ADVANCES IN USING ASSOCIATED GASES IN SOLAR TURBINES' DLE INDUSTRIAL GAS TURBINES THE FUTURE OF GAS TURBINE TECHNOLOGY

LUKE COWELL, ANDREW PADILLA, PRIYANK SAXENA

A CULTURE OF CUSTOMER CARE

8TH INTERNATIONAL GAS TURBINE CONFERENCE

12-13 OCTOBER 2016, BRUSSELS, BELGIUM

Solar® Turbines

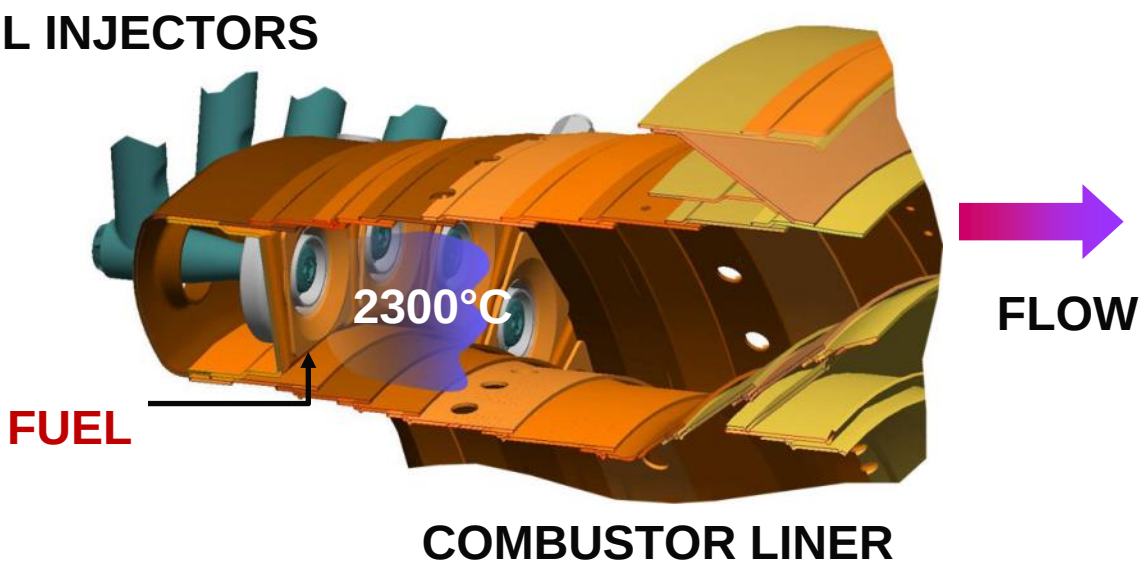
A Caterpillar Company

AGENDA

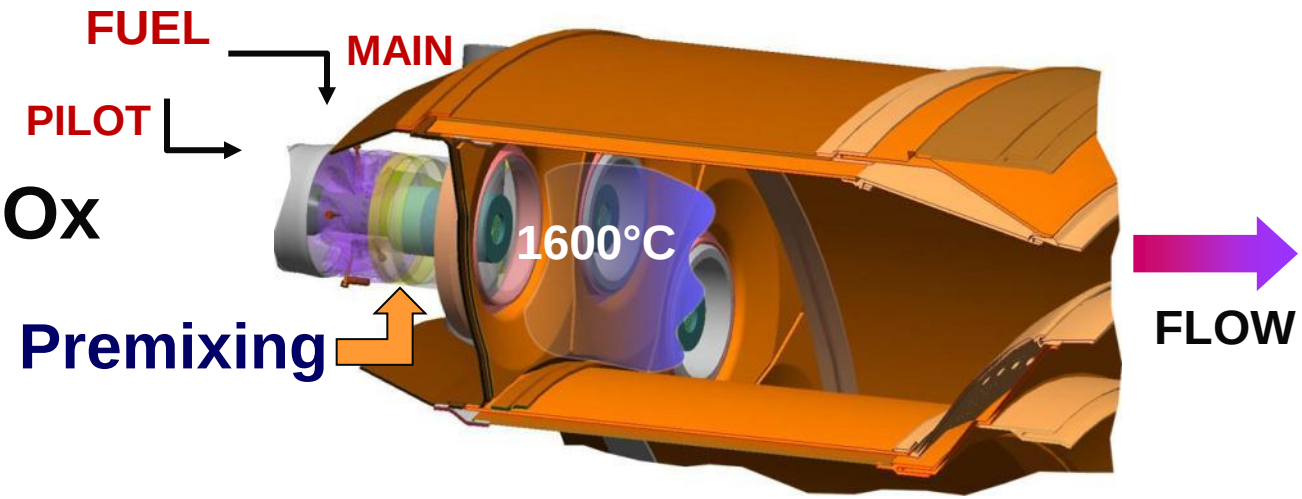
- Combustion System Overview
- Gas Turbine Fuels and Associated Gases
- Combustion Parameters Affected by Fuel Composition
- Expanding Fuel Flexibility
- Experience

SOLAR'S COMBUSTION SYSTEMS

Conventional



SoLoNOx



SOLAR'S COMBUSTION SYSTEMS

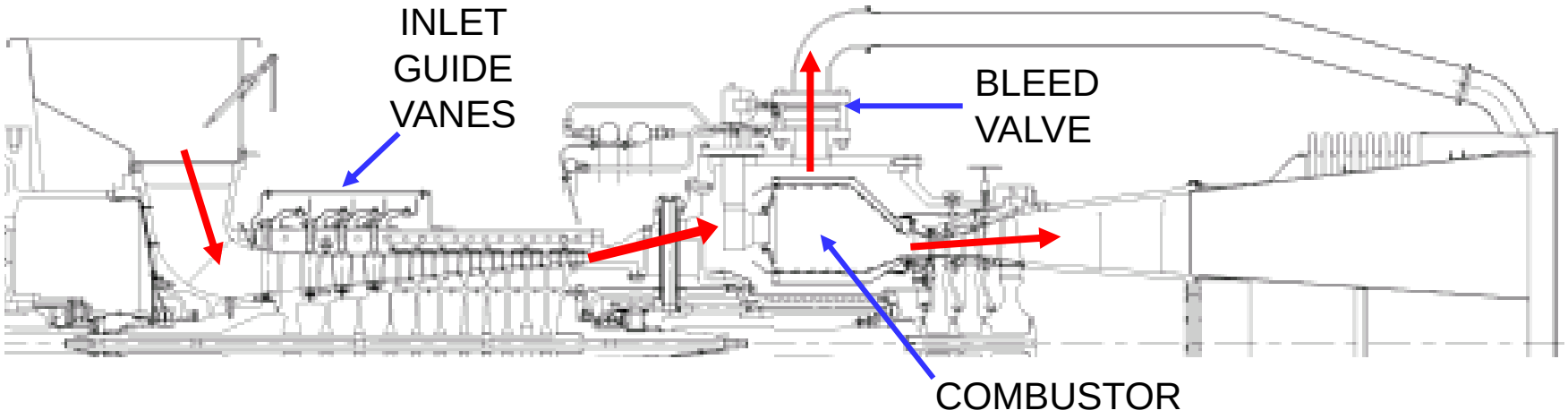
CONVENTIONAL SOLONOX

COMBUSTOR LINERS

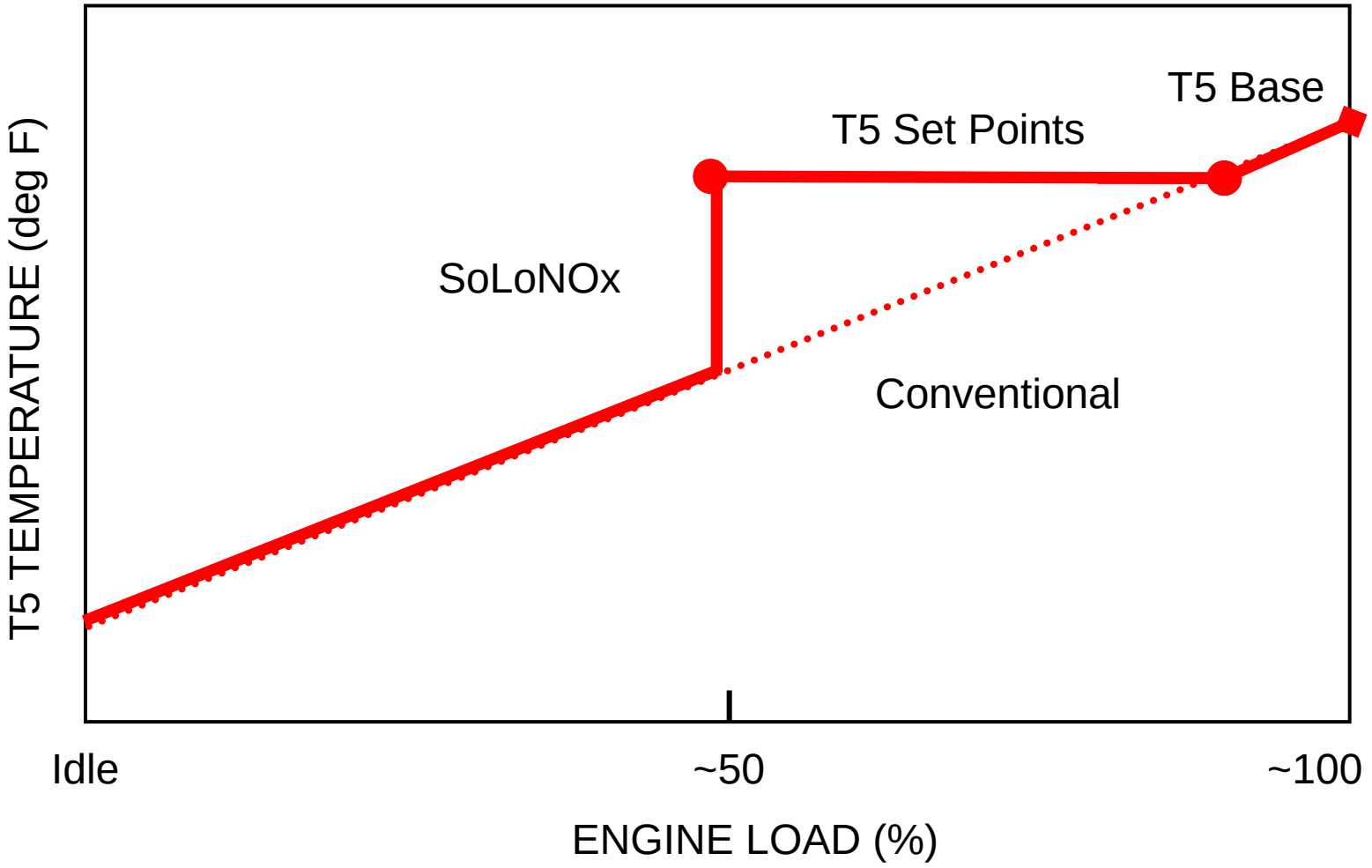
FUEL INJECTORS

UNIQUE SOLONOX CONTROL FEATURES

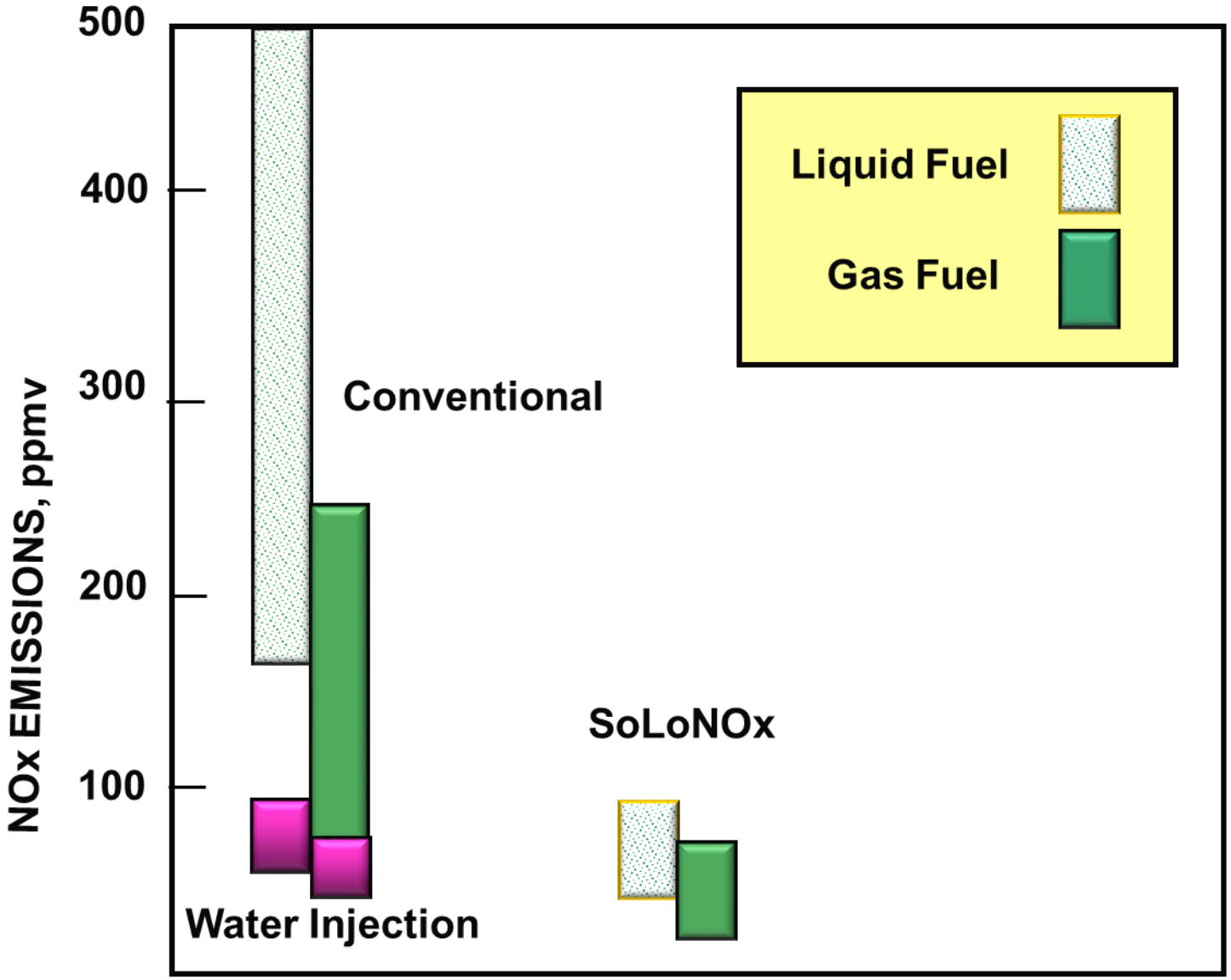
- **Pilot Fuel**
- **Combustor Air Management**



SOLONOX VS CONVENTIONAL T5 TRENDS



COMBUSTION SYSTEM PERFORMANCE



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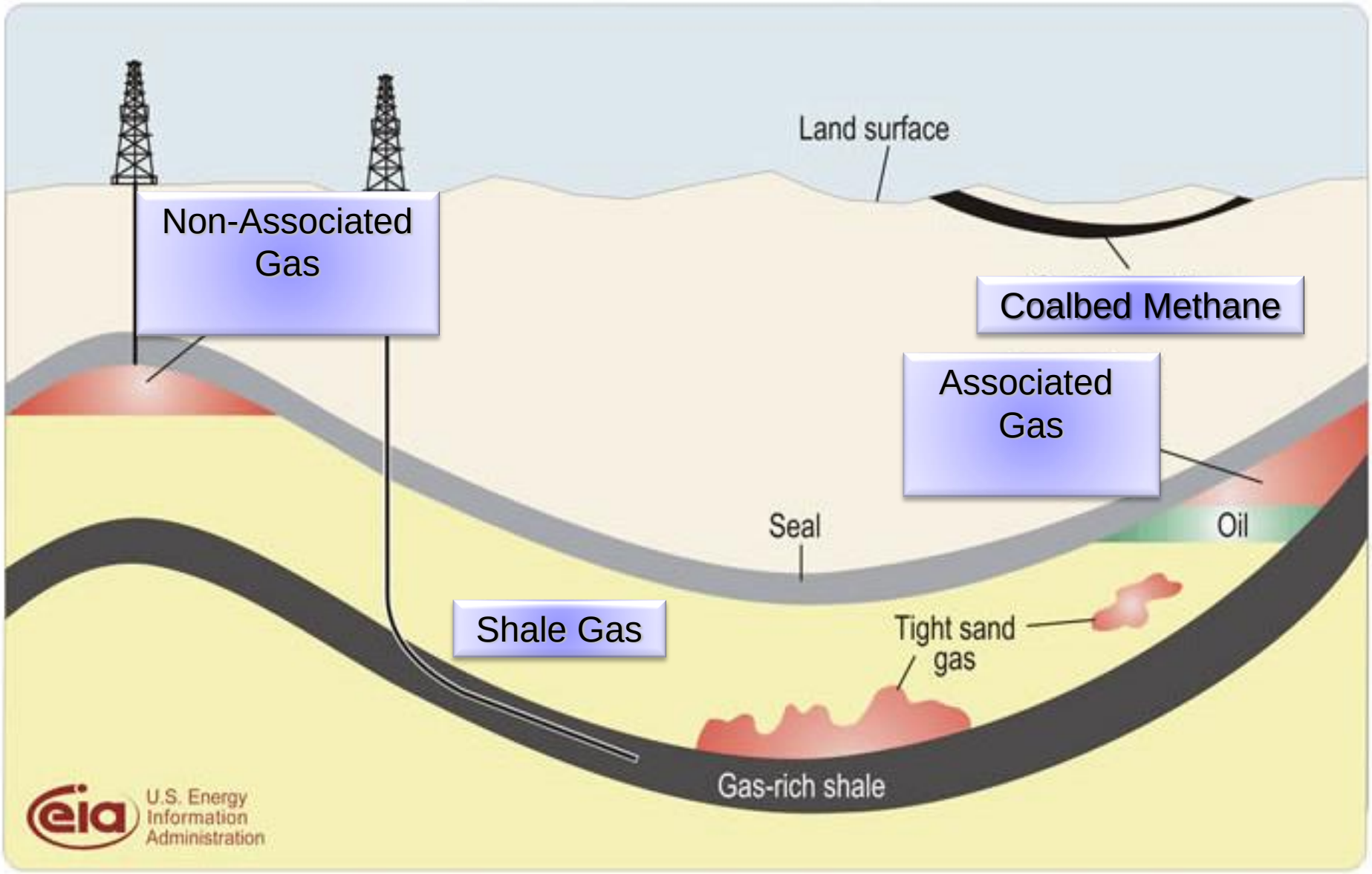
OIL AND GAS FOSSIL FUEL SOURCES



GASEOUS FUEL TERMINOLOGY

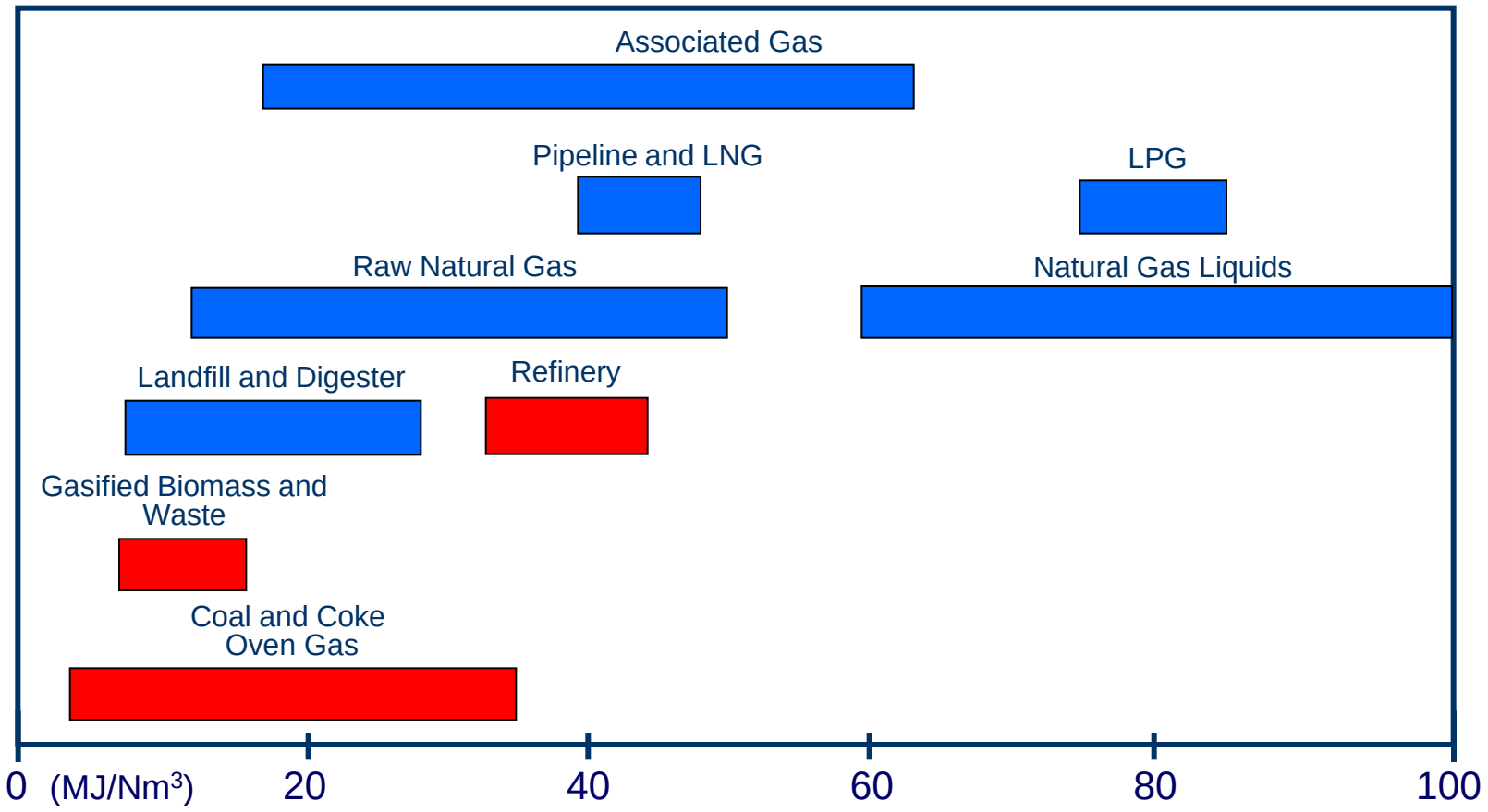
Wobbe Index

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

LHV = Lower Heating Value
SG = Specific Gravity

U.S. Pipeline Natural Gas Ranges Gas Processors Association				
	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

TYPICAL GASEOUS FUELS FOR GAS TURBINES



WOBBE INDEX, $WI = \frac{LHV}{\sqrt{SG}}$

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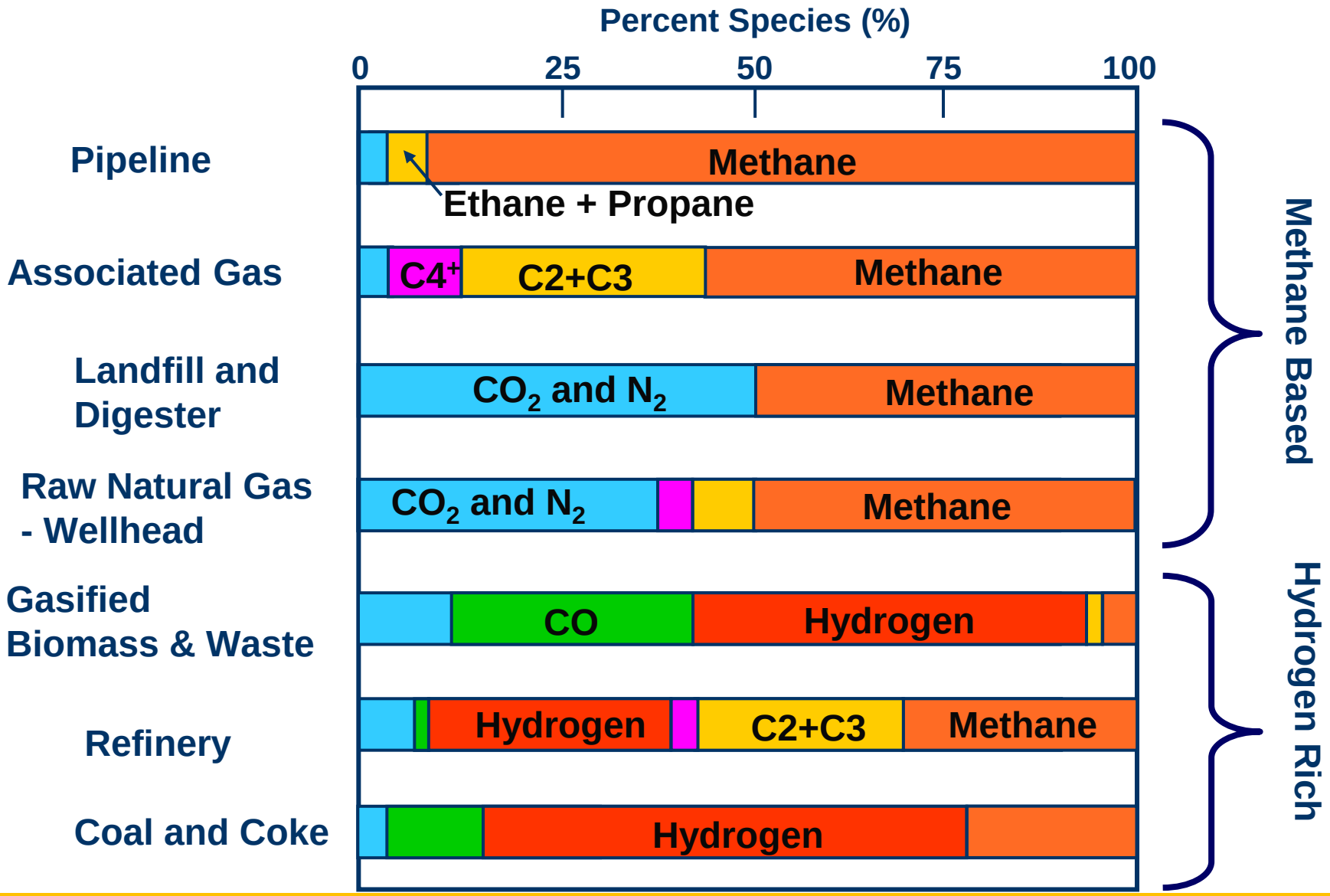
GASEOUS FUEL COMPOSITIONS



GASEOUS FUEL CONSIDERATIONS

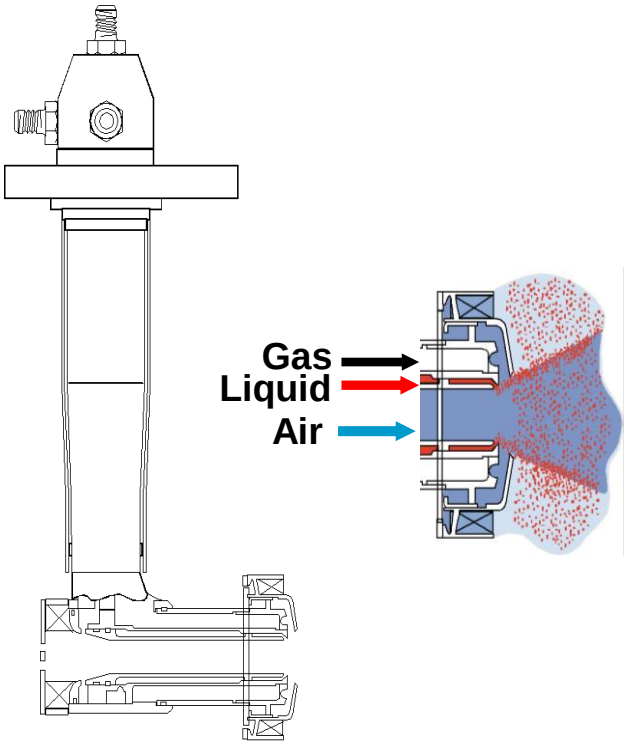
Conventional

- Heating Value
  - Skid Edge Pressure
- Flammability Limits
- Adiabatic Flame Temperature
- Dew Point
- Contaminants

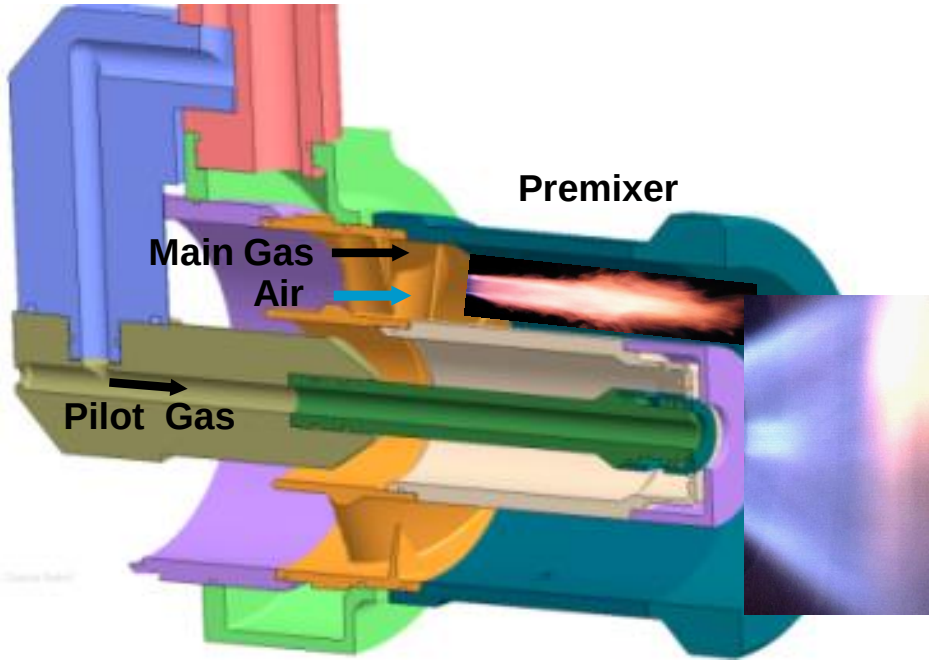
DLE

- Heating Value
  - Skid Edge Pressure
- Flammability Limits
- Adiabatic Flame Temperature
- Dew Point
- Flame Speed ($C4^{+}$+H2+Alkenes)
- Autoignition Delay Time
- Emissions
- Combustion Stability
- Contaminants

CONVENTIONAL & SOLONOX FUEL INJECTOR CONCEPTS

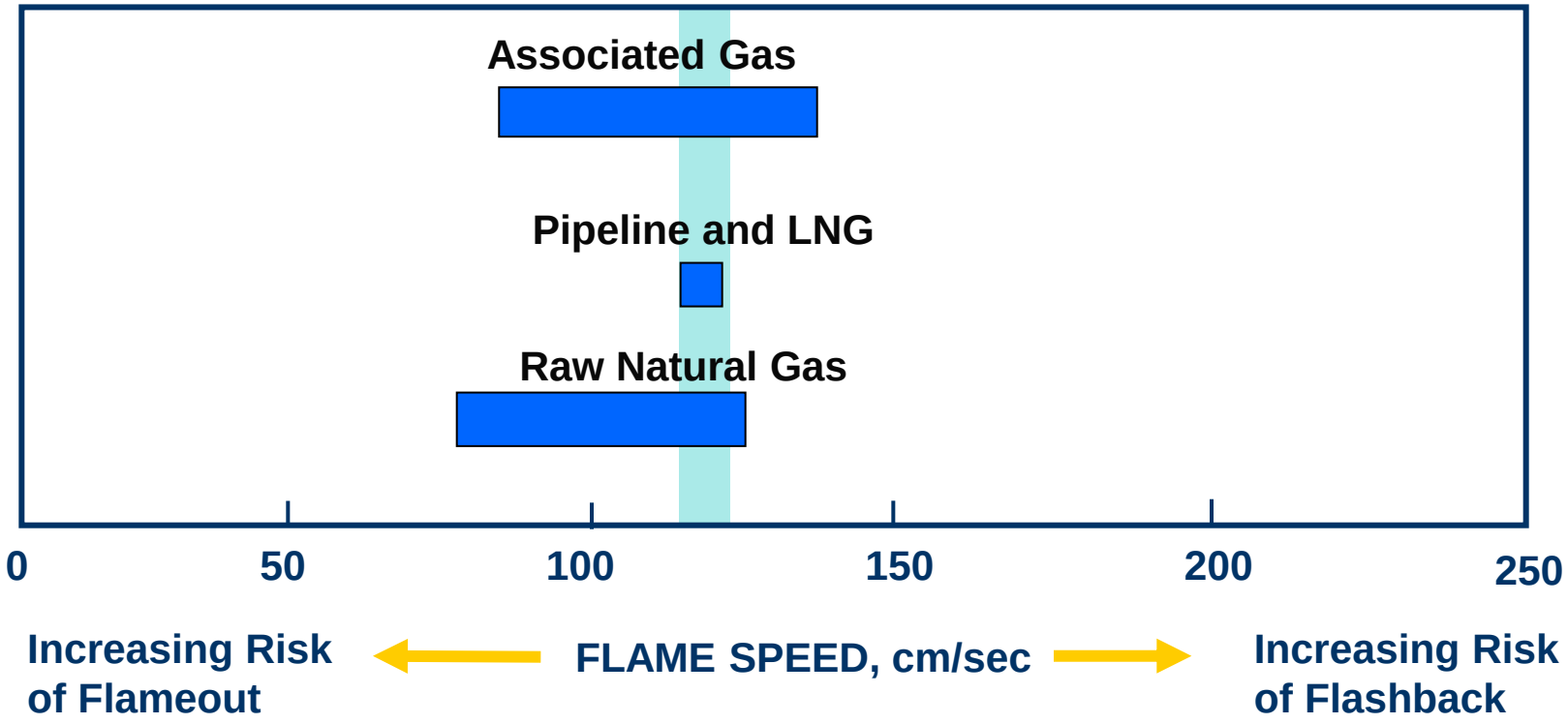


CONVENTIONAL



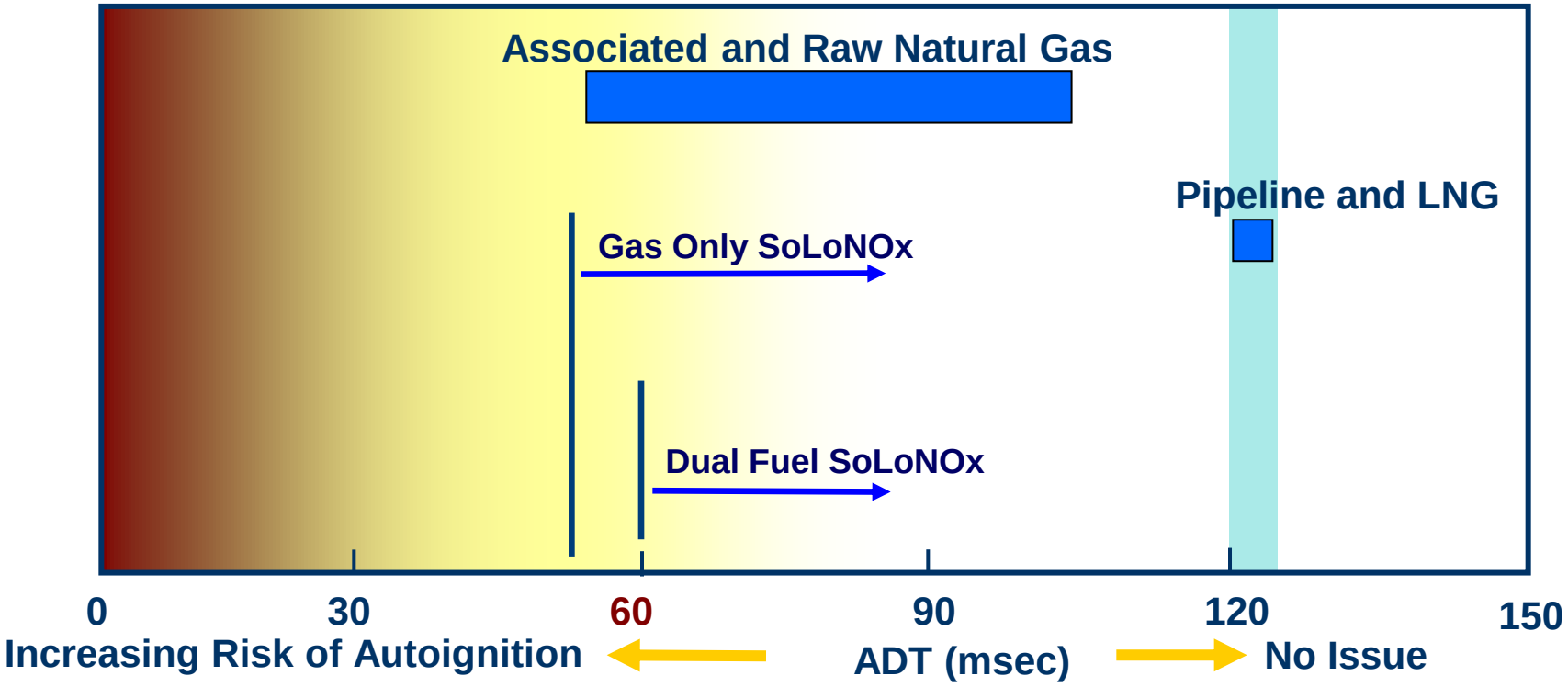
SOLONOX

Gas Fuel – Flame Stability

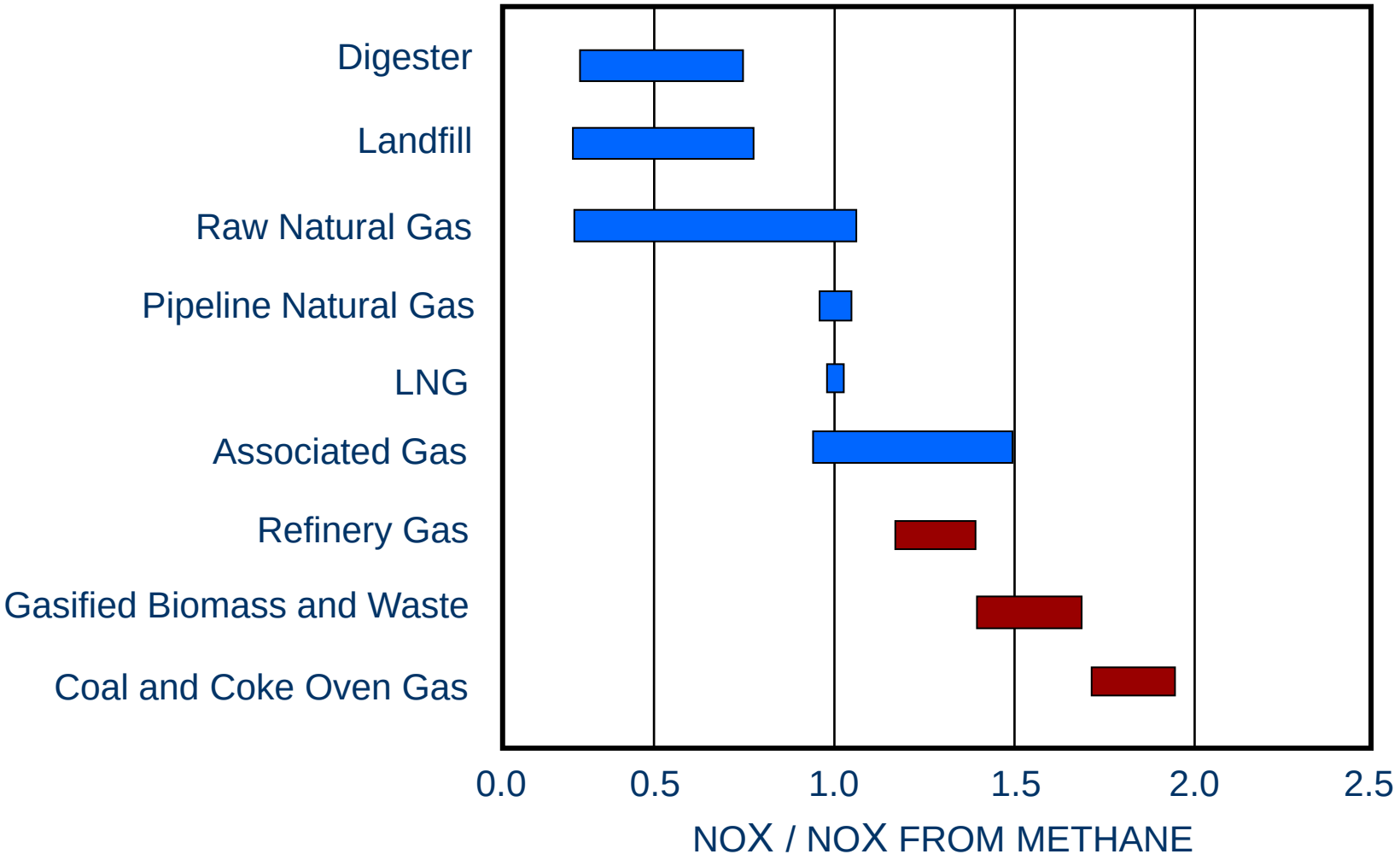


Gas Fuel – Autoignition Delay Time

- Time for Fuel Air Mixture to Self Ignite (No Match or Spark)
- Of Concern for SoLoNOx…Not Conventional

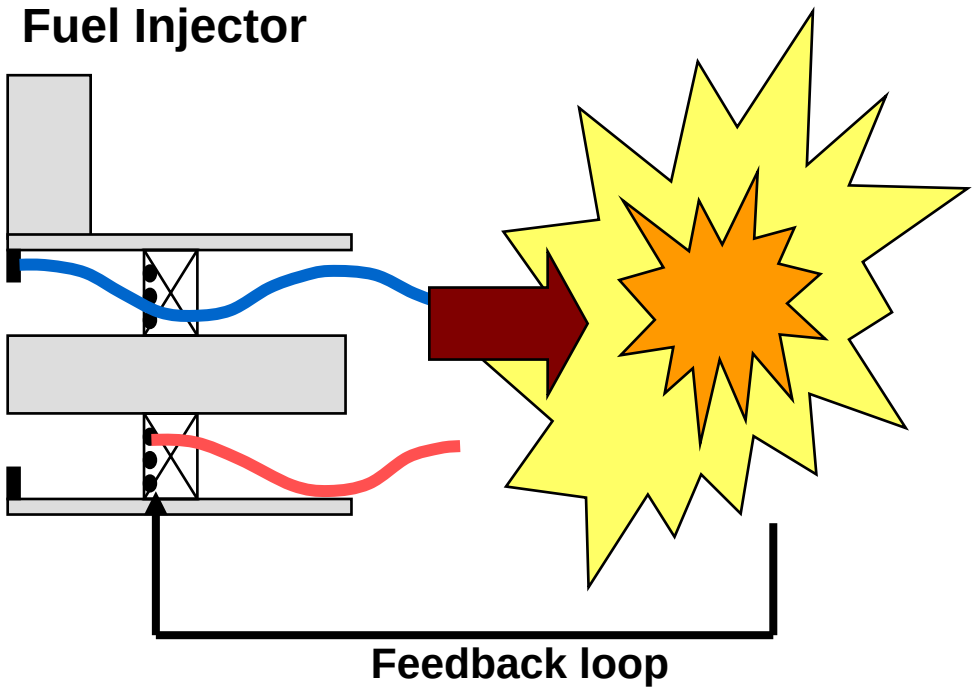


GAS NOX EMISSIONS RULE OF THUMB (CONVENTIONAL)



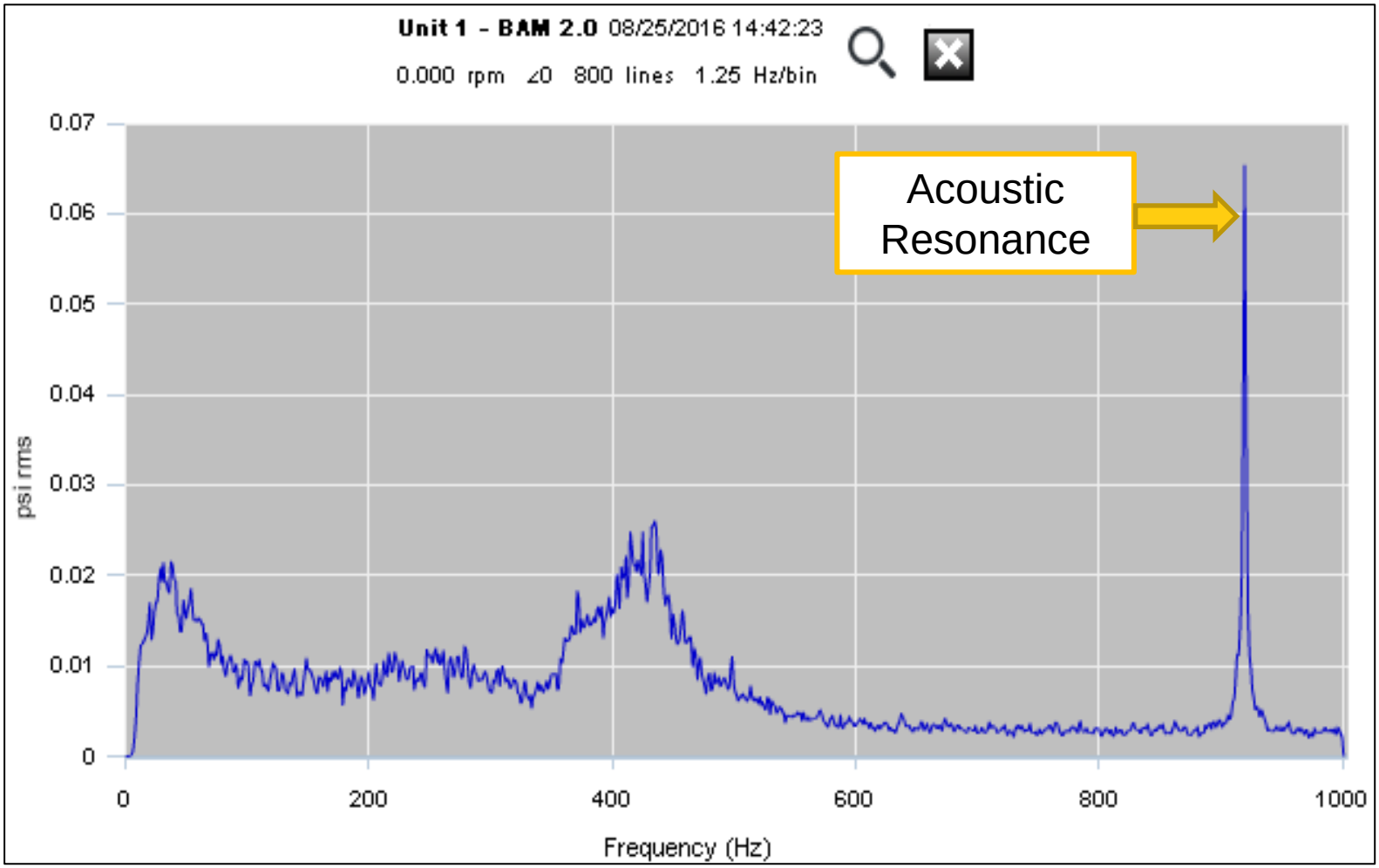
COMBUSTION STABILITY - PRESSURE OSCILLATIONS

- Combustor Pressure Oscillations Due to Acoustic Feedback
  - Excite at 100 to 1000 Hz



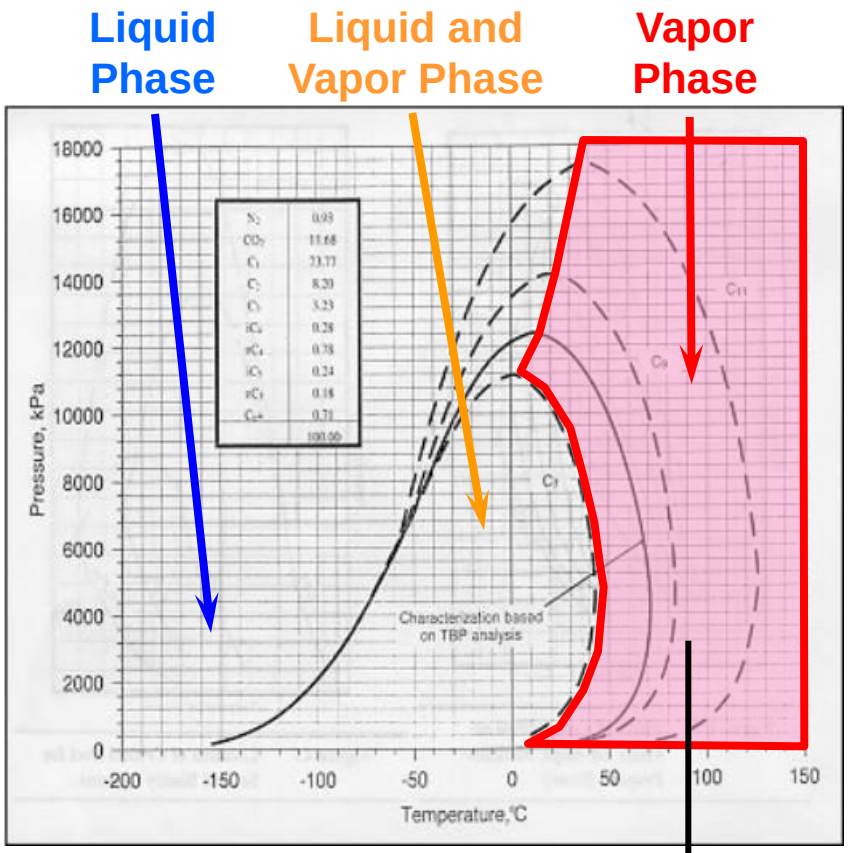
- Combustor Rumble Due to Local Flame-out
  - < 100 Hz

COMBUSTION SYSTEM ACOUSTIC STABILITY



DEW POINT AND SUPERHEAT

- **Heavy Hydrocarbons (HC)**
  - Increase HC Dew Point
  - Lead to Liquid Dropout
- **Fuel Heating**
  - HC Dewpoint
  - Water Dewpoint
- **Accurate Fuel Analysis**
  - C6 to C10 Analysis
  - Or Measure Dew Point
  - Minimum T_{fuel} Required



Must Keep Gas Fuel in **Superheated Vapor** Region

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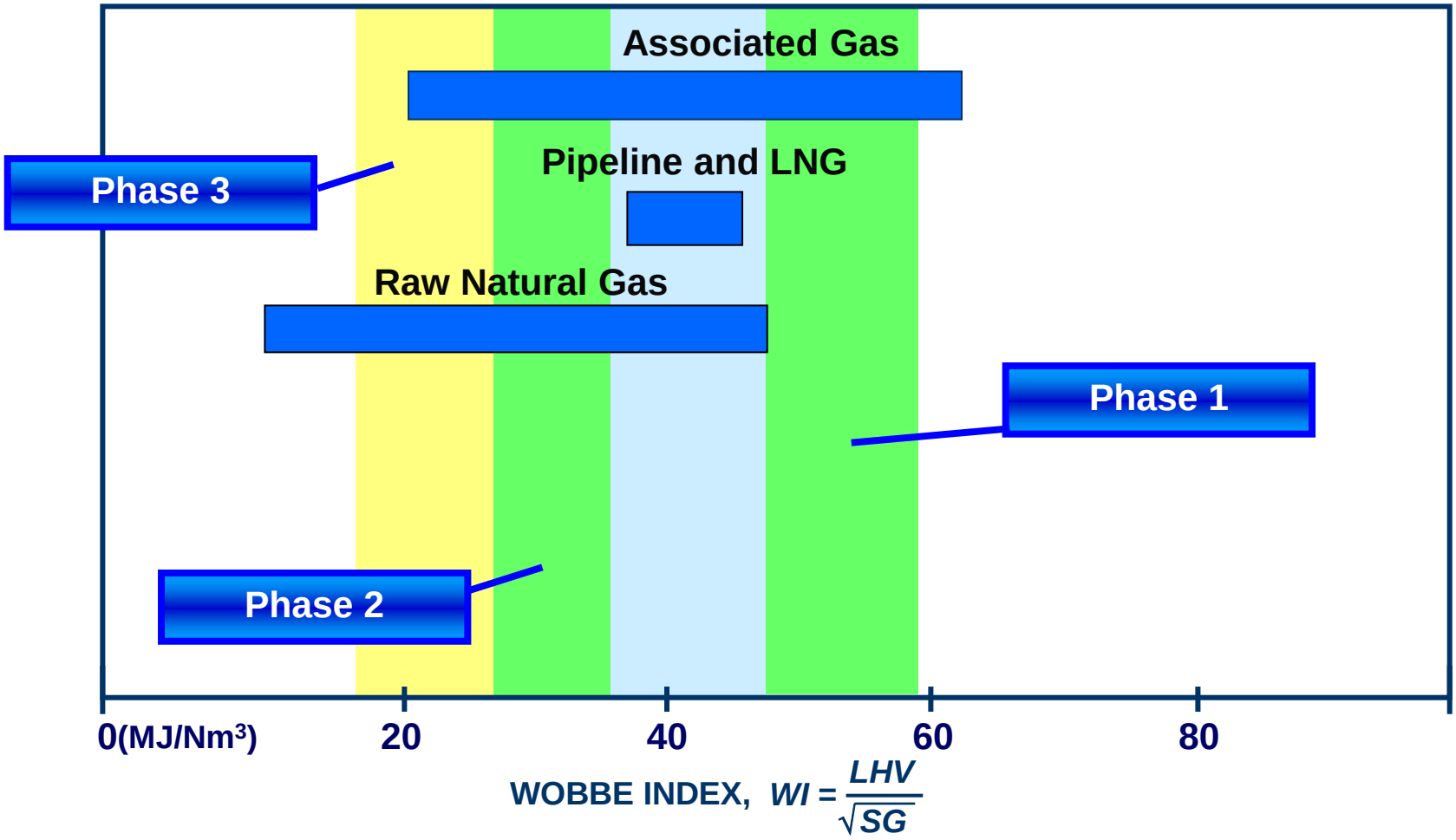
ASSOCIATED GAS – DLE DEVELOPMENT STRATEGY



SOLONOX FUEL EXPANSION METHODOLOGY

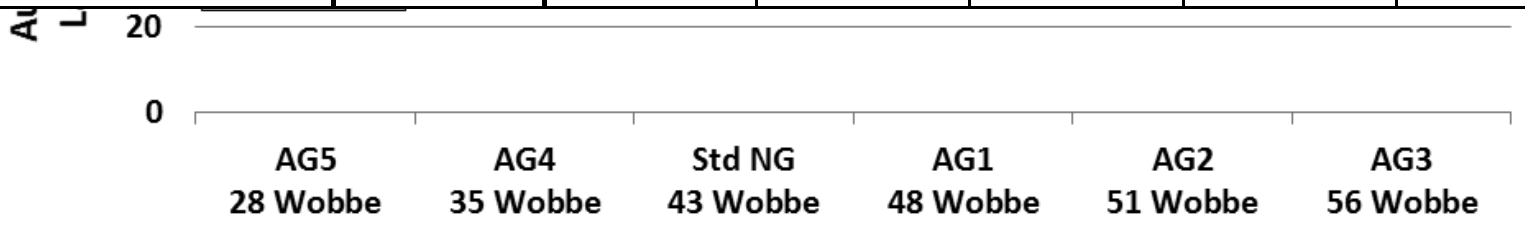
- **Modeling for Flow, Combustion and Heat Transfer Characteristics**
  - CHEMKIN-PRO
  - STAR CCM+
- **Single Injector Rig Testing**
  - Flashback/Blow-Out
  - Injector Temperatures
  - Emissions
- **Engine Testing**
  - Liner Temperatures
  - Emissions
  - Combustion Stability
  - Transient Testing

ASSOCIATED GAS TEST FUELS

- Blend of Methane + Ethane + Propane + Butane + CO_2

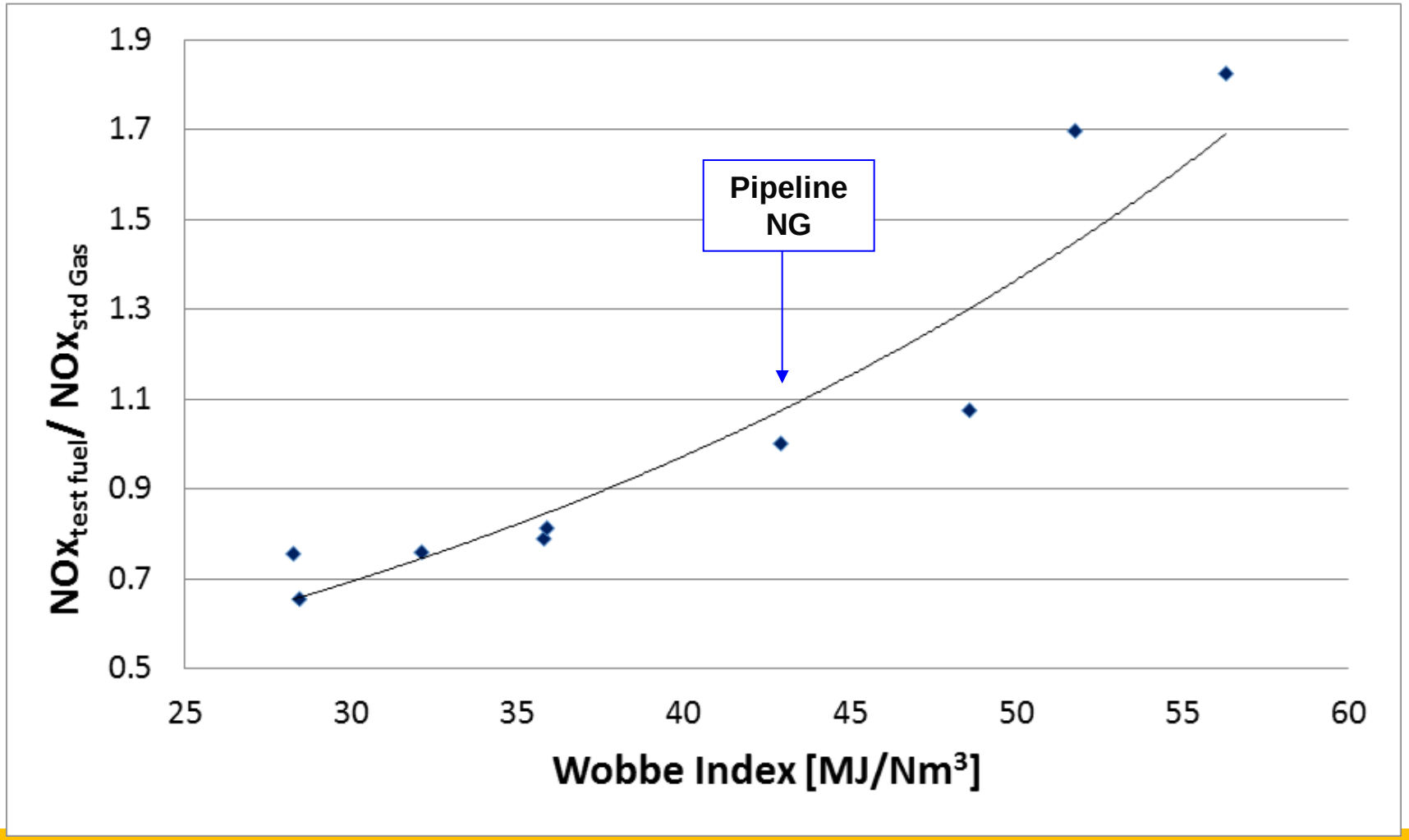
Associated Gas Test Fuels Compared to Natural Gas

	Std NG	Associated Gases				
		#5	#4	#1	#2	#3
Wobbe (MJ/Nm3)	43	28	35	48	51	56
Methane (%vol)	93	71	83	74	68	51
Ethane (%vol)	4	3	4	3	3	2
Propane (%vol)	1	0.6	0.7	21	19	30
Butane (%vol)	0.2	0.1	0.2	0.1	9	15
CO2 (%vol)	2	24	11	0.4	0.3	0.2
Dewpoint (C)	-37	-27	-32	13	42	62



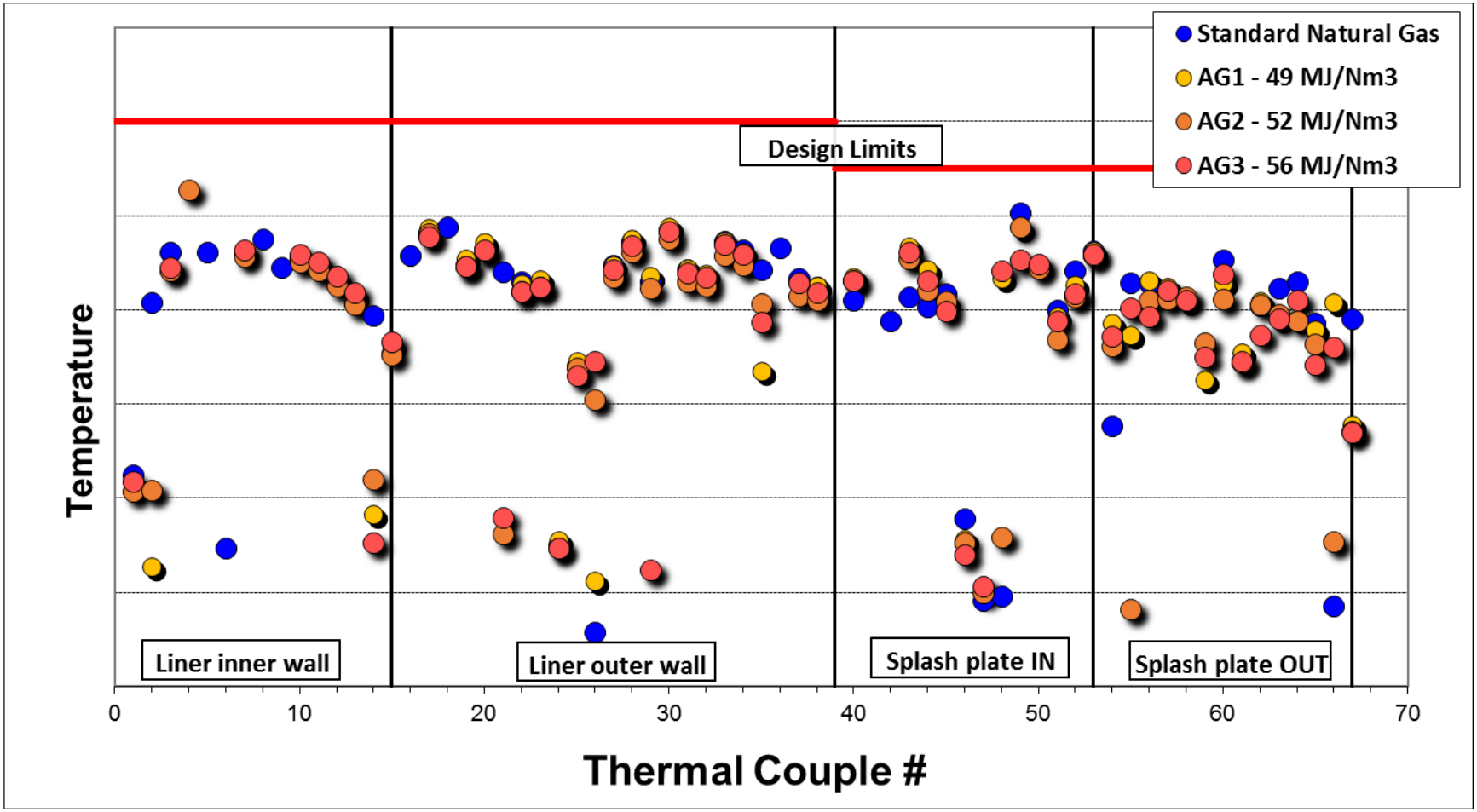
FULL LOAD EMISSIONS – TITAN 130S

- Natural Gas Blended with Propane and Butane and CO2
- No Increase in Combustor Pressure Oscillation Amplitude

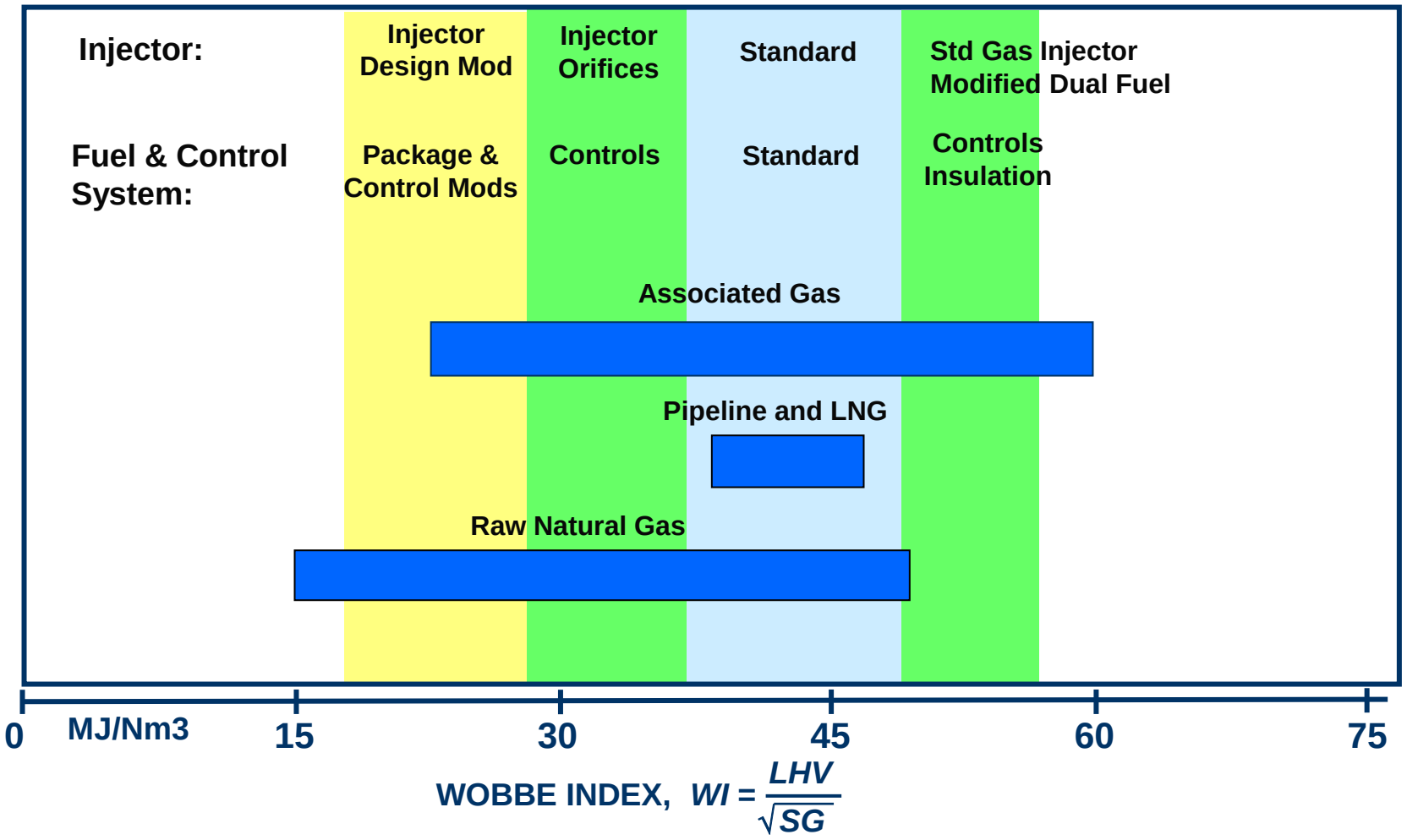


COMBUSTOR LINER WALL TEMPERATURES

- Titan 130 at Full Load Operation
- No Change in Temperature



DLE ENGINE & PACKAGE CHANGES



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ASSOCIATED GAS – PRODUCT EXPERIENCE

Engine	Conventional	SoLoNOx
Saturn	>1100	-
Centaur	>1200	>60
Taurus 60	>500	>120
Taurus 70	>150	>40
Mars	>400	>80
Titan 130	>175	>90
Titan 250	2	>5
Total Units	>3500	>400

- **SoLoNOx Units Achieving Standard Overhaul Hours**

SUMMARY

- Drive to Reduce Pollutant Emissions On-Shore and Off-Shore
- Associated Gas Fuels Can Be Used in Gas Turbines
- DLE Gas Turbine Combustion System Qualified to Use Broad Raneg of Associated and Raw Natural Gas Fuels
  - From 19 to 60 MJ/Nm^3
- Demonstrated
  - Low Emissions
  - Acceptable Stability
  - Acceptable Combustion System Metal Temperatures
  - Standard Reliability Targets

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