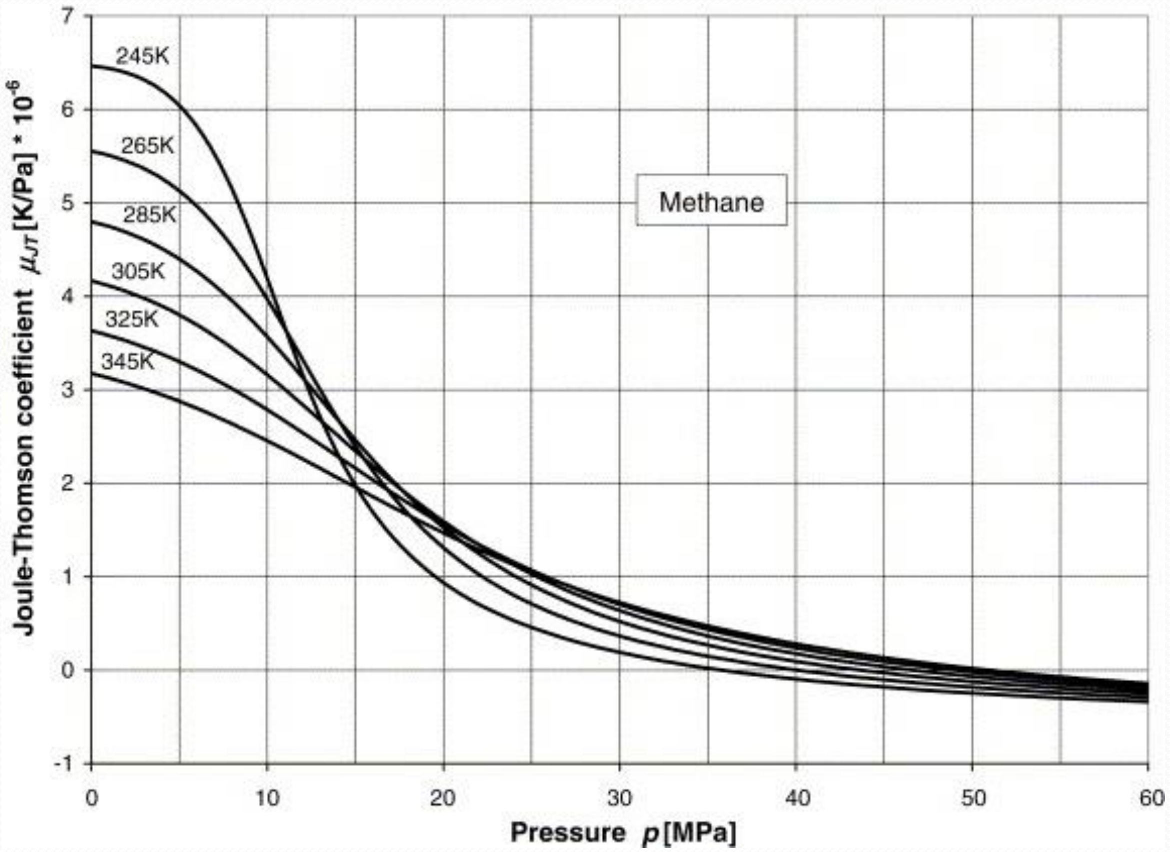
Line Heater CO2 Emission Reduction

By Sean Carron, P.Eng
Combustion Solutions Inc

COMBUSTION SOLUTIONS INC.

Why Line Heaters - Joule Thomson Effect

A sudden drop in pressure causes a drop in temperature



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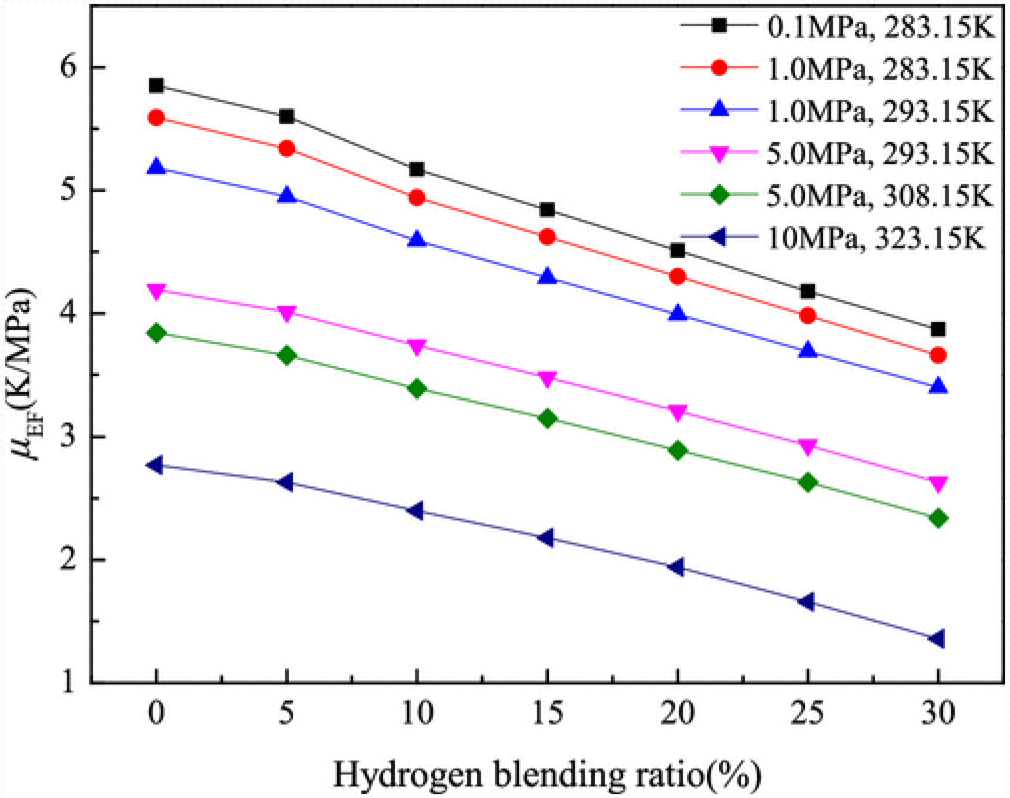
H2 can have a big impact on the JT coefficient



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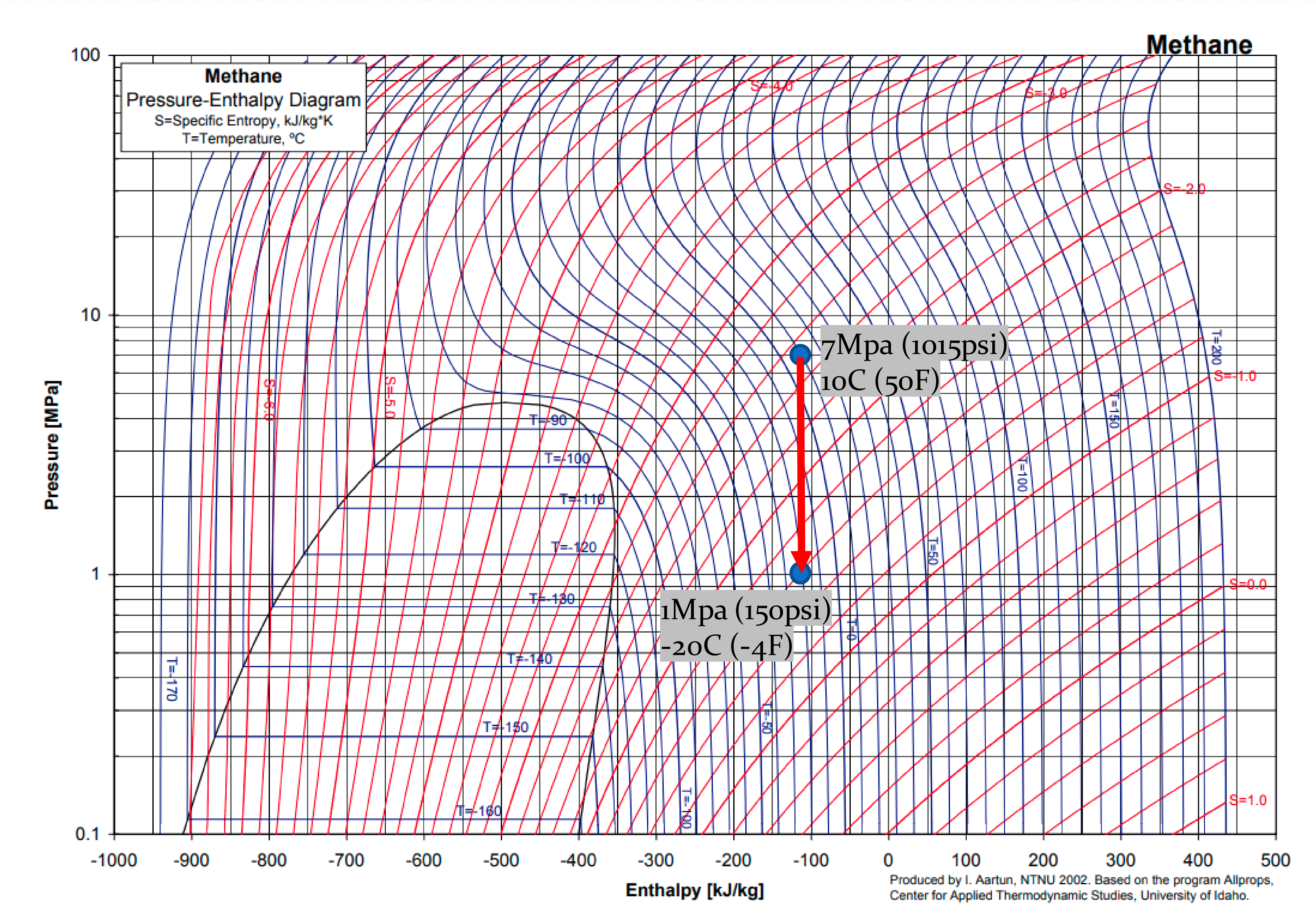

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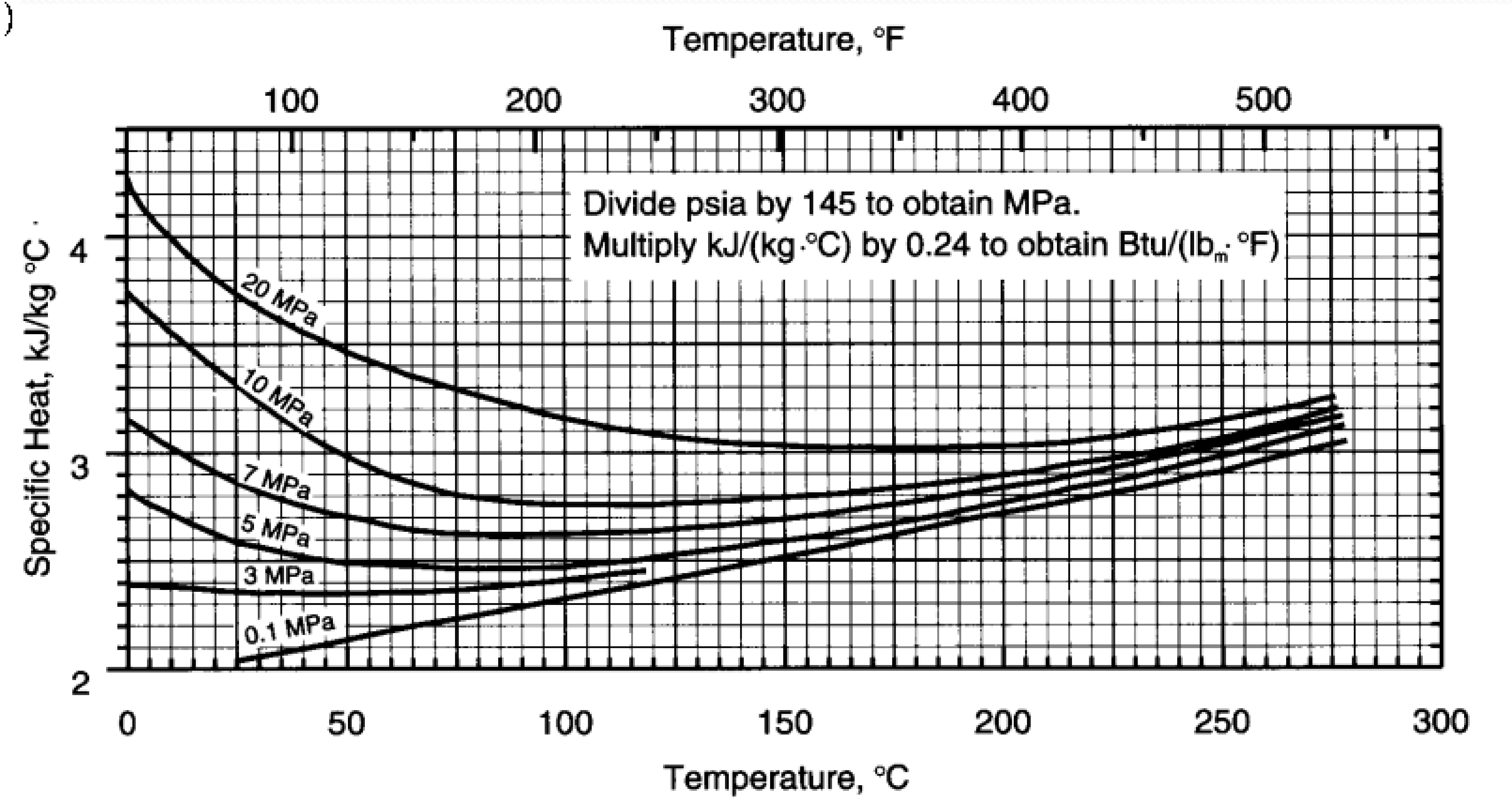
Heat Capacity of Natural Gas vs Temperature and Pressure

$$Q = (m)(C_{PAvg})(T_2 - T_1)$$



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Quick Example

- 6” line 10MMSCFD (11,808 m3/hr) @ 50F(10C) and 1100psi (7.65 MPa).
- Mass flow ~ 19,000 lbs per hour 8,600 (kgs/hr)
- Pressure drop to 100 psi (7 Mpa) → temperature drop would be ~ 65F (36C) = Freezing of regulator
- To heat the gas requires on average 0.58 Btu/lb/F (2.4 KJ/kg/C)
- Total heat is therefore 19,000 * 0.58 * 65 = 740,000 Btu/hr (220kW)
- Realistically would size for 1,000,000 Btu/hr

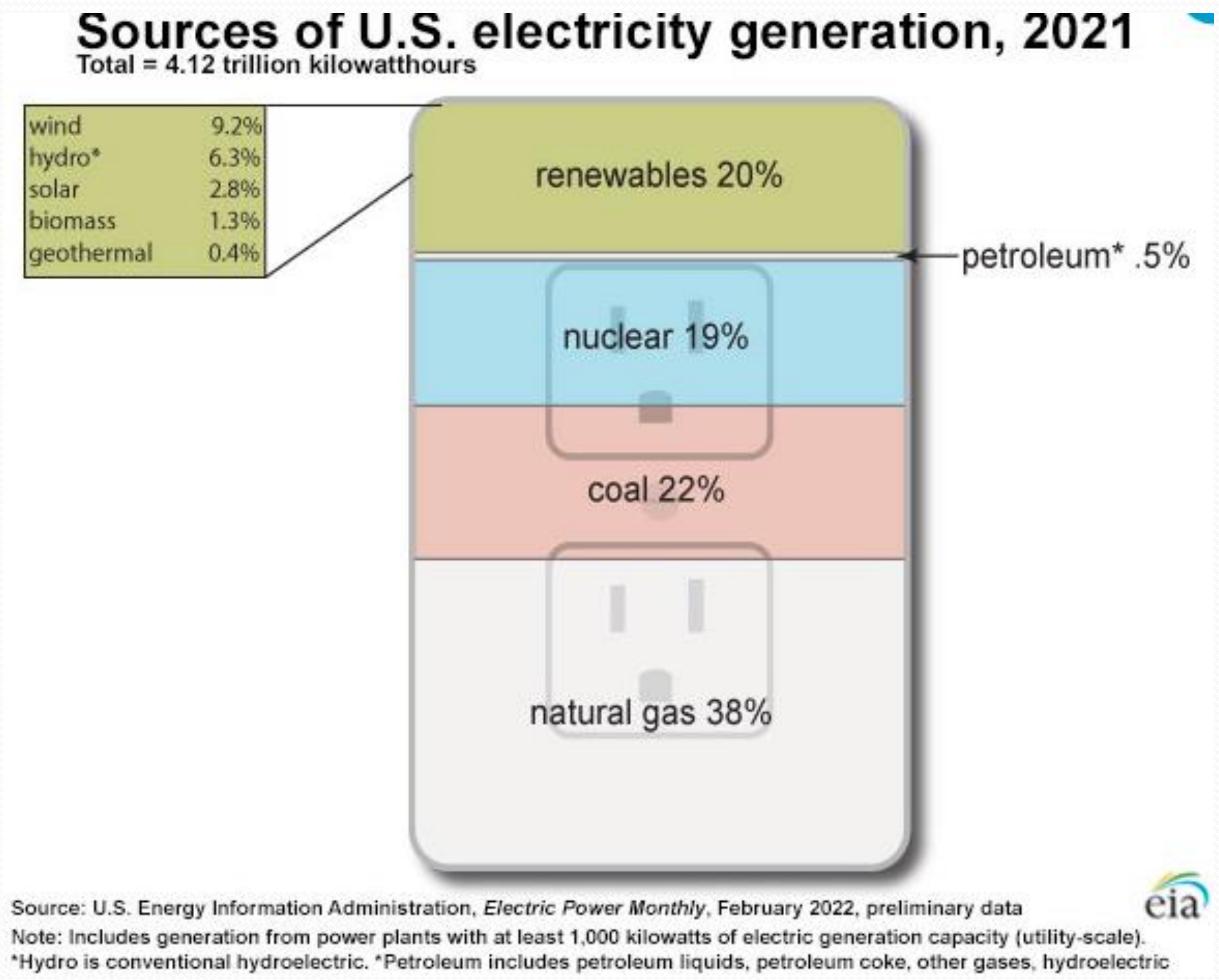
Heating options

- Electric heat
- Infra Red Radiant
- Glycol/Water bath line heater
- Vacuum Glycol / Steam line heater

Electric heater options

- >95% efficient, zero emissions
- But !!!!!

Since 60% of electrical energy comes from hydrocarbon sources, we must include the powerplant emissions in our global warming calculations.



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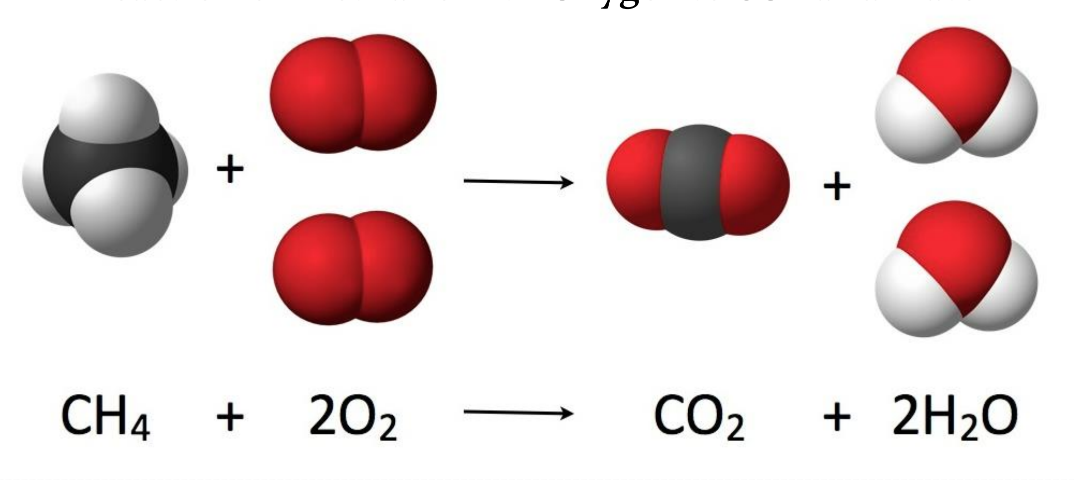
Electrical heat revisited

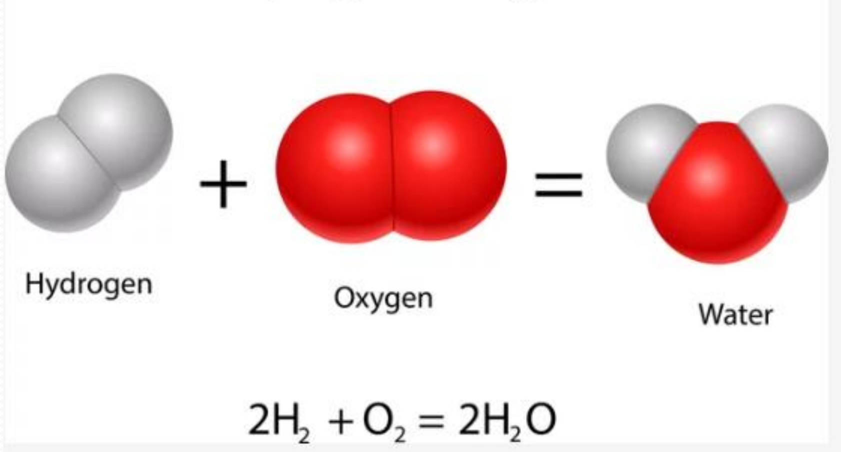
- A modern simple cycle power plant is ~40% efficient (fuel energy to electrical energy)
- A combine cycle power plant can be up to 60% efficient.
- For each kW of energy used for heating loads, the power plant must produce the equivalent of 2kW of CO_2 emissions.
- The use of electric heat will result in a net increase in CO_2 emissions.
- Until the electrical grid is carbon free, using electricity for heating natural gas makes no sense.

Gas Fired Equipment

Reaction of Methane with Oxygen to CO2 and Water



Reaction of Hydrogen and Oxygen to Water



- For every molecule of CH4 burned completely, one molecule of CO2 is created.
- To reduce CO2, the only option is to reduce fuel consumption or switch to H2
- Our primary objective is to reduce CO2 emissions while preventing the line from freezing.
- Therefore efficiency must be maximized

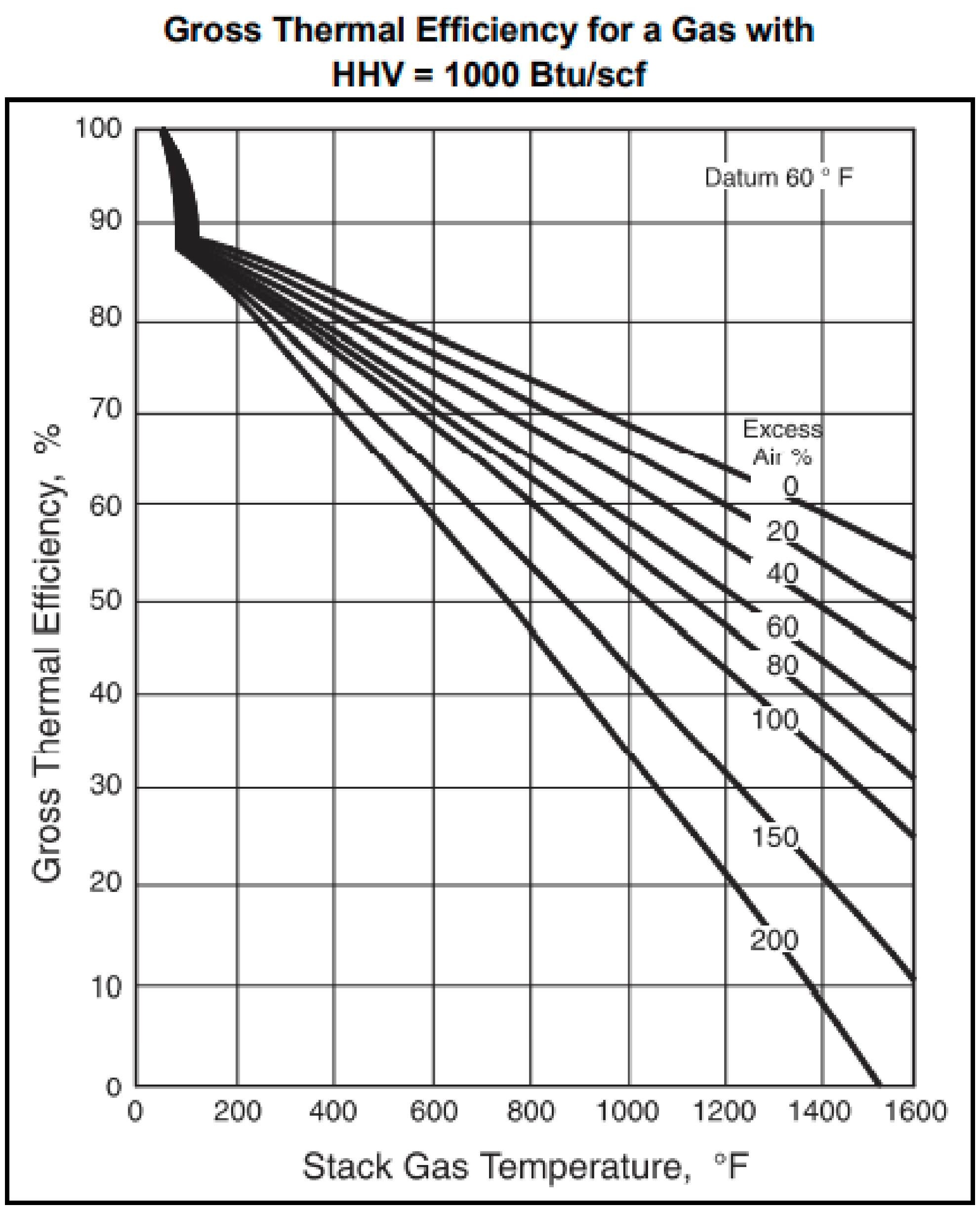
Efficiency (function of stack temp and %O2)

- 85% is a common upper limit

Combustion Efficiency for Natural Gas

Excess, %		Combustion Efficiency: Flue Gas Temperature Minus Combustion Air Temperature, °F				
Air	Oxygen	200	300	400	500	600
9.5	2.0	85.4	83.1	80.8	78.4	76.0
15.0	3.0	85.2	82.8	80.4	77.9	75.4
28.1	5.0	84.7	82.1	79.5	76.7	74.0
44.9	7.0	84.1	81.2	78.2	75.2	72.1
81.6	10.0	82.8	79.3	75.6	71.9	68.2

Assumes complete combustion with no water vapor in the combustion air.



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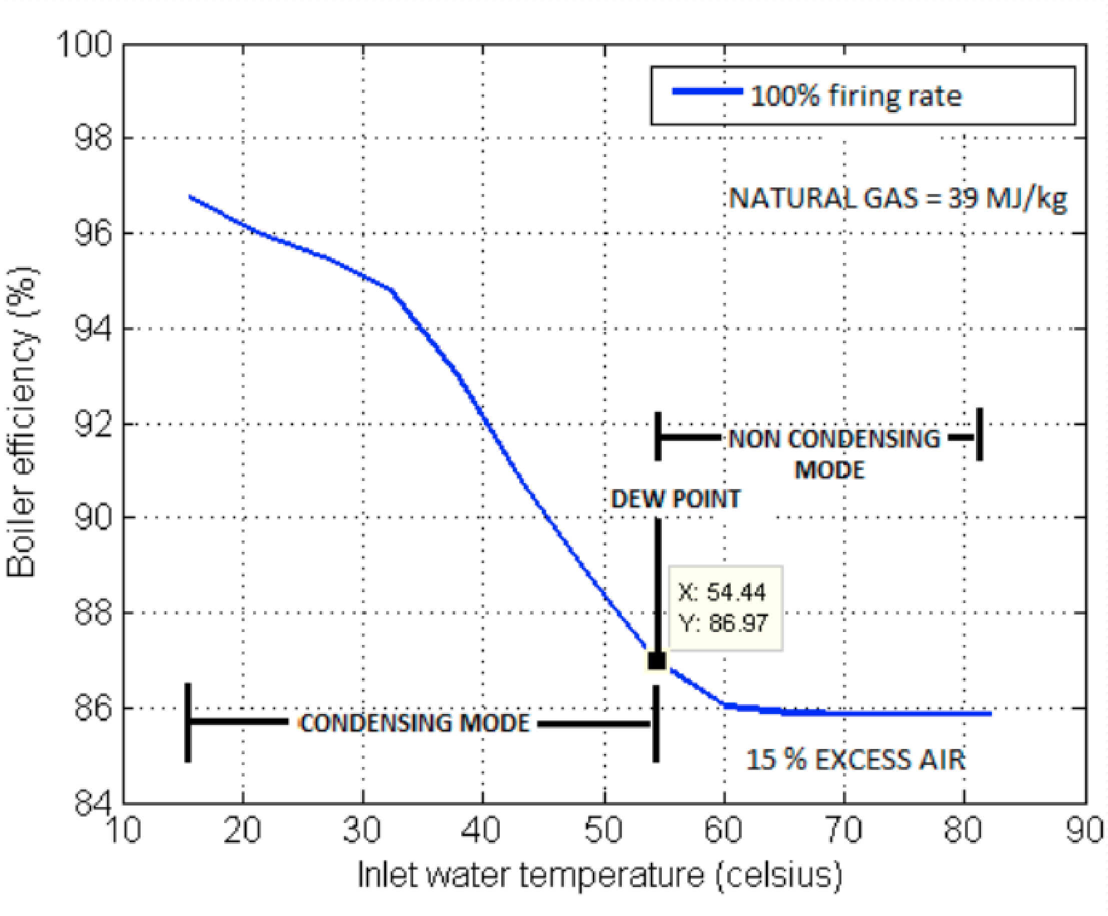
Flue Gas Condensation

- Efficiency can be improved beyond 87% but requires condensing the water.
- Flue gas condensate is acidic with pH of ~3.
- It also must be drained continuously
- ~1gallon per 100,000 Btu



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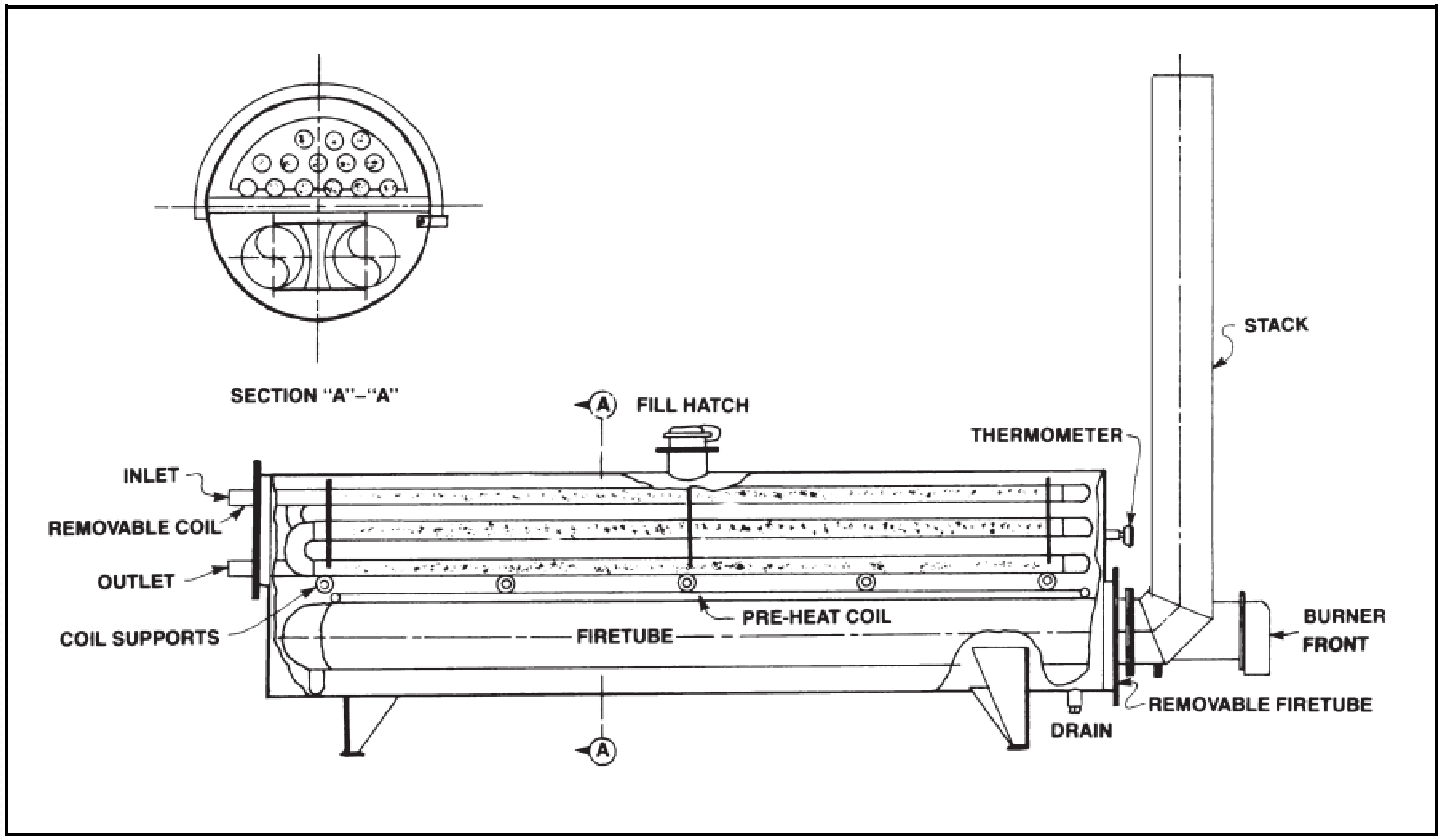
Types of gas fired heaters

- Catalytic infra red radiant heaters
- Indirect glycol/ water bath heaters
- Vacuum Steam heaters

Indirect Fired Water Bath Heater



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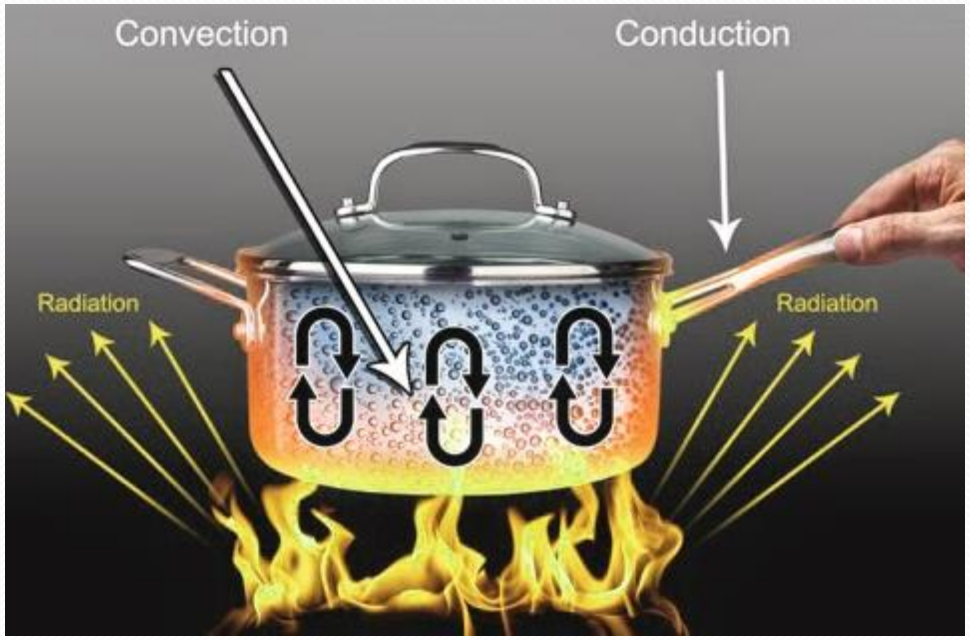
Heat Transfer is the key to efficiency



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Typical Heat Transfer Coefficients

Typical values of the convective heat transfer	
Process	h ($W/m^2 \cdot K$)
Free convection	
Gases	2 - 20
Liquids	50 - 1000
Forced convection	
Gases	25 - 300
Liquids	100 - 40,000
Convection with phase change	
Boiling or condensation	2500 - 100,000

Type	Application	Overall Heat Transfer Coefficient - U -	
		$W/(m^2 K)$	$Btu/(ft^2\ ^oF\ h)$
Tubular, heating or cooling	Gases at atmospheric pressure inside and outside tubes	5 - 35	1 - 6
	Gases at high pressure inside and outside tubes	150 - 500	25 - 90
	Liquid outside (inside) and gas at atmospheric pressure inside (outside) tubes	15 - 70	3 - 15
	Gas at high pressure inside and liquid outside tubes	200 - 400	35 - 70
	Liquids inside and outside tubes	150 - 1200	25 - 200
	Steam outside and liquid inside tubes	300 - 1200	50 - 200
Tubular, condensation	Steam outside and cooling water inside tubes	1500 - 4000	250 - 700
	Organic vapors or ammonia outside and cooling water inside tubes	300 - 1200	50 - 200
Tubular, evaporation	steam outside and high-viscous liquid inside tubes, natural circulation	300 - 900	50 - 150
	steam outside and low-viscous liquid inside tubes, natural circulation	600 - 1700	100 - 300
	steam outside and liquid inside tubes, forced circulation	900 - 3000	150 - 500

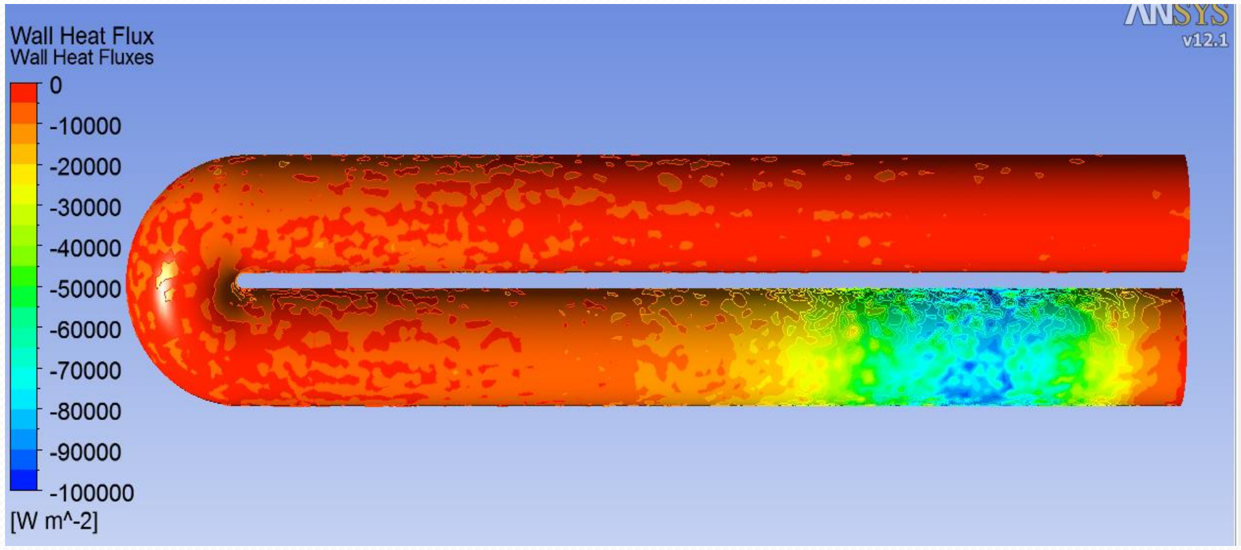
Firetube

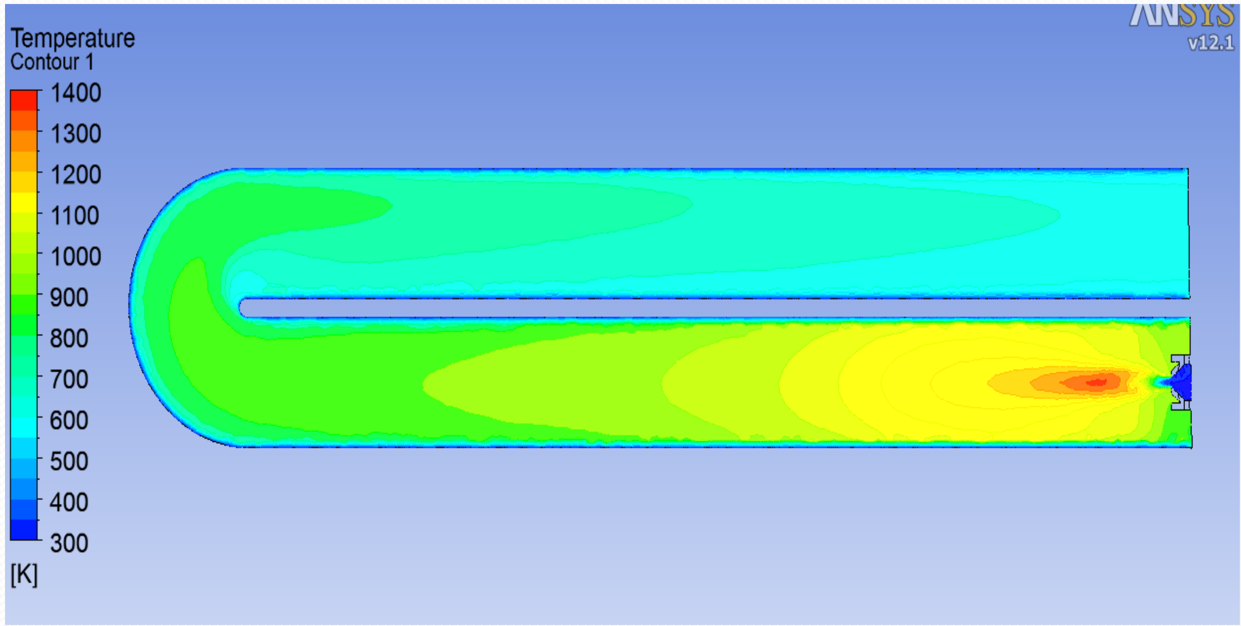
Gas Coil

CFD study of bath style line heater

Combustion Efficiency (%) – Natural Gas

Excess %		Net Stack Temperature				
Air	O2	200°F 93°C	300°F 149°C	400°F (204°C)	500°F (260°C)	600°F (315°C)
9.5	2.0	85.4	83.1	80.8	78.4	76.0
15	3.0	85.2	82.8	80.4	77.9	75.4
28.1	5.0	84.7	82.1	79.5	76.7	74.0
44.9	7.0	84.1	81.2	78.2	75.2	72.1
81.6	10	82.8	79.3	75.6	71.9	68.2





For half the firetube, there is very little heat transfer. Typical exhaust temperatures are 600F to 700F.

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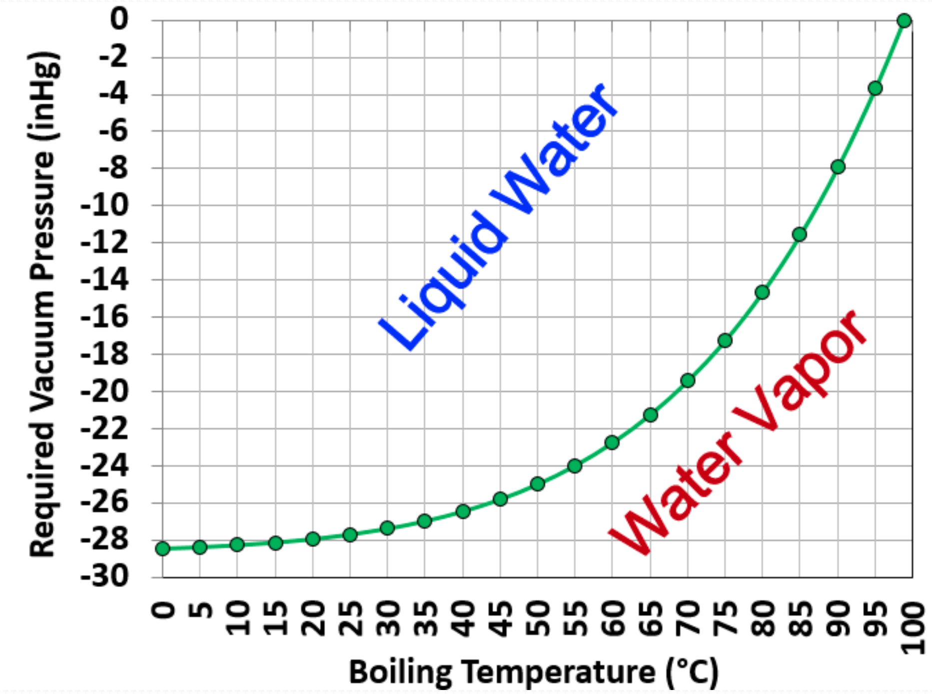
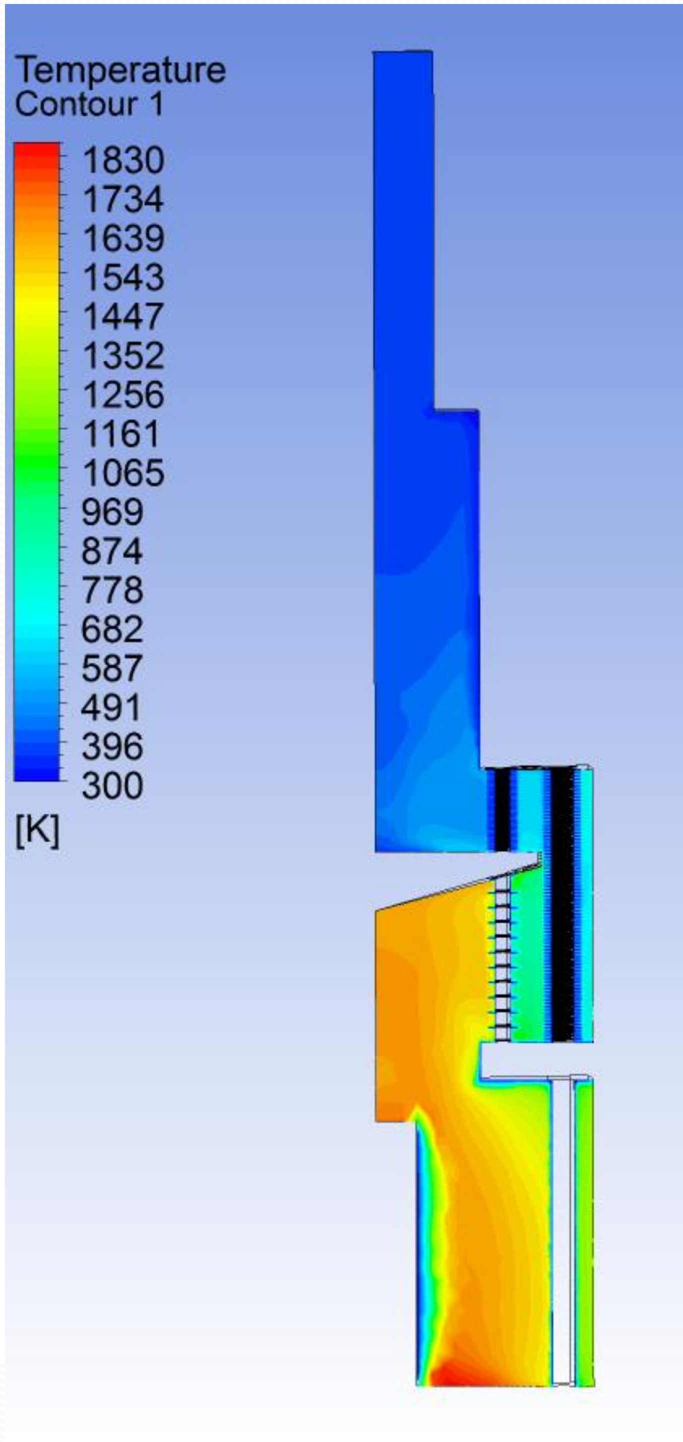
How to improve the line heater efficiency

- Increased liquid heat transfer coefficients with phase changes
- Increase flue gas side surface area with finned tubes
- Operate at a vacuum to reduce boiling temperature.
- Operate close to the flue gas dewpoint (55C).





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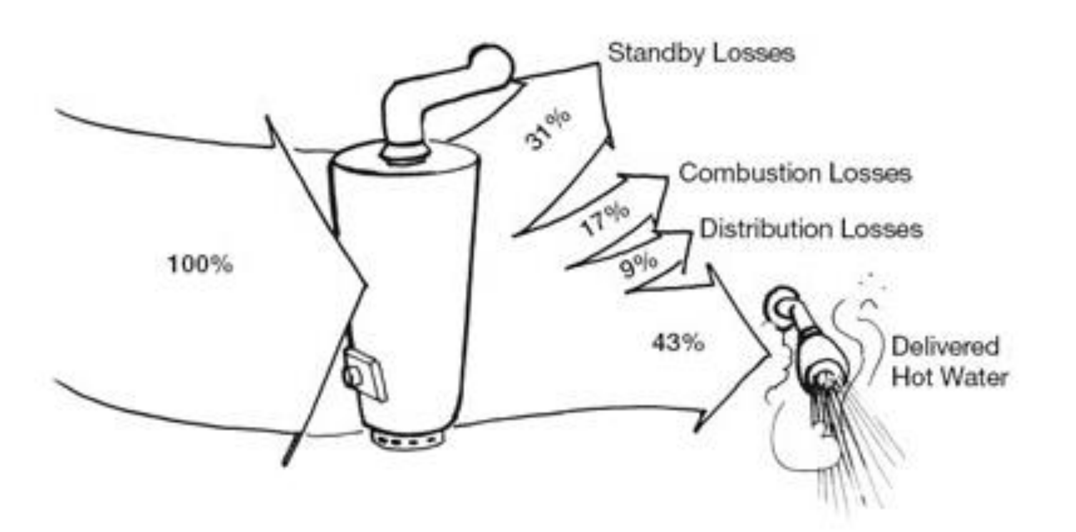
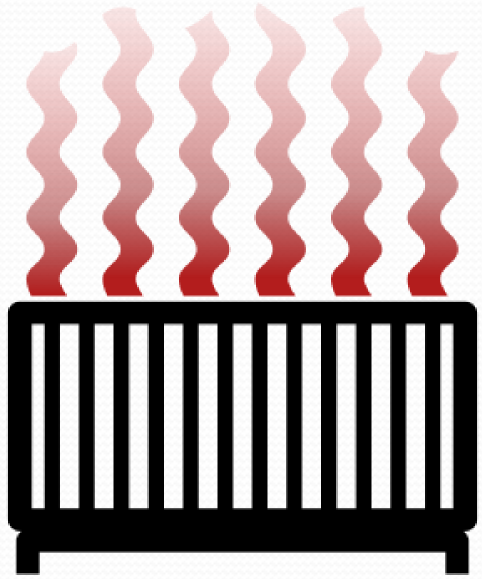
Heater Off Cycle Losses

- Similar to a residential tank type water heater
- When a burner is not firing, it becomes a radiator.
- Continuous pilots keep airflow through the firetube.
- Seasonal loads require <50% of the heat 80% of the time. Most heaters are off most of the time.
- Effective Energy Use Factor ~ 60%





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Efficiency effects on CO_2 emissions

- Using a line heater with an energy use factor of 0.6 produces an equivalent of 1.67X CO_2 equivalent per kW of heat
- Using a line heater with an energy use factor of 0.85 produces an equivalent of 1.18 X CO_2 equivalent per kW of heat
- by simply utilizing more efficient line heating technology, CO_2 emissions can be reduced by 40%.

Model Number	Rated Nominal Volume U.S. Gal.	Rated Nominal Volume Imp. Gal.	DOE Rated Storage Volume Gal.	BTU/Hr. Input	LP BTU/Hr. Input	First Hour Rating Gal.	Uniform Energy Factor	Recovery at 90°F Rise* U.S. GPH	Recovery at 90°F Rise* Imp. GPH	Recovery at 90°F Rise* LP U.S. GPH	Recovery at 90°F Rise* LP Imp. GPH
RG130T6N*	30	25	29	27,000	27,000	46	0.54	29	24	29	24
RG230T6N*	30	25	29	32,000	31,000	60	0.60	34	28	33	23
RG230S6N	30	25	29	30,000	26,000	49	0.54	32	37	32	27
RG140T6N*	40	33	38	34,000	34,000	64	0.59	37	31	37	31
RG240T6N*	40	33	38	40,000	36,000	75	0.64	43	36	34	33
RG240S6N*	40	33	38	40,000	38,000	69	0.58	43	36	41	34
RG150T6N*	50	42	47	34,000	34,000	75	0.63	37	31	37	31
RG250T6N*	50	42	48	40,000	36,000	81	0.63	43	36	41	34
RG250L6N	48	40	47	40,000	38,000	77	0.63	43	36	41	34
RG250S6N*	50	42	47	50,000	48,000	75	0.63	54	45	52	45

Model Number	Rated Nominal Volume Liters	DOE Rated Storage Volume Liters	kW Input	LP kW Input	First Hour Rating Liters	Uniform Energy Factor	Recovery at 50°C Rise* Liters/Hour	Recovery at 50°C Rise* LP Liters/Hour
RG130T6N*	114	110	7.9	7.9	174	0.54	110	110
RG230T6N*	114	110	9.4	9.1	227	0.60	129	125
RG230S6N	114	110	8.8	7.6	186	0.54	121	121
RG140T6N*	151	144	10.0	9.9	243	0.59	139	139
RG240T6N*	151	144	11.7	10.6	284	0.64	163	129
RG240S6N*	151	144	11.7	11.1	262	0.58	163	155
RG150T6N*	189	178	10.0	9.9	284	0.63	139	139
RG250T6N*	189	182	11.7	10.6	307	0.63	163	155
RG250L6N	182	178	11.7	11.1	292	0.63	163	155
RG250S6N*	189	178	14.7	14.1	284	0.63	204	197

A standard Utherm heater is comprised of the following two separately registered components:

- Firecage
- Process Coil

ASME Section IV

ASME Section VIII Division I Indirect-Fired Process Coil

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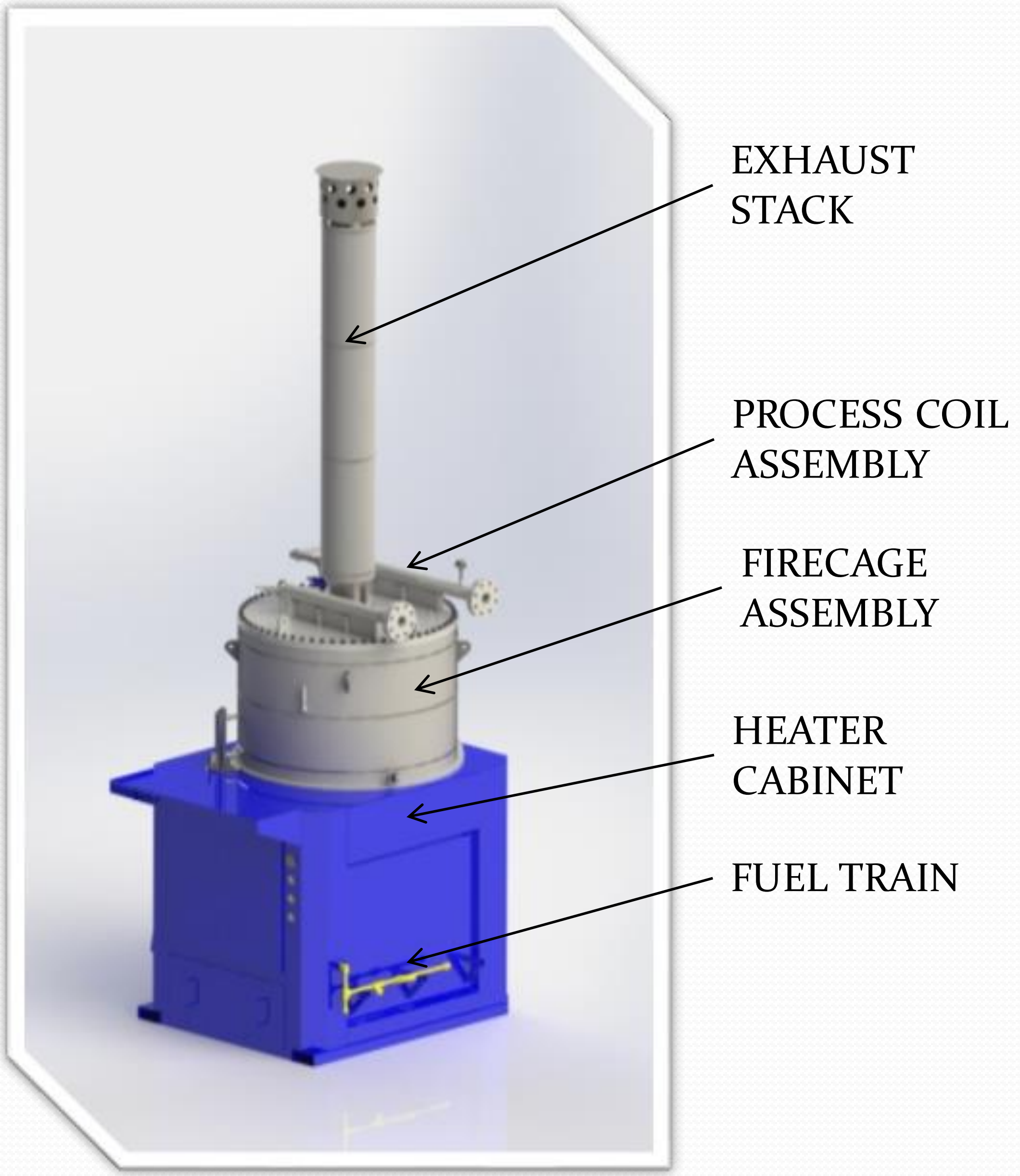
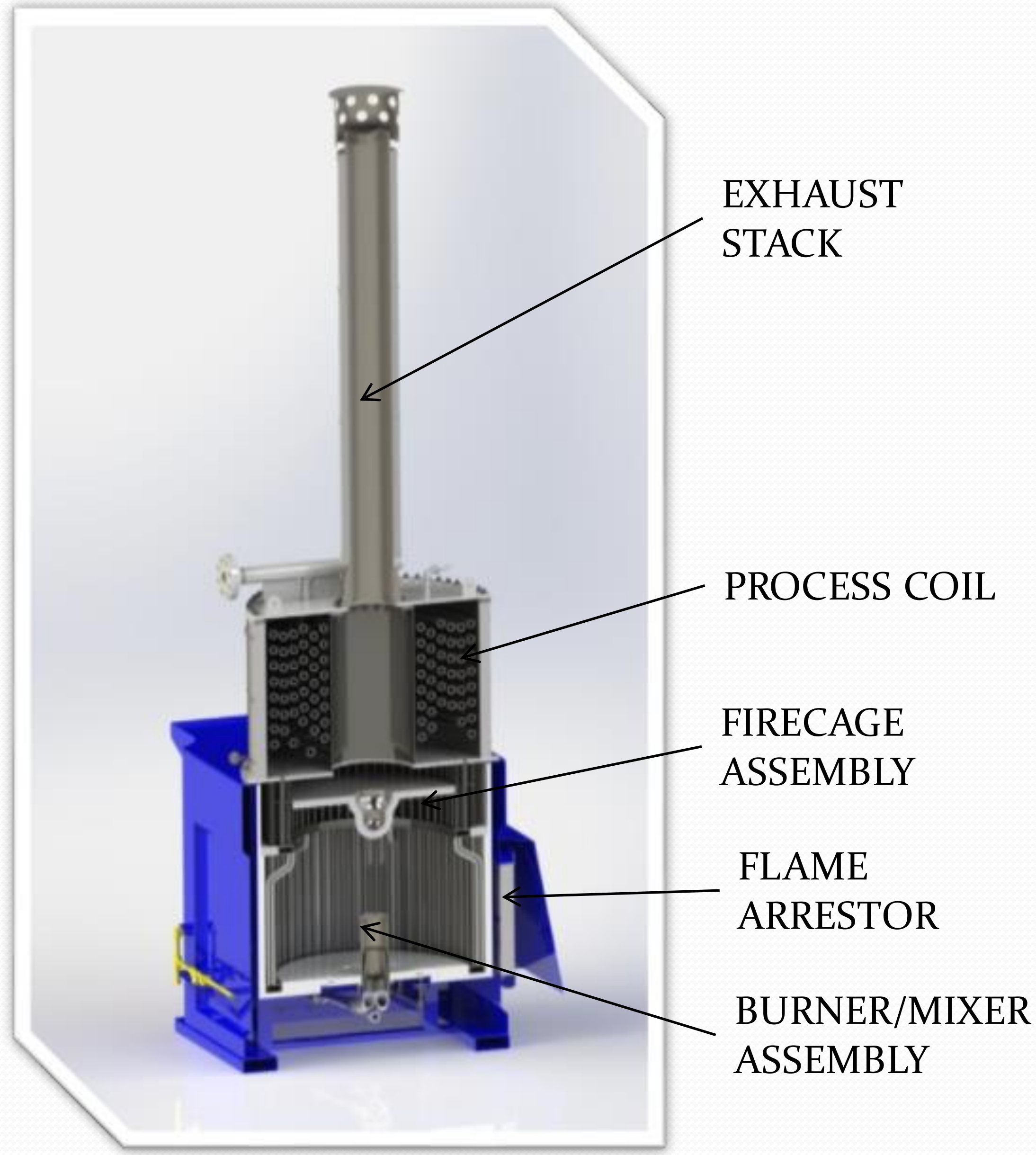
Heater Mechanical Overview





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Utherm Firecage

- COMPONENT FUNCTION: TRANSFER RADIANT HEAT FROM BURNER TO 50/50 WATER/GLYCOL MIXTURE WITHIN FIRECAGE
- DESIGN TO: ASME Section IV / ASME Section VIII
- EXTERNAL DESIGN PRESSURE: 103kPag
- VACUUM DESIGN PRESSURE: 100kPag
- NORMALLY OPERATES AT SLIGHT VACUUM TO SLIGHTLY POSITIVE PRESSURE
- DESIGN TEMPERATURE: -20C TO 100C
- MATERAILS OF CONSTRUCTION: SA516 GR.70N / SA179 / SA105N / SA106 GR.B
- OVERPRESSURE PROTECTION: RUPTURE DISK WITH 69kPag SETPOINT (NOT SHOWN)

Utherm Process Coil

- COMPONENT FUNCTION: TRANSFER HEAT FROM 50/50 WATER/GLYCOL MIXTURE WITHIN FIRECAGE TO THE PROCESS COIL / PROCESS FLUID
- CRN NUMBER: L0275.1
- DESIGN TO: ASME B31.3; INDIRECT FIRED HEATER COIL
- DESIGN PRESSURE: 18,000kPa
- DESIGN TEMPERATURE: -20C TO 100C
- MATERAILS OF CONSTRUCTION: SA105N / SA106 GR.B / SA234 GR.WPB

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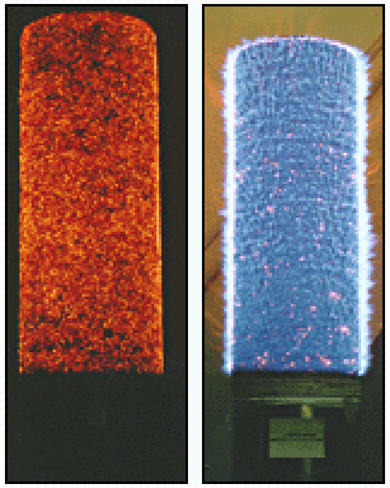
Typical high efficiency line heater installation

Radiant Metal Fiber Matrix Burners

Ultra Low Emissions Burners - Developed by Shell & Bekaert in 1987

Fully Pre-Mixed (no secondary air)

The radiant metal fiber matrix burner is designed to operate in fully premixed mode which no secondary air. This is ideal for natural draft process heaters and reduces off cycle losses.



Low Pressure Drop

The radiant metal fiber matrix burner provides a very low back pressure (<0.3"wc) which is ideal for natural draft heaters utilizing standard mixers.

High Turndown ratio

The firing intensity of a metal fiber burner can easily be modulated between 100 kW/m² (31,800 Btu/h.ft²) and 5000 kW/m² (1,590,000 Btu/h.ft²) with a gradual transition between the different modes. The Utherm heater is provided with a 5:1 turndown in the range between 140kW/m2 and 1000 kW/m2.

Low Noise

An added bonus of the fiber matrix burner is the noise free and resonance-free combustion. Because of the textile structure of the metal fibre burner there is no flame front resonance. The flame is laminar through most firing rates of the Utherm heater.

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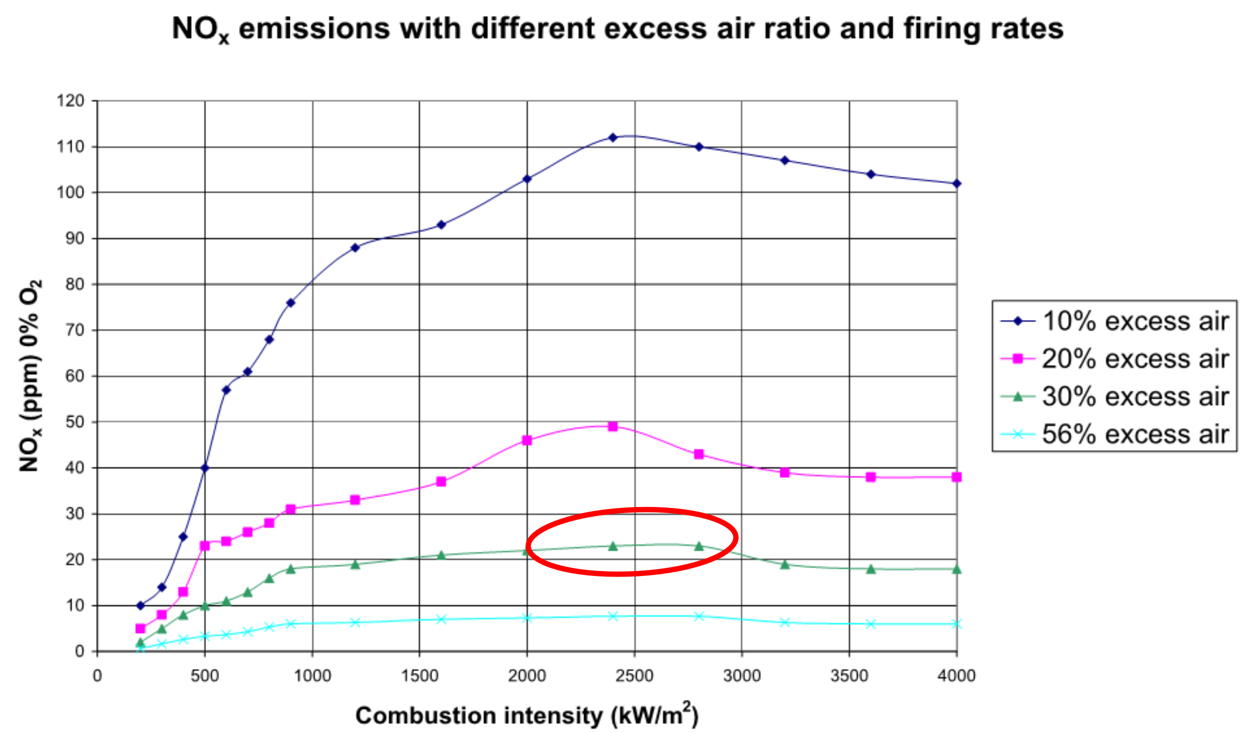
Low Emissions

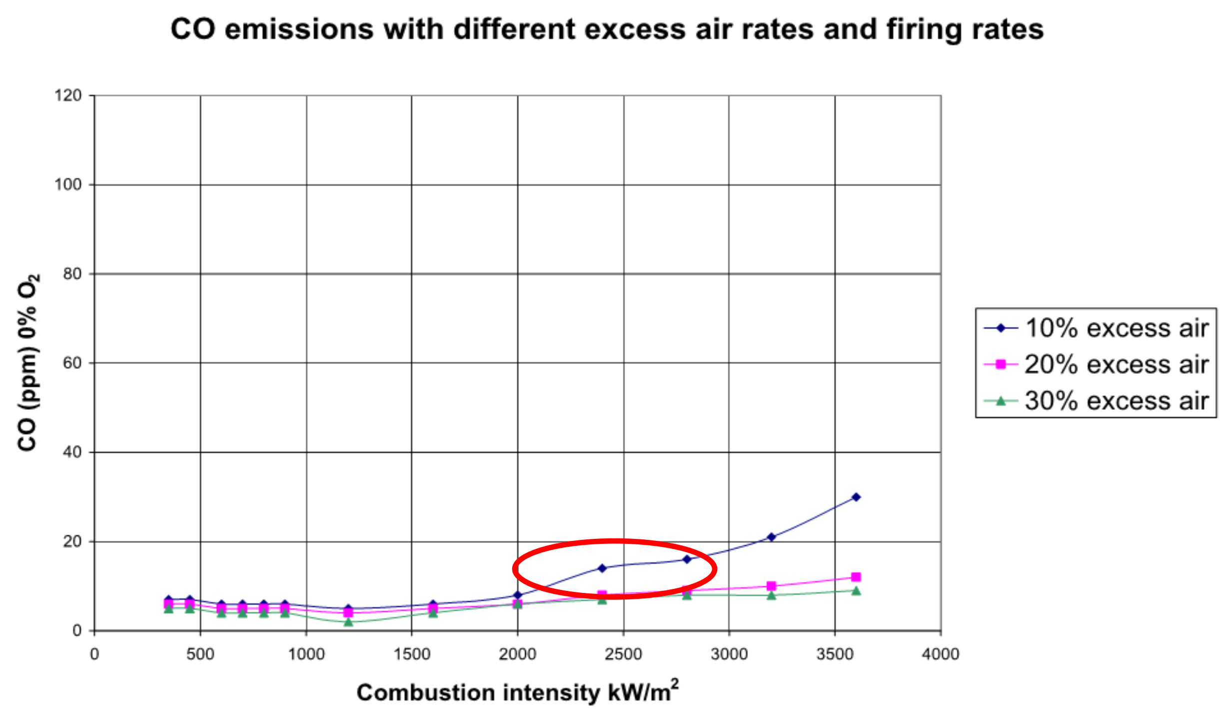
Low NOx and CO emissions

Surface combustion with the metal fibre burner leads to extremely low emissions of NOx, CO and unburned fuel.

As a result of the intimate contact between the gases and the fibres, flame temperature is significantly reduced leading to far lower NOx levels than with other burner technologies.

Utherm heaters typically produce <30ppm NOX an CO and reduce CO2 by 30%





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Utherm Natural Draft Fired Heaters

- High efficiency – typically 80% to 95% of LHV depending on process temperature.
- Low Emissions – can provide to <30ppm Nox

Testo t350 XL

Testo t350 XL

SN: 01580068 /USA

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NONAME GREG

01/04/04 10:41:11

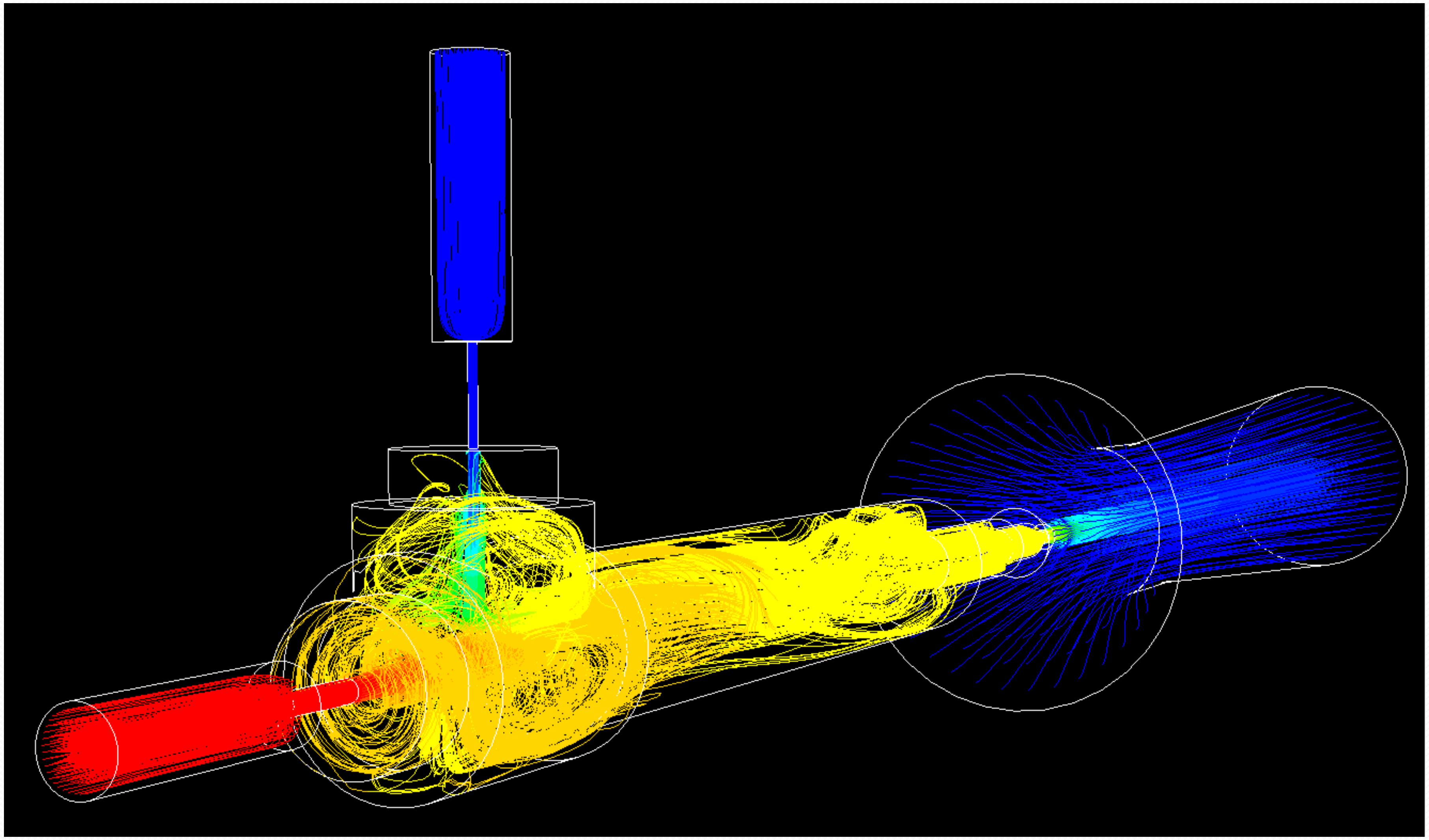
Fuel: Natur.gas

111.8	°C	Tf
5.31	%	Oxygen
8.73	%	CO2
0	ppm	CO
30	ppm	NO
1.1	ppm	NO2
31	ppm	NOx
86.5	%	Efficiency
30.0	%	Excess air
1.21	l/m	Pump
9.6	V	Batt.
------	inW	ΔP
13.5	%	loss

Heat transf.°F: --- °F

0118

Running Utherm Mixers
with Natural Gas and Hydrogen Mixture



By Latif Bouhadji, Ph.D., P.Eng

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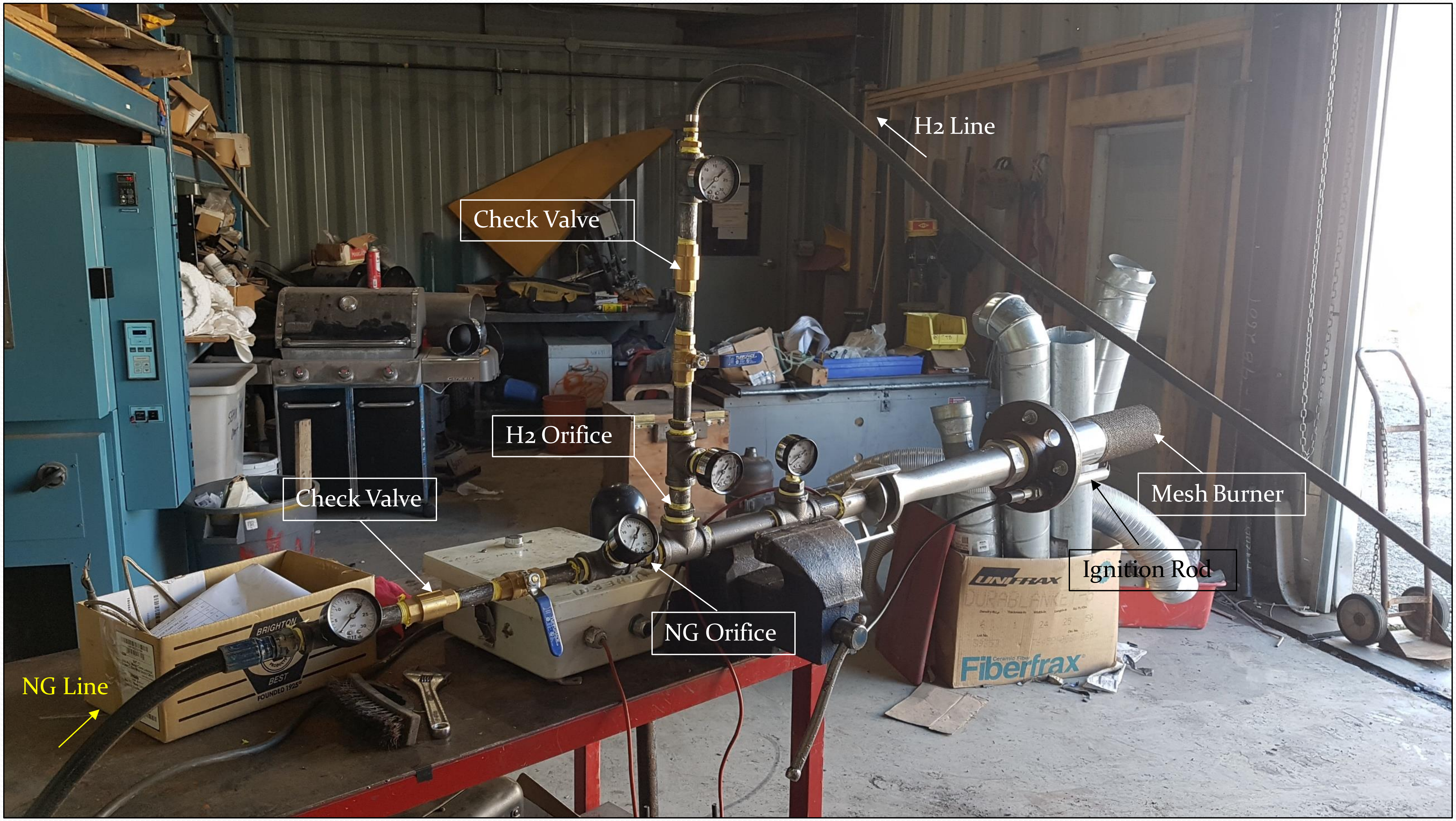
NG-H_2 Mixture Shop Test



Gas Composition (%Mole) & Calculated Properties

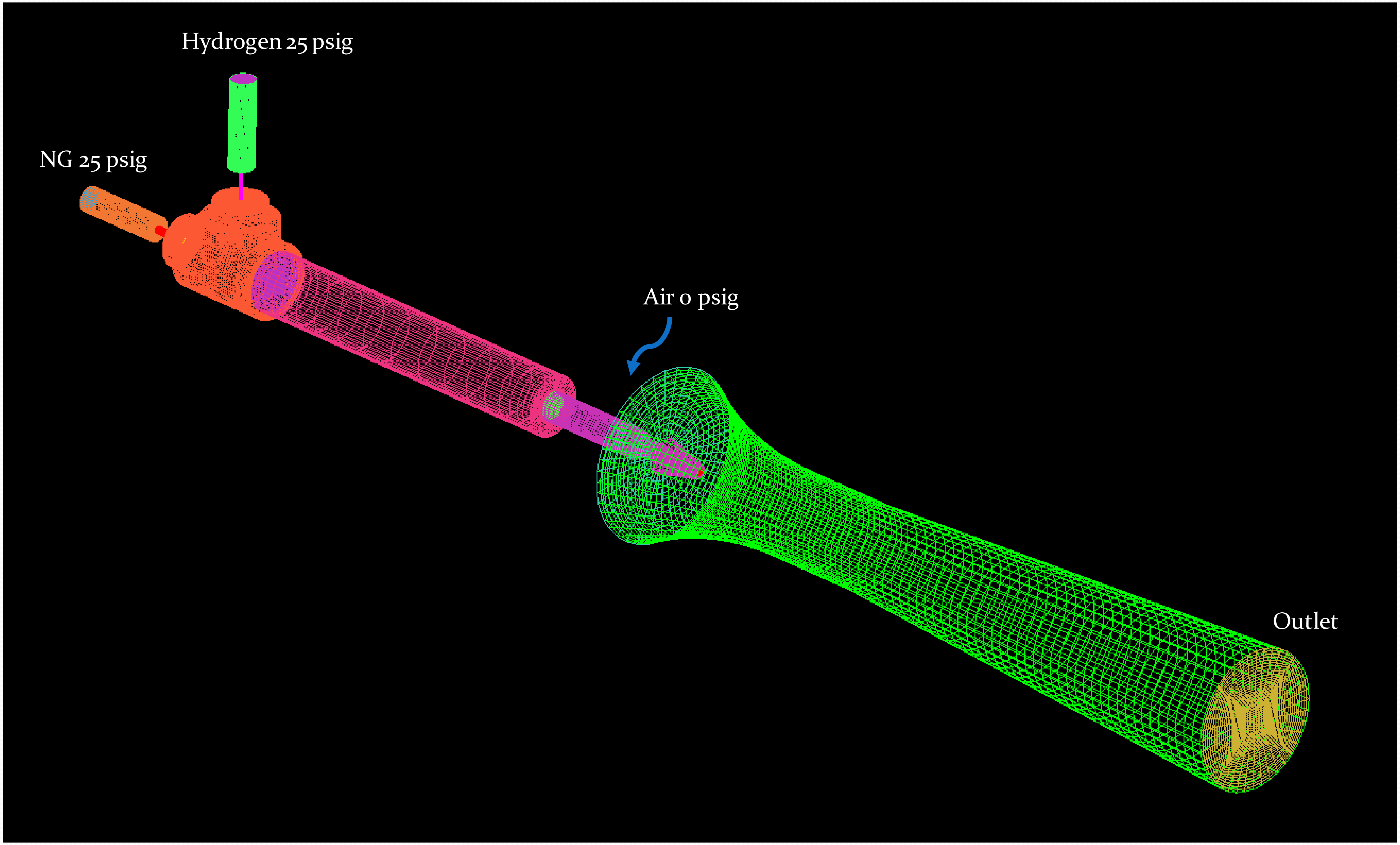
Natural Gas (%)		Natural Gas (70%) Hydrogen (30%)	
H_2	0	H_2	30
CO_2	0.7	CO_2	0.49
N_2	2.4	N_2	1.68
CH_4	93.4	CH_4	65.38
C_2H_6	2.7	C_2H_6	1.89
C_3H_8	0.6	C_3H_8	0.42
C_4H_{10}	0.2	C_4H_{10}	0.14

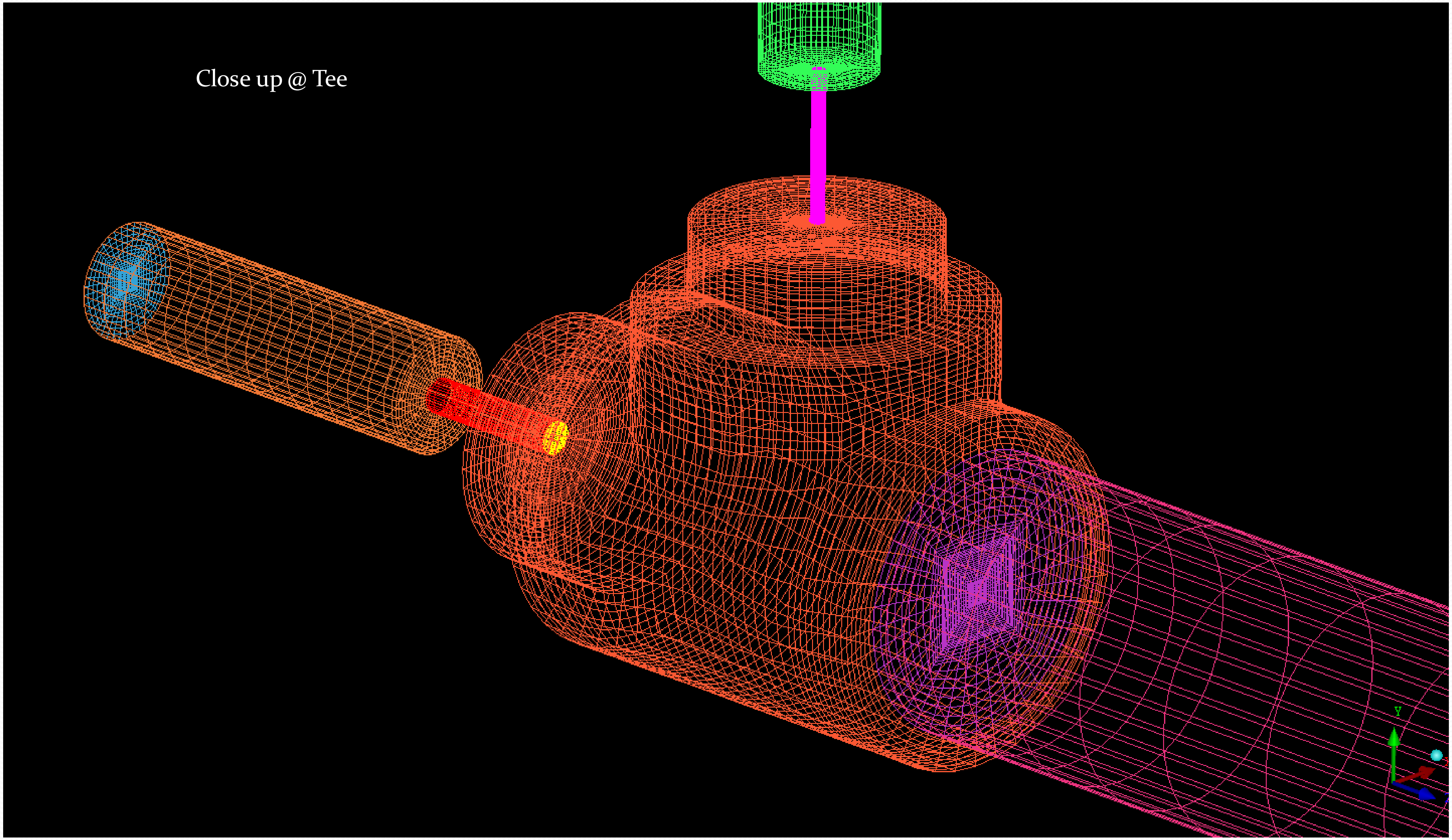
Gas Properties	Natural Gas	Natural Gas-Hydrogen
MW (g/mol)	17.15	12.61
Density (lb/Sft^3)	0.0453	0.0333
Specific Gravity	0.6	0.44
Specific Heat Ratio	1.31	1.34
LEL / UEL	5.0 / 15.3	4.8 / 20.1
LHV (Btu/Sft^3)	917	724
HHV (Btu/Sft^3)	1,017	809
AFR Stoic (Mass Basis)	16.07	16.93

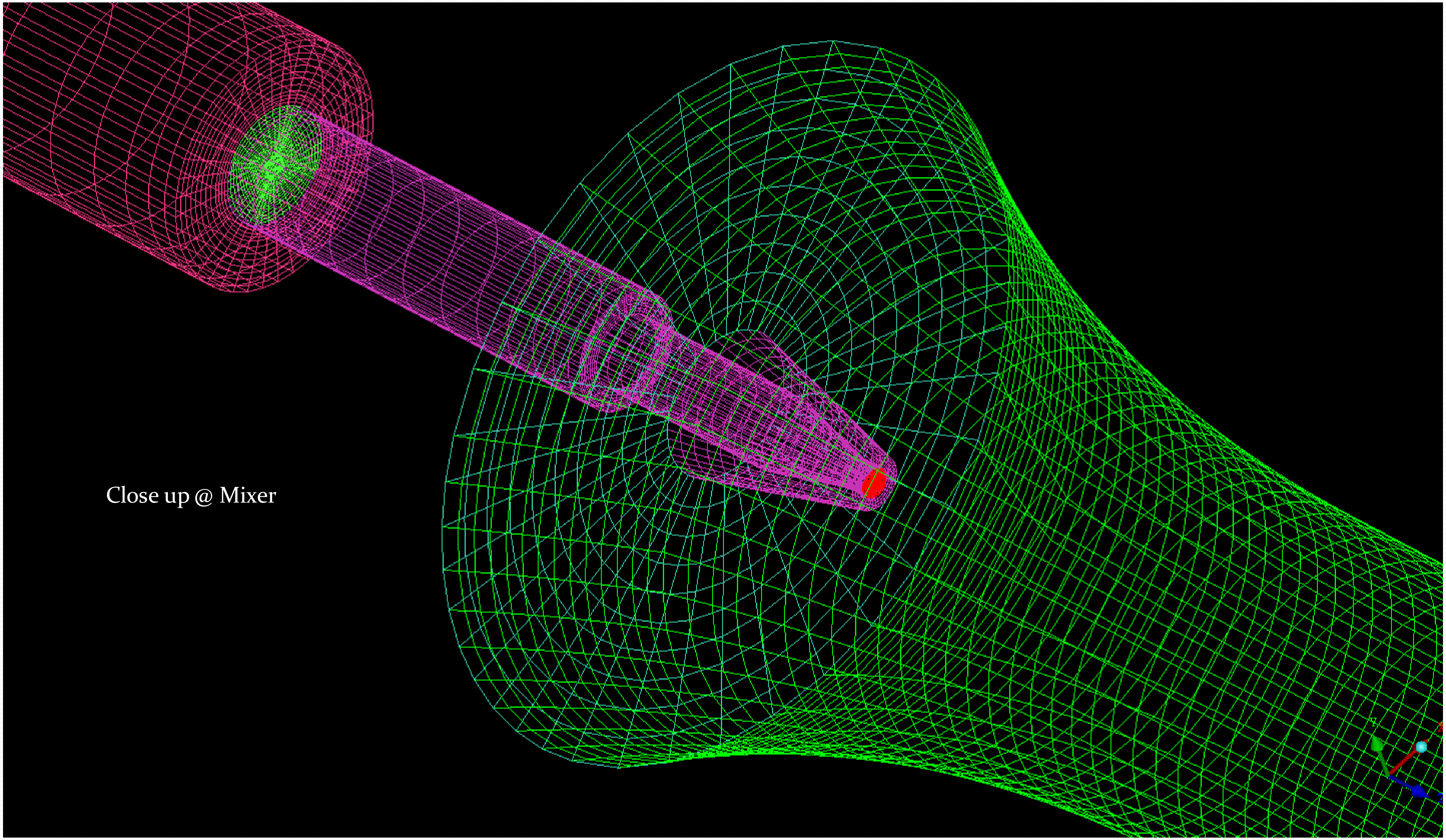
Mixer Gas Orifice Sizing Calc.

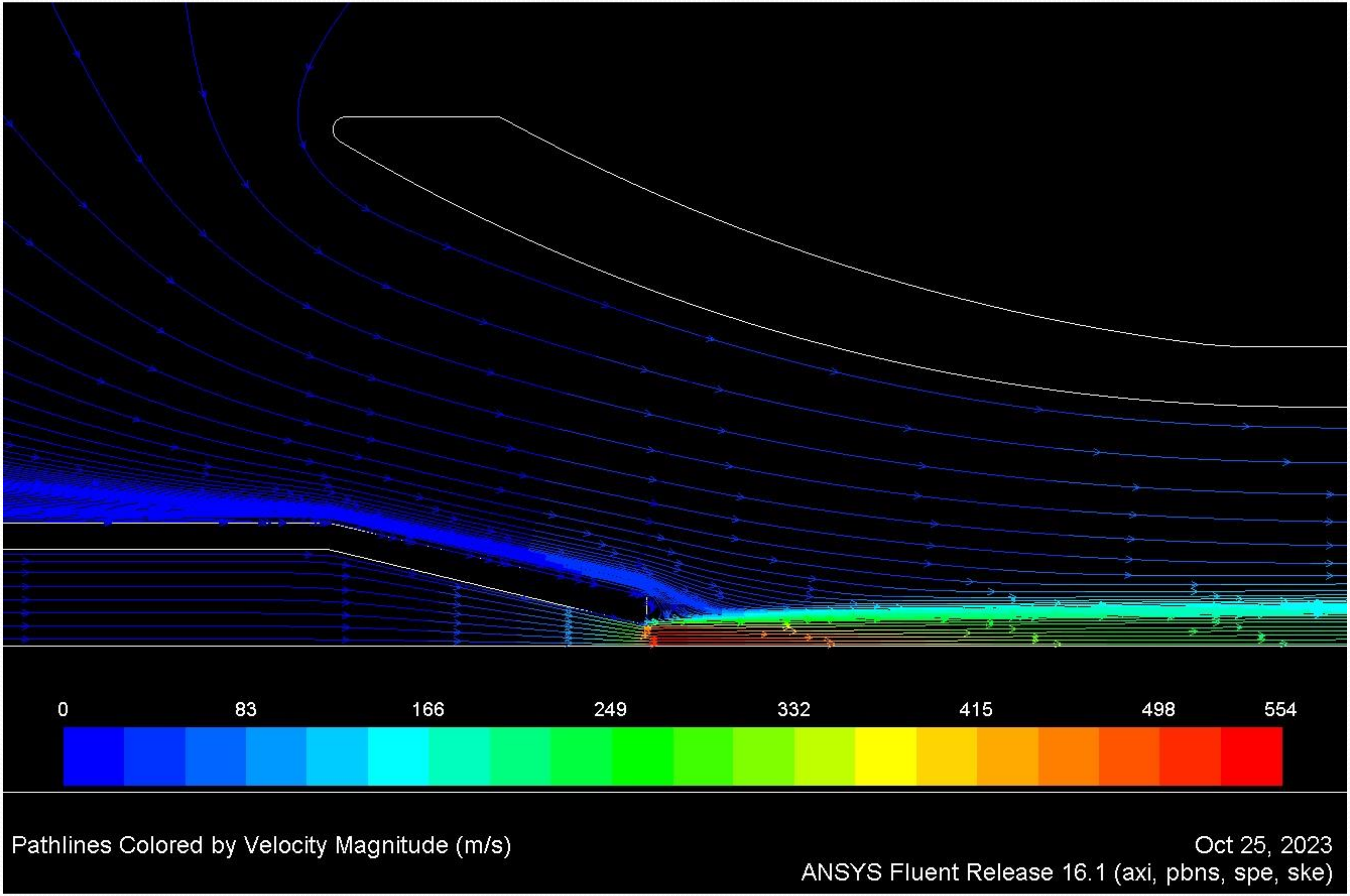
	Natural Gas	Natural Gas-Hydrogen (70/30)
Heat Release (Btu/h)	500,000	500,000
Gas Pressure (psig)	20	20
Mass Flow (lb/h)	24.73	23.02
Flow (Sft^3/h)	546	691
Mixer Gas Orifice	1/8”	#30 (0.1285”)
Gas Orifice Cd	0.94	0.94

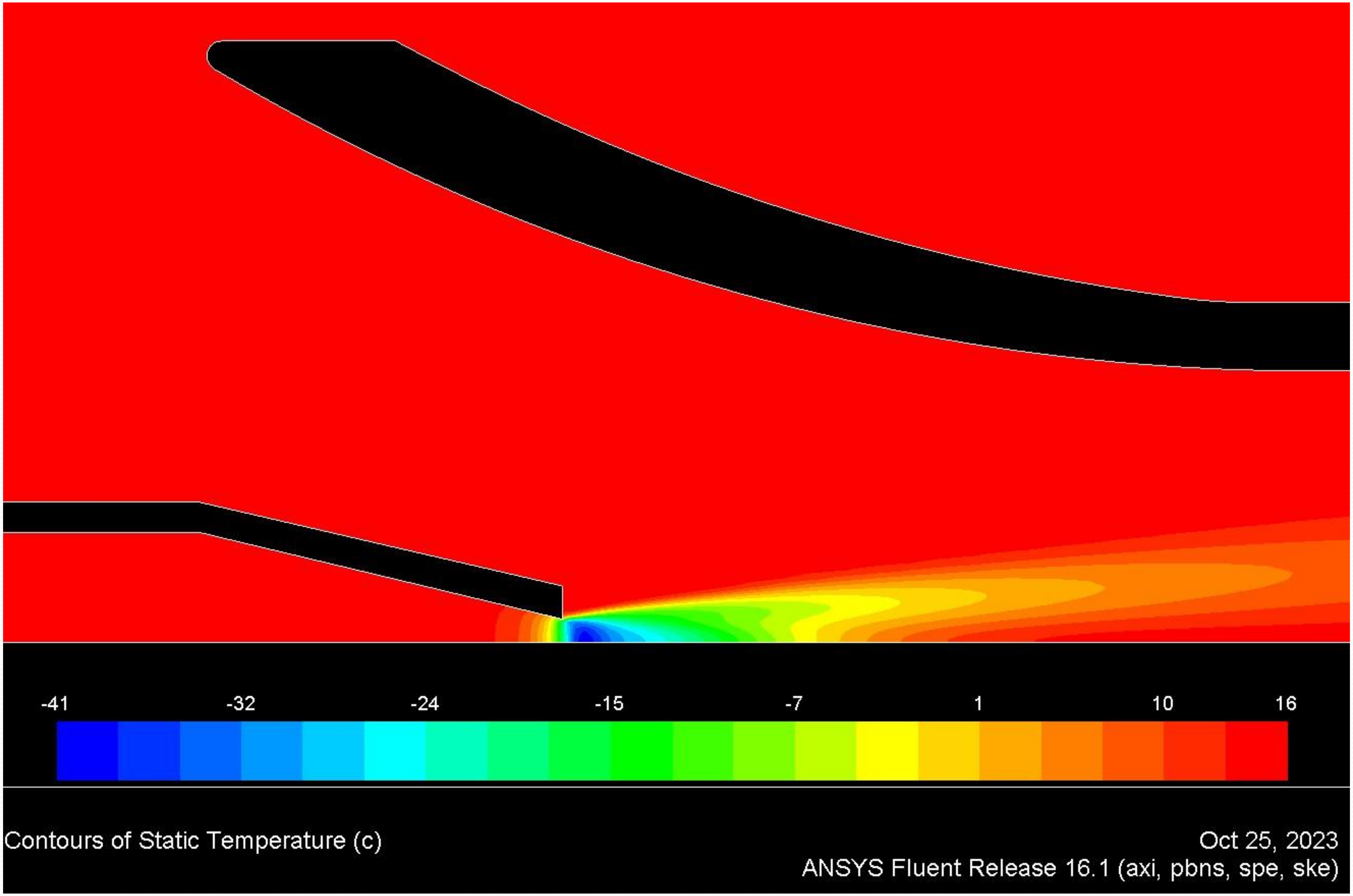
CFD ANALYSIS: NG-H_2 Mixture Shop Test




Close up @ Tee


Close up @ Mixer

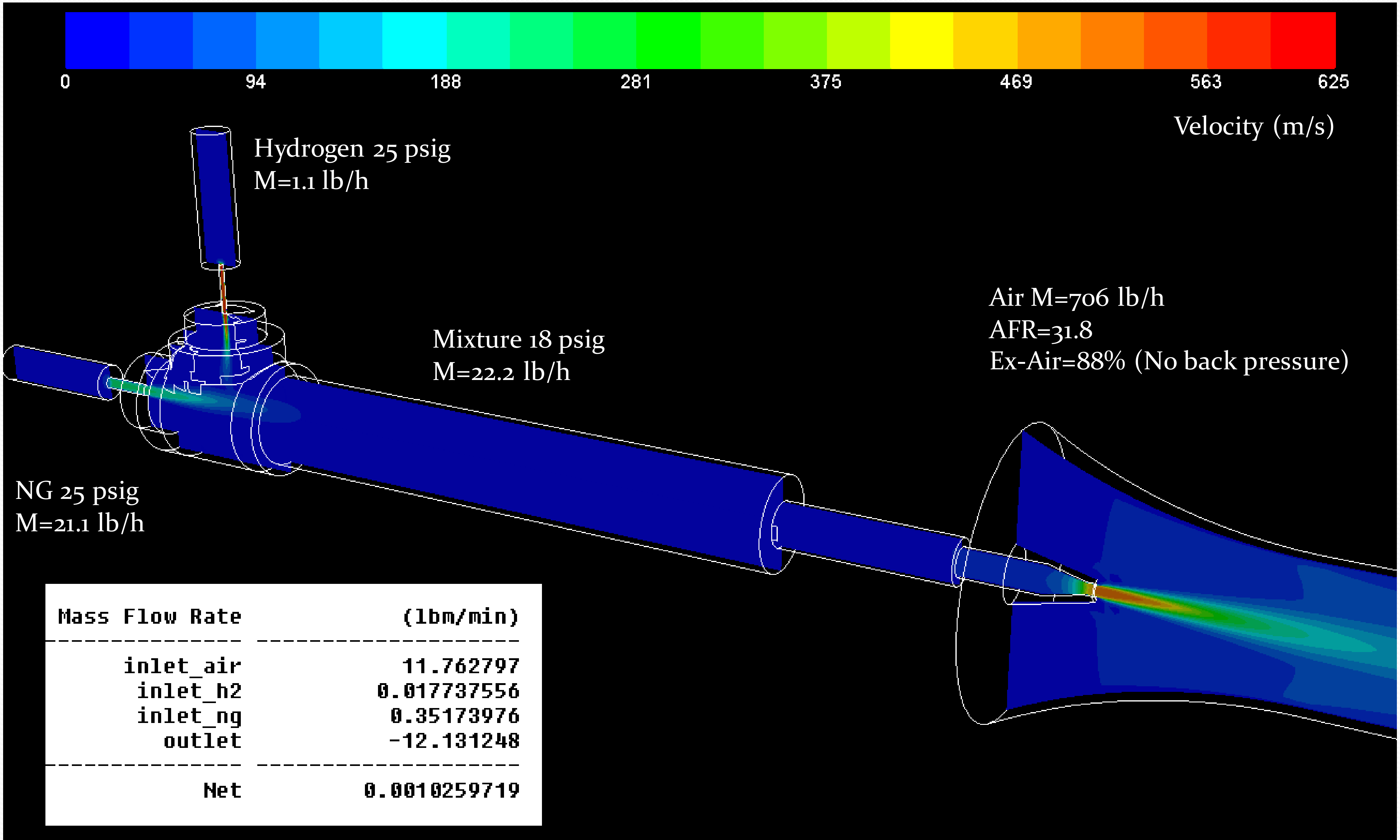

0
83
166
249
332
415
498
554
Pathlines Colored by Velocity Magnitude (m/s)
Oct 25, 2023
ANSYS Fluent Release 16.1 (axi, pbns, spe, ske)


-41
-32
-24
-15
-7
1
10
16
Contours of Static Temperature (c)
Oct 25, 2023
ANSYS Fluent Release 16.1 (axi, pbns, spe, ske)

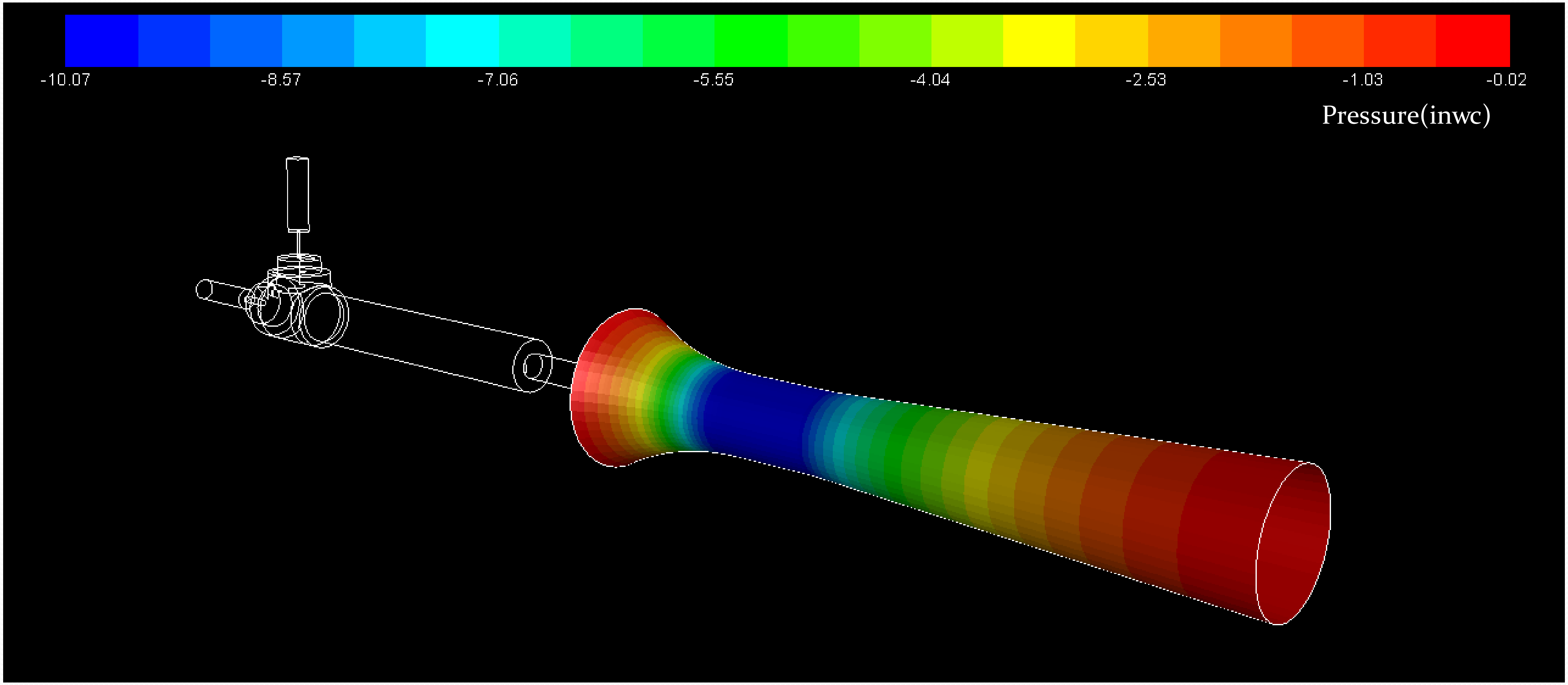
$NG\text{-}H_2$ Mixture Shop Test

	NG (70 % Volume)	Hydrogen (30% Volume)	Mixture
Volume Flow (Scfh)	483	207	690
Gas Density (lb/Sft^3)	0.0453	0.0053	0.0333
Gas Mass Flow (lb/h)	21.9	1.1	23
Heating Value (Btu/Sft^3)	917	275	724
Stoich. Air (Volume Basis)	9.55	2.38	7.40
Heat Release (Btu/h)	443,108	56,893	500,000
Inlet Pressure (psig)	25	25	-
Orifice Size	#55	#30	#30

CFD Results: NG-H_2 Mixture Shop Test Model



Mass Flow Rate	(lbm/min)
inlet_air	11.762797
inlet_h2	0.017737556
inlet_ng	0.35173976
outlet	-12.131248
Net	0.0010259719


-10.07
-8.57
-7.06
-5.55
-4.04
-2.53
-1.03
-0.02
Pressure(inwc)

NG-H_2 Mixture CFD Results

	NG-H_2 Mixture	
Gas Mass Flow (lb/h)	25.6	25.6
Mixture Pressure (inwc)	0	1.1
Air Mass Flow (lb/h)	696.5	607
AFR	27.2	23.7
Excess Air (%)	61	40
Gas Flow (Sft^3/h)	769	769
Air Flow (Sft^3/h)	9,164.5	7,987
Air Flow (Sft^3/min)	153	133

NG-H_2 Mixture Shop Test

NG-H_2 Mixture Shop Test

Decreasing Natural Gas Pressure until Flash Back

Conclusions

To reduce CO_2 emissions, look at the entire energy distribution chain. With 60% of the grid supplied by fossil fuels, electric heaters produce more CO_2 than a natural gas fired heater.

Increasing heater efficiency is the most effective way to reduce CO_2 emissions. Efficiency should be >85%

Efficiency is increased through higher heat transfer coefficients on the flue gas side (fins) and through phase change on the heat medium side.

Efficiency must consider off cycle losses which can have a significant impact – energy factors vs just efficiency.