Assessing Gas Turbine Fleet Readiness for a Low-Carbon Future

Hydrogen Fueling

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11th International Gas Turbine Conference
October 10-11, 2023
Brussels, Belgium

Background

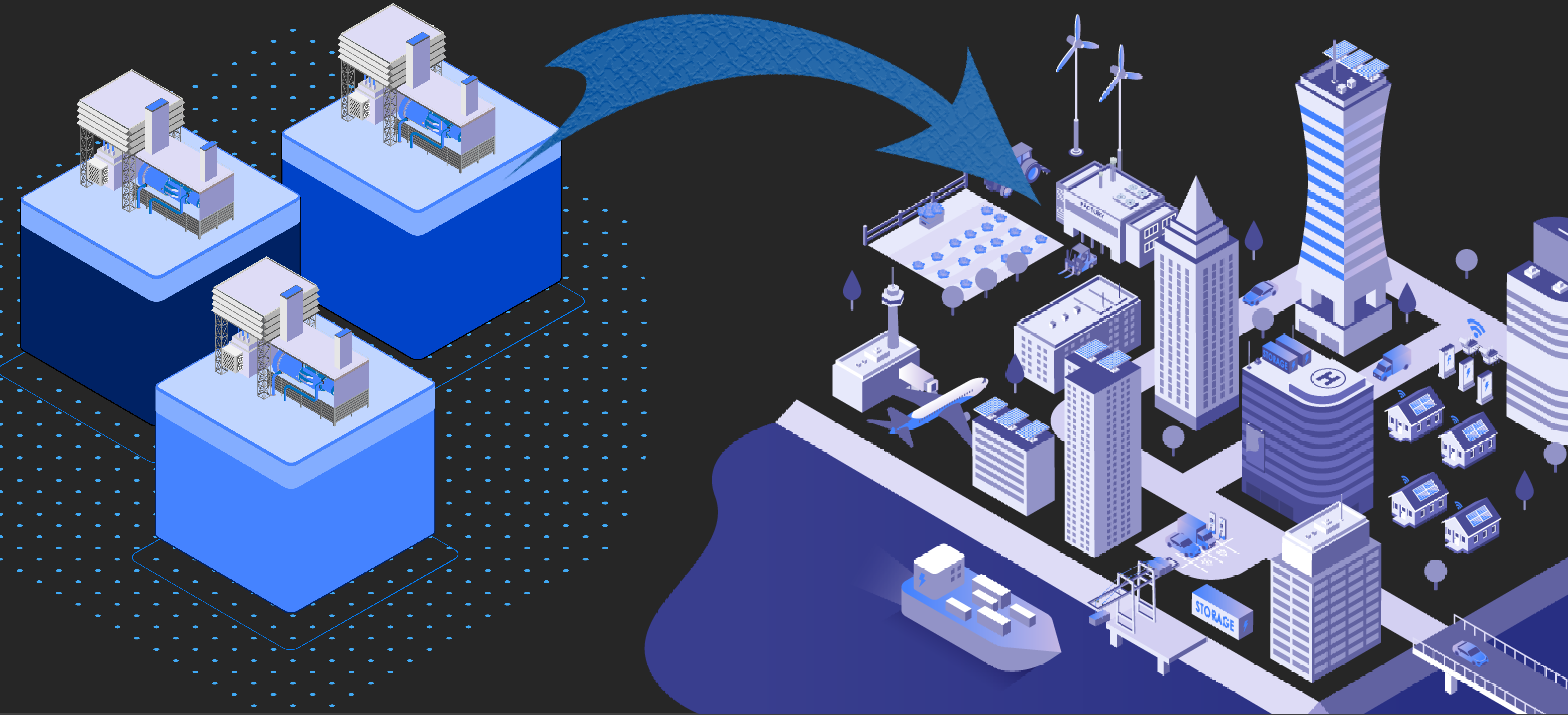
- Carbon Reduction Goals are forcing fleet owners to evaluate options
- Hydrogen Capability is not a single answer of current or future capability
- Practical evaluation of all aspects of capability is important for informed decisions
- This work provides a template of considerations in evaluating gas turbine fleets for hydrogen fueling

Research Goals

- **Develop a list of considerations plant owners need to consider in a hydrogen upgrade**
- Focus on existing turbines
- More detailed then typically provided by OEMs in conference environments
- Less detailed than a full detailed quote
- General enough to be valuable for all land-based GTs
- Detailed enough to provide insight into questions which need more thorough investigations

Site Topics

Assessing GT Asset Needs for Low-Carbon Plans



Safety, Codes, Procedures and Training

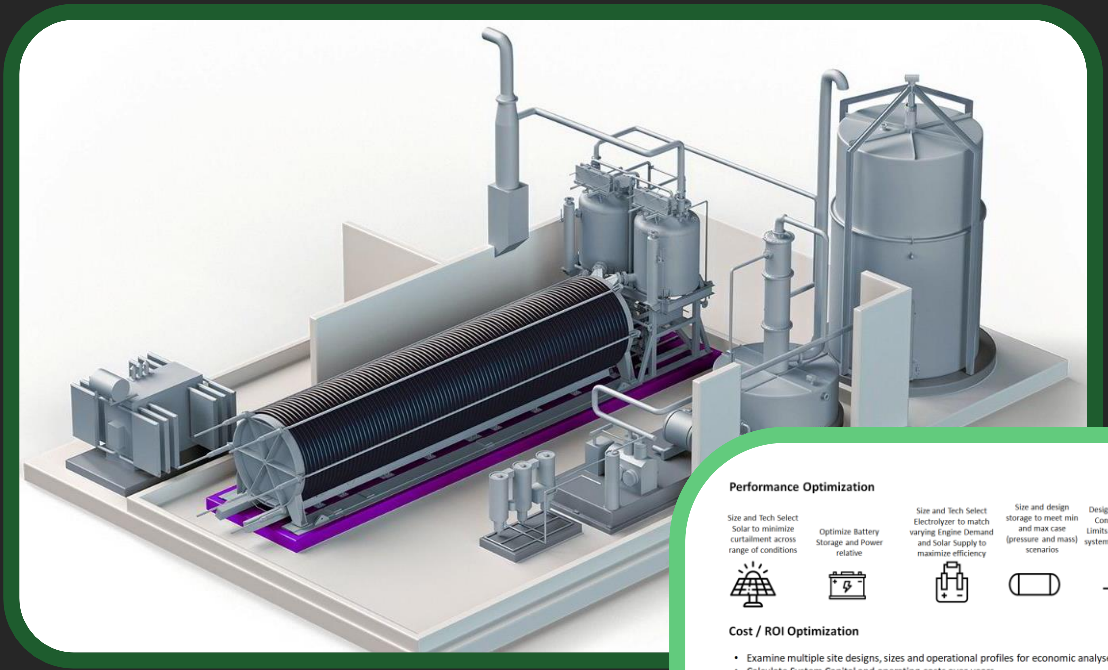
Piping Codes

Enclosures Ratings

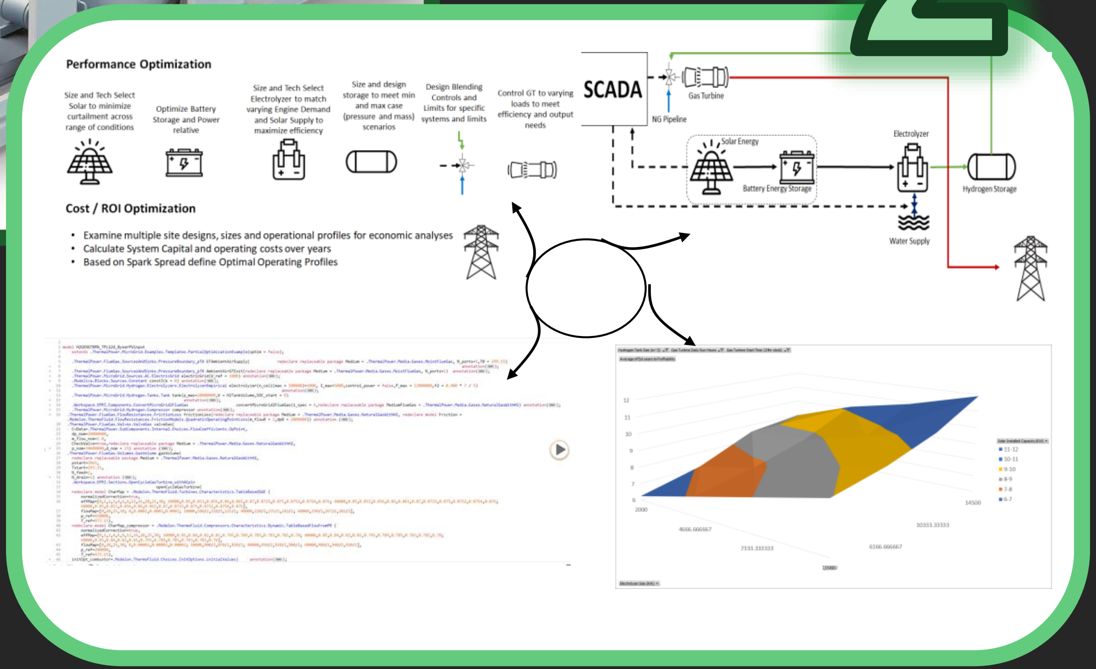
Site Procedures

- Material Selection and Component Design Requirements
- Procedure Updates
  - Commissioning
  - Startup and shutdown
  - Pressure and leak testing
  - Gas line Flushing / Cleanliness
  - Purging and Gas charging

Pre-Design work – Feasibility/FEED Studies & Analysis



H_2



- Prioritize intentions for site needs
- Layout system for site integration
- Model interactions for production, storage, & usage
- Compile engineering plan for action

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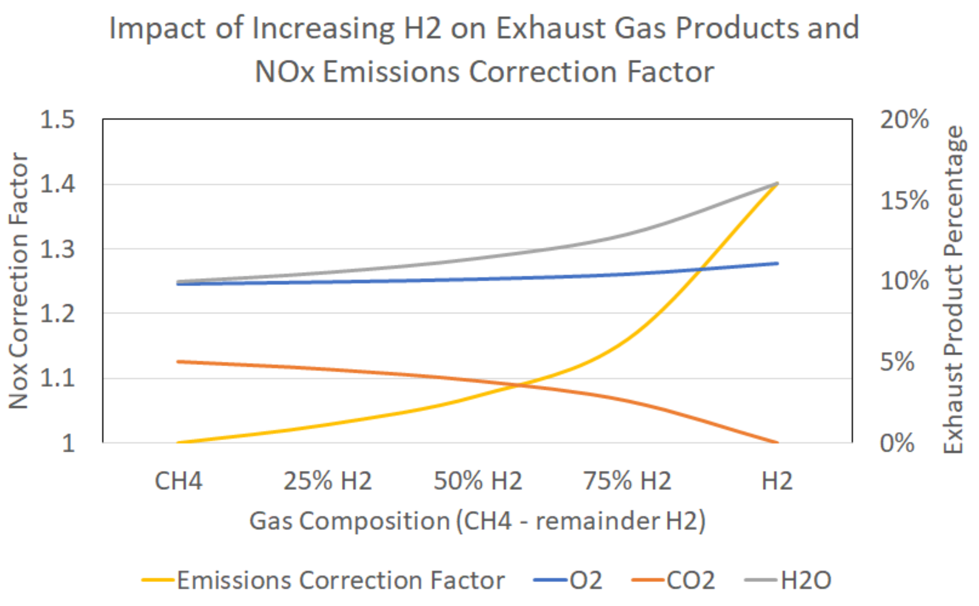
Emissions Regulations

- Regulations – Changing (min Hydrogen usage, CO_2 limits)
- Hydrogen
  - Impacts NOx volume Based Corrections
  - Impacts Mass Based Calculations



F Factor Calculation

Using Method 19:

scf/lb % mass basis (converted from % molar basis given in the fuel analysis)

$$F_d = \frac{K(K_{hd}\%H + K_c\%C + K_s\%S + K_n\%N - K_o\%O)}{GCV} \quad \text{Eq. 19-13}$$

Btu/lb

K = Conversion factor, 10^{-5}(kJ/J)/(%) [10^6 Btu/million Btu].

K_c = (9.57 scm/kg)/% [(1.53 scf/lb)/%].

K_{cc} = (2.0 scm/kg)/% [(0.321 scf/lb)/%].

K_{hd} = (22.7 scm/kg)/% [(3.64 scf/lb)/%].

K_{hw} = (34.74 scm/kg)/% [(5.57 scf/lb)/%].

K_n = (0.86 scm/kg)/% [(0.14 scf/lb)/%].

K_o = (2.85 scm/kg)/% [(0.46 scf/lb)/%].

K_s = (3.54 scm/kg)/% [(0.57 scf/lb)/%].

K_w = (1.30 scm/kg)/% [(0.21 scf/lb)/%].

F_d will change as the fuel blend changes

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Hydrogen GT Impacts Summary

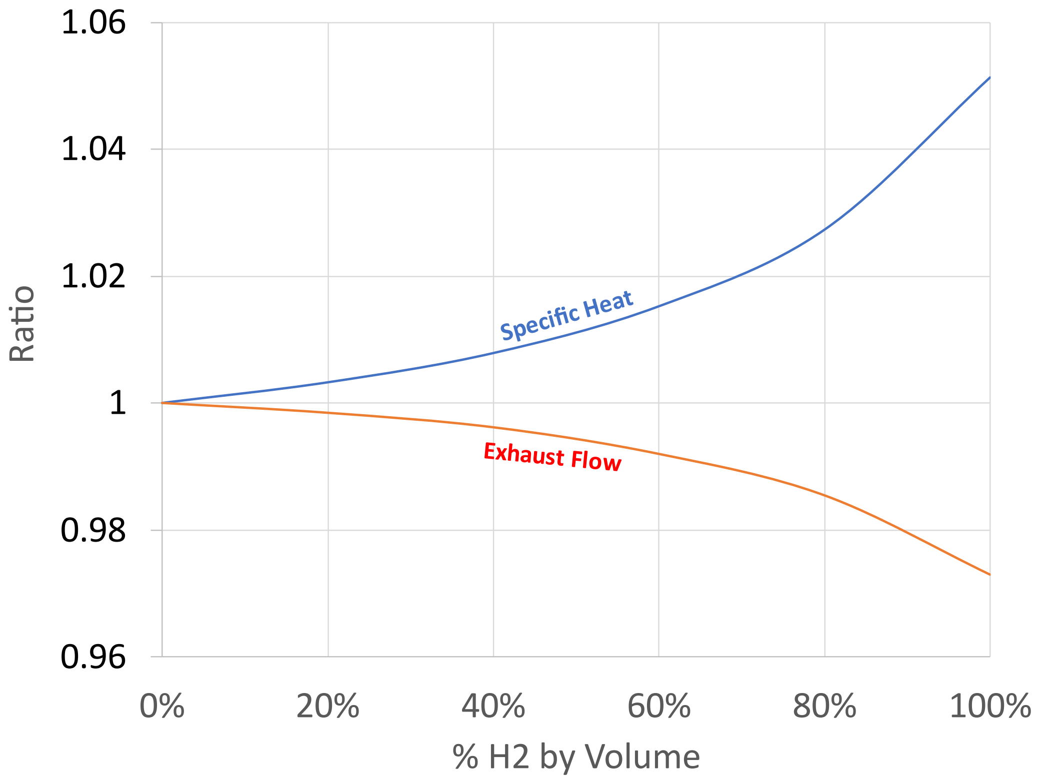
- Major Takeaways

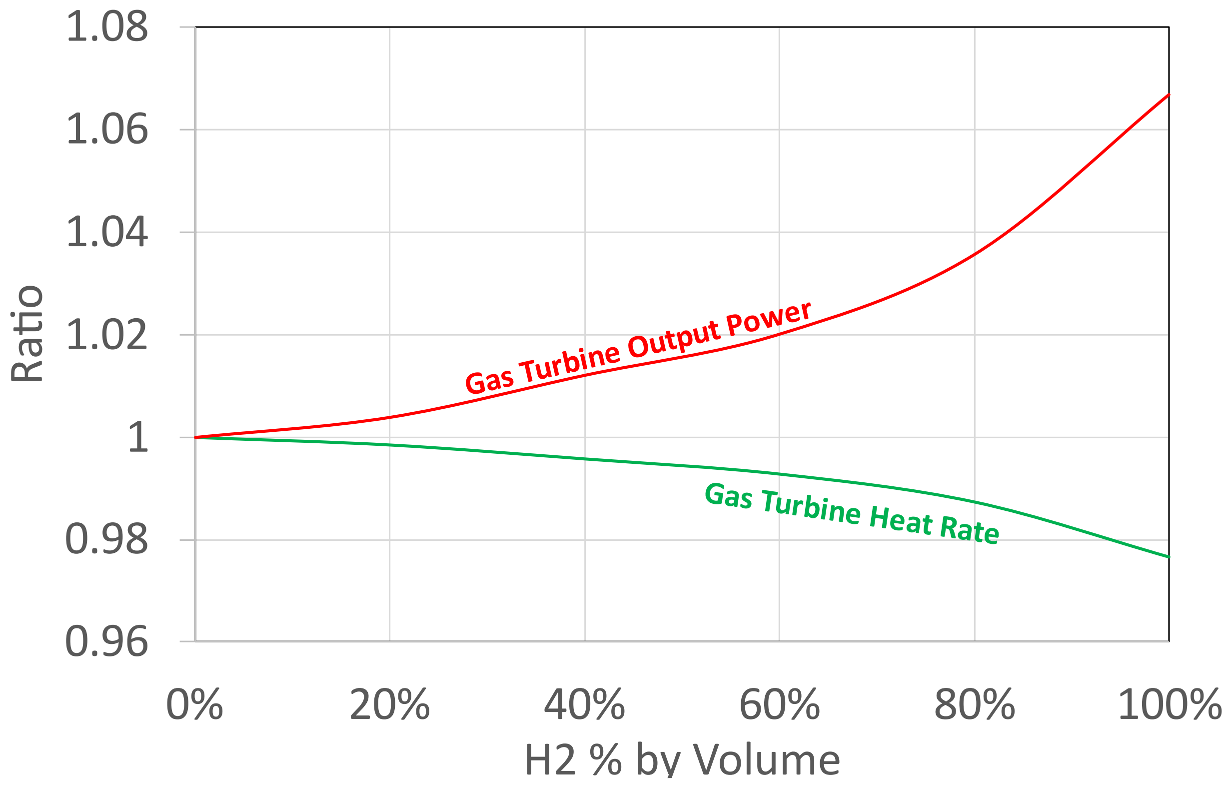
Parameter	Effect of Increasing H_2
Load	↑
Firing Temperature	↔
Heat Rate	↓
Total Fuel Flow (Mass)	↓
CPR	↔
Mass Flow Rate (Inlet), Compressor Power Draw	↔
Mass Flow Rate (Exhaust), Turbine Power	↑
CO_2	↓
H_2O, O_2	↑

Unit Topics

Performance and Efficiency

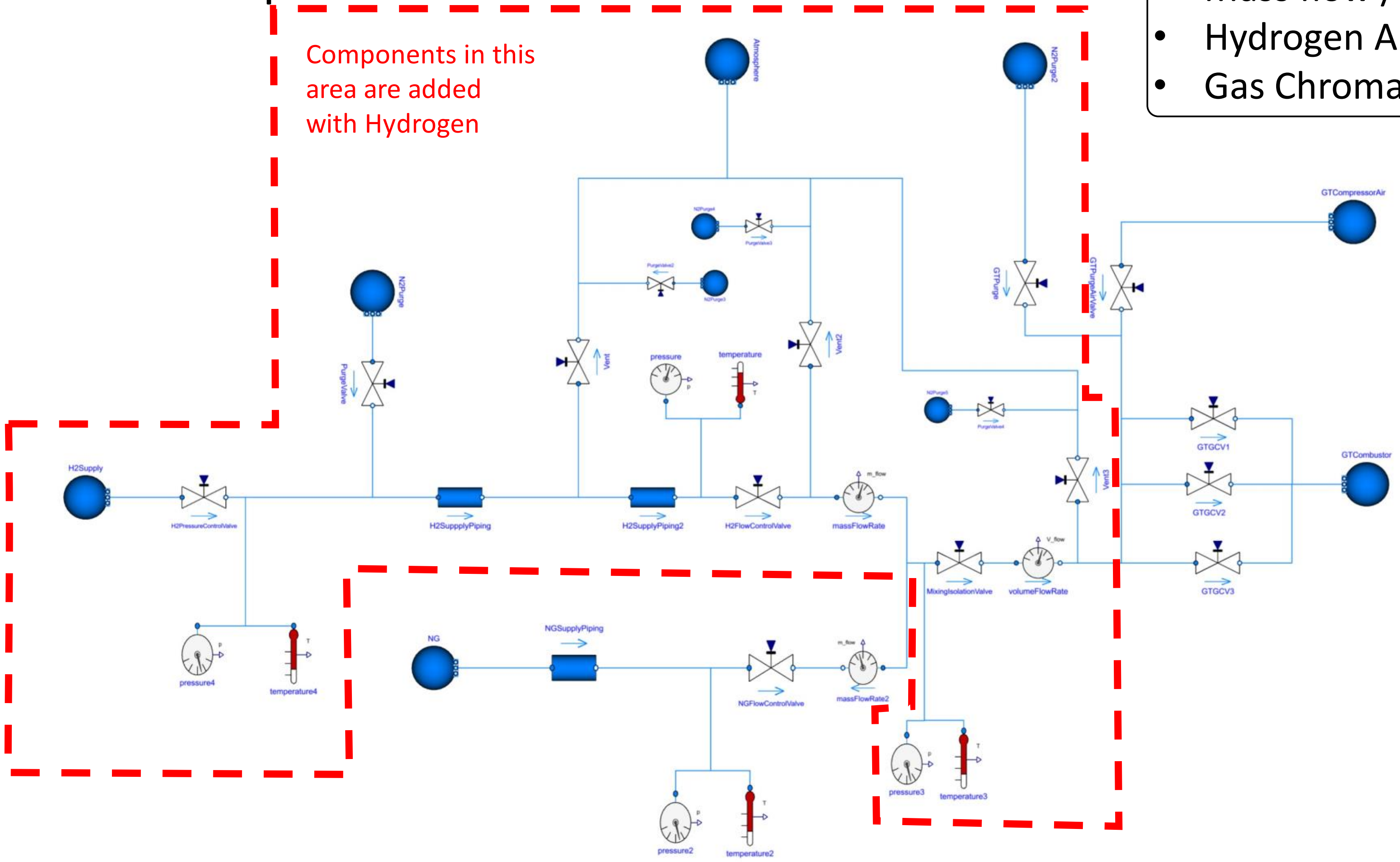
- Hydrogen Blending will impact Power, Heat Rate, Exhaust Flow and Component heat transfer via changes in exhaust products





Fuel Delivery

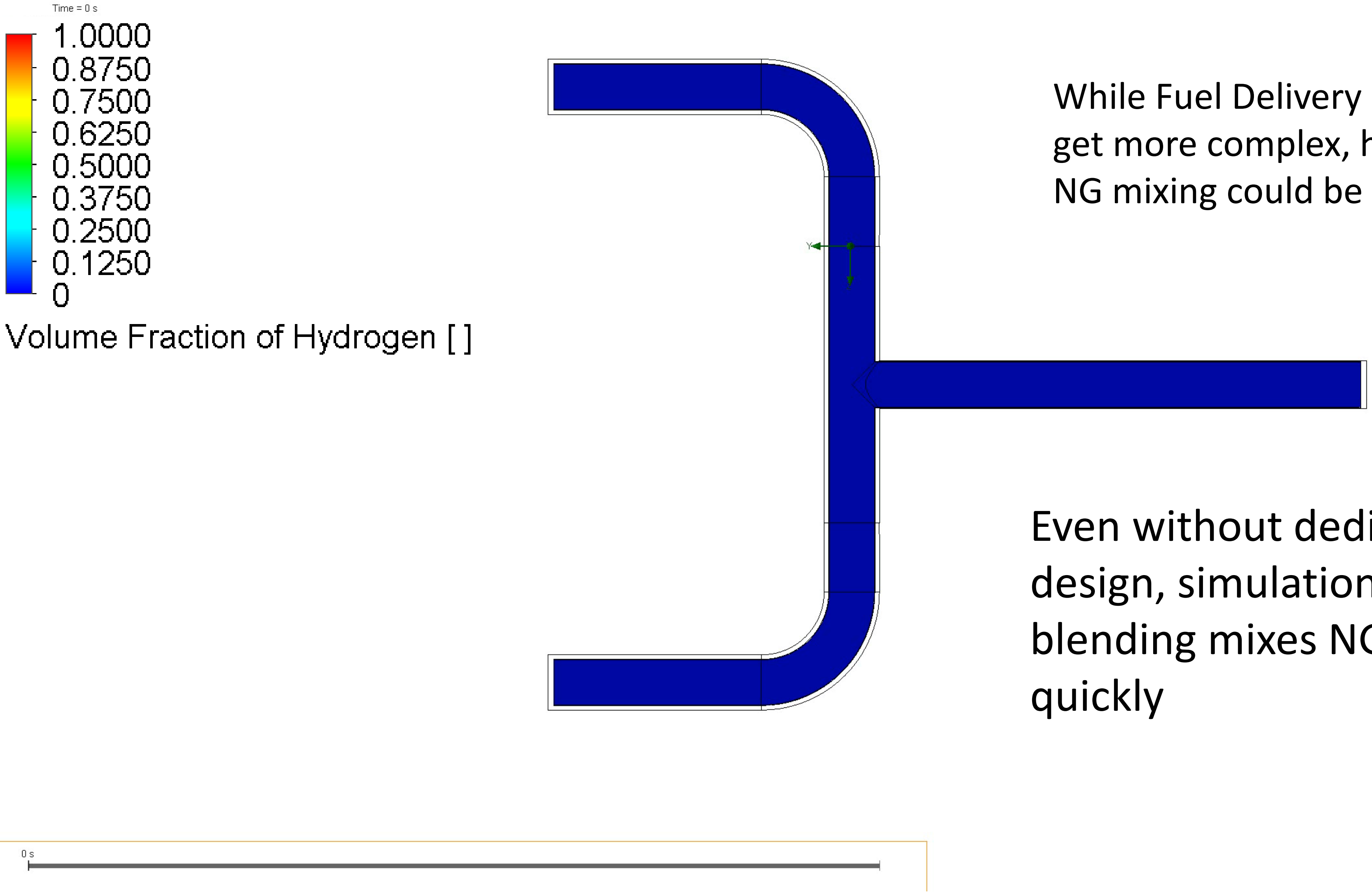
Fuel Supply Systems may get significantly more complex



Systems will vary as components options have advantages /disadvantages, e.g. for gas composition:

- Mass flow / Volume Flow Meters
- Hydrogen Analyzers
- Gas Chromatographs

Fuel Delivery



While Fuel Delivery Systems may get more complex, hydrogen and NG mixing could be simple

Even without dedicated Mixing design, simulation suggests simple blending mixes NG and hydrogen quickly

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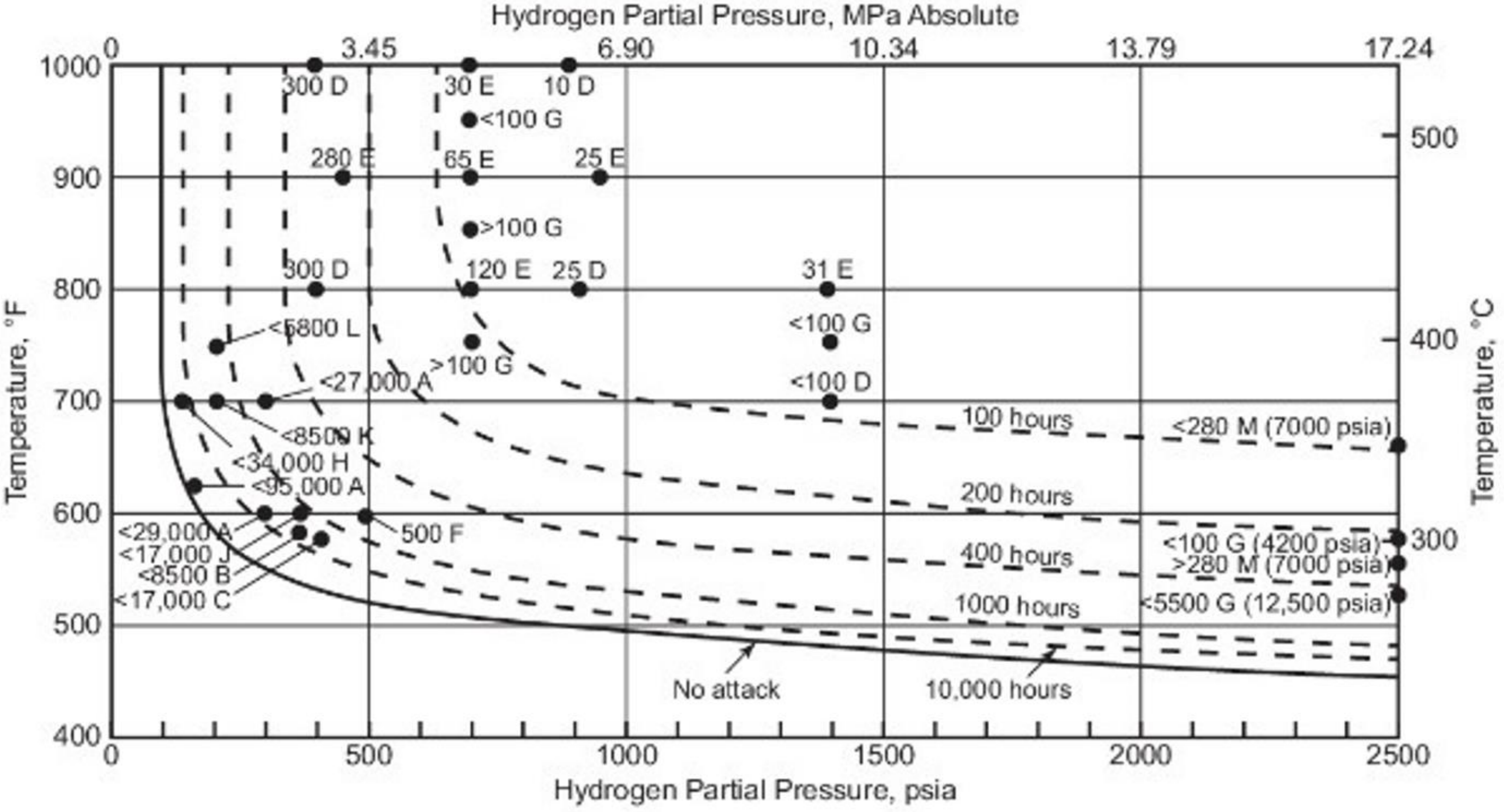
Material Impact and Selection with Hydrogen

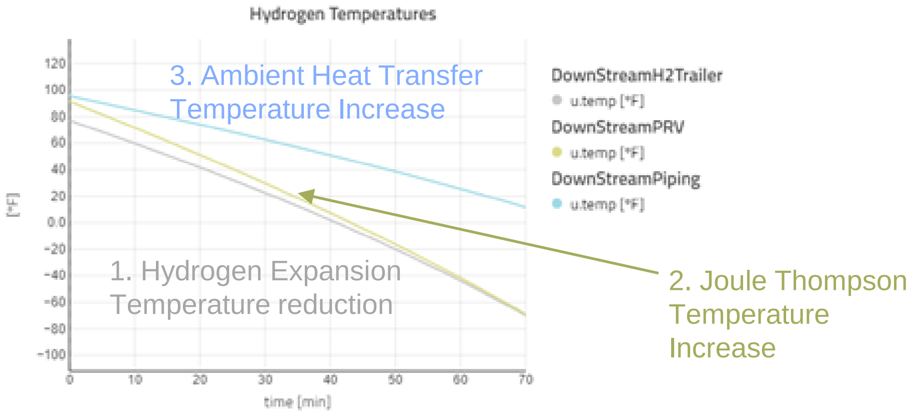
Hydrogen Codes / Standards will need experts to determine impact on hardware / design

Nelson Curve and High Temperature Hydrogen Attack Analysis

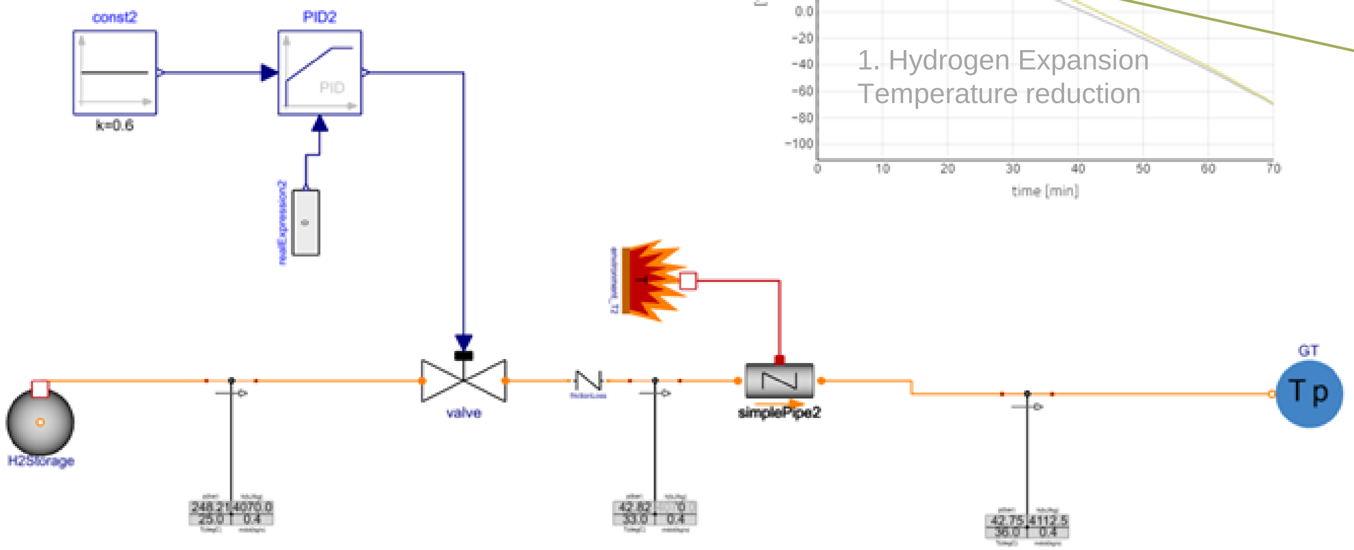


Ref: API RP941 HTHA nelson curve table

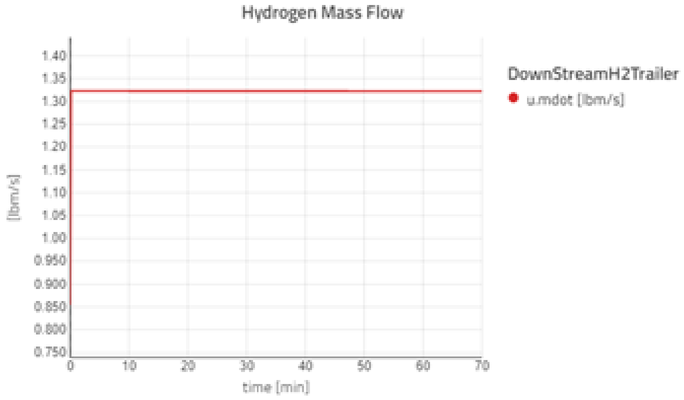
Source of Hydrogen will impact Fuel Delivery Controls and Demands

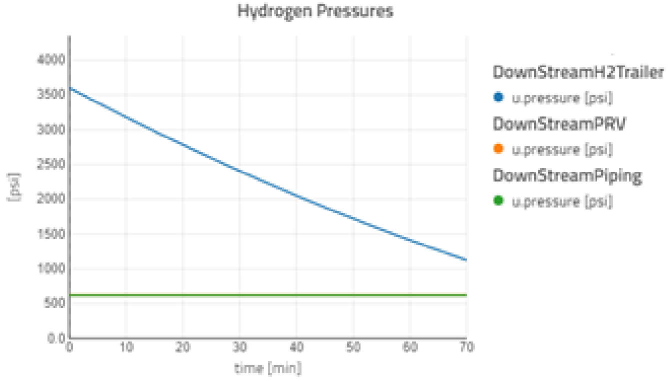


Hydrogen Temperature change with compression/ expansion, JT, and Ambient Heat Transfer



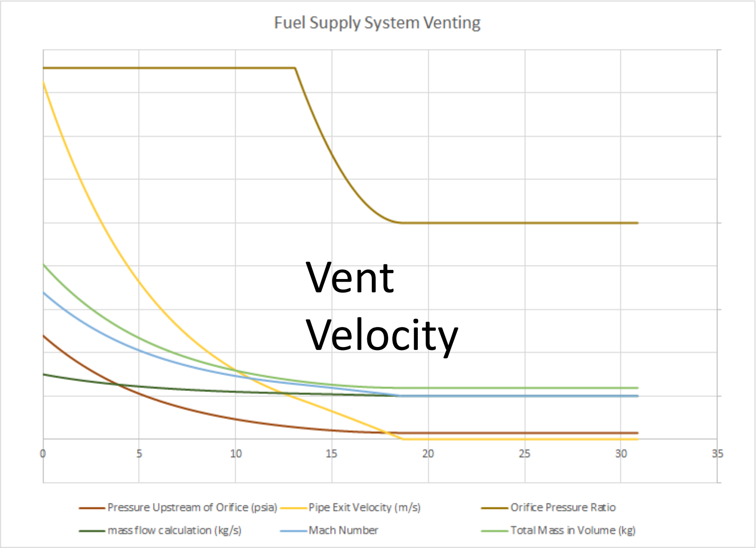
Ambient Heat Transfer and Local H_2 storage may mean H2 temperature is a strong function of tank pressure, flow rate, GT pressure, and time



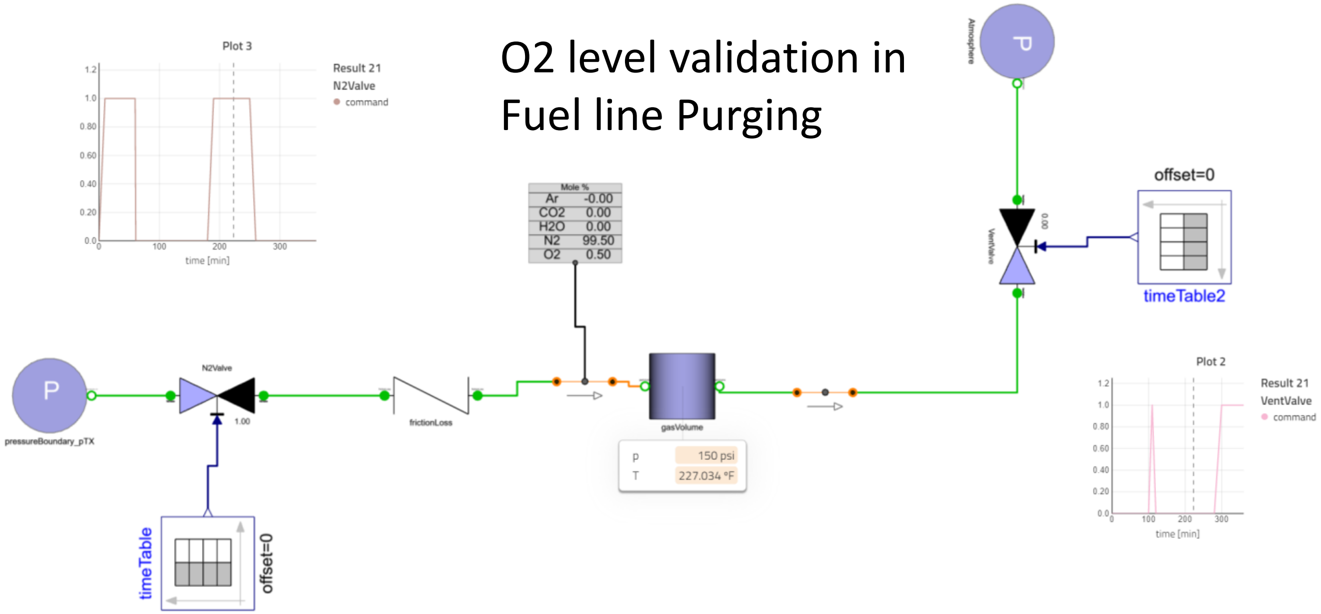


Leak Detection, Inert Purging, Venting, Gas Charging

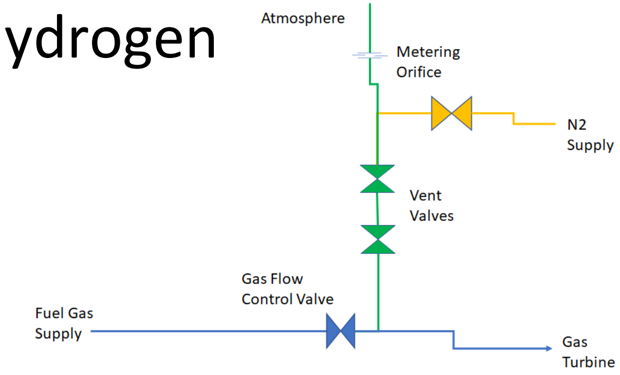
- Hydrogen impacts operations before startup and during fueling



O2 level validation in Fuel line Purging

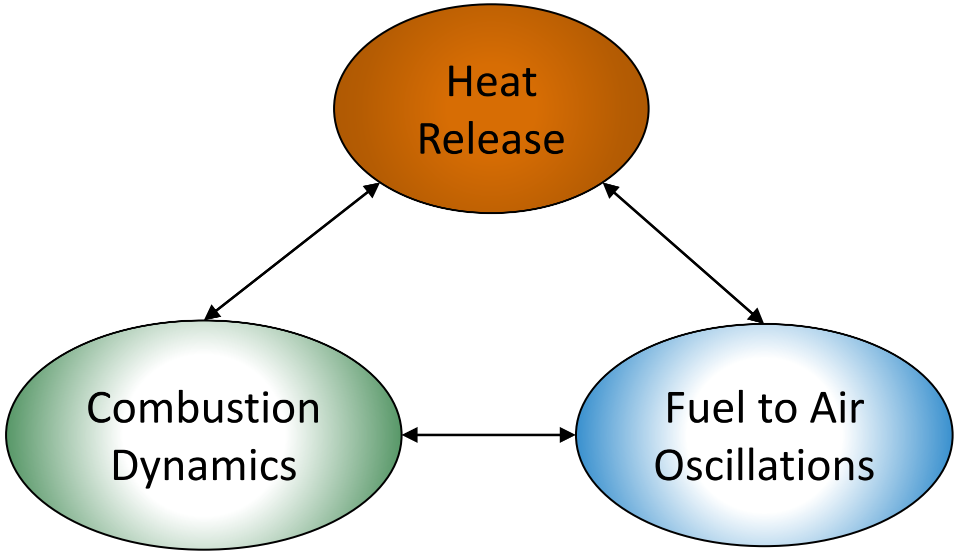


Gas Venting to Change with Hydrogen

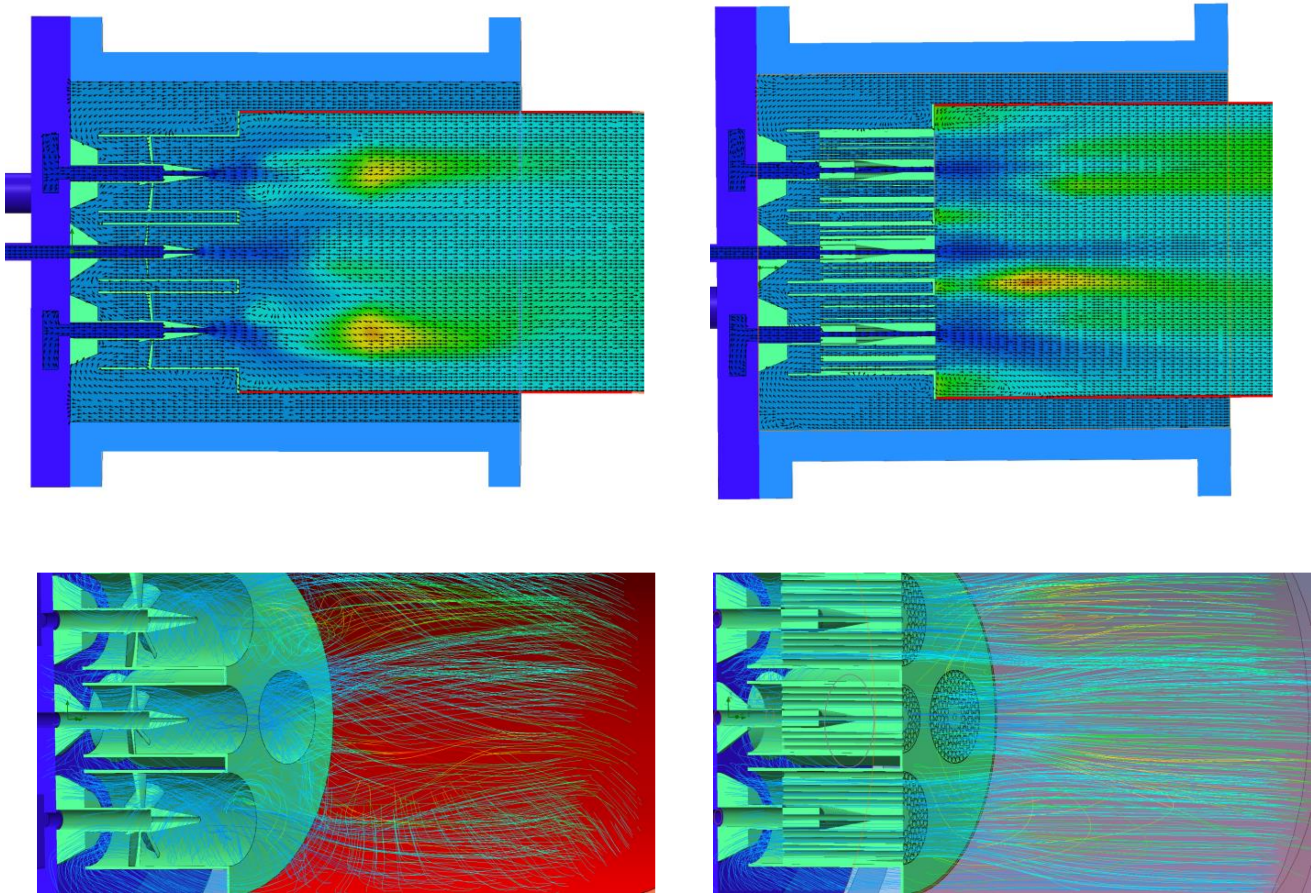


Combustion System –Design: Emissions, Dynamics and Flameholding

- Emissions may drive design changes
- Flameholding/Flashback prevention
  - Change in heat release, combustion properties may result in design change
- Combustion Dynamics / Control
  - Change in design and heat release may result in combustion dynamics changes



Example Design Progression resulting in temperature and flow field changes



(NOT REPRESENTATIVE OF ANY PARTICULAR DESIGN)

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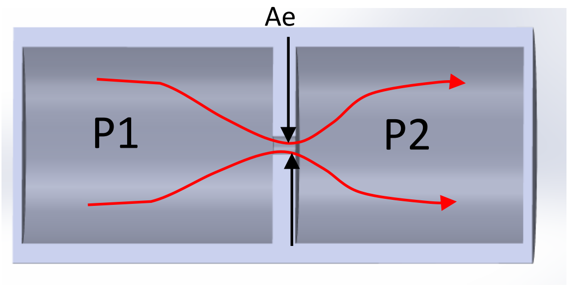
Fuel Composition Impact on Fuel Nozzle Pressure Ratio “Effective Area”

$$MWI = \frac{LHV}{\sqrt{SG * T_g}}$$



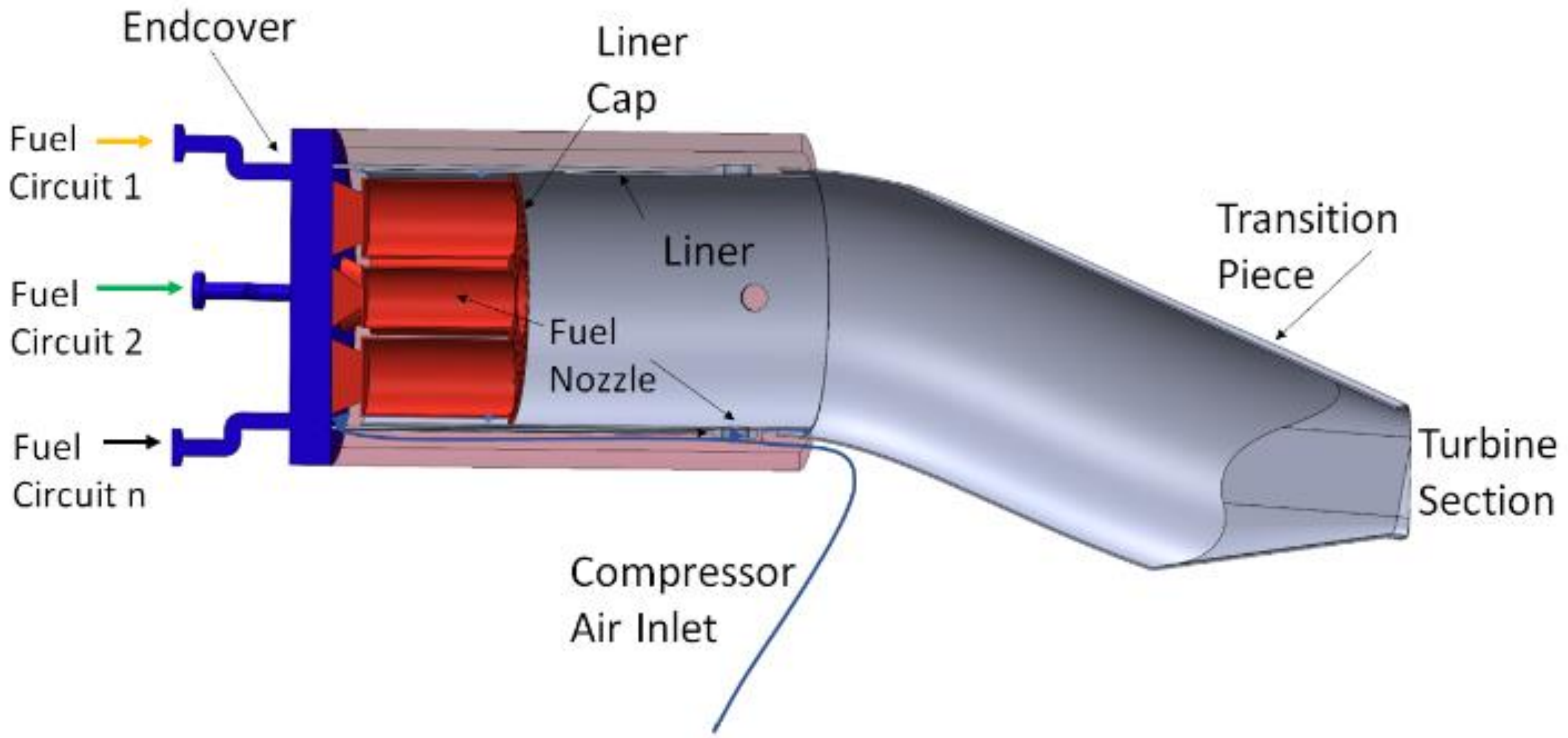
- Effective Area is a measure of useful flow area
- Relates the fuel and fuel composition to the mass flow and pressure drop
- Related to the MWI through fuel composition and fuel Temperature
- Effective area flow relationship shown to the right
- Can be used to calculate flow and nozzle pressure ratio impact of fuel composition changes

$$\dot{m} = \frac{A_e P_1}{P_R}\sqrt{\frac{2}{RT}\left(\frac{\gamma}{\gamma - 1}\right) P_R^{\frac{\gamma-1}{\gamma}}\left(1 + \left(\frac{1}{P_R}\right)^{\frac{\gamma-1}{\gamma}}\right)}$$

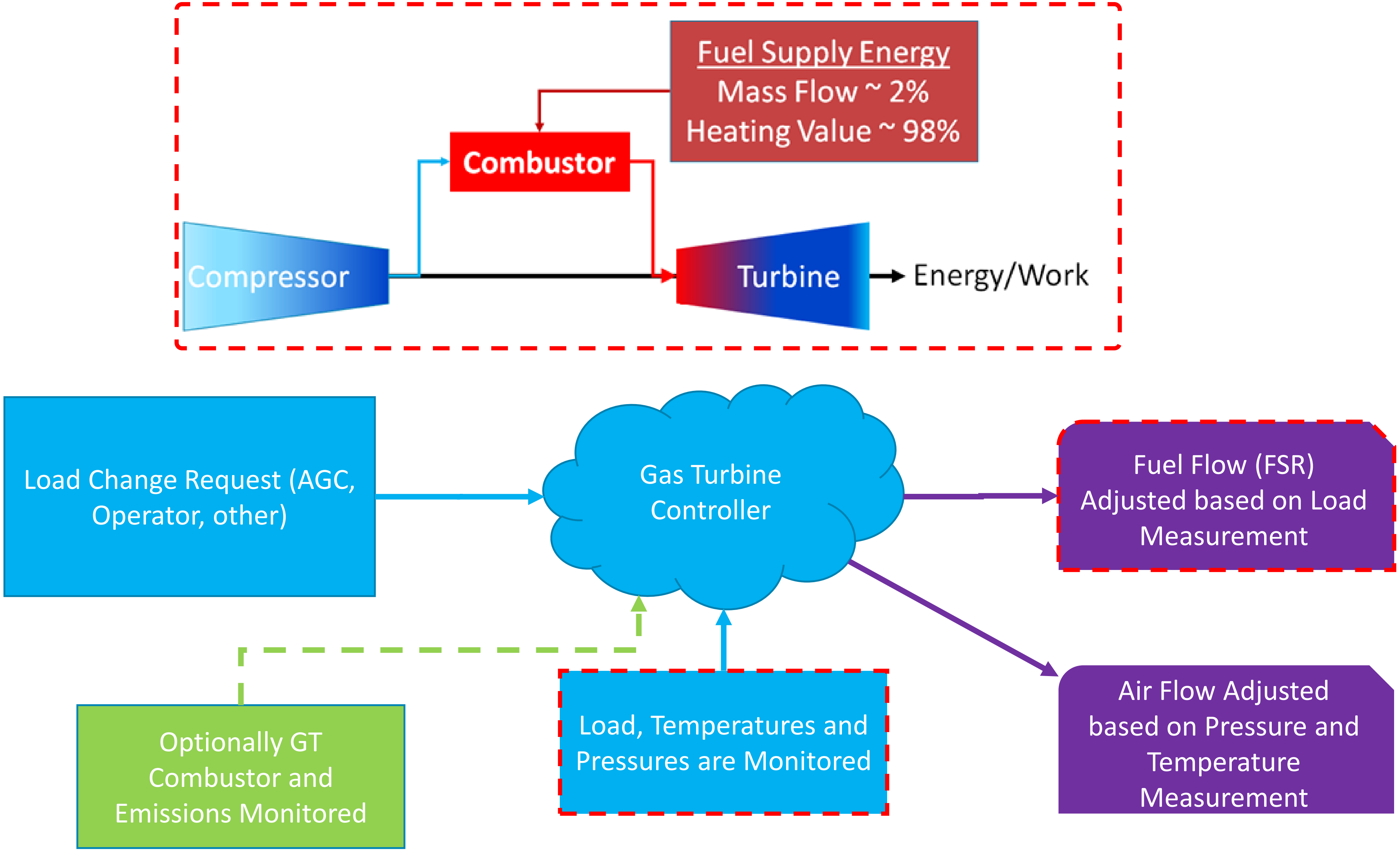
- Where
  - m is mass flow through the component (Fuel Orifice)
  - Ae is the “effective area” of the component
  - P_1 upstream pressure of component
  - P_R pressure ratio across component
  - γ Ratio of specific heats
  - R Specific Gas Constant; R= 287 Pa*m^3*K
  - T Compressor Exit Temperature (K)

Combustion System – Other Components Potential Updates

- Coatings
  - May change based on new flame structures
- Liner/Transition Piece Length / Diameter
  - Based on hydrogen flame speed may need to be changed
- Combustor Pressure Drop
  - May require changes to account for updated performance and turbine cooling requirements



Control System



Gas Turbine Combustion System Commissioning

Gas Turbine Metric	Turbine Operating Temperature	Flame Tuning Through Fuel Splits
Performance	Proportional	Negligible Impact
Operability	Impact if Lowered Too Much	Direct Impact
NOx	Proportional (Exponential)	Direct Impact (tune specific)
CO	Inversely Proportional (strongly Exponential)	Direct Impact (tune specific)

Hydrogen Impacts all Metrics

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I/O Updates

- Valves
- H2 Analyzers, Chromatographs/Wobbe
- Flow Meters: Mass/Volume
- LEL / H_2 leak detectors
- New Gas/Blend Pressure / Temperature

Blending and Fuel Control Updates

- Blending control / Fuel Scheduling
  - Fuel Mode control with Blends
  - Manage instrumentation and valve feedback
  - Blend Control during all operation
- Fuel Gas Purging

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