DECARBONIZATION OF INDUSTRIAL FIRED HEATERS BY USING HYDROGEN FUEL

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INNOVATION BUILDERS

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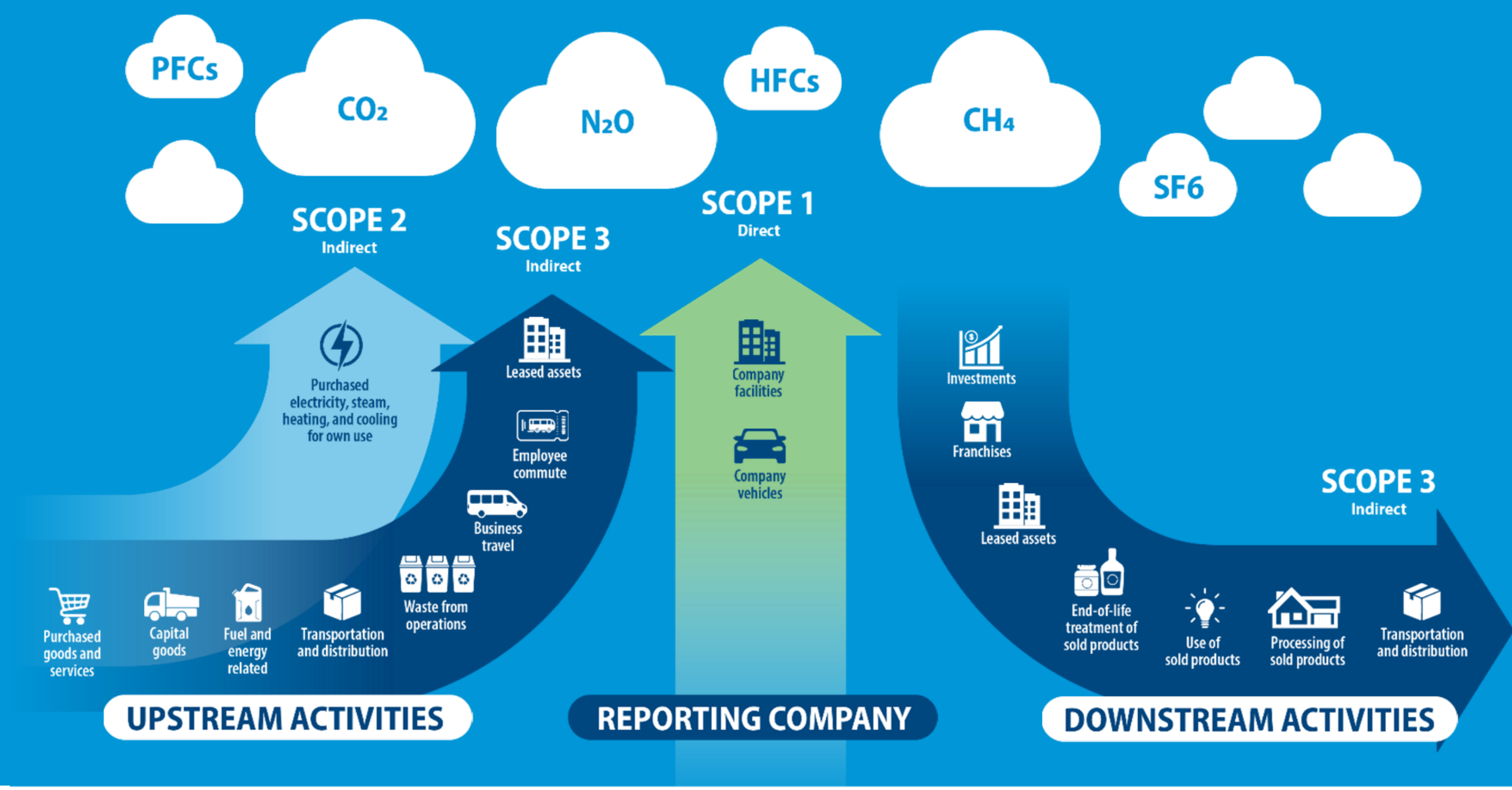
- 30+ years in Fluor
- BS Chemical Engineering in Texas A&M University
- Published and presented more than 30 technical articles about process design and project execution

AGENDA

- Introduction
- Combustion and Heater Basics
- H_2 and CH_4 Combustion Reactions and Impacts
- Switching Existing Gas Heaters to Hydrogen Fuel
- Economic Comparison
- Summary

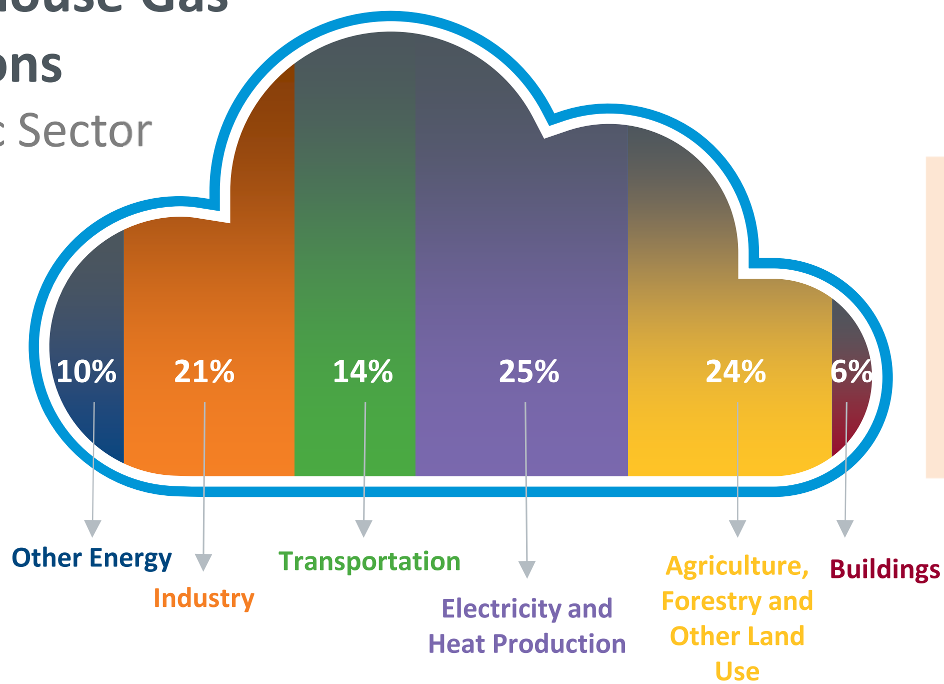
SCOPE 1/2/3 EMISSIONS



GREENHOUSE GAS EMISSIONS

Global Greenhouse Gas Emissions

by Economic Sector



- Industry Sector includes Scope 1 emissions from production of goods, including chemicals, fuels, mineral transformation and manufacturing
- Primary emissions are due to fossil fuels combusted on site for energy

https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

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INCREMENTAL CO_2 EMISSIONS REDUCTION OPTIONS

- Energy Efficiency
  - Improve energy efficiency of existing process

- Electrification
  - Convert existing fuel gas or steam heat to lower carbon emissions electricity

Previous Fluor Innovation Builders Webinars cover these topics! Available at:
https://www.fluor.com/about-fluor/corporate-information/innovation/innovation-builders

FIRED HEATERS MAJOR CO_2 EMISSIONS REDUCTION OPTIONS

- **Carbon Capture**
  - Using air as oxygen source and adding a carbon capture, compression and treating system
  - Using 100% oxygen, and adding a carbon compression and treating system
- **Convert to 100% Hydrogen as Fuel**
  - Impacts to heater and fuel gas distribution system will require some scope
  - Potential increase in NO_x emissions must be mitigated

HYDROCARBON COMBUSTION CO_2 EMISSIONS

General hydrocarbon combustion formula:

$$\text{Fuel} + O_2 \rightarrow CO_2 + H_2O$$

For a hydrocarbon expressed as CxHy:

$$C_xH_y + (x+y/4)O_2 \rightarrow xCO_2 + (y/2)H_2O$$

Fuel gas molecules with more carbons produce more energy per volume of gas, but also produce more CO_2

When pure hydrogen is used as the fuel, the formula simplifies to:

$$2H_2 + O_2 \rightarrow 2H_2O$$

Fuel	Relative CO_2 emissions from combustion
Hydrogen	0.00
Methane	1.00
Ethane	1.12
Propane	1.15
n-butane	1.22
n-pentane	1.24
Fuel Oil	1.50

At constant heat release, based on LHV

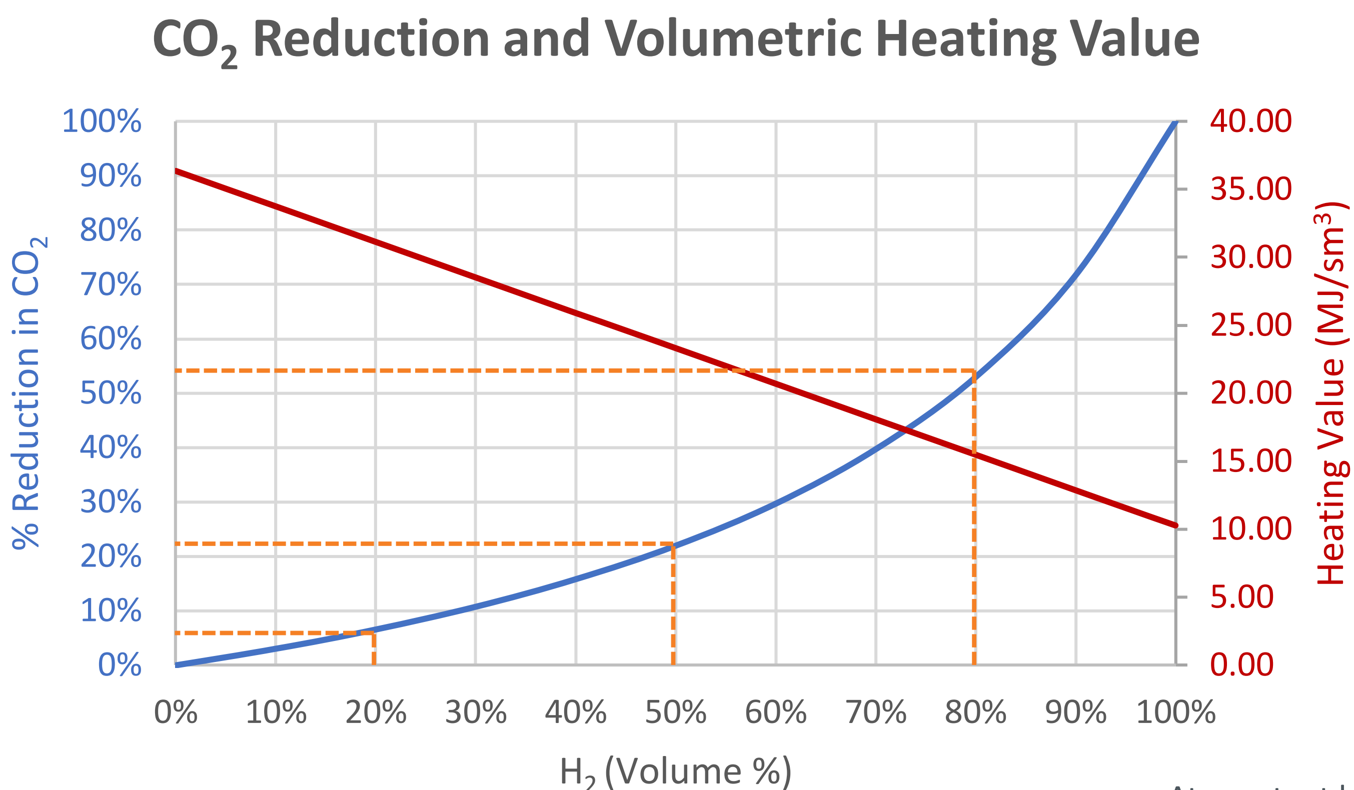
FUEL FLAME TEMPERATURES

Component	Formula	Flame Temperature	
Hydrogen	**H_2**	**2254 °C**	**4089 °F**
Methane	CH_4	1963 °C	3565 °F
Ethylene	C_2H_4	2343 °C	4249 °F
Ethane	C_2H_6	1955 °C	3551 °F
Propane	C_3H_8	1980 °C	3596 °F
n-Butane	C_4H_{10}	1970 °C	3578 °F
n-Pentane	C_5H_{12}	1977 °C	3591 °F

COMBUSTION REACTIONS

Reaction	Lower Heating Value (BTU/scf)
Hydrogen Fuel	
$2H_2 + (O_2 + 3.76N_2) \rightarrow 2H_2O + 3.76N_2$	275
Methane Fuel	
$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$	910

CO_2 REDUCTION FOR HYDROGEN/METHANE BLENDS



At constant heat release, based on LHV

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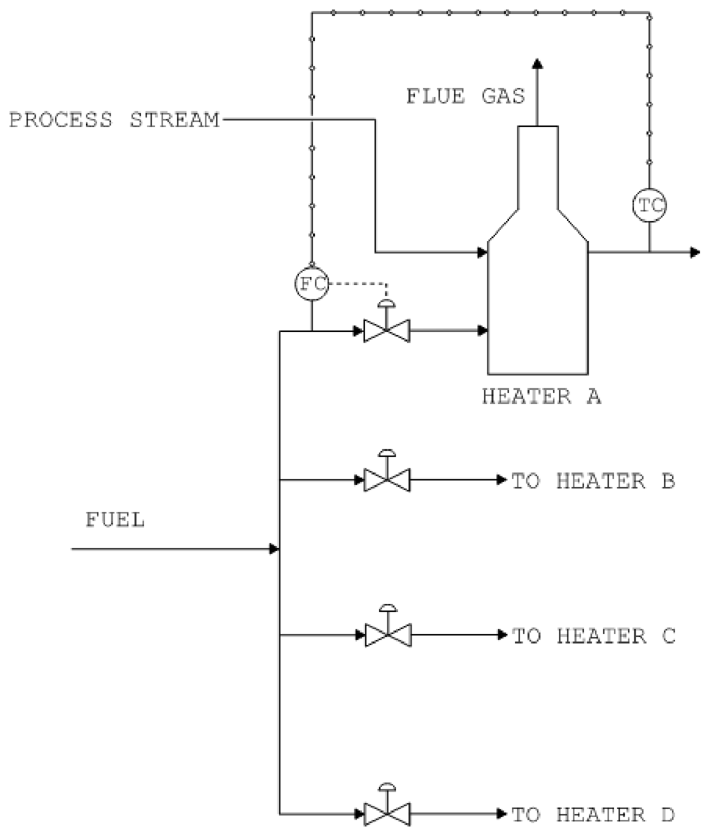
COMBUSTION REACTIONS

Reaction	Volume Ratio, Fuel*	Volume Ratio, Flue Gas*
Hydrogen Fuel		
$3.3H_2 + 1.66(O_2 + 3.76N_2) \rightarrow 3.3H_2O + 6.25N_2$	3.32	0.91
Methane Fuel		
$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$	1.0	1.0

At constant fired duty
*Volume Ratio shown in in reference to Methane

FUEL GAS DISTRIBUTION SYSTEM



Comparing 100% hydrogen to 100% methane fuel, at constant fired duty:

- Hydrogen volumetric flow is 3.3 times that of methane
- Hydrogen mass flow is ~60% less

Volume ratio is much more important

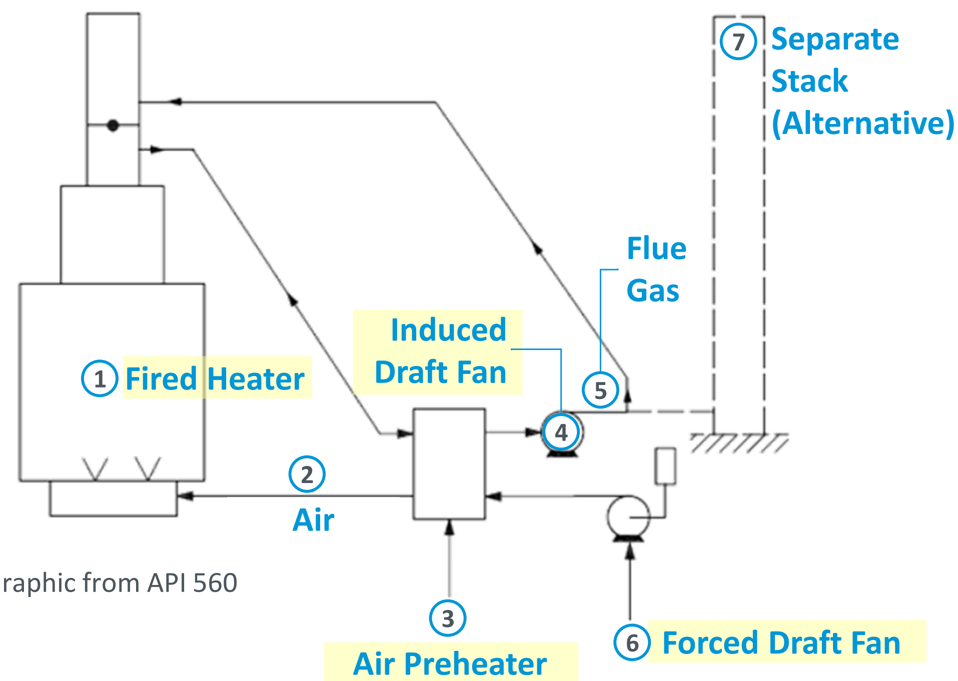
- Piping pressure drop will be ~50% higher for hydrogen
- Many control valves may require revamp or replacement
- For materials/specifications, most fuel gas systems can handle 100% hydrogen

For most fuel gas distribution systems, cost for revamp will not be excessive

AIR BLOWER TYPES

Four Types of Blower Systems:

1. **Natural Draft**
   No blower
2. **Induced Draft**
   Blower on flue gas after heater
3. **Forced Draft**
   Blower on air before heater
4. **Balanced Draft**
   Both forced and induced draft fans



Graphic from API 560

POTENTIAL 100% HYDROGEN FUEL ISSUES

- Burners that work well with 100% hydrogen generally do not work well with other fuel gases
- Increased flame speed and flame temperature may lead to higher temperatures in the heater – some materials changes may be required to convert existing heaters
- A reduction in the flow of flue gas through the convection section may lead to reduced convection section efficiency
- Air control may require changes due to reduced airflow requirement
- Existing flame scanners may not work properly for 100% hydrogen fuel
- NOx production is increased from the higher adiabatic flame temperature

COMPARISON OF HYDROGEN AND METHANE FUEL

	Units	100% H2	100% CH4	Comment
Lower Heating Value	BTU/SCF	275	910	
Lower Heating Value	MJ/kg	120	50	
At constant heat release, assuming no flue gas recycle:				
Volumetric flow rate	Volume/time	3.3	1.0	
Mass flow rate	Mass/time	0.42	1.0	
Piping Pressure Drop	any	1.50	1.0	Approximate – changes based on pipe operating conditions
Combustion O2 required	any	0.83	1.0	
Combustion products	Volume/time	0.91	1.0	
Combustion products	Mass/time	0.81	1.0	
Heater efficiency		Up to 3.5 % higher		The increase of efficiency depends on process conditions.
Flame temperature		Higher		Depending on original design, may require materials upgrades due to higher firebox temp.
TMT (tube metal temperature)		Higher		Depending on original design, may require materials upgrades due to higher TMT.
Radiant Duty		Potentially Higher		Flue gas recirculation may help manage radiant and convection section duty splits
NOx emissions		2.0	1.0	

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ECONOMIC CALCULATIONS (ENGLISH UNITS)

$$\$/MT\ CO_2 = 150*(H_2\ Cost) - 17.3*(NG\ Cost) + 108*(CapEx\ Cost)$$

H_2 cost is in $/kg

NG Cost is in $/MMBTU

CapEx is in $/(BTU/hr) fired

Based on CapEx divided evenly over a 20-year operation

ECONOMIC CALCULATIONS (SI UNITS)

$$\$/MT\ CO_2 = 150*(H_2\ Cost) - 58.9*(NG\ Cost) + 31.6*(CapEx\ Cost)$$

H_2 cost is in $/kg

NG Cost is in $/MWh

CapEx is in $MM/MW fired

Based on CapEx divided evenly over a 20-year operation

EXAMPLE ECONOMIC CALCULATION

Assumptions:

- Hydrogen fuel compared to Methane
- Cost of "clean" Hydrogen: $2/kg
- Cost of Methane: $5/MMBTU
- Capital cost of modifications: $0.1 MM/MMBTU/HR, spread over 20 years

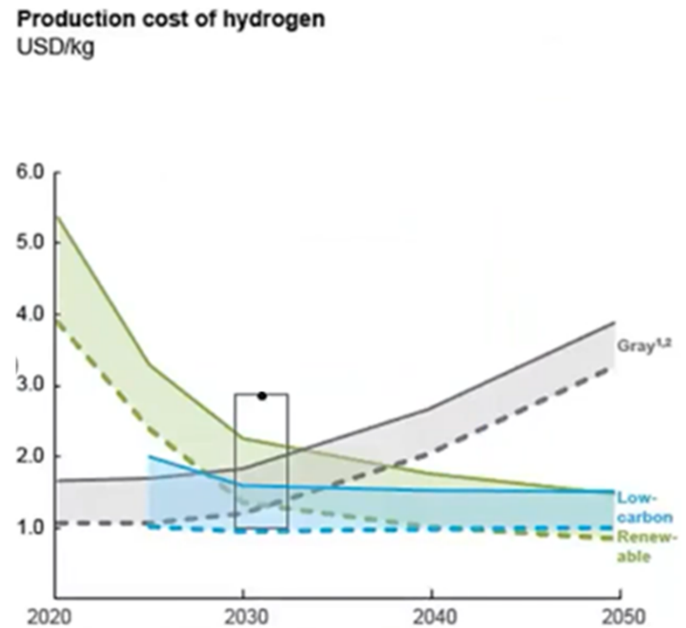


Image Credit: Hydrogen Council, Hydrogen Insights 2021

EXAMPLE ECONOMIC CALCULATION

$$\$/MT\ CO_2 = 150*(H_2\ Cost) - 17.3*(NG\ Cost) + 108*(CapEx\ Cost)$$

Assumptions:

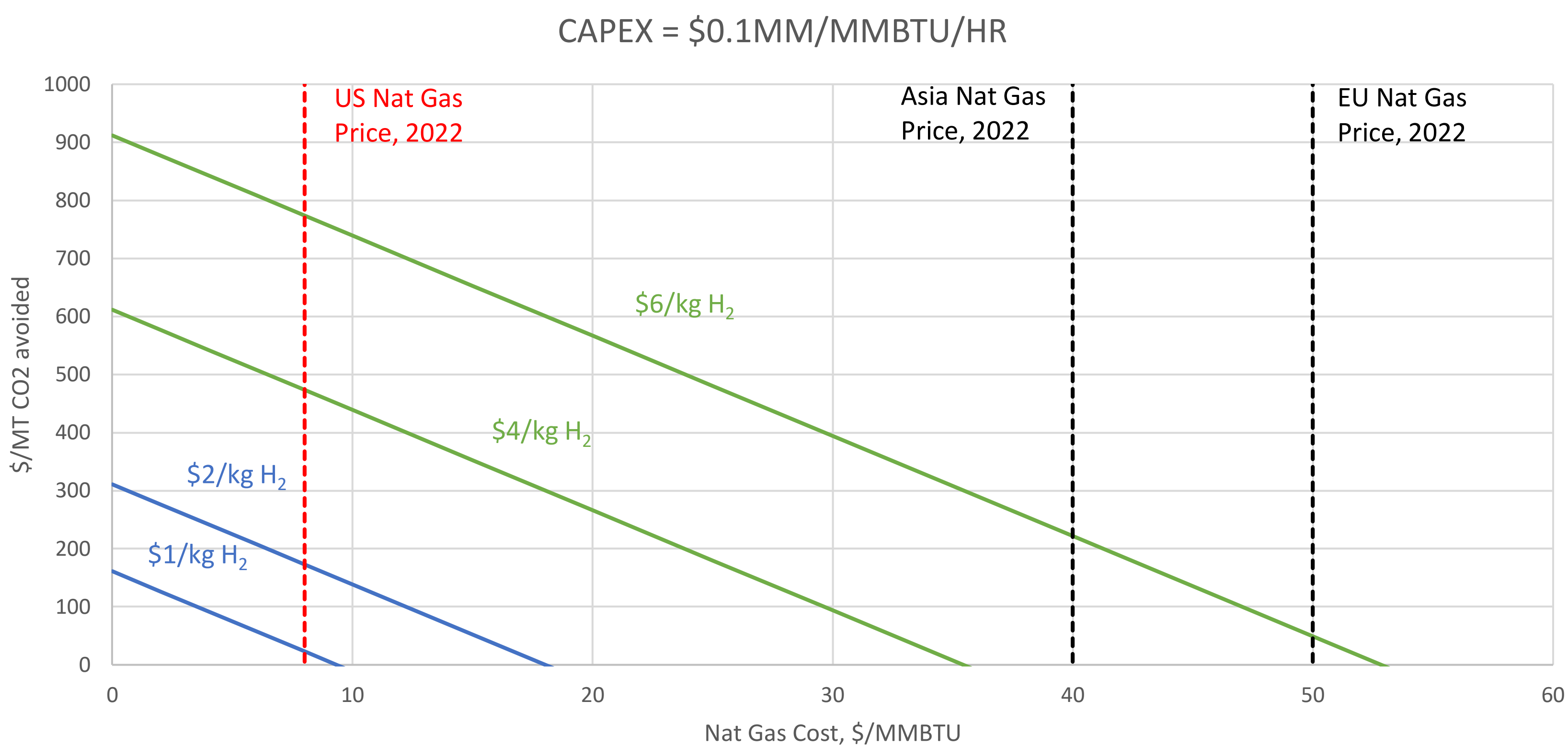
- H_2 cost is $2/kg
- NG Cost is $5/MMBTU
- CapEx is $0.1 /(BTU/hr) fired

$$\$/MT\ CO_2 = 300 - 86 + 11 = \mathbf{\$225/MT}$$

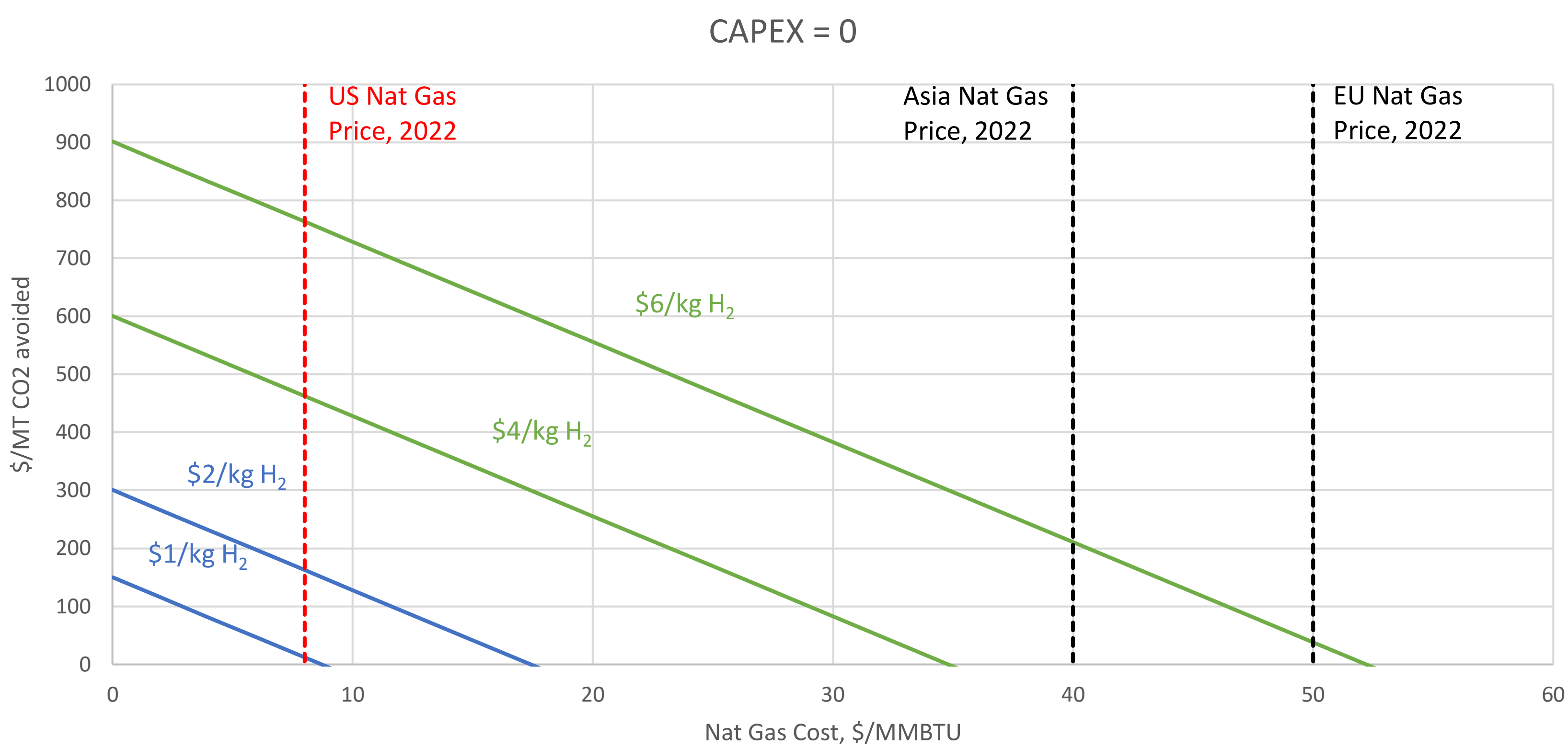
Relative impact for each factor in example calculation:

H_2 Cost 75%
NG Cost 22%
CapEx 3%

ECONOMIC CALCULATIONS - RESULTS



ECONOMIC CALCULATIONS - RESULTS



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FREQUENTLY ASKED QUESTIONS (FAQs)

Do existing burners require replacement for 100% H_2?

Yes – almost always, new or modified burners will be required

Is existing metallurgy a concern in fuel gas piping?

Since fuel gas distribution systems are low pressure, typical piping line class specs for fuel gas can handle 100% H_2

Is existing fuel gas piping too small for 100% H_2?

Pressure drop in piping is typically less than 10% of system drop, so a 50% increase is typically a small impact that can be absorbed by the gas control valve

Are existing fuel gas control valves too small for 100% H_2?

It depends, but often no. Without doing individual hydraulics, one can assume 50% of CVs will require replacement

FREQUENTLY ASKED QUESTIONS (FAQs)

Do fuel gas flowmeters require replacement or recalibration for 100% H_2?

All will require recalibration – some will require replacement

Will converting to 100% H_2 cause a NO_x emissions issue?

NO_x emissions per volume of flue gas or on mass/hr basis will likely increase. It may be possible to specify burners to meet NO_x emissions per fired duty. This applies to ultra-low NO_x requirements also.

Can a heater be designed for both a 100% H_2 case and a 100% CH_4 case?

This appears to be very difficult. In theory, separate burners and fuel systems could be installed for each fuel.

QUESTIONS?

COMMENTS?