GT Combustion and Emissions

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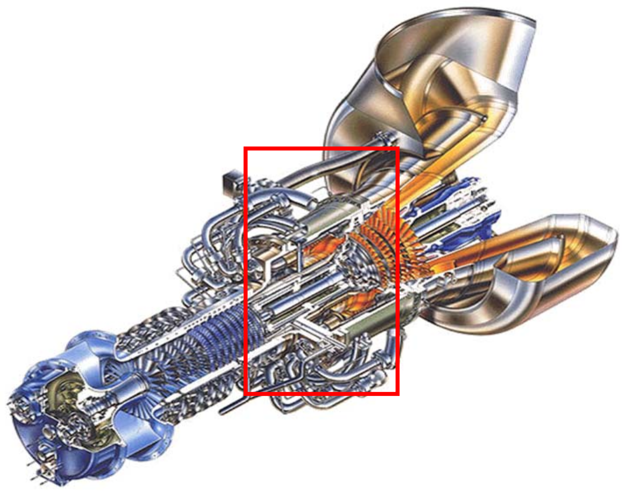
AGENDA

- Combustion
- Emissions
- Combustion System Description
- Fuels and Fuel Flexibility
- Summary

COMBUSTOR



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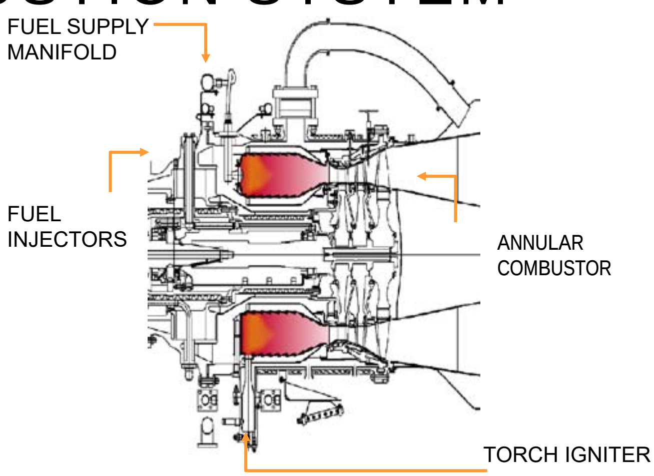
TYPICAL GAS TURBINE COMBUSTION SYSTEM



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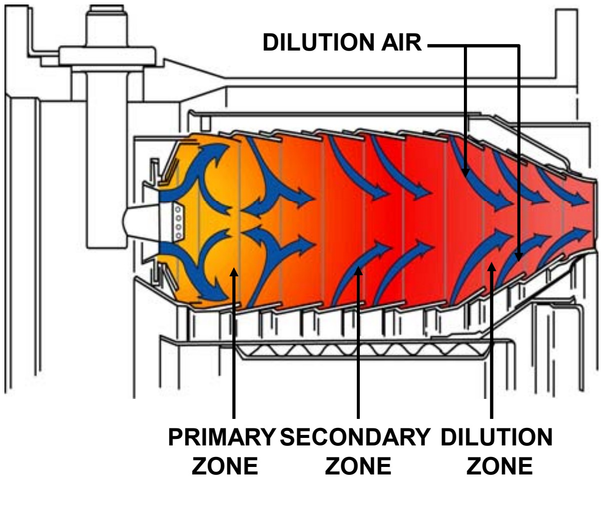
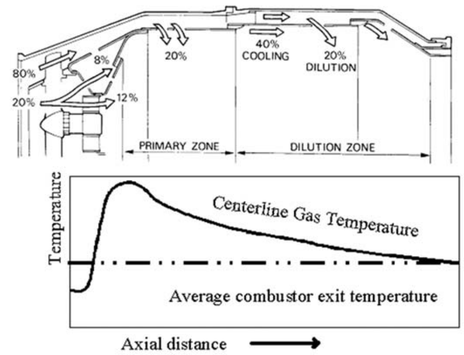
Combustion Chamber





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Combustion

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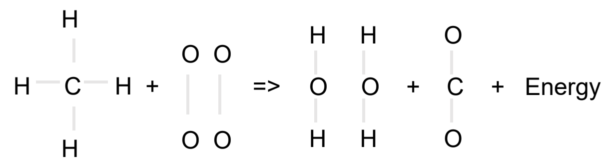
Combustion Reactions



Methane Oxygen Water Carbon Dioxide

$CH_4 + 2O_2 \Rightarrow 2H_20 + CO_2 +$ Energy

Good OK Very Good

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Emissions

Air Is 78% Nitrogen (N_2), 21% Oxygen, Fuel is Hydrocarbons (C and H):

Incomplete Combustion:
- Unburned Hydrocarbons, Volatile Organic Compounds
- CO

Combustion Byproducts:
-NO, NO_2

If the fuel contains Sulfur (Sulfur, H_2S, Mercaptanes), they will be completely oxidized

Theoretical (Stoichiometric) Air-to-Fuel Ratio for Ideal Combustion

$CH_4 + 2\,O_2 = 2\,H_2O + CO_2$

Molecular Weights:
Methane (CH_4) = 16.04
Oxygen (O_2) = 31.99

$$\left(\frac{\text{Oxygen}}{\text{Methane}}\right)_{\text{weight}} = \frac{2 \cdot 31.99}{16.04} = 3.99$$

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Theoretical (Stoichiometric) Air-to-Fuel Ratio for Ideal Combustion

Air Is Approximately 21% Oxygen

thus:

$$\left(\frac{\text{Air}}{\text{Fuel}}\right)_{\text{weight}} = \frac{3.99}{0.21} = 18.99$$

To Burn 1 kg of Methane We Need 18.99 kg of Air

Actual for Mars 100:

$$\left(\frac{\text{Air}}{\text{Fuel}}\right) = 65!$$

Because of Temperature Limitation.
Note: Actual Flame Front is about stoichiometric (in a conventional system)

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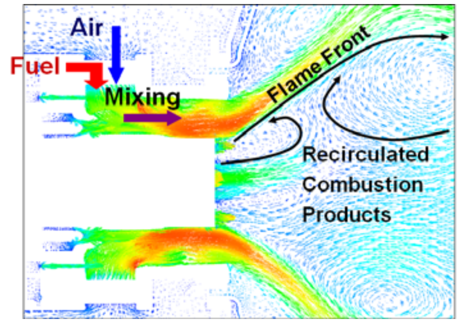
TYPES OF COMBUSTION FLAMES

- Diffusion Flame *(Conventional)*
  - Air, Fuel Injected into Combustor Separately
  - Burning at Interface (Flame Front), *Stoichiometric* Fuel-to-Air Ratio

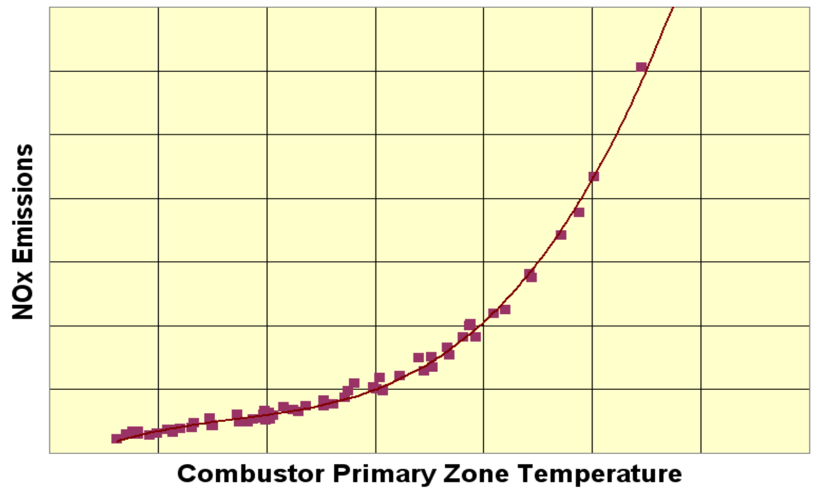
- Lean, Premixed Flame *(SoLoNOx,DLN,DLE)*
  - Air, Fuel *Premixed* in Fuel Injector
  - Burning at Lower Temperature, *Fuel-Lean Conditions*

A Few Comments on NOx

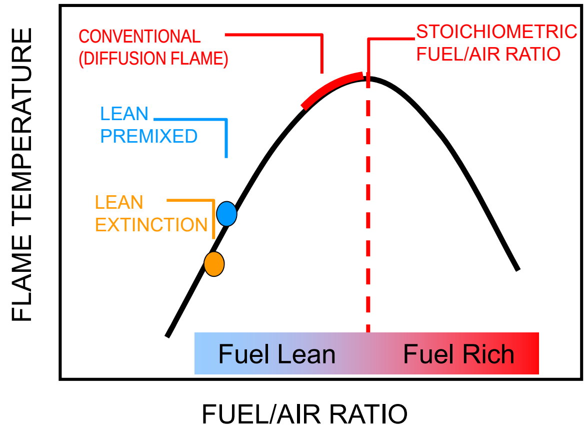
- The best NOx is always achieved with perfect premixing of fuel and air.
- NOx emissions for well-mixed systems are independent of flameholder geometry
- A well-mixed flame is insensitive to pressure or inlet temperature. A diffusion flame is sensitive to both, leading to high pressure ratio engines having higher NOx than low pressure ratio machines. But a high pressure ratio DLE system should be able to achieve the same NOx as a low pressure ratio machine.
- NOx for a well-mixed system is independent of residence time. So a DLE system can have a larger combustor liner without increasing Nox to allow for complete combustion.



Nox is a function of Flame Temperature



STOICHIOMETRY EFFECT ON FLAME TEMPERATURE



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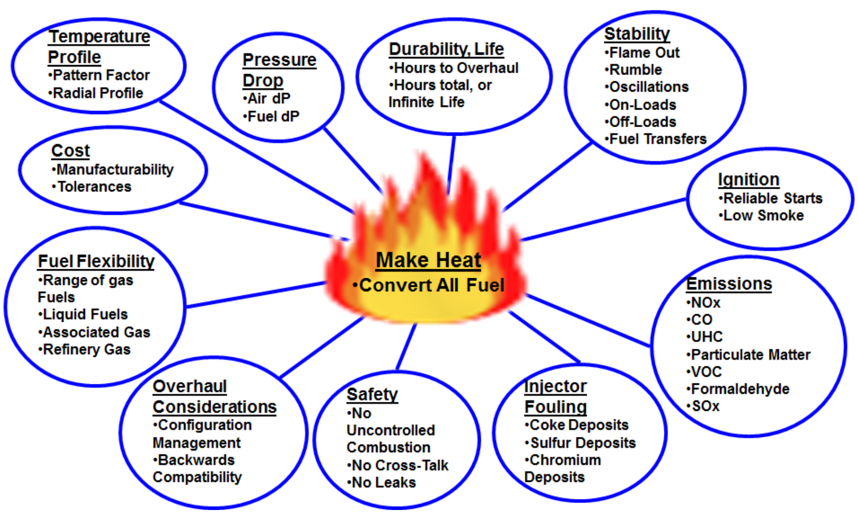
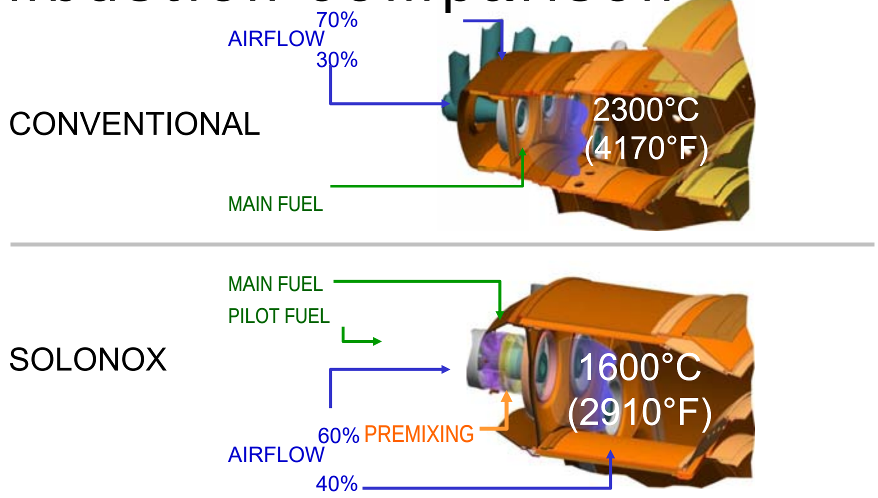
Combustion Systems

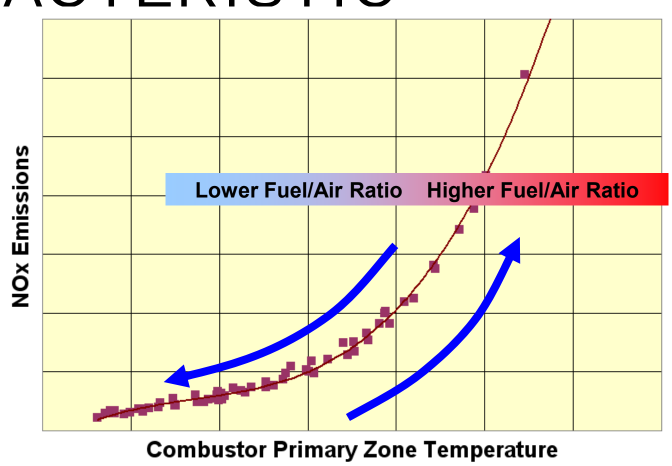
Design Requirements and Considerations for a Gas Turbine Combustion System



Combustion comparison



NOX EMISSIONS CHARACTERISTIC



COMBUSTION SYSTEM COMPONENTS

COMBUSTOR LINERS

Conventional SoLoNOx

FUEL INJECTORS

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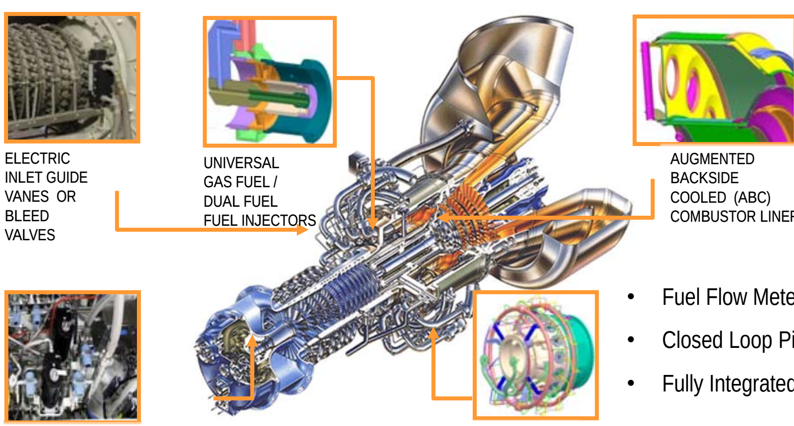
FEATURES FOR IMPROVED EMISSIONS



- Fuel Flow Metering
- Closed Loop Pilot Logic
- Fully Integrated System

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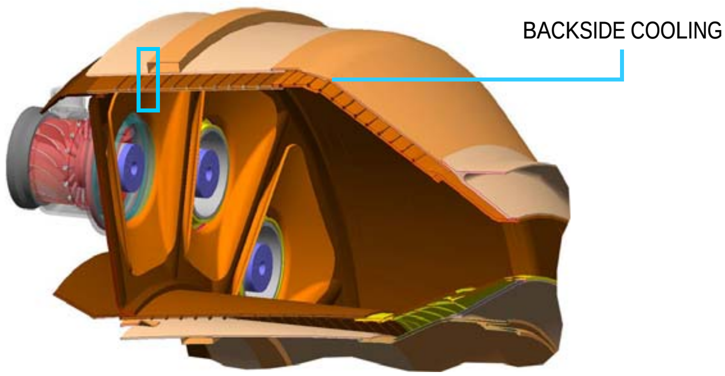
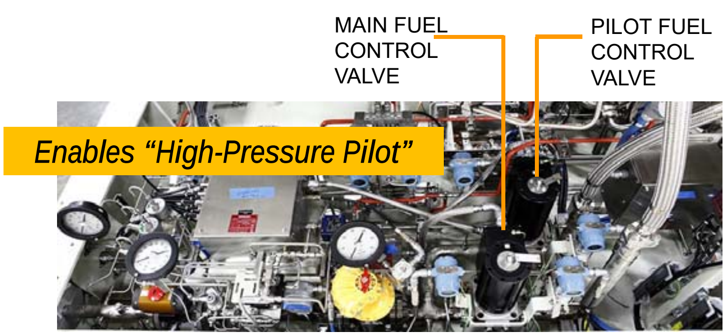
AUGMENTED BACKSIDE COOLED – (abc) LINER TECHNOLOGY



- No Film or Effusion Cooling in Primary Zone
- Rumble, CO Improved over Previous Generations

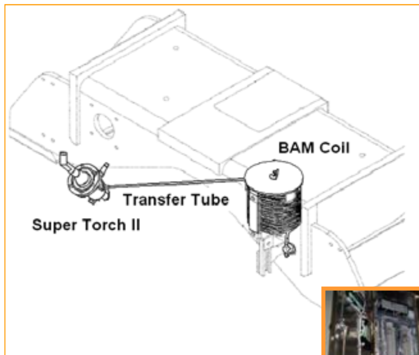
FUEL SYSTEM IMPROVEMENTS

- Parallel Main and Pilot Fuel Valve Arrangement
- Improved % Pilot Control
  - Based on Main and Pilot Flow Measurements



GAS ONLY FUEL MODULE

BURNER ACOUSTIC MONITOR – STANDARD



DYNAMIC PRESSURE PROBE

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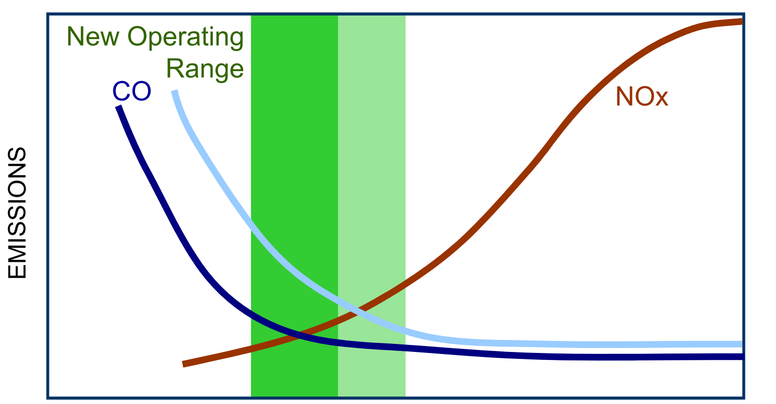
COMBUSTION SYSTEM EMISSIONS CHARACTERISTICS



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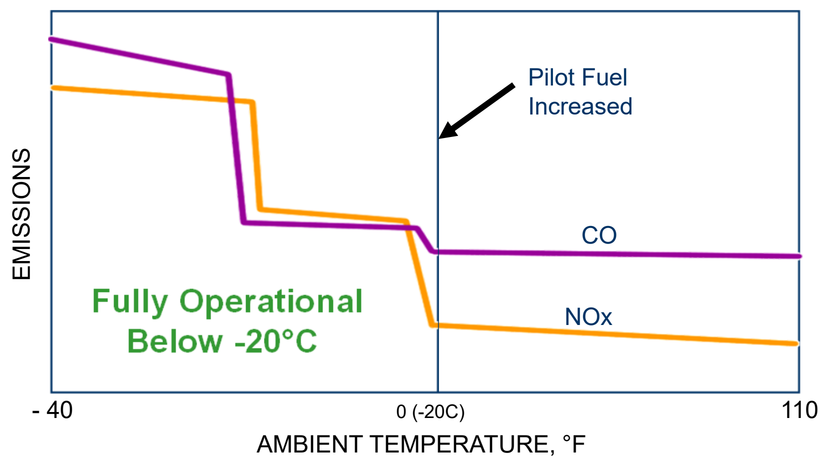
GENERAL TRENDS FOR NOX AND CO WITH AMBIENT TEMPERATURE



GASEOUS FUEL TERMINOLOGY

Wobbe Index

$$WI = \frac{LHV}{\sqrt{SG}}$$

LHV = Lower Heating Value

SG = Specific Gravity

Corrected Wobbe Index

$$WI_{CORR} = WI\sqrt{\frac{60 + 459.67}{T_{fuel} + 459.67}}$$

U.S. Pipeline Natural Gas Ranges *Gas Processors Association (1998)*				
	Btu/scf		MJ/Nm^3	
	Minimum	Maximum	Minimum	Maximum
Higher Heating Value	950	1150	35.4	42.9
Lower Heating Value	856	1040	31.9	38.8
Wobbe Index	1085	1296	40.5	48.3

GASEOUS FUELS SUITABLE FOR GAS TURBINES

SOURCES OF GASEOUS FUELS

OIL AND GAS OPERATIONS
- Raw Natural Gas
- Associated Gas
- Pipeline Gas
- LNG
- Natural Gas Liquids
- Liquefied Petroleum Gas

INDUSTRY
- Blast Furnace Gas
- Coke Oven Gas
- Refinery Gas
- High Hydrogen

BIOMASS
- Landfill Gas
- Digester Gas
- Gasified Biomass (Syngas)

COAL DERIVED
- Coal Mine Methane
- Coal Bed Methane

GASEOUS FUEL CONSIDERATIONS

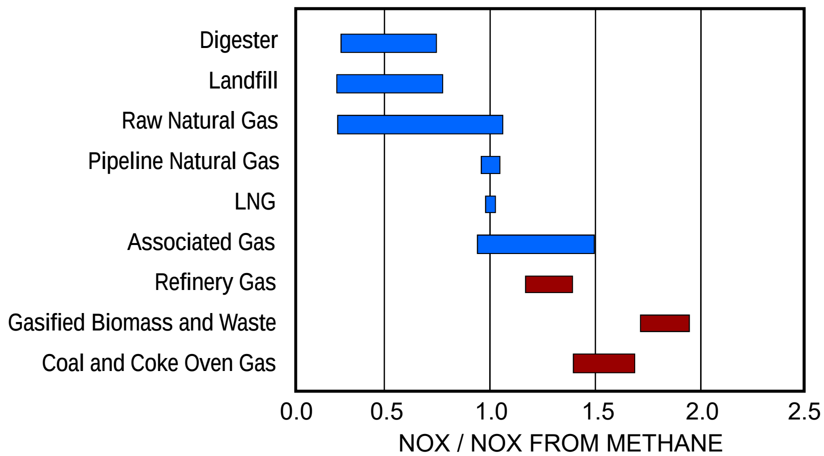
Conventional

- Heating Value
  - Skid Edge Pressure
- Dew Point
  - Liquid Dropout
- Flammability Limits
- Adiabatic Flame Temperature
  - NOx Emissions
- Contaminants

SoLoNOx

- Same as “Conventional”
- Plus:
  - Flame Speed ($C4^{+}$+H2+Alkenes)
  - Autoignition Delay Time
  - Emissions
  - Oscillations

GAS NOX EMISSIONS RULE OF THUMB (CONVENTIONAL)



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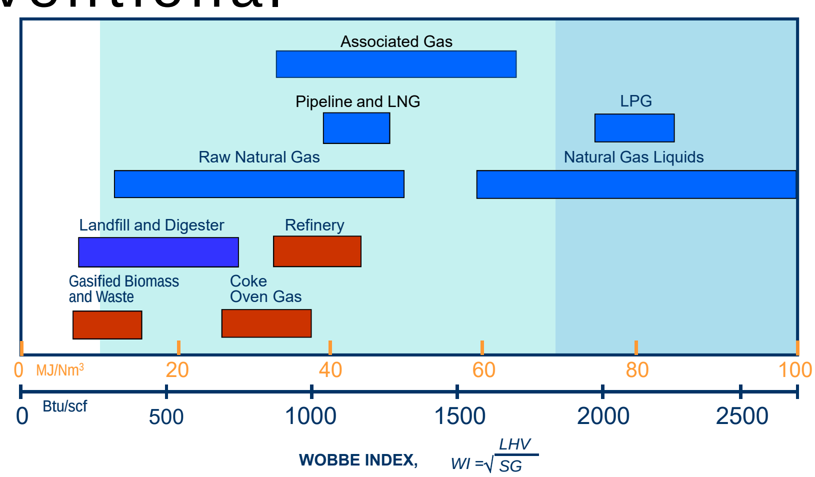
GASEOUS FUEL RANGE – Conventional



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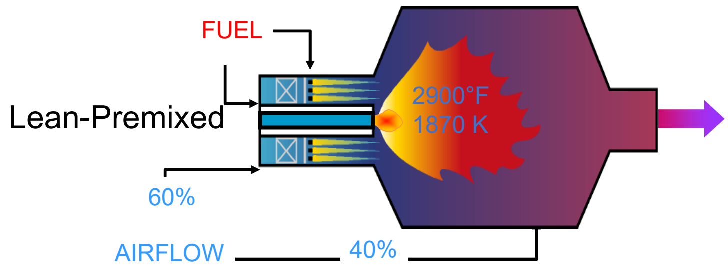
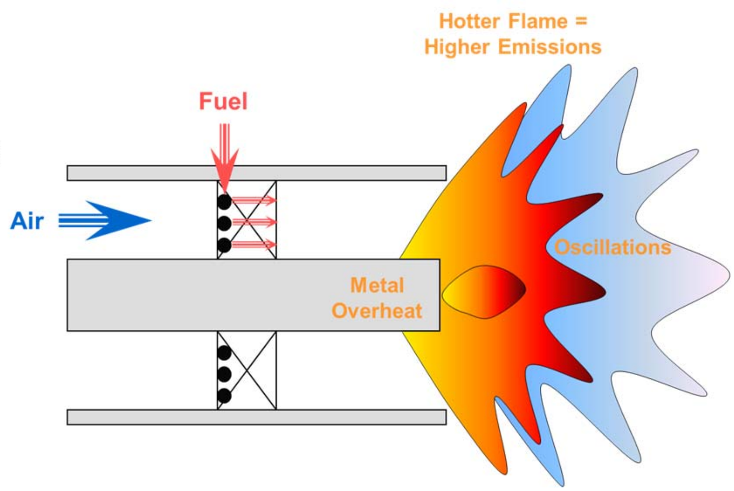
Auto Ignition and Flashback

- Autoignition Delay Time
  - Longer for lean mixtures
  - Shorter for higher pressure and temperature
- Flashback
  - Flame Speed vs Bulk Velocity
  - Flame speed higher for Propane or Hydrogen



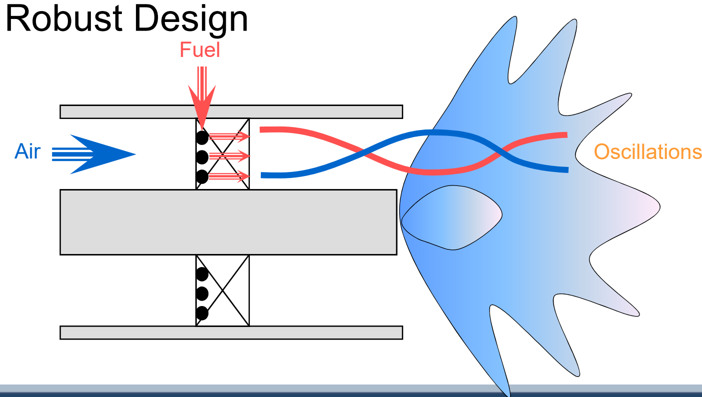
Flame Instability

- Flame Movement
  - Durability Issues
  - Emissions Issues
  - Acoustic Coupling



Combustion Acoustic Modeling

- Enhance Understanding of Oscillations
- Provide Accurate Predictions
- Allow for Up-Front Robust Design



GASEOUS FUEL BLENDING FACILITIES

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SUMMARY

- SoLoNOx Significantly Lowers Emissions with Some Effect on Complexity
- Recent Advancements in SoLoNOx Technology
  - Improved Operability and Durability
  - Range of Conditions for Low Emissions
- Wide Range of Fuels Can Be Run in Conventional Combustion Systems
- Development and Qualification in Process to Expand Fuel Flexibility of SoLoNOx Systems