Impact of Gasification Fuels on Gas Turbine Operation

by

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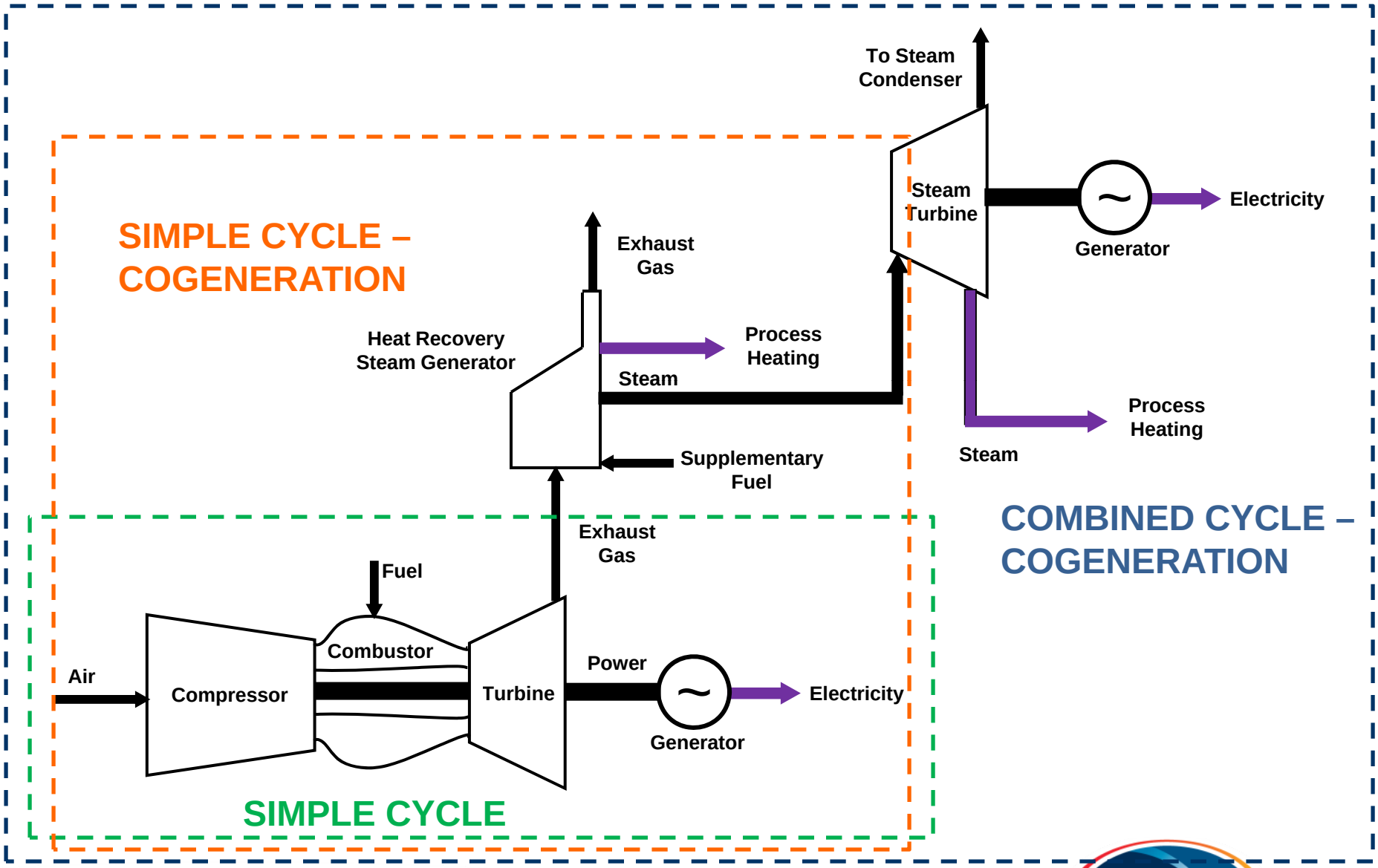
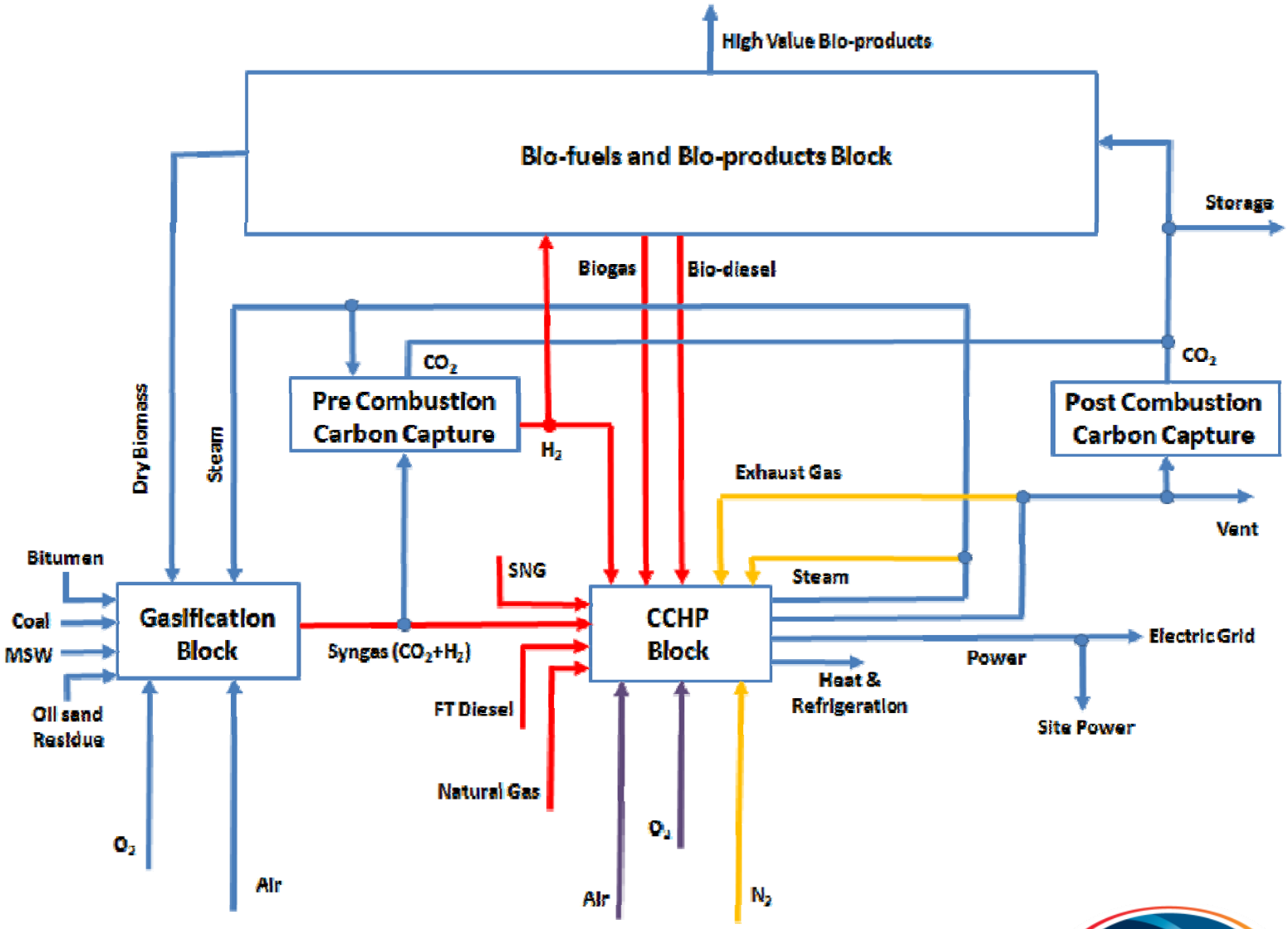
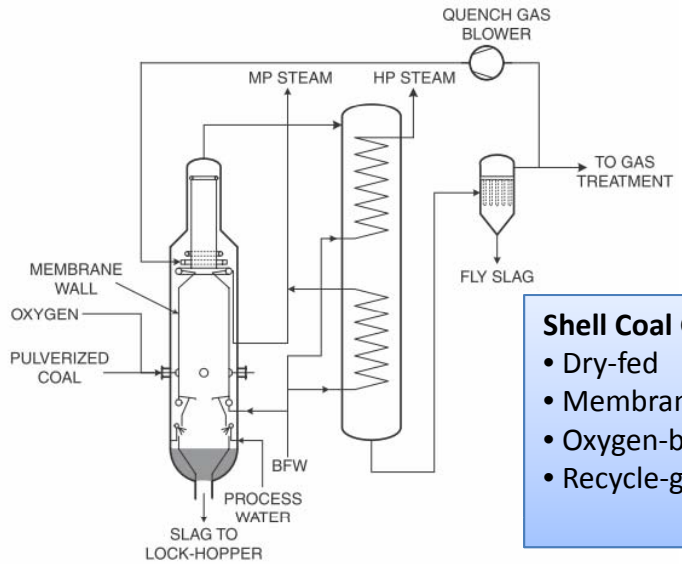
Gas Turbine Plant Configurations



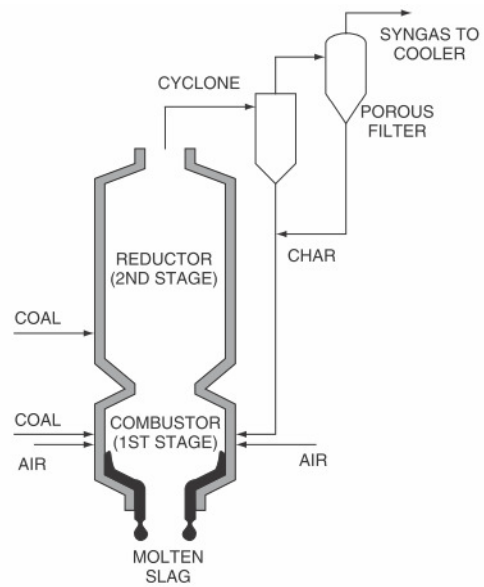
Integrated Gasification Combined Cycle with Polygeneration



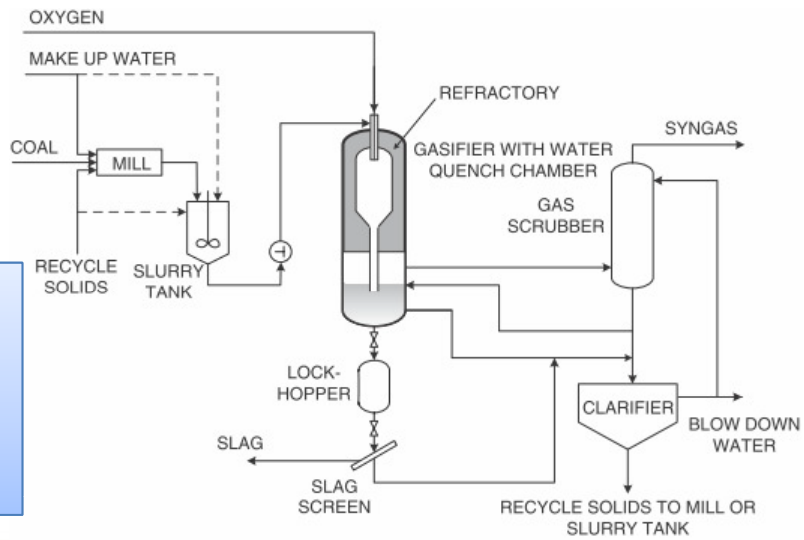
Gasifier Types



Shell Coal Gasification Process:
- Dry-fed
- Membrane-walled
- Oxygen-blown
- Recycle-gas quenched



MHI Coal Gasification Process:
- Two-staged dry-fed
- Membrane-walled
- Air-blown
- Chemical quenched
- Full char recycle



GE-Texaco Coal Gasification Process:
- Slurry-fed
- Refractory-lined
- Oxygen-blown
- Water quenched

(Ref: Parulekar, 2011)

Some IGCC Examples – US and Europe

Wabash River, Indiana

Puertolleano, Spain

Tampa, Florida

Buggenum, The Netherlands

Project / Location	Gasification Technology	Gas Turbine	Capacity (MWe)	Startup Year
Wabash River / Indiana, USA	DOW-ConocoPhillips	GE-7FA	192	1995/2000
Tampa Electric / Florida, USA	GE-Texaco	GE-7FA	250	1996/2001
Nuon Power, Demkolec / Buggenum, The Netherlands	Shell	Siemens – SGT5-2000E	253	1993/1998
ELCOGAS / Puertollano, Spain	Uhde Prenflo	Siemens – SGT5-4000F	317	1996

(Ref: Dennis, et al, 2007)

Some IGCC Examples – Canada

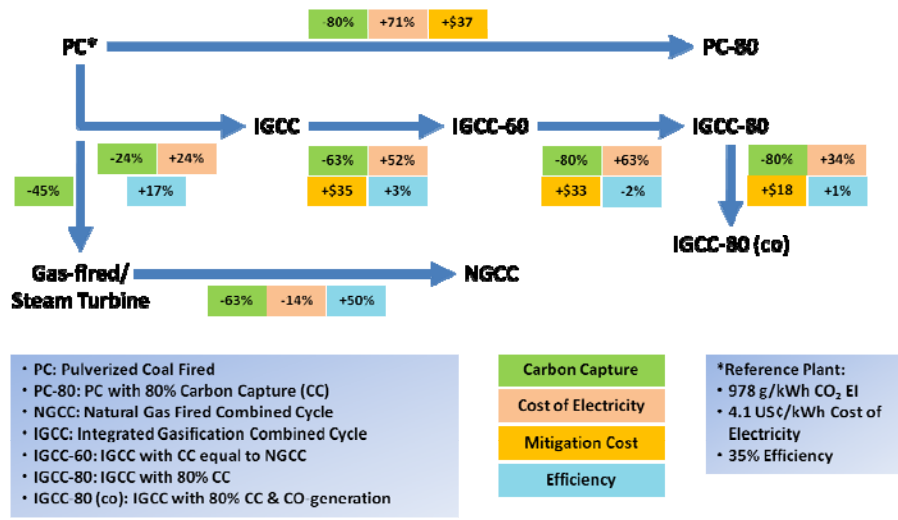
OPTI-Nexen, Long Lake

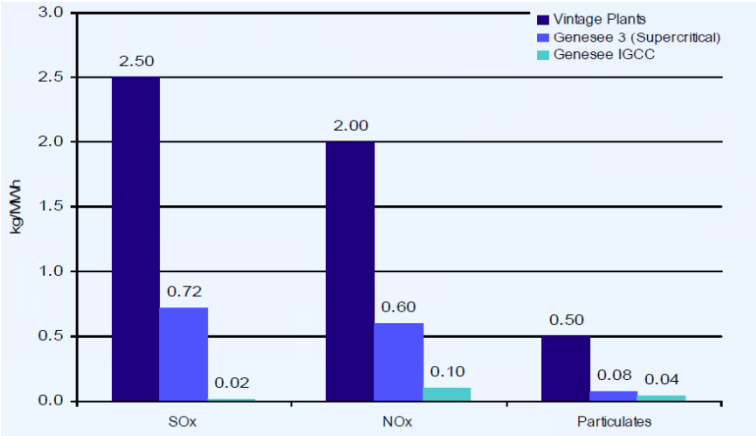
EPCOR, Genesee

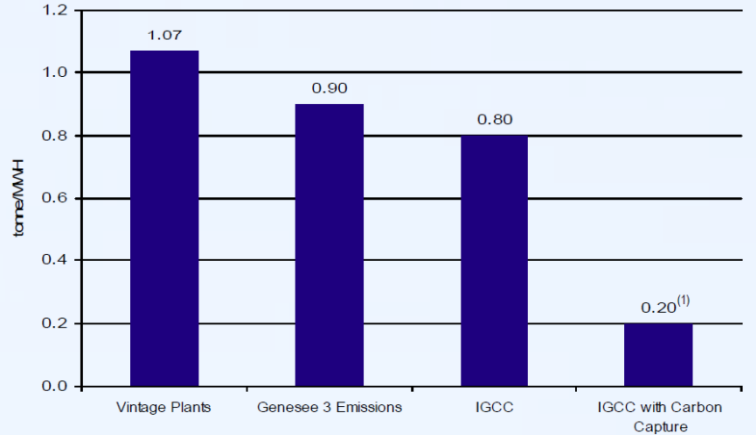
Project / Location	Gasification Technology	Gas Turbine	Capacity (MW)	Startup Year
OPTI-Nexen / Long Lake, AB	Shell	GE-7EA	170 (120/50)	2006
EPCOR Utilities / Genesee, AB	Siemens	Siemens	270	2015

Why IGCC with Polygeneration

- Lower CO_2 by 60~80%
- Lower air pollutants up to 95%
- Applicability to multiple sector
- Energy security through multiple feedstock
- Fuel flexibility through reduced reliance on natural gas and oil
- Simultaneous production of High-value by-products

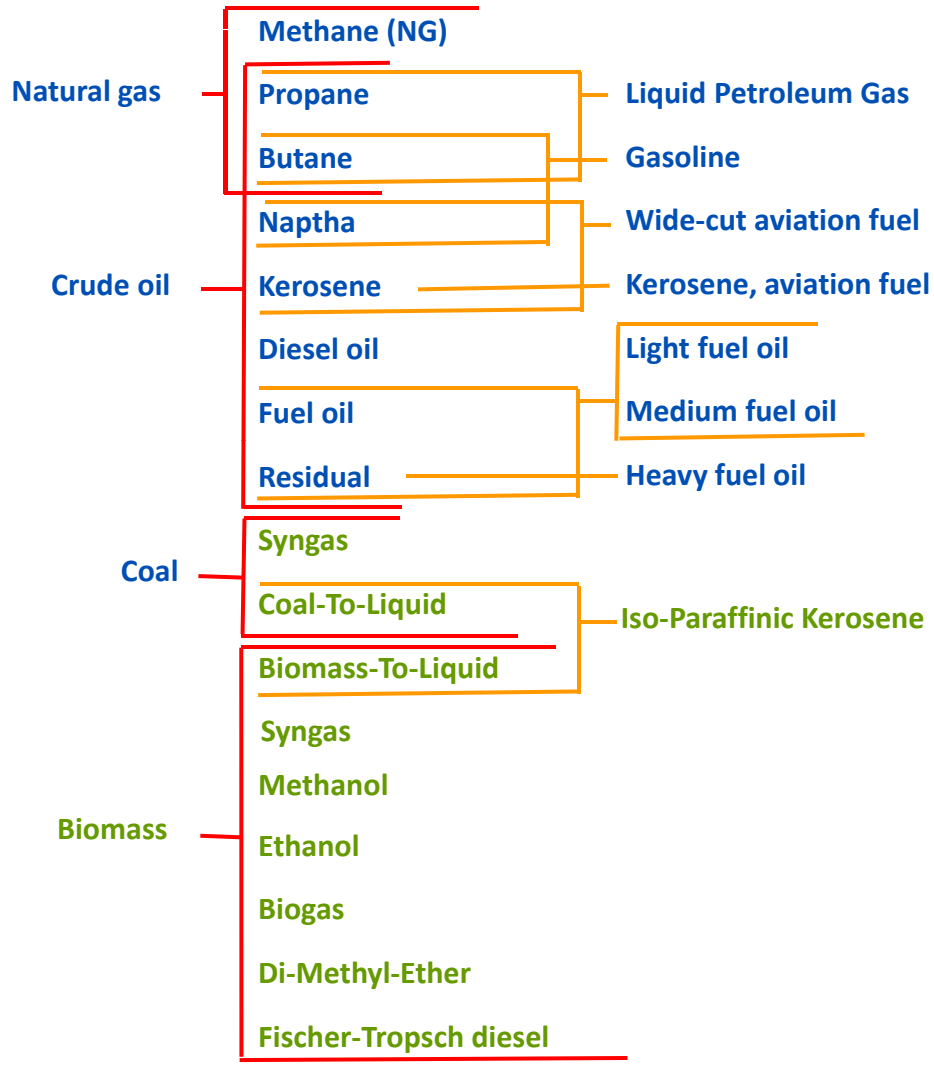




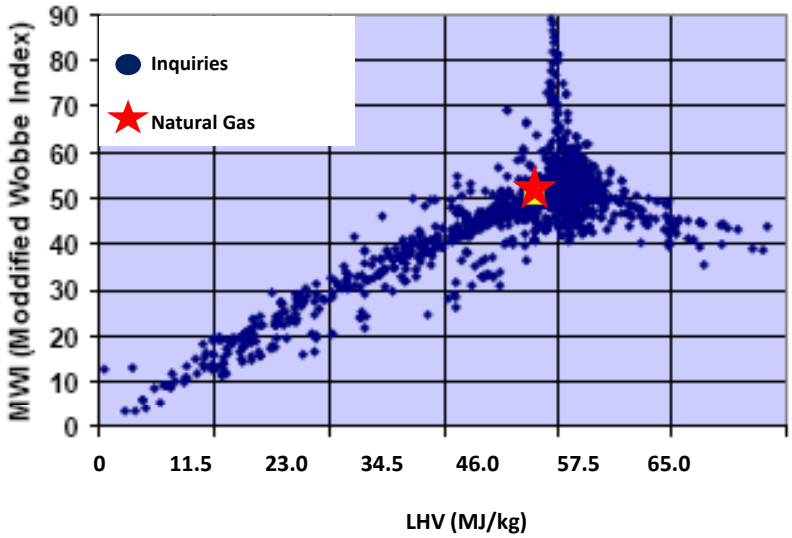


(Ref: EPCOR, 2008)

Gas Turbine Fuels – Conventional & Alternative

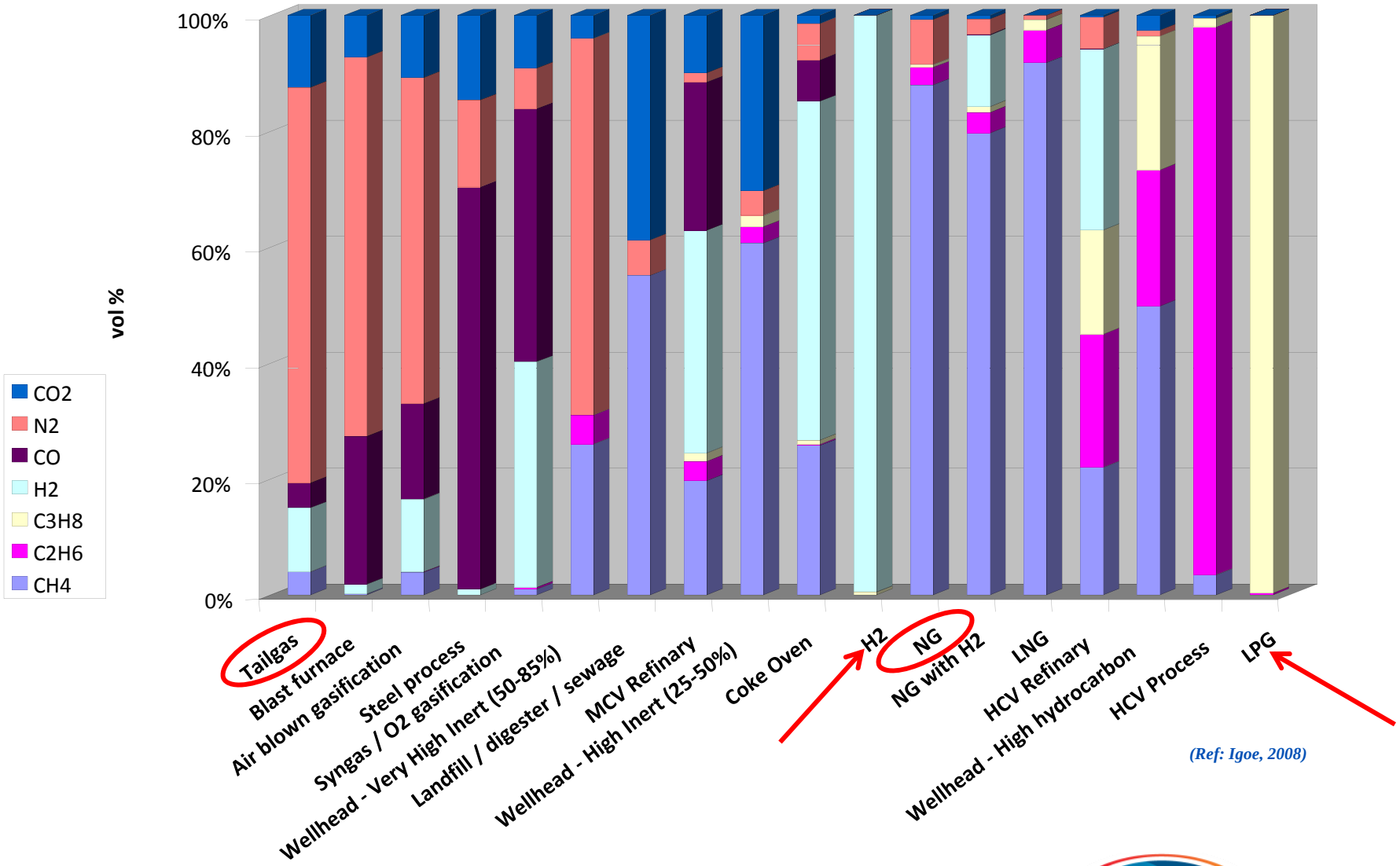


- Much tighter control (regulations) requirement on fuel specification in aviation gas turbines
- Requirement for industrial gas turbine – burn anything



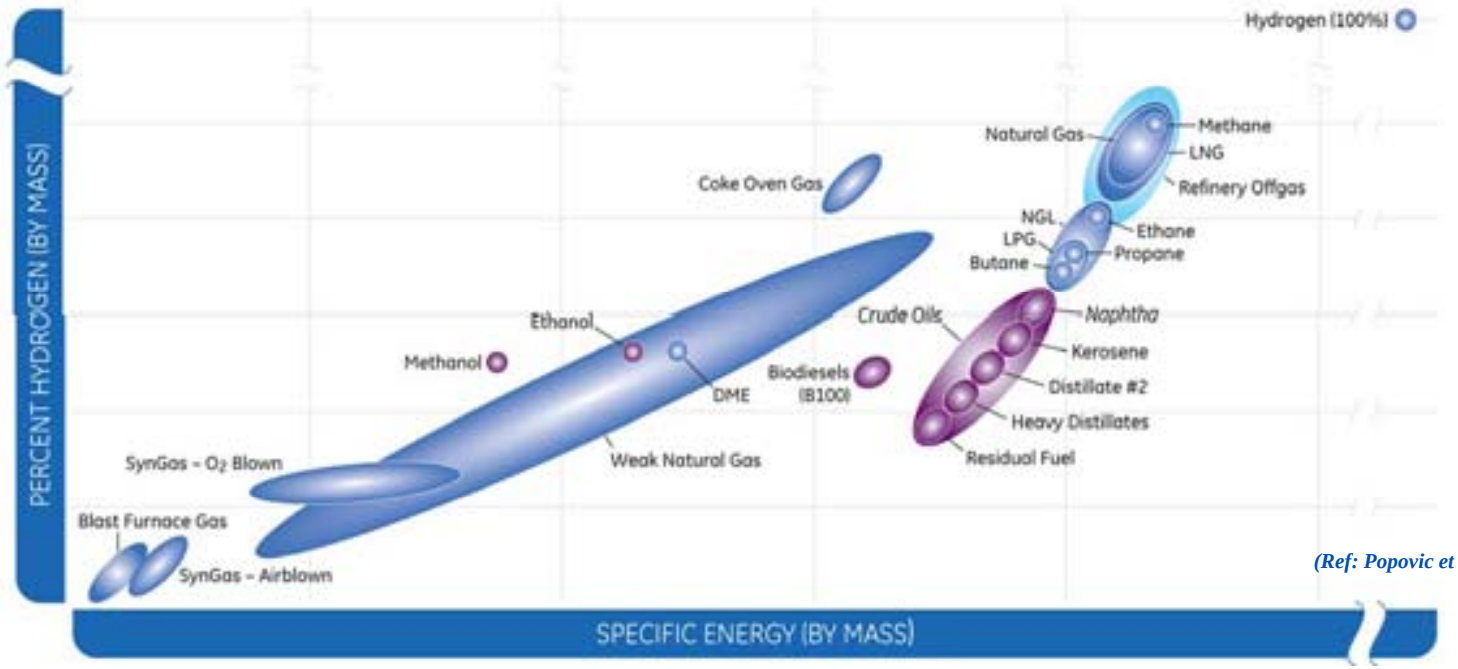
(Ref: Wisniewski & Handelsman 2010)

Gas Turbine Fuels' Composition – Siemens' Experience



(Ref: Igoe, 2008)

Gas Turbine Fuels' Properties – GE's Experience



(Ref: Popovic et al, 2010)

	Main Constituents	LHV (MJ/m³)		U/L Flammability Ratio	
		Min.	Max.	Min.	Max.
Natural Gas	CH_4, C_2H_6	31.971	47.957	2.20	3.00
LPG	C_3H_8, C_4H_{10}	91.917	127.885	4.00	5.00
Air Blown Syngas	H_2, CO, N_2 , H_2O, CO_2	5.195	7.993	2.40	5.40
Oxygen Blown Syngas	H_2, CO, H_2O, CO_2	7.993	15.986	6.00	12.00
Blast Furnace Gas	H_2, CO, N_2 , H_2O, CO_2	2.997	4.996	1.50	3.00
Refinery Off-gas	H_2, C_2H_6, C_3H_8, C_4H_{10}, C_2H_4, C_3H_6	11.989	63.942	3.00	18.00
Coke Oven Gas	H_2, CO, N_2 , H_2O, CO_2	11.989	19.982	6.00	8.00

Syngas Related Issues – Composition Variations

- Gasifier type
  - Oxygen vs. air blown
  - Dry vs. slurry fed
- Process temperature
- Feed rate
- Amount of Oxygen
- H:C ratio in feedstock

Feedstock Variation

Composition (Volume %)	Coal-Gas	Bio-Gas	Natural Gas
Hydrogen (H_2)	14.0%	18.0%	--
Carbon Monoxide (CO)	27.0%	24.0%	--
Carbon Dioxide (CO_2)	4.5%	6.0%	--
Oxygen (O_2)	0.6%	0.4%	--
Methane (CH_4)	3.0%	3.0%	90.0%
Nitrogen (N_2)	50.9%	48.6%	5.0%
Ethane (C_2H_6)	--	--	5.0%
HHV (kJ/m^3)	6,417	5,315	39,450

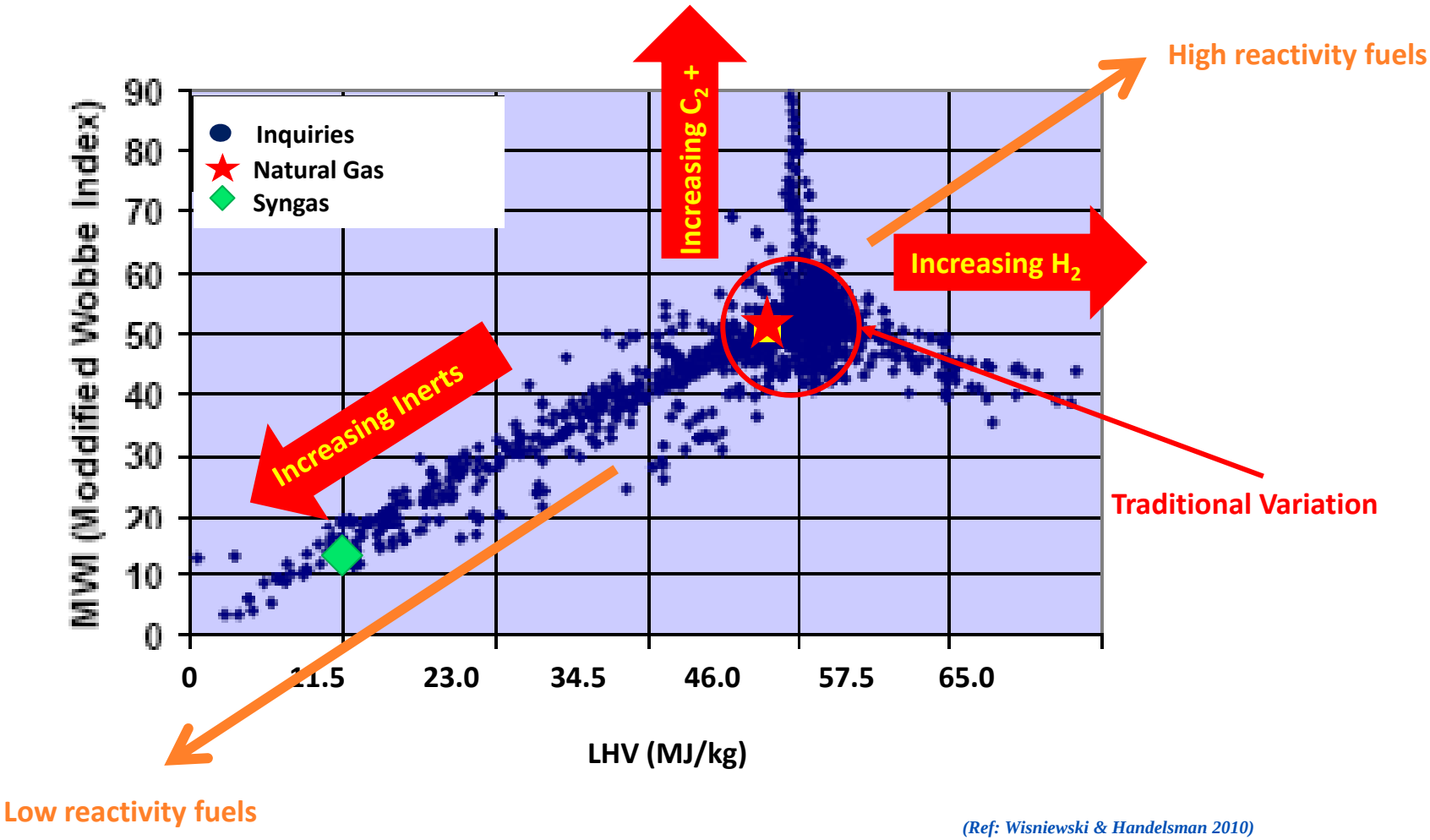
Process Variation

Composition (Volume %)	Min.	Max.	Avg.
Hydrogen (H_2)	8.6	61.9	31.0
Carbon Monoxide (CO)	22.3	55.4	37.2
Carbon Dioxide (CO_2)	1.6	30	12
Methane (CH_4)	0	8.2	2.2
Nitrogen (N_2) + Argon (Ar)	0.2	49.3	12.2
Water (H_2O)	0.1	39.8	7.8
Hydrogen/Carbon Monoxide Ratio	0.33	0.8	0.86

Fuel Constituents – Characteristic Values

		LHV (MJ/m³)	LHV (MJ/kg)	Flammability Limits (Vol. %)		Autoignition (°C)	Laminar Flame Speed (cm/s)
				Lean	U/L Ratio		
Methane	CH_4	36.447	50.048	5.00	3.00	537	44.8
Ethane	C_2H_6	64.862	47.511	3.00	4.13	472	47.6
Propane	C_3H_8	92.836	46.330	2.10	4.52	450	46.4
Butane	C_4H_{10}	120.651	45.725	1.80	4.67	462	44.9
Pentane	C_5H_{12}	148.586	45.343	1.40	5.57	284	43
Hexane	C_6H_{14}	176.441	44.925	1.20	6.17	225	
Carbon Monoxide	CO	12.828	10.113	12.50	5.92	609	52
Hydrogen	H_2	10.990	120.071	4.00	18.75	400	325

Fuel Flexibility Spread



(Ref: Wisniewski & Handelsman 2010)

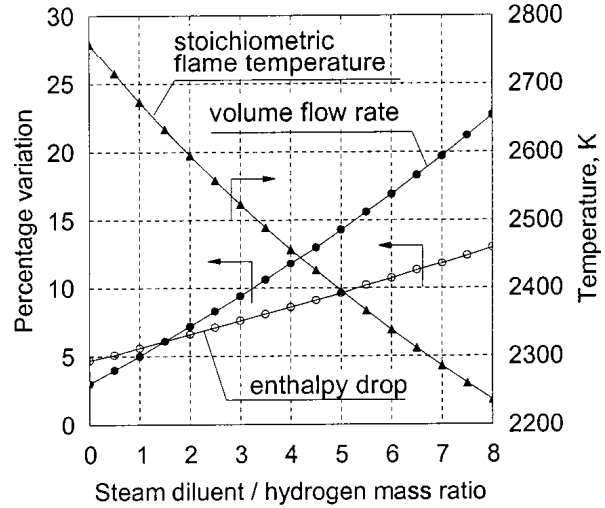
Fuel Flexibility Challenge

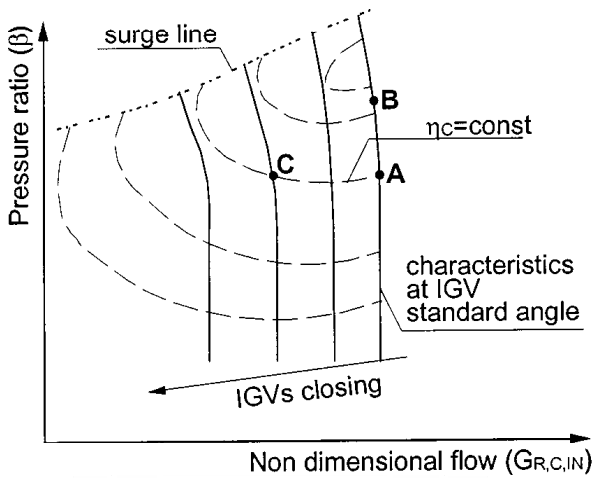
- How does/can non-conventional (high vs. low reactivity) fuels affect gas turbine operation?
  - Combustion
  - Turbomachinery
  - Emissions
  - Hot gas path components
  - Maintenance

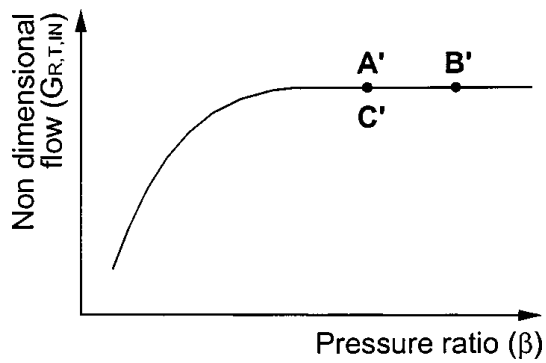
- Decision to utilize alternative fuels depends on these effects and the associated economics

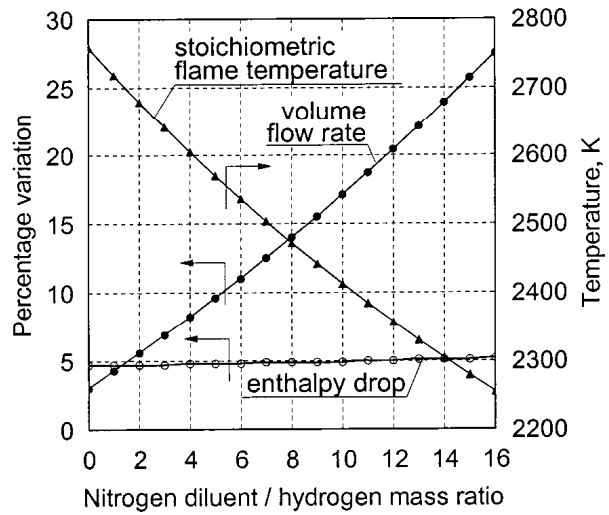
Turbomachinery Issues

- Variation in enthalpy drop in the expansion
- Variation of the flow rate at turbine inlet and the effect on turbine compressor matching
- Variation in heat transfer coefficient on the turbine blades, affecting blade cooling performance









(Ref: Chiesa, et al, 2005)

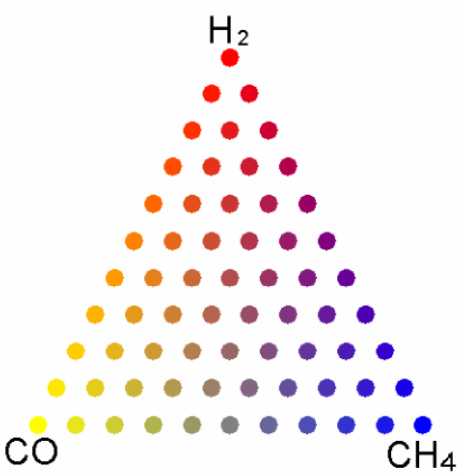
Important Combustor Performance Parameters

- Wide operability
  - Blow-off limits
  - Flashback and auto-ignition limits
  - Static and dynamic stability (spatial and temporal flame anchoring)
- Low emission
- Good turndown
- Durability

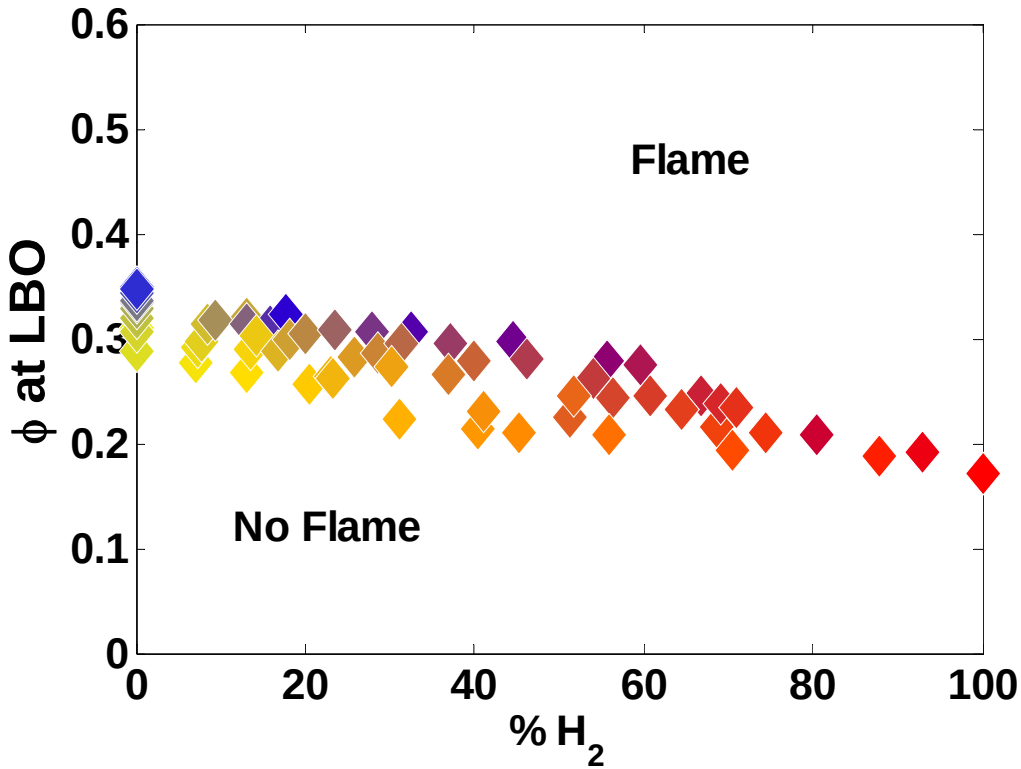
Fuel Composition Issues – Flame Blowoff

H_2 addition significantly extends blowoff limits

Diluent addition contracts blowoff limits



Conditions: U_0=60 m/s, T=460K, P=4.4atm,



(Ref: Lieuwen et al, 2008)

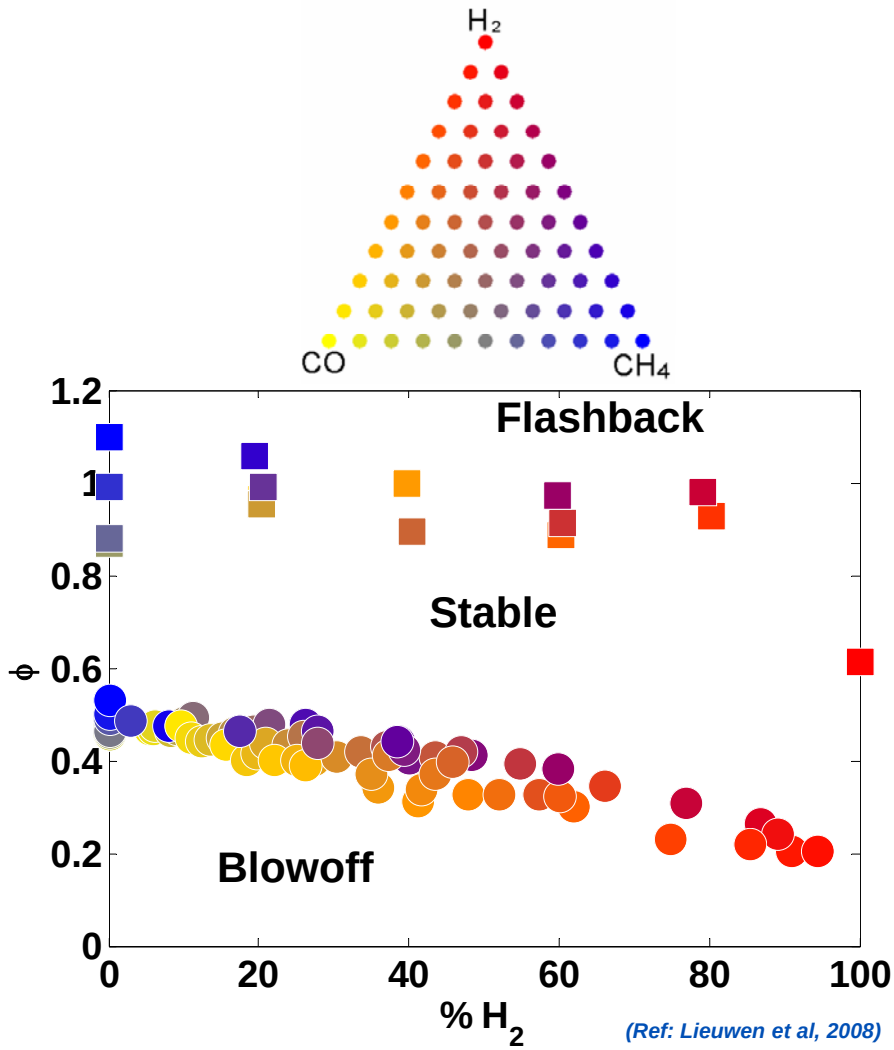
Fuel Composition Issues – Flame Flashback

Multiple flashback mechanisms

- In boundary layer
- In core flow
- Strong acoustic pulsations lead to nearly reverse flow
- Combustion induced vortex breakdown

Different fuel properties influence these mechanisms differently

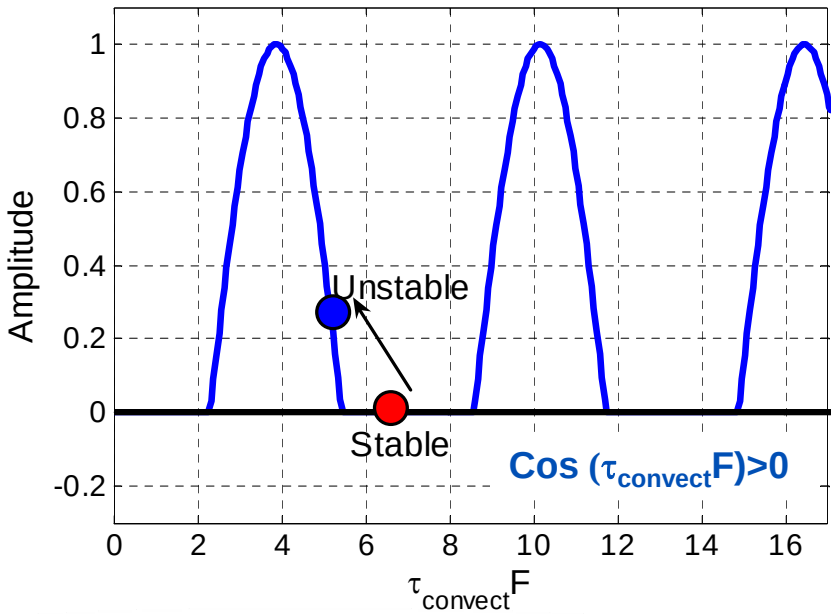
- Strong dependence of turbulent flame speed on fuel composition
- Hydrogen influence on flashback

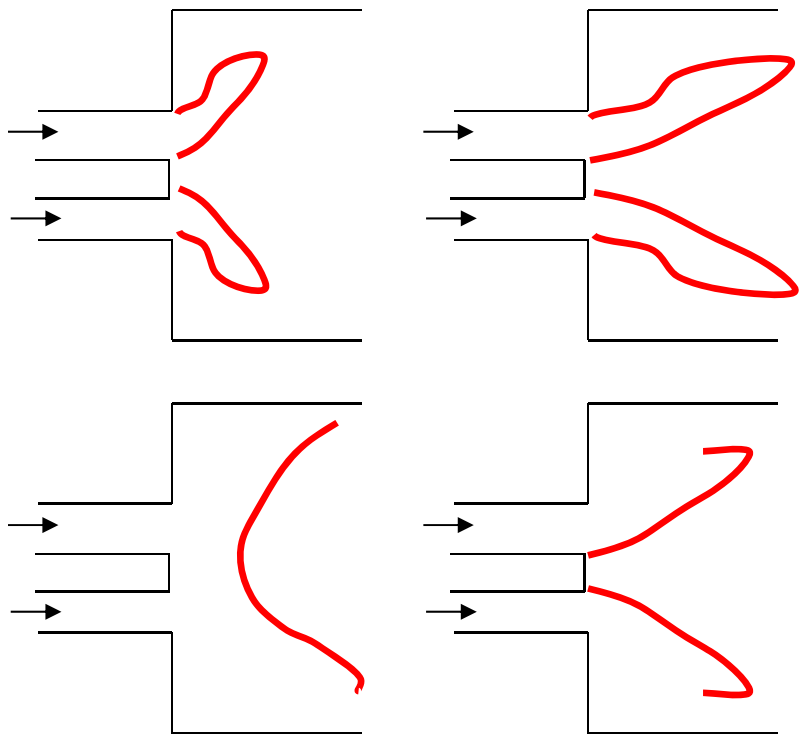


(Ref: Lieuwen et al, 2008)

Fuel Composition Issues – Flame and Combustion Stability

- Fuel composition variations influence
  - Flame shape
  - Flame standoff location
- Alteration in flame shape and location can worsen or improve combustor dynamics via $\tau_{convect}$





(Ref: Lieuwen, 2008)

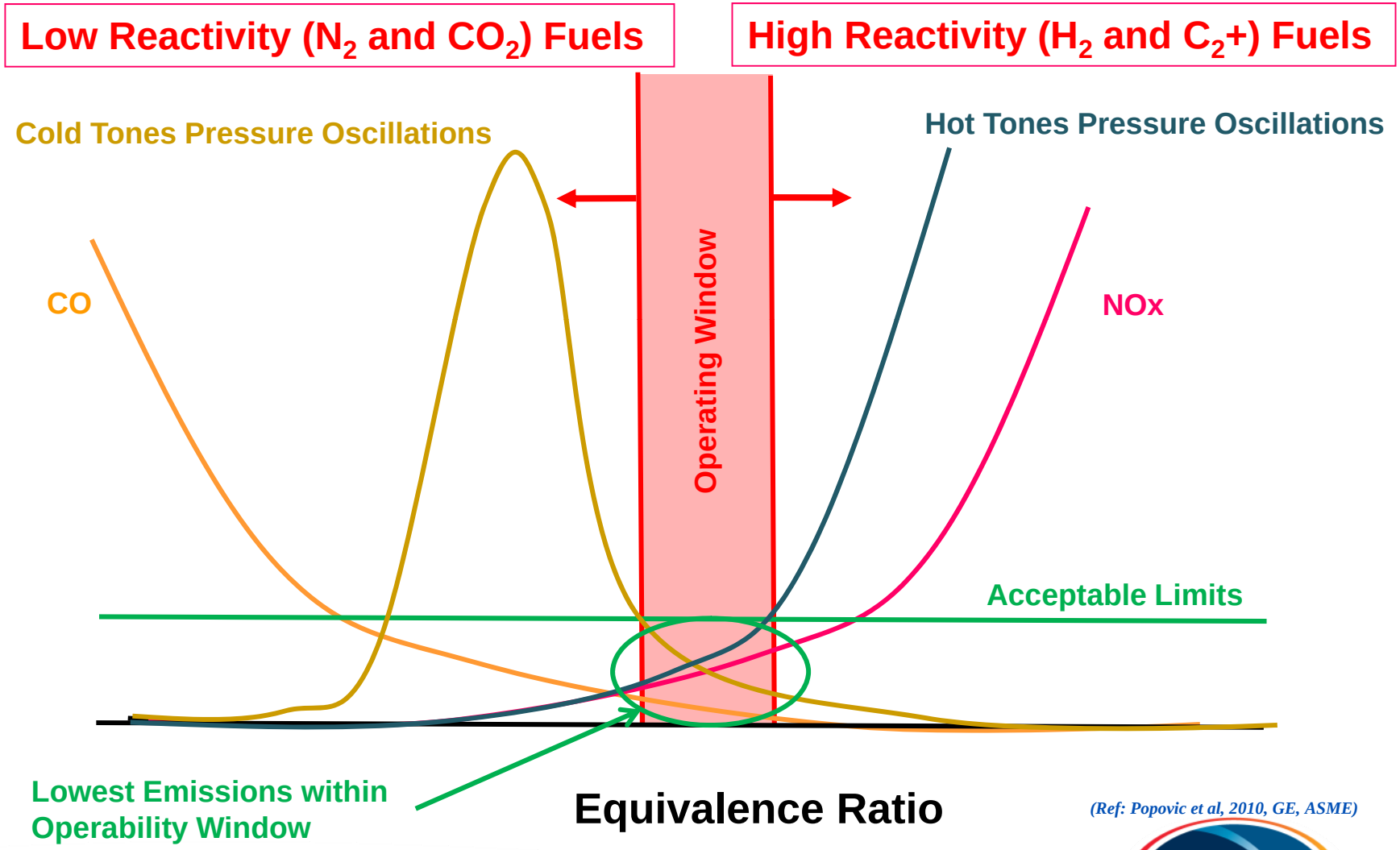
Fuel Composition Issues – Emissions

- Strongly dependant on composition
- Reactive fuel blends having high H_2 or C_2+ compositions
  - Increase NOx formation
  - Decrease CO formation at part load
- Fuels having high inert constituents
  - Reduce NOx formation
  - Increase concentration of CO and UHC in exhaust

Syngas Emissions

- Strongly dependant on composition
- In general syngas produce lower emissions for combined cycles
- VOC emissions low
- SOx emissions low
- CO emissions
  - Unburned syngas CO from insufficient mixing and equivalence ratio lower than ignition range
  - Incomplete combustion of HC contents
- NOx emissions
  - Thermally generated: Increase with increase in H2 contents due to higher firing temperatures. Decrease with increase in H2 contents due to leaner combustion potentials
  - Flame-generated: Increase with increase in H2 contents due to higher flame temperatures
  - Fuel-bound: Increase if ammonia not removed prior to combustion. Decrease if burned rich.
  - Increase with increase in CO:H2 ratio

Dry Low NOx Operation within Emissions & Dynamics Limits



(Ref: Popovic et al, 2010, GE, ASME)

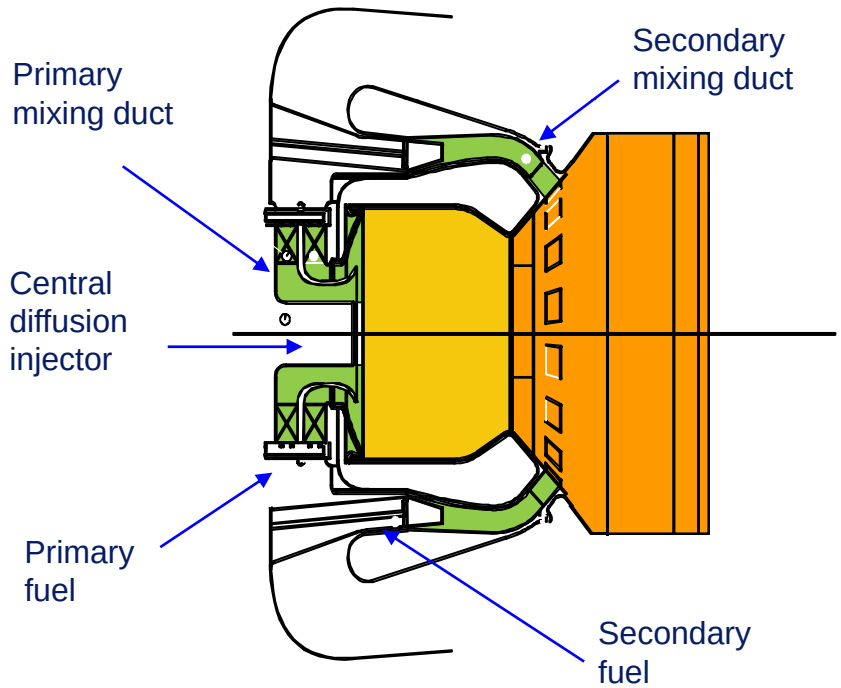
Effects on Hardware Changeability & Durability

- Increased fuel reactivity causes thermal distress to premixer and hot gas-path components due to:
  - Higher flame temperature and flashback propensity
  - Susceptibility to high temperature thermoacoustic pressure oscillations
- High reactivity fuels require
  - Alternate fuel as well as purging system for starting and shutdown
- Reduced fuel reactivity due to addition of Inerts require
  - Larger sized injectors to compensate for higher fuel flow rate requirement
- Reduced fuel reactivity cause hardware distress due to
  - Low temperature combustion dynamics
- Syngas use may cause increased component corrosion

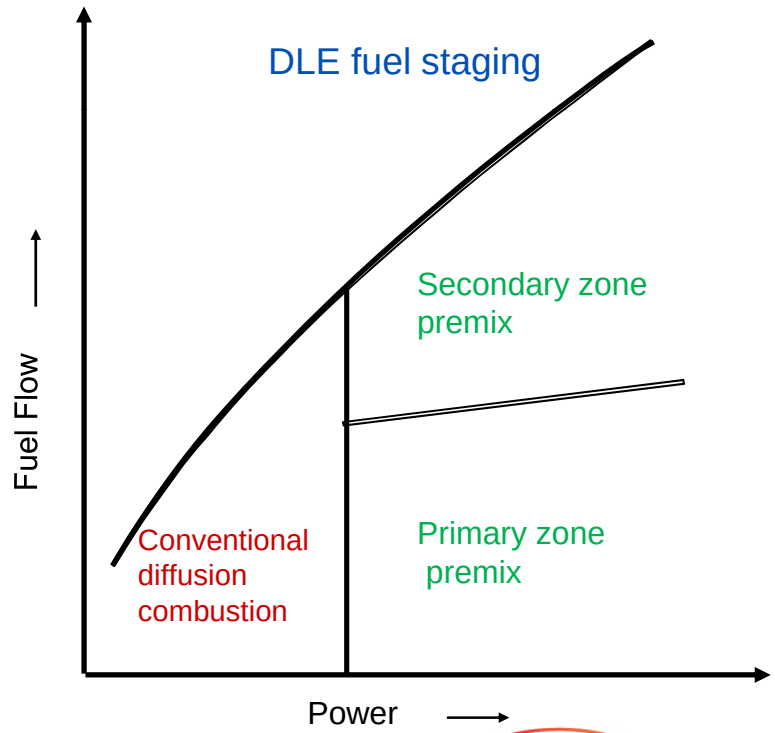
Solutions to Fuel Flexibility Challenge – Rolls-Royce Experience

Series Staging

- Simple control system with only 4 fuel control valves
  - diffusion, primary and secondary (2) VSS
- Diffusion circuit allows for reliable starting
- Primary and secondary enables individual zone temperature control.
  - This gives flexibility for optimum emissions control.

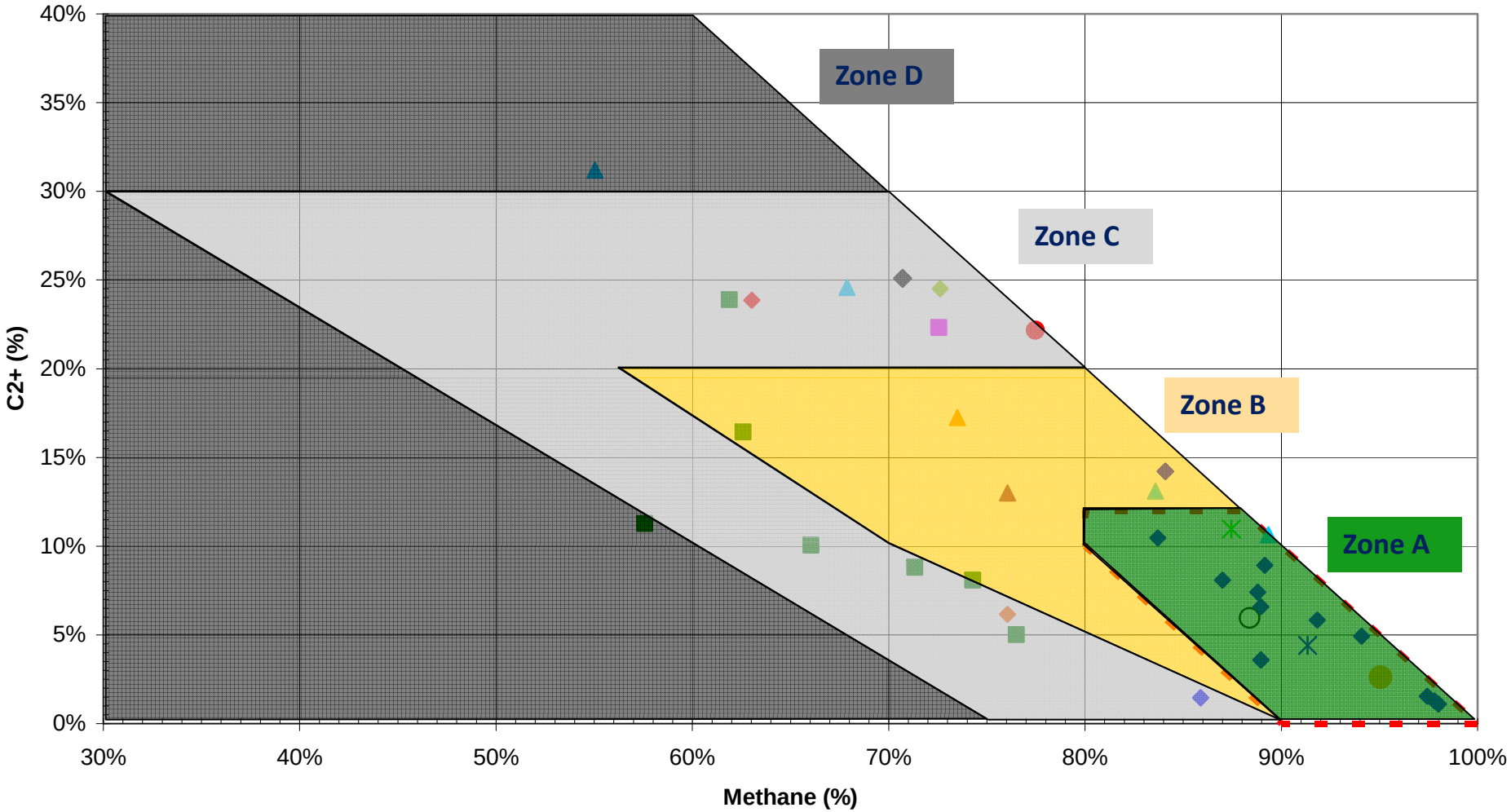


Premix lean burn series staged combustor



(Ref: Rolls-Royce, 2011)

Series Staging– Operational Mapping



(Ref: Rolls-Royce, 2011)

For more information on the presented material, please contact:

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