Project 201: Assessing NG to H2 Industrial Transition for SoCalGas

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Client: SoCalGas

Spring to Fall 2024 Cohort

CAL STATE LA
CALIFORNIA STATE UNIVERSITY, LOS ANGELES

SoCalGas
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Team Members:

From left to right:
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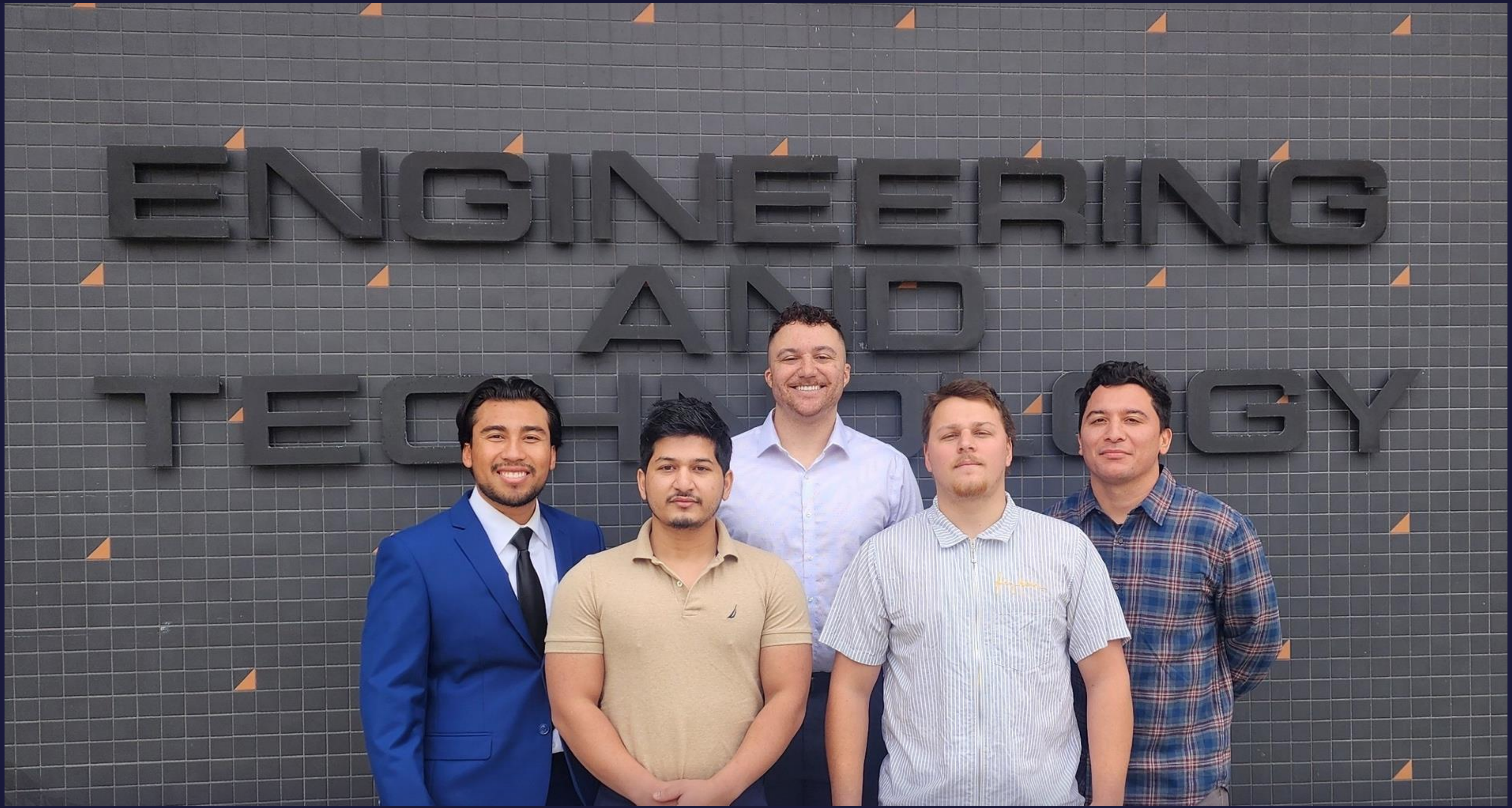

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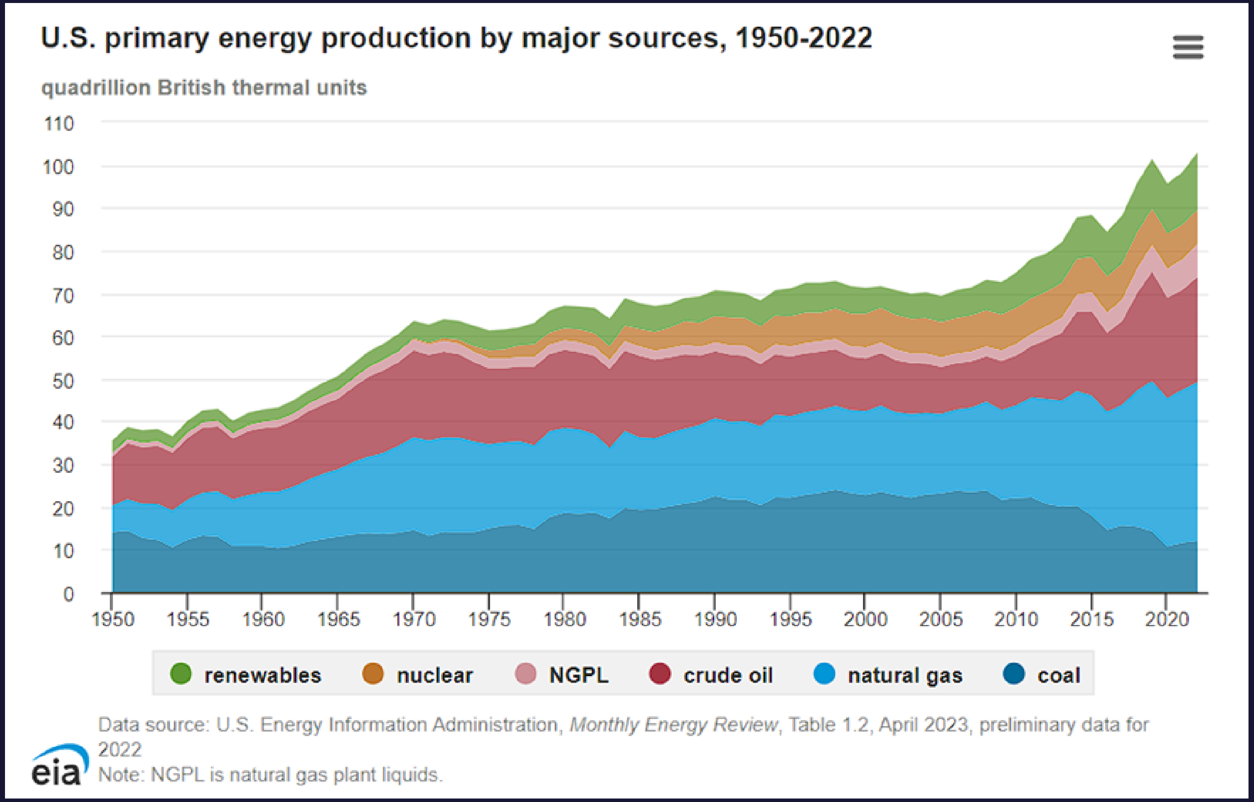
Project Background:

- NG contributes significantly to climate change through greenhouse gas emissions
- Industry Relevance and project Impact
- NG to H2 blend benefits
- Job Creation and Economic Growth
- Energy Security
- Alignment with SoCalGas Goal
- Emission Reduction Targets
- Operational Feasibility



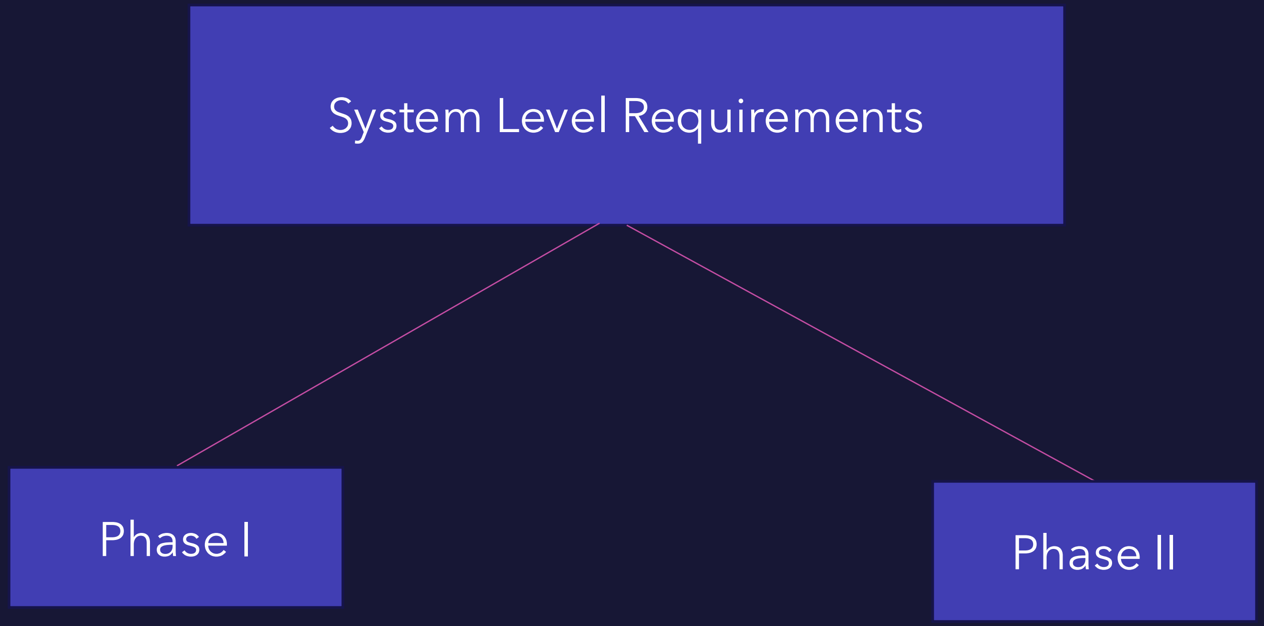
US Emission by energy source

Objective:

- Conduct an assessment the transition from natural gas to hydrogen for SoCalGas (via Prototype Test), with a focus on identifying key engineering challenges, opportunities, and feasibility factors with the transition.
- Analyze NG-H2 flame characteristics, emissions (CO, NOx, CO2), equipment modifications, flow rate changes, safety measures like leak detection.

System Level Requirements:

- Ensures the project meets goals and expectations.
- Guides design, testing and risk management.



System-Level Requirements:

Phase I:

Establish understanding of NG-H2 combustion, process, materials and emissions.

Identify materials, components, flow rates, and procedures for testing.

Design test stand with schematics, CAD models, simulations, and safety assessments.

Incorporate sensors for gas detection, emission monitoring.

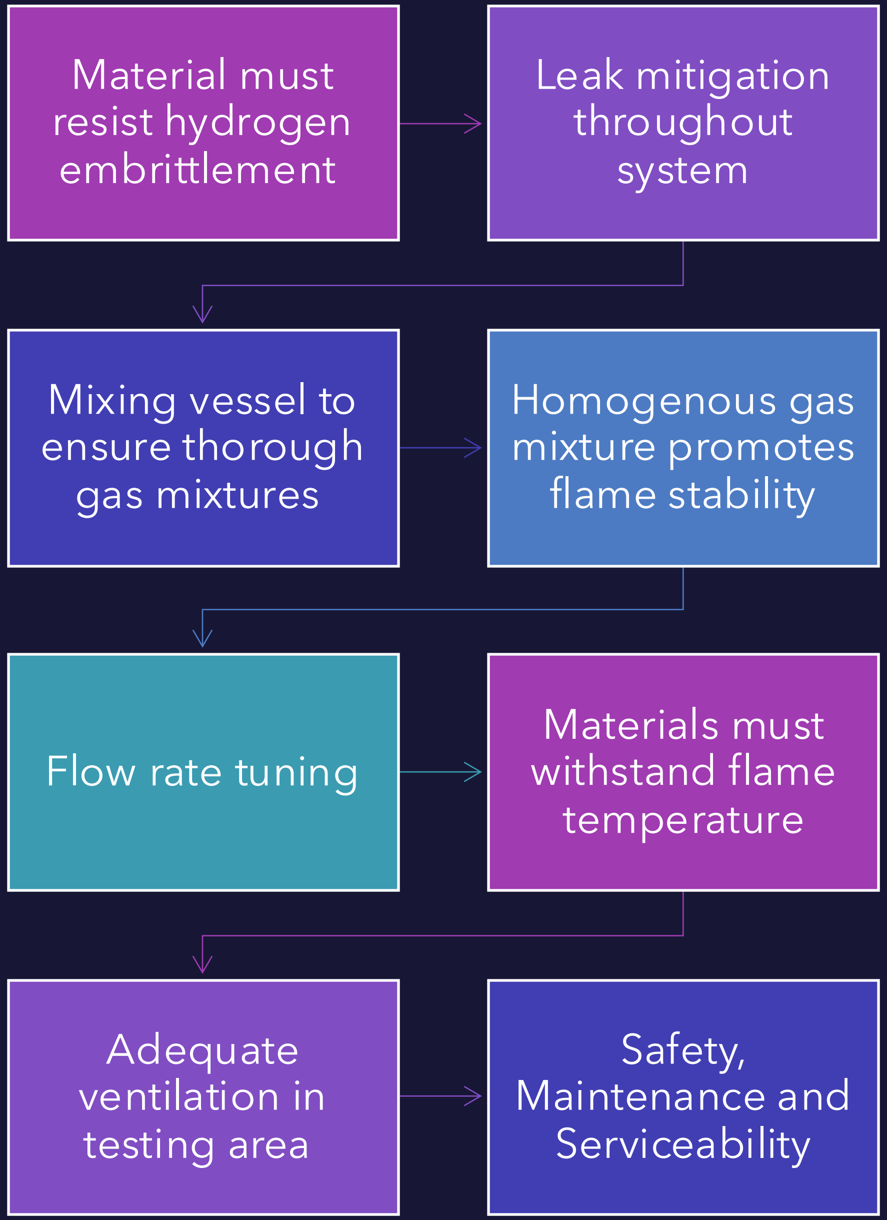
Conduct risk assessments and plan mitigation strategies.

System-Level Requirements:

Phase II:

- Fabricate burner test fixtures with safety measures for high pressure operation.
- Design fixtures to test a wide range of hydrogen percentages in blends.
- Measure blend percents, flow rates, and emissions to compare with theoretical projections.
- Optimize burner design for performance and safety with various NG-H2 blends.
- Implement real-time data transmission and combustible gas leak alerts for a safe working environment.
- Present results, test stand, and findings to the client.

Key Design Considerations:



Safety: Operational & Emergency

- Hydrogen/Natural Gas Blending:
  - Limit hydrogen blend to less than 20% to avoid any operability issues
  - Monitor hydrogen levels to stay within safe flammability limits
- Flashback Prevention:
  - Ensure flame arrestors are installed on all equipment
- Emergency Procedures:
  - Response Plan: Clear emergency response plan for gas leaks or fires
  - Close stove, stop blending on fusion flow, close lines
  - Incident Reporting: A report to keep track and understand the reason of gas leaks or safety incidents

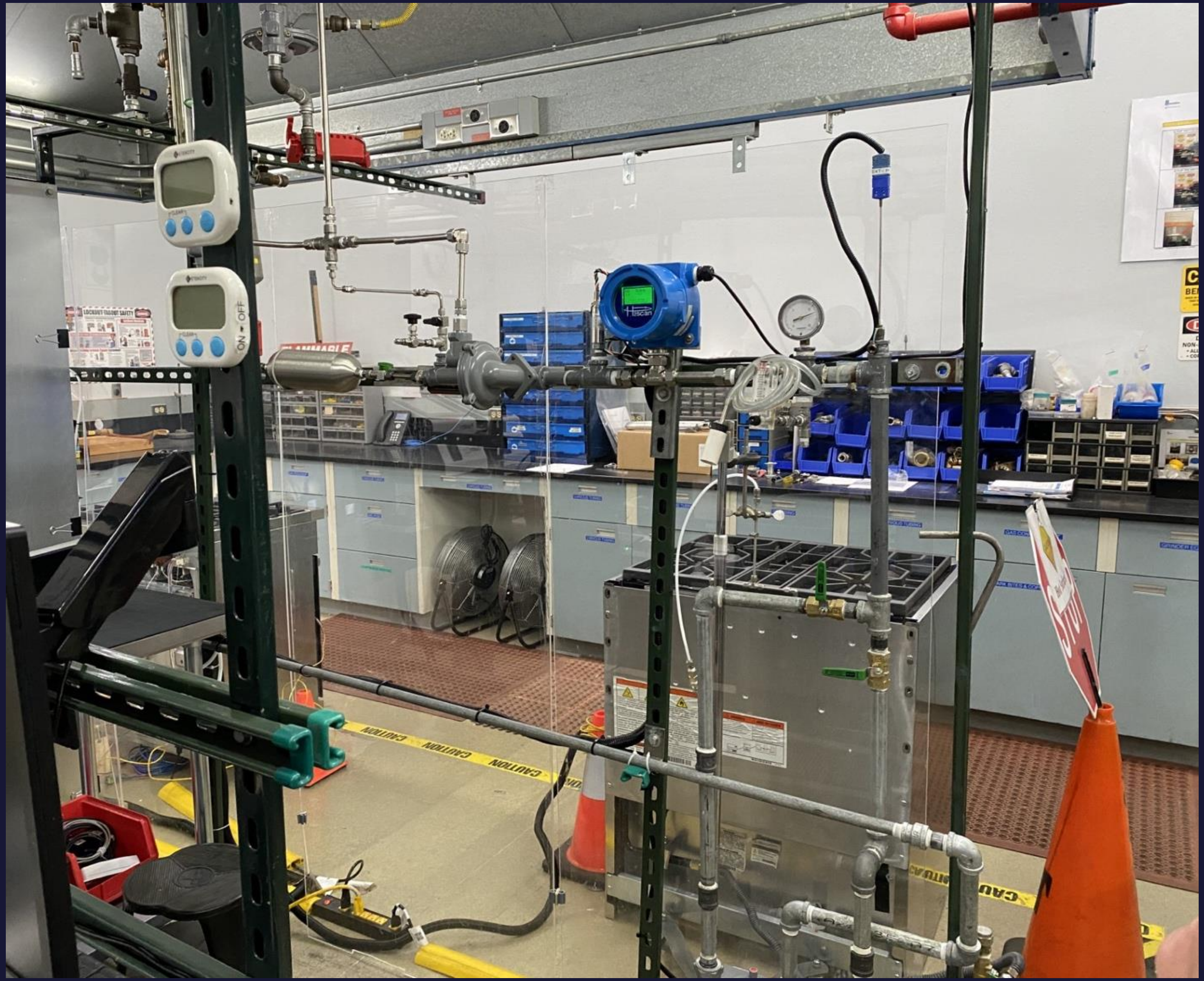
Safety: Precautions & Risk Reduction

- General Safety:
  - Training –
    Ensure all personnel are trained on hydrogen's flammability and emergency procedures.
  - Work Environment –
    Maintain proper ventilation and install gas detectors for leak detection
  - PPE: Safety goggles, flames-resistant clothing, and proper footwear. (If long hair, tie it)
- Equipment Safety:
  - Burner & Ignitions Systems: Ensure compliance with ANSI Z21.1 standards
  - Hood height of 12.7 cm (5in)
  - Safety shut off valves for quick shutdown.
  - Inspect hydrogen and natural gas tanks and connections as routine maintenance.

Team member pictured by emergency SOV, Extinguisher, and Combustible Gas Detector

Overall Design Approach

- Safety Requirements
  - Ensure the safety of equipment
  - Design pressure relief mechanisms
- Flow Rate Calculations
  - Calculate fluid velocities
  - Optimized flow control mechanisms
- Flame Characteristics
  - Analyze flame temperature and heat distribution
  - Evaluate flame stability and propagation
- Material Selection
  - Choose corrosion-resistant alloys for fuel lines
  - Understand house fuel lines



Material Selection

SCORES ARE OUT OF 80

Burner Material

	Material Properties (Density, Material Grains for Hydrogen Embrittlement)	Temperature and Pressure Condition	Cost	Manufacturability	Safety and Environmental Consideration	Durability and Service Life	Compatibility With Other Componets	Total Score Out of 80
Max Score	14	19	12	10	7	10	8	80
Stainless Steel 316	5	6	4	3	1	3	6	28
Inconel	6	9	2	2	2	5	1	27
Aluminum	3	4	6	5	3	2	2	25

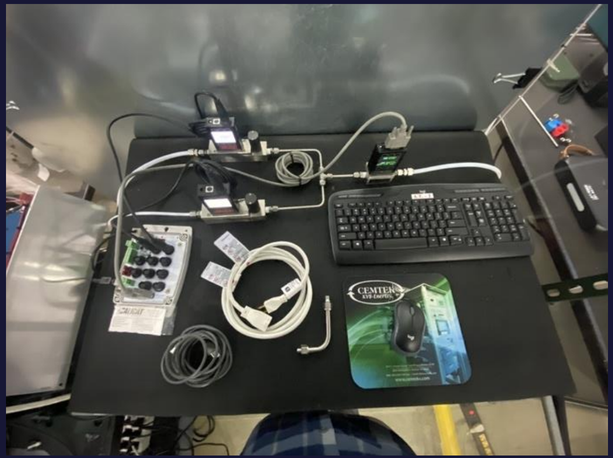
Fittings (1/4")

	Cleaning Process	Corrosion Risk	Cost	Leakage	Max Stress	Durability and Service life	Compatibility With Other Componets	Total Score Out of 80
Max Score	10	20	10	10	12	10	8	80
Quick Release	8	10	3	2	6	6	3	38
Tapered	2	10	5	6	8	8	5	44
Straight Connection (Push Fit)	4	17	6	7	10	7	1	52

Pipes

	Material Properties (density, material grains for hydrogen embrittlement)	Temperature and pressure condition	Cost	Manufacturability	Safety and Environmental consideration	Durability and Service life	Compatibility with another componets	Total Score Out of 80
Max Score	14	19	12	10	7	10	8	80
PVC	2	1	8	5	3	1	1	21
Copper	5	8	1	3	2	3	2	24
Stainless Steel 316/316L	7	10	3	2	2	6	5	35

- Leveraging insights from our trade study and hydrogen research facility, we'll use Swagelok's straight connection crush flange technology as the optimal solution
- Stainless steel 316 is only utilized on 100% hydrogen fuel lines and 100% Natural gas line



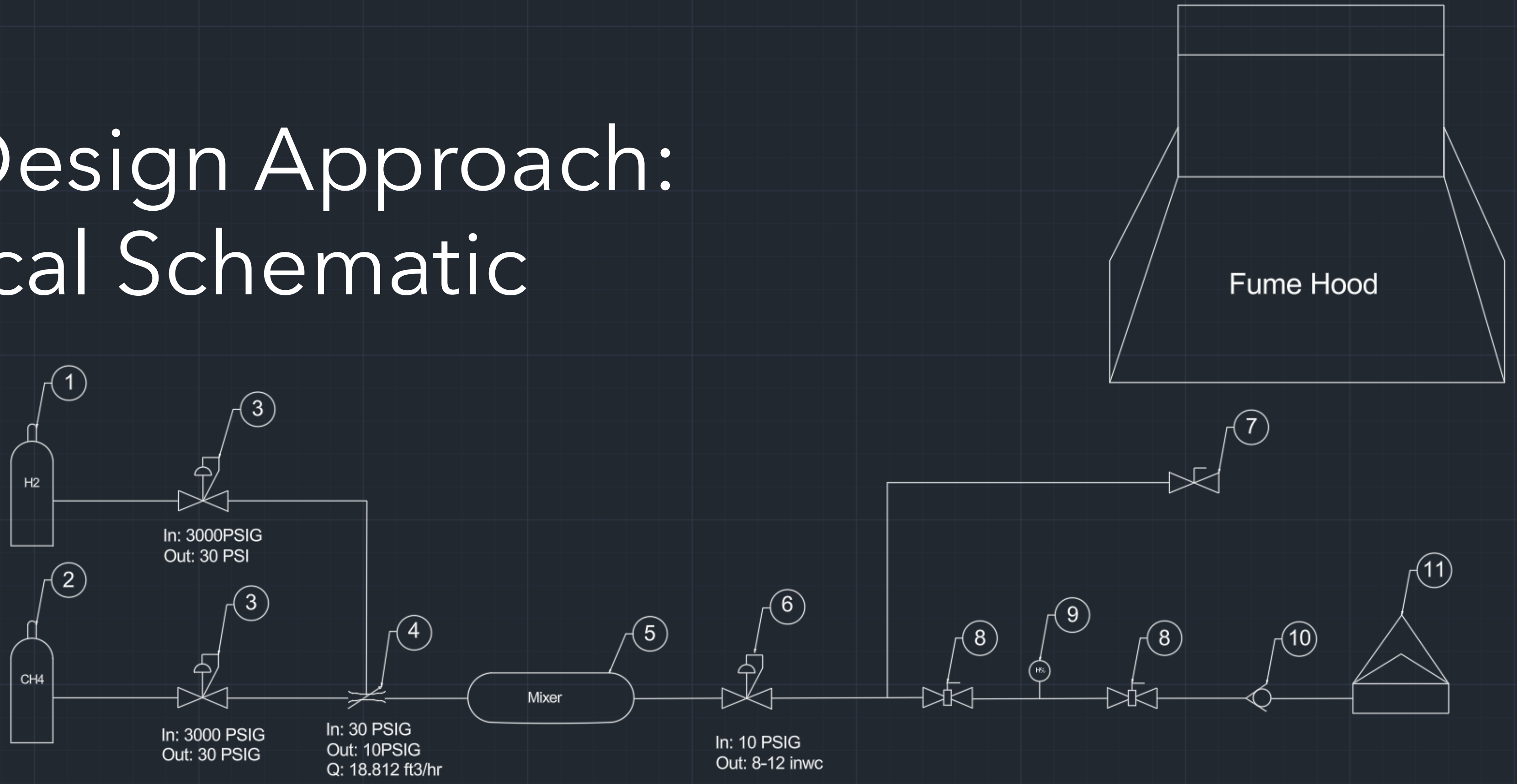
Material Selection

- **Brass Components**
  - Application: Pressure regulators on methane and hydrogen tanks
  - Key Property: Minimal susceptibility to hydrogen embrittlement
  - Advantages: Corrosion resistance
  - Durability under pressure

- **Teflon Tubing**
  - Application: Post-fusion flow sections and stove connection
  - Characteristics: Gas-grade, chemically resistant
  - Purpose: Safe containment and transport of mixed gases

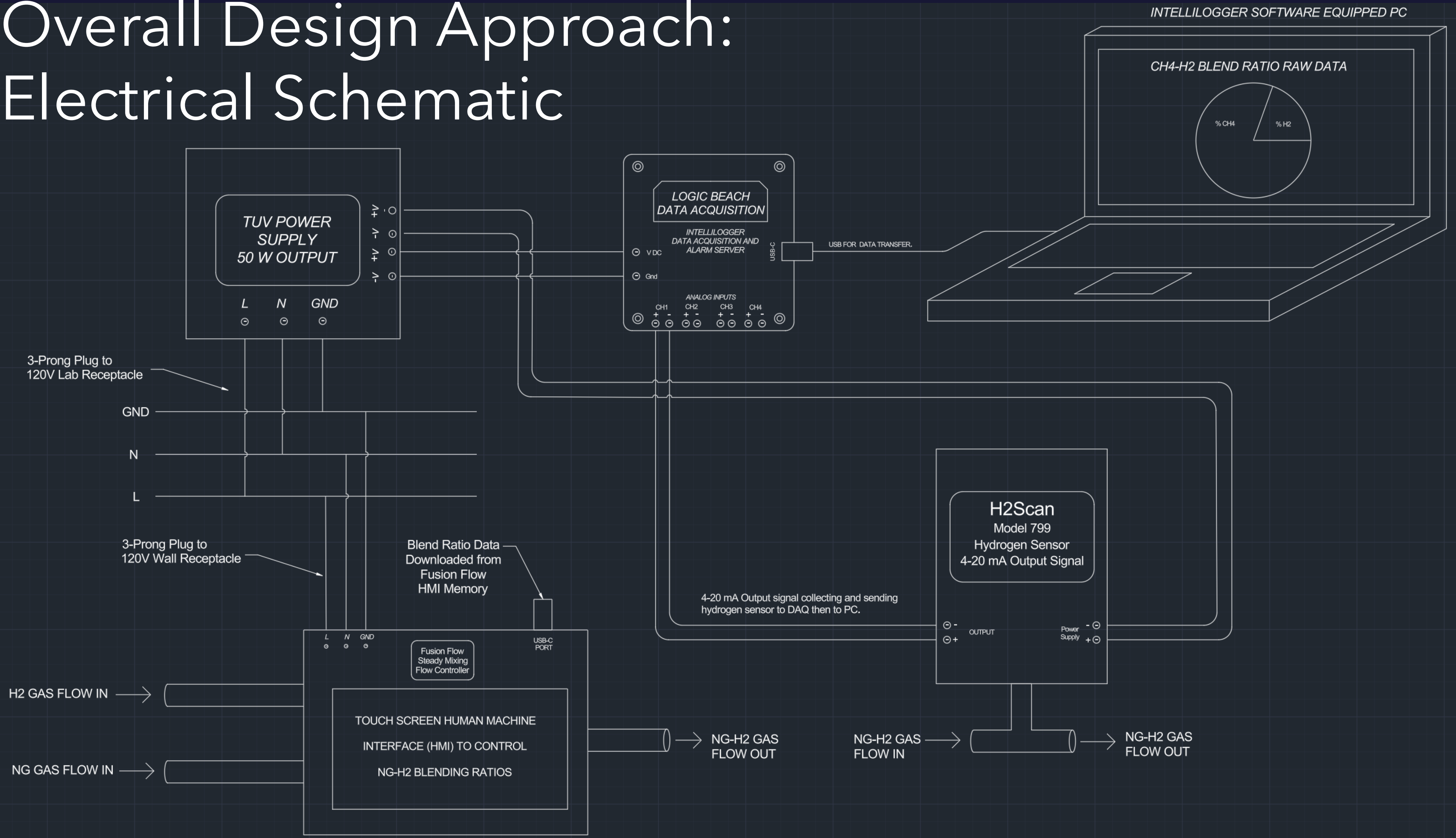
- **Black Steel**
  - Application: After mixing the vessel, the overall main line
  - In the everyday household fuel supply
  - Decrease in component costs

Overall Design Approach: Mechanical Schematic

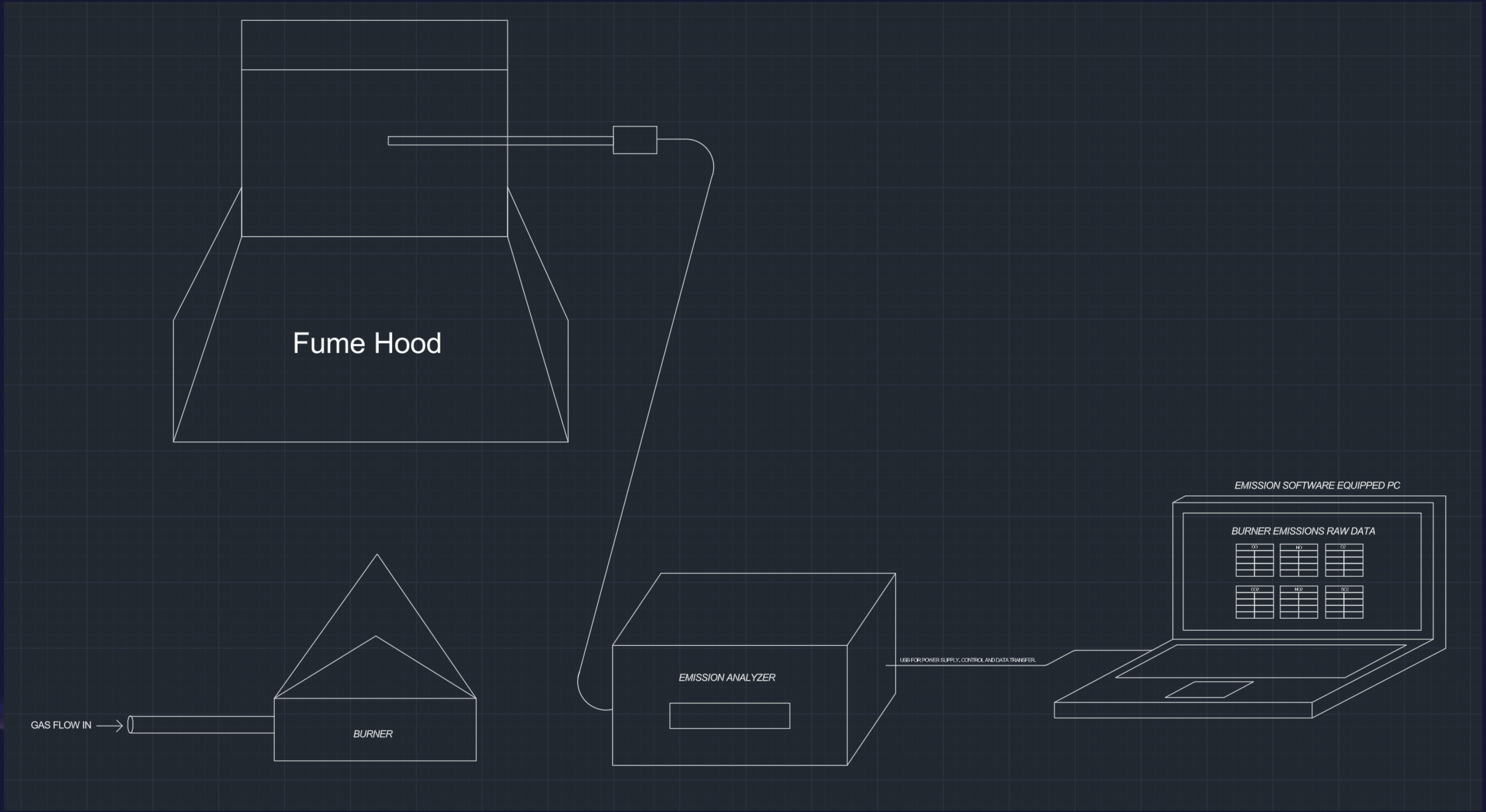


BILL OF MATERIALS							
Item #	Component	Manufacturer	Part Number	Quantity	Unit Cost	Total Cost	Description
1	Compressed Hydrogen Gas Tank	Gilmore Gas	N/A	1	$384.80	$384.80	CGA 350 outlet, size 200 cylinder.
2	Compressed Methane Gas Tank	Gilmore Gas	N/A	1	$384.80	$384.80	CGA 350 outlet, size 200 cylinder.
3	CGA 350 Pressure Regulators	Harris	KH1138	2	$881.25	$1762.50	CGA 350 fitting, Max Inlet P = 4350 PSIG, Max Outlet P = 125 PSIG
4	Fusion Flow: Flow Controller	Alicat	N/A	1	N/A	N/A	Max Operating Pressure = 30 PSIG, Inlet: $\frac{1}{4}$ FNPT , Outlet: $\frac{1}{4}$ FNPT
5	Buffer Mixing Vessel	SwageLok	316L-50DF4-150	1	$314.34	$314.34	Inlet: $\frac{1}{4}$ in tube , Outlet: $\frac{1}{4}$ in tube
6	(Low) Pressure Regulator	ITRON	B42R	1	N/A	N/A	Pressure Setpoint = 10 inwc (Supplied pressure to burner)
7	Bleed Valve	SwageLok	SS-BBM4	1	$67.50	$67.50	Inlet: $\frac{1}{4}$ MNPT , Outlet: Atmosphere
8	Manual Plug Valve	SwageLok	SS-43GS4-SC11	2	$143.88	$287.76	Inlet: $\frac{1}{4}$ in tube , $\frac{1}{4}$ in tube
9	Hydrogen Sensor (% H)	H2Scan	799	1	0	0	Max Operating Pressure = 20 PSIG, Inlet: $\frac{1}{2}$ in tube , Outlet: $\frac{1}{2}$ in tube
10	Check Valve	SwageLok	SS-4C-10	3	$69.50	$208.50	Inlet: $\frac{1}{4}$ in tube , Outlet: $\frac{1}{4}$ in tube
11	Stovetop Burner	AUODGDNT	AUODGDNT003	1	0	0	5000 BTU, 8500 BTU burners with thermocouple Flame-Out Failure Device feature.

Overall Design Approach: Electrical Schematic



Overall Design Approach: Emissions Data Collection



Overall Design Approach: Fluid Calculations

Solving for Volumetric Flowrates (Q) and Heat O:

$$If\, P_{Total,80NG-20H2} = 15{,}000\,\frac{BTU}{hr},\, then\ Q_{80\%\,NG} =?\ Q_{20\%\,H2} =?$$

Assumptions:

- $Steady\ State\ Flow\ of\ an\ Ideal\ Gas$
- $Energy\ and\ Mass\ is\ Conserved$
- $Temperature\ of\ Gases: T = 72\,°F$
- $Density\ of\ Gases\ @\ T = 72\,°F:$

$$\rho_{NG} = 0.04235\,\frac{lb_m}{ft^3};\ \rho_{H2} = 0.00523\,\frac{lb_m}{ft^3}$$

- $Heat\ Output\ of\ Burner\ with\ NG:$

$$P = 15{,}000\,\frac{BTU}{hr}$$

- $HV = Heating\ Values\ of\ Gases\ \left[\frac{BTU}{ft^3}\right]$
- $HV_{v,NG} = 950\,\frac{BTU}{ft^3}$
- $HV_{v,H2} = 325\,\frac{BTU}{ft^3}$

Overall Design Approach: Fluid Calculations

Relevant Equations:

$$P\left[\frac{BTU}{hr}\right] = Q\left[\frac{ft^3}{hr}\right] HV\left[\frac{BTU}{ft^3}\right] \{Equation\ 1\}$$

$$P_{Total,80NG-20H2}\left[\frac{BTU}{hr}\right] = Q_{80\%\ NG}\left[\frac{ft^3}{hr}\right] HV_{v,NG}\left[\frac{BTU}{ft^3}\right] + Q_{20\%\ H2}\left[\frac{ft^3}{hr}\right] HV_{v,H2}\left[\frac{BTU}{ft^3}\right] \{Equation\ 2\}$$

$$Q = Volumetric\ Flow\ Rate\left[\frac{ft^3}{hr}\right] = \frac{P\ \left[\frac{BTU}{hr}\right]}{HV\ \left[\frac{BTU}{ft^3}\right]} \{Equation\ 3\}$$

Overall Design Approach: Fluid Calculations

Relevant Equations:

$$\dot{m} = Mass\ Flow\ Rate \left[\frac{lb_m}{hr}\right] = \rho \left[\frac{lb_m}{ft^3}\right] Q \left[\frac{ft^3}{hr}\right] \{Equation\ 4\}$$

$$\dot{m}_{Total,80NG-20H2} = \rho_{NG} \left[\frac{lb_m}{ft^3}\right] Q_{80\%\ NG} \left[\frac{ft^3}{hr}\right] + \rho_{H2} \left[\frac{lb_m}{ft^3}\right] Q_{20\%\ NG} \left[\frac{ft^3}{hr}\right] \{Equation\ 5\}$$

$$Q_{80\%\ NG} \left[\frac{ft^3}{hr}\right] = 0.8 Q_{Total} \left[\frac{ft^3}{hr}\right] \{Equation\ 6\}$$

$$Q_{20\%\ NG} \left[\frac{ft^3}{hr}\right] = 0.2\ Q_{Total} \left[\frac{ft^3}{hr}\right] \{Equation\ 7\}$$

Overall Design Approach: Fluid Calculations

Solution:

$$Q\left[\frac{ft^3}{hr}\right] = \frac{P\left[\frac{BTU}{hr}\right]}{HV\left[\frac{BTU}{ft^3}\right]}\{Equation\ 3\} \rightarrow Q_{100\%\ NG}\left[\frac{ft^3}{hr}\right] = \frac{P_{100\%\ NG}\left[\frac{BTU}{hr}\right]}{HV_{NG}\left[\frac{BTU}{ft^3}\right]}$$

$$\rightarrow Q_{100\%\ NG}\left[\frac{ft^3}{hr}\right] = \frac{15{,}000\ \left[\frac{BTU}{hr}\right]}{950\left[\frac{BTU}{ft^3}\right]} = 15.790\frac{ft^3}{hr}$$

$$\rightarrow \dot{m}_{100\%\ NG} = Q_{100\%\ NG}\rho_{NG} = \left(15.490\frac{ft^3}{hr}\right)\left(0.04235\frac{lb_m}{ft^3}\right) = 0.669\frac{lb_m}{hr}$$

Overall Design Approach: Fluid Calculations

Solution:

$$P_{Total,80NG-20H2}\left[\frac{BTU}{hr}\right] = Q_{NG}\left[\frac{ft^3}{hr}\right] HV_{v,NG}\left[\frac{BTU}{ft^3}\right] + Q_{H2}\left[\frac{ft^3}{hr}\right] HV_{v,H2}\left[\frac{BTU}{ft^3}\right] \{Equation\ 2\}$$

$$Q_{80\%\,NG}\left[\frac{ft^3}{hr}\right] = 0.8Q_{Total,80NG-20H2}\left[\frac{ft^3}{hr}\right] \{Equation\ 6\}$$

$$Q_{20\%\,H2}\left[\frac{ft^3}{hr}\right] = 0.2Q_{Total,80NG-20H2}\left[\frac{ft^3}{hr}\right] \{Equation\ 7\}$$

$$\rightarrow P_{Total,80NG-20H2}\left[\frac{BTU}{hr}\right] = 0.8Q_{Total,80NG-20H2}\left[\frac{ft^3}{hr}\right] HV_{v,NG}\left[\frac{BTU}{ft^3}\right] + 0.2Q_{Total,80NG-20H2}\left[\frac{ft^3}{hr}\right] HV_{v,H2}\left[\frac{BTU}{ft^3}\right]$$

$$\rightarrow P_{Total,80NG-20H2}\left[\frac{BTU}{hr}\right] = Q_{Total,80NG-20H2}\left[\frac{ft^3}{hr}\right]\left(0.8HV_{v,NG}\left[\frac{BTU}{ft^3}\right] + 0.2HV_{v,H2}\left[\frac{BTU}{ft^3}\right]\right)$$

Overall Design Approach: Fluid Calculations

Solution:

$$\rightarrow Q_{Total,80NG-20H2}\left[\frac{ft^3}{hr}\right] = \frac{P\left[\frac{BTU}{hr}\right]}{\left(0.8HV_{v,NG}\left[\frac{BTU}{ft^3}\right] + 0.2HV_{v,H2}\left[\frac{BTU}{ft^3}\right]\right)}$$

$$\rightarrow Q_{Total,80NG-20H2}\left[\frac{ft^3}{hr}\right] = \frac{15{,}000\left[\frac{BTU}{hr}\right]}{0.8\left(950\left[\frac{BTU}{ft^3}\right]\right) + 0.2\left(325\left[\frac{BTU}{ft^3}\right]\right)} = 18.182\frac{ft^3}{hr}$$

$$\rightarrow Q_{80\%\,NG} = 0.8Q_{Total} = 0.8\left(18.182\frac{ft^3}{hr}\right) = 14.546\frac{ft^3}{hr}$$

$$\rightarrow Q_{20\%\,H2} = 0.2Q_{Total} = 0.2\left(18.182\frac{ft^3}{hr}\right) = 3.636\frac{ft^3}{hr}$$

Overall Design Approach: Fluid Calculations

Solution:

$$P_{Total,80NG-20H2}\left[\frac{BTU}{hr}\right] = Q_{80\%\,NG}\left[\frac{ft^3}{hr}\right] HV_{v,NG}\left[\frac{BTU}{ft^3}\right] + Q_{20\%\,H2}\left[\frac{ft^3}{hr}\right] HV_{v,H2}\left[\frac{BTU}{ft^3}\right] \{Equation\ 2\}$$

$$\rightarrow\ P_{Total,80NG-20H2}\left[\frac{BTU}{hr}\right] = \left(14.546\frac{ft^3}{hr}\right)\left(950\frac{BTU}{ft^3}\right) + \left(3.636\frac{ft^3}{hr}\right)\left(325\frac{BTU}{ft^3}\right) = 15{,}000\frac{BTU}{hr}$$

$$\dot{m}_{Total,80NG-20H2}\left[\frac{lb_m}{hr}\right] = \rho_{NG}\left[\frac{lb_m}{ft^3}\right] Q_{80\%\,NG}\left[\frac{ft^3}{hr}\right] + \rho_{H2}\left[\frac{lb_m}{ft^3}\right] Q_{20\%\,NG}\left[\frac{ft^3}{hr}\right] \{Equation\ 5\}$$

$$\rightarrow\ \dot{m}_{Total,80NG-20H2}\left[\frac{lb_m}{hr}\right] = \left(0.04235\frac{lb_m}{ft^3}\right)\left(14.546\frac{ft^3}{hr}\right) + \left(0.00523\frac{lb_m}{ft^3}\right)\left(3.636\frac{ft^3}{hr}\right) = 0.635\frac{lb_m}{hr}$$

Overall Design Approach: Fluid Calculations

Solution:

$$\rightarrow P_{Total,80NG-20H2} = 15{,}000\,\frac{BTU}{hr} = 15{,}000\,\frac{BTU}{hr} = P_{100\%\,NG}$$

$$\rightarrow Q_{Total,80NG-20H2}\left[\frac{ft^3}{hr}\right] = 18.182\,\frac{ft^3}{hr} > 15.790\,\frac{ft^3}{hr} = Q_{100\%\,NG}$$

$$\rightarrow \dot{m}_{Total,80NG-20H2} = 0.635\,\frac{lb_m}{hr} < 0.669\,\frac{lb_m}{hr} = \dot{m}_{100\%\,NG}$$

Gas & Flame Characteristics:

	Natural Gas:		Hydrogen Gas:
Adiabatic Flame Temperature	Adiabatic Flame Temperature: 1973 °C ~ 3583 °F		Adiabatic Flame Temperature: 2182 °C ~ 3960 °F
Flame Color	Flame Color: Blue		Flame Color: Almost invisible, faint blue
Flame Speed	Flame Speed: 1.312 ft/s		Flame Speed: 5.577/s
Stoichiometric Ratio by mass	Stoichiometric Ratio by mass: 9.5 air : 1 CH_4		Stoichiometric Ratio by mass: 34 parts air : 1 part H_2
Stoichiometric Ratio by mols	Stoichiometric Ratio by mols: 2 mol air : 1 mol CH_4		Stoichiometric Ratio by mols: 2 mol H_2 : 1 mol air
Autoignition Temperature	Autoignition Temperature: 999-1103 °F		Autoignition Temperature: 1040-1085 ° F
Odorants	Odorants: Yes – Mercaptan		Odorants: No
Toxicity	Toxicity: Some		Toxicity: None
Buoyancy	Buoyancy relative to air: ~2x lighter		Buoyancy relative to air: ~14x lighter

American Gas Association (AGA) Flame Indices:

20% H_2
559F

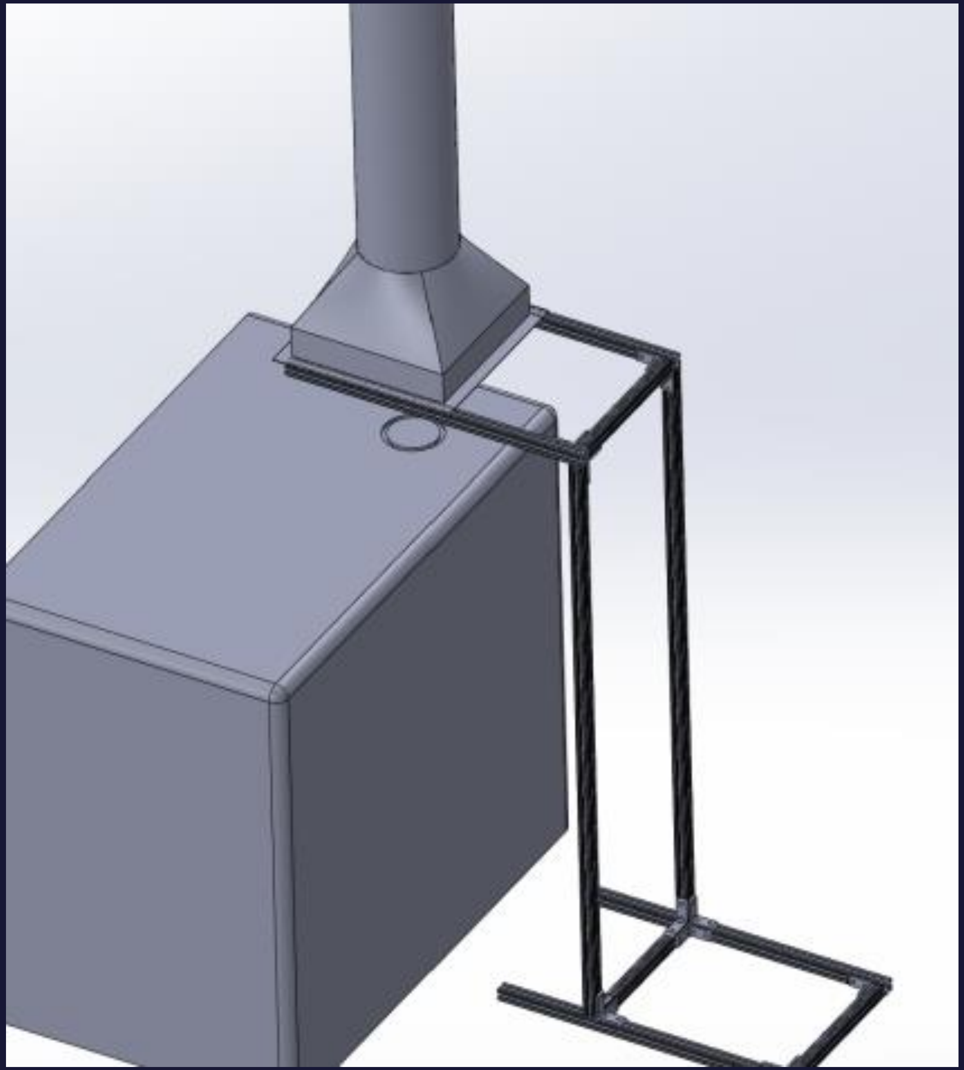
Flame Stability – measures the ability of a flame to maintain a consistent size and shape. This is essential for safe and efficient combustion.

Flame Shape – the width, height, and shape are assessed to ensure mixing of air and fuel.

Flame Color – is used to indicate the temperature, whether there is incomplete combustion, or contaminants in the fuel.

Flame Length – this is an important indicator of burner performance and should be consistent.

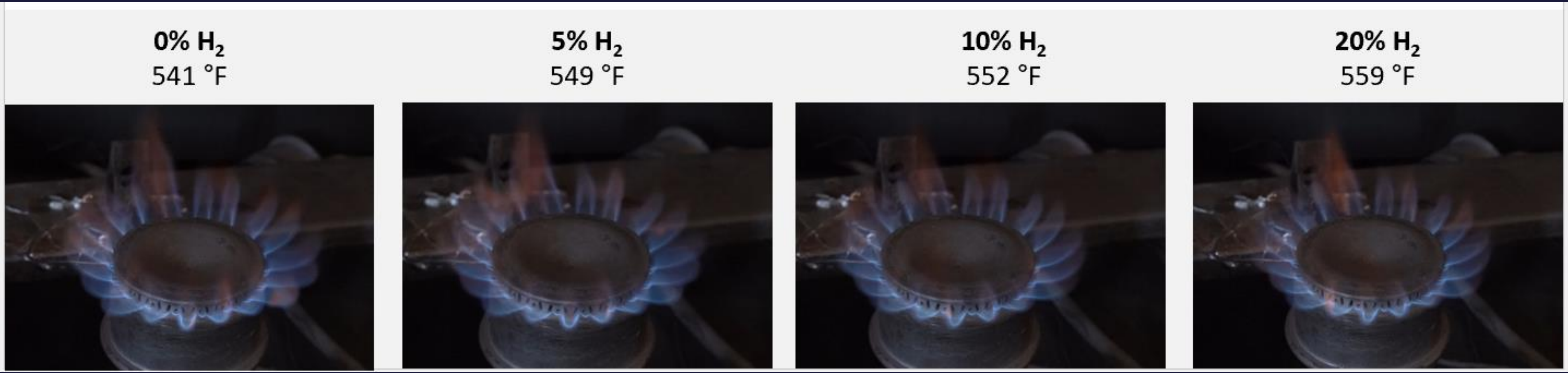
Flame Temperature – helpful in determining the efficiency of the combustion process.



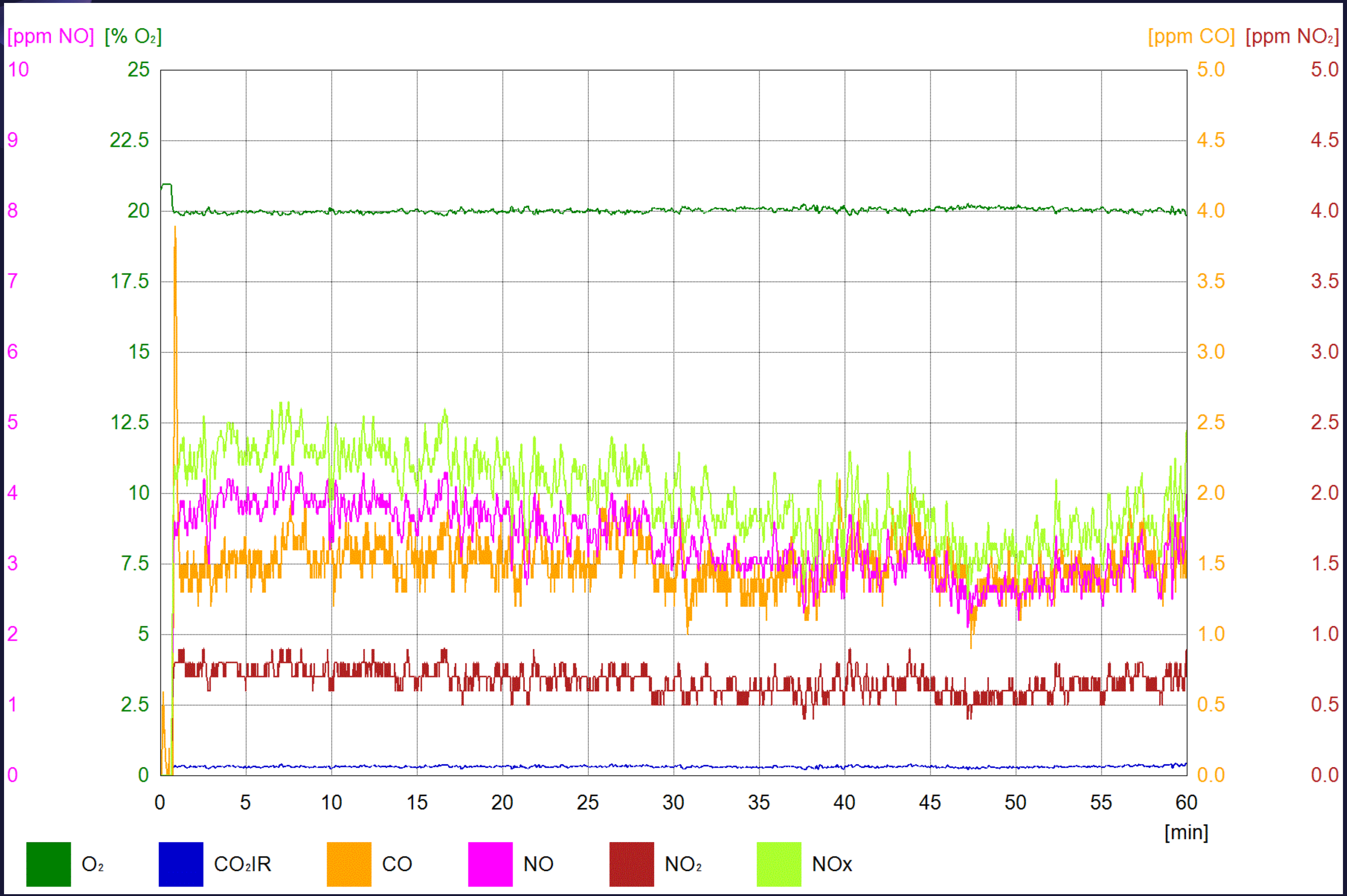
Emissions Test Stand

- Overview
  - Designed to isolate emissions from a single burner for accurate testing
  - Equipped with a port for inserting the probe of an emissions analyzer
- Key Features
  - Lightweight frame for easy movement and positioning
  - Works with various burner sizes and configurations
  - Ensures no interference from environmental factors

Combustion Results

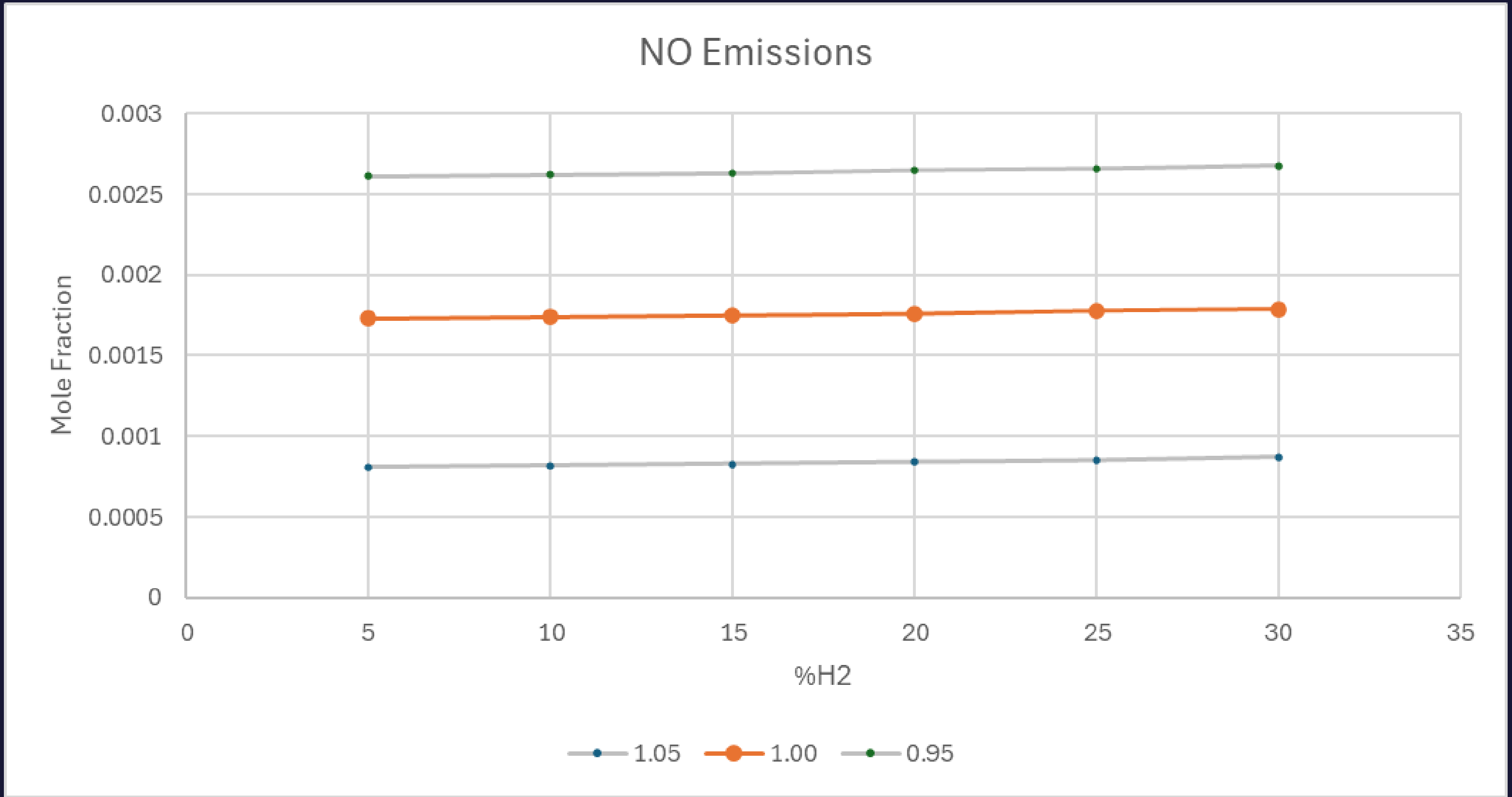


Results: Emissions Testing



Increase in NO

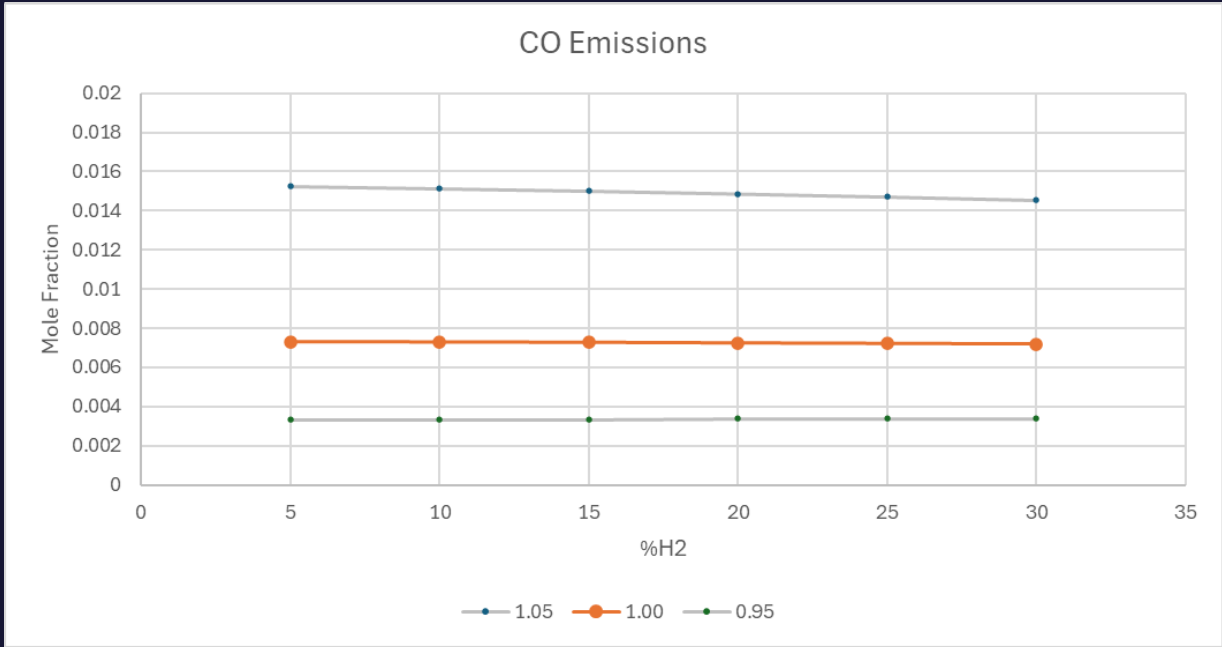
- NO formation is influenced by flame temperature
- Hydrogen blending increases flame temperature slightly, promoting the thermal NOx mechanism
- Focusing on burner design can mitigate Nox emissions
- NO: 0.00173->0.00176 mol fraction

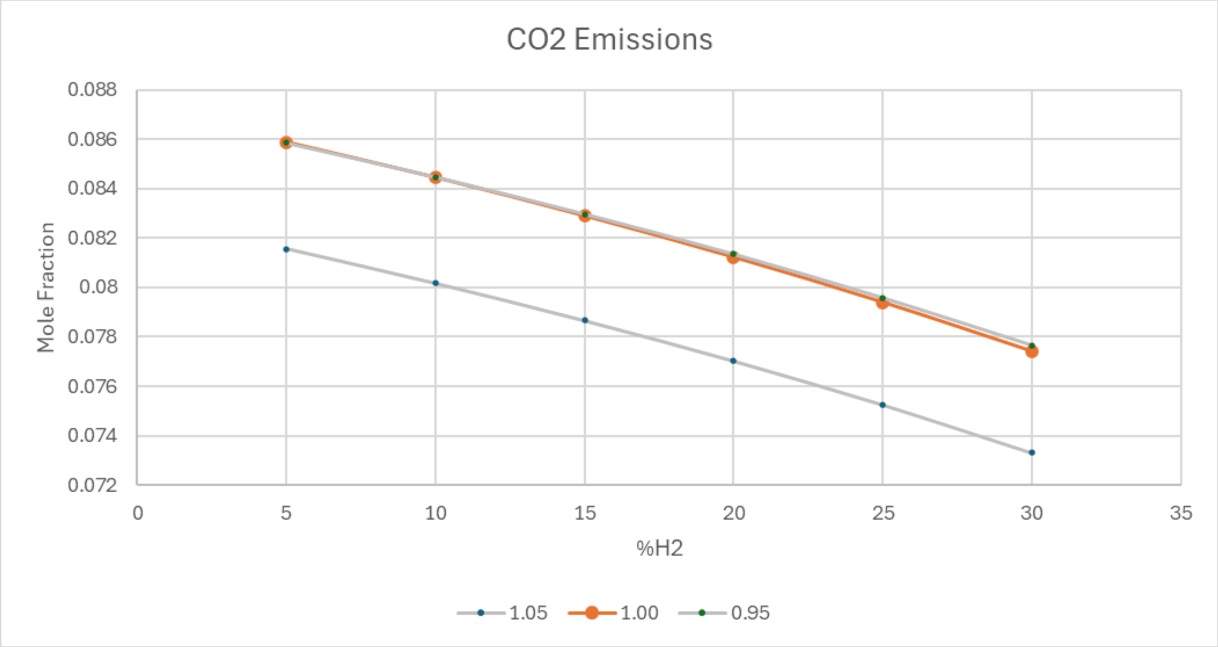


Reduction in CO and CO2

- Hydrogen blending reduces carbon emissions
- CO reduction reflects more complete combustion due to hydrogens improved efficiency
- CO2 decreases due to the reduces carbon content in the fuel mixture

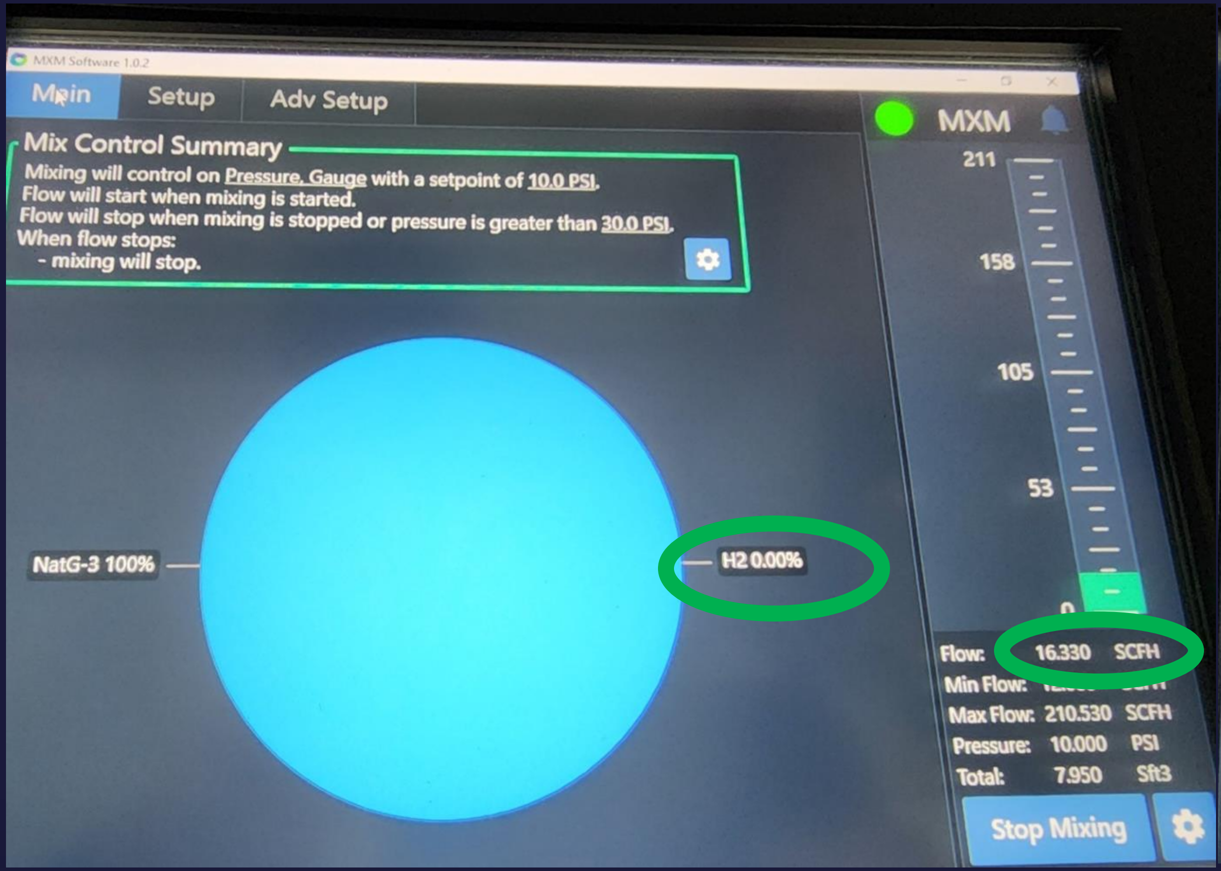
- CO: 0.00732->0.00722
- CO2: 0.08587->0.08122

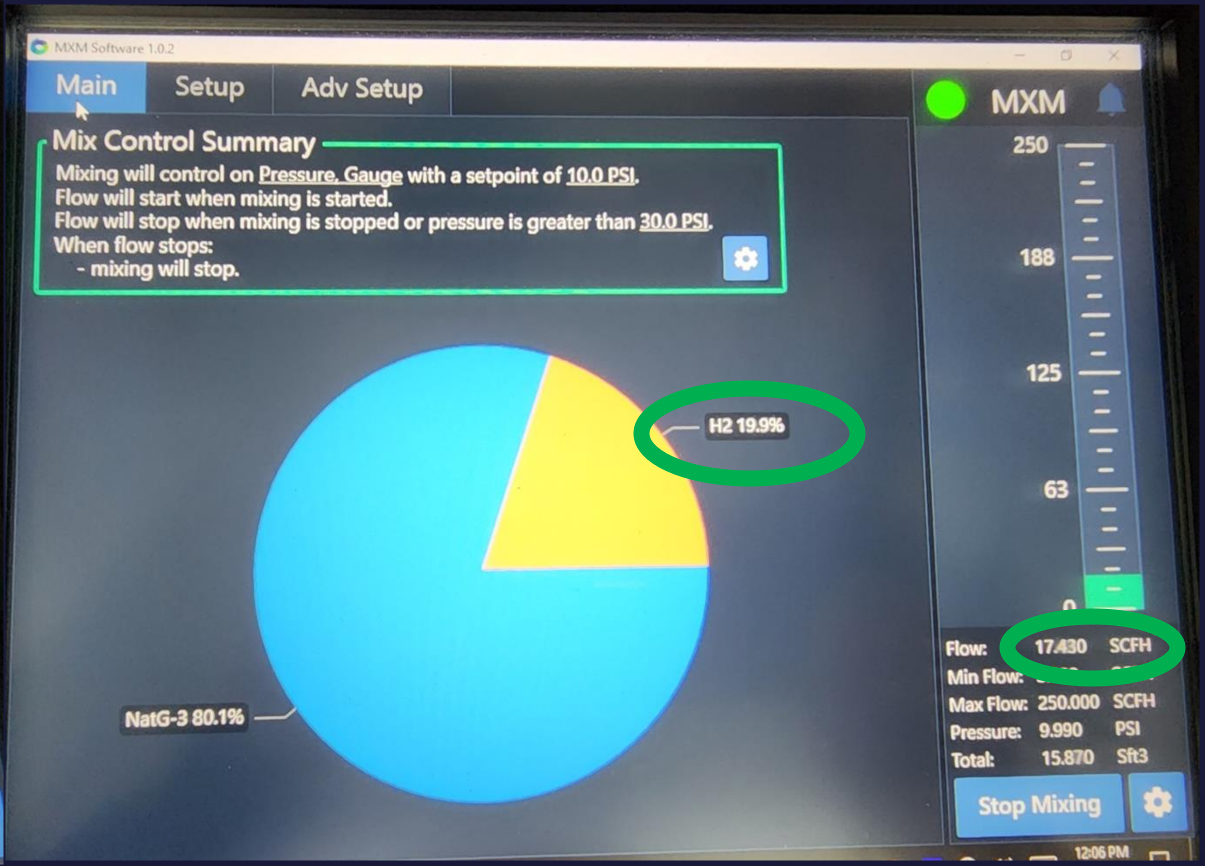




Flow Rate Control Results

$$Q_{\substack{100\%\,NG\\ Theoretical}} = 15.790\frac{ft^3}{hr} \approx 16.33\frac{ft^3}{hr} = Q_{\substack{100\%\,NG\\ Actual}} \;\&\; Q_{\substack{Total,80NG-20H2\\ Theoretical}} = 18.182\frac{ft^3}{hr} \approx 17.430\frac{ft^3}{hr} = Q_{\substack{Total,80NG-20H2\\ Actual}}$$





Conclusion

There was a reduction in CO, CO_2, and NO_x proving use as an alternative form of energy.

Greater flow rates required to compensate for greater flame speed as blend percent increases

Flow controllers required upstream of mixing vessels for consistent mixing and flame stability

Mixing vessel or other mixers are required to blend gases for burner use

Hydrogen gas specific materials and components are required to prevent leaks and to optimize the delivery of blended gas to burner outlet