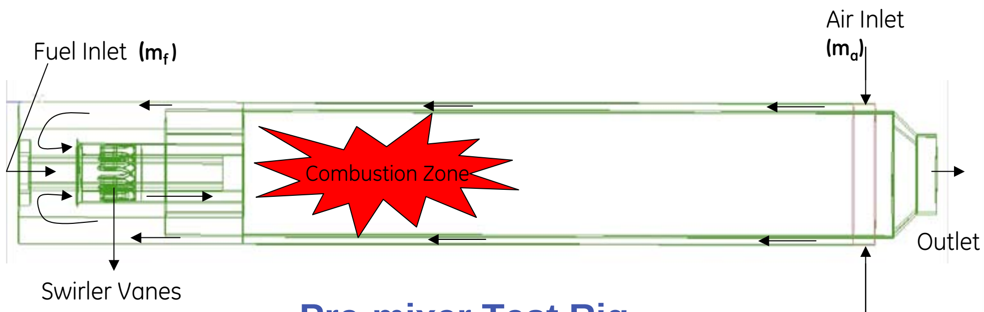
Goal: Determine Flame Holding Margin as a function of fuel composition to understand capability limits



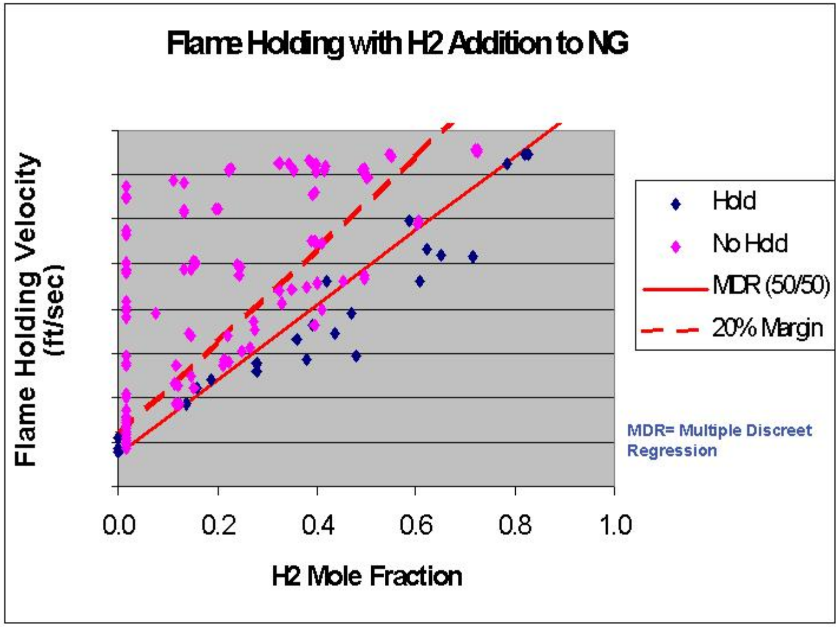
Testing Strategy:

1. Examine Flame Holding and Auto Ignition in Single Nozzle Rig
2. Examine Dynamics & Emissions in Full Scale Combustor Rig

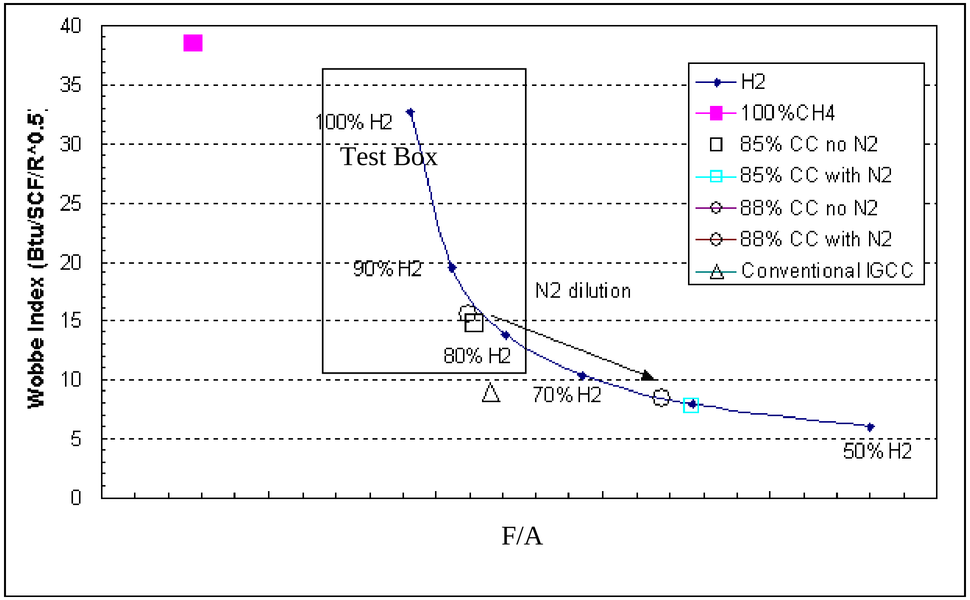
Flame-Holding Experiments With H_2



Pre-mixer Test Rig



Flame-Holding Resistance



Test Window for H2/N2 Flame Holding Tests

Single Nozzle Pre-Mixer Testing With H2

- **20% Flame holding margin up to 65% H2**
- **Emissions <10 ppm**
- **Wide Wobbe Range**
- **Tested up to 100% H2**

US DOE H2/IGCC Turbines Program

"The objective of this project is to design and develop a fuel flexible (coal derived hydrogen or syngas) gas turbine for IGCC and FutureGen type applications that meets DOE turbine performance goals."

<u>DOE Goals:</u>

- Performance:
  - +2 to 3 % pts efficiency by 2010
  - +3 to 5 % pts efficiency (total) by 2015
- Combustion
  - 2 ppm NOx by 2015
  - Fuel flexibility - FutureGen & traditional IGCC
- Capital cost <$1000/kW

imagination at work

Latest Evolution of F Technology... 7FB / 9FB Low Cost of Electricity (COE)

7FB - 60 Hz

280 MW – 57.3% CC Efficiency

Eight Gas Turbines COD

- 307FB Hunterstown, PA
- 307FB Choctaw, MS
- 207FB Fox Energy, WI

12,127 Fleet Operating Hours

Orders for 3 additional units

9FB - 50 Hz

412.9 MW – 58% CC Efficiency

Launch Units COD March, 2006

- 209FB Arcos Group 3, Spain
- <2,000 hours and 90 starts to date

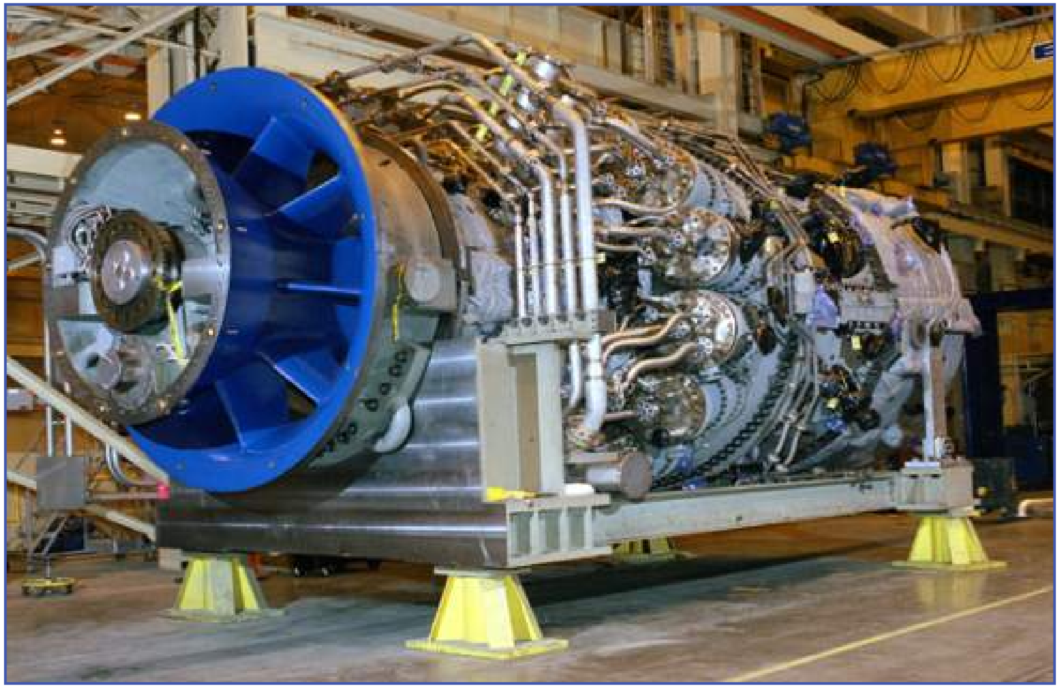
Orders for 13 units

LOI agreement for 5 additional units

18 Unit Fleet Total

Arcos Group 3, Spain

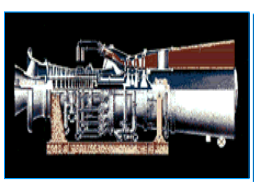
7FB Syngas Product Evolution



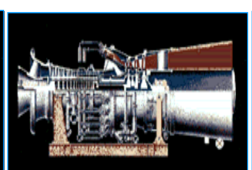
FB Platform

- ***Increased firing temperature***
- ***Increased Pressure Ratio***
- ***Select hot gas path component redesign for syngas operations***

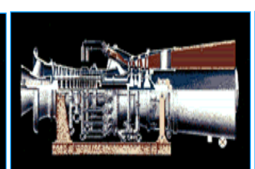
7F
PG7191



7FA
PG7221

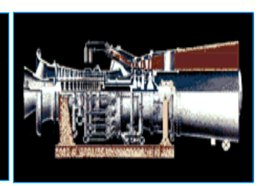


7FA+
PG7231



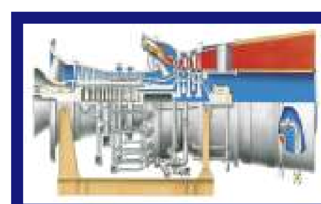
Syngas
192 MW

7FA+e
PG7241



Syngas
197 MW

7FB
PG7251



Syngas Rating*
232 MW

* ISO oper. conditions w/O2 blown medium Btu Fuel Gas (LHV=200-300 Btu/scf)

GE's DOE H2/IGCC Turbines Program

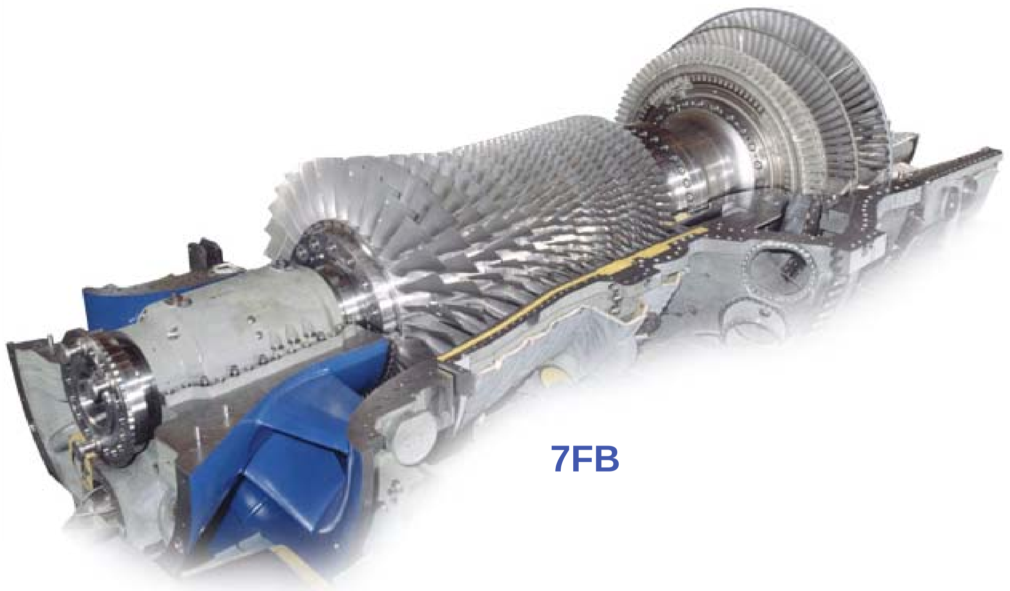
Technology

Systems Design

Combustion Development

Turbine Technology

Materials Technology



7FB

Structure

Phase 1: (2 yrs)
Technology Development

Phase 2: (4 yrs)
Design and Component Validation

Phase 3*: (4 yrs)
Build, install, validation testing

imagination at work

** Not awarded yet (will be separate solicitation)*

Summary

- GE gas turbine product experience with H_2 content fuel gas is extensive including E-class and advanced F-class units
- Feasibility of high H_2 fuel combustion with low emissions has been demonstrated at F-class conditions using proven syngas MNQC combustor design
- The 7FB syngas product evolution leverages extensive "F" product line experience & advances in technology to set higher IGCC efficiency and reliability standards

- GE Energy partnership with the DOE H_2 Turbine Program supports the objective to design and develop a gas turbine for IGCC and FutureGen that meets DOE turbine performance goals
- GE/DOE program technology leverages combustion developments & advancements with prospect for future H_2 DLN retrofit to FutureGen and other carbon capture programs

Reducing CO_2

"We now live in a carbon-constrained world where the amount of CO_2 must be reduced,"

"GE has built a history on solving the world's toughest problems, and this one is no exception."

Jeff Immelt, CEO GE
Rolling Stone Magazine, November 2005

Q & A ?