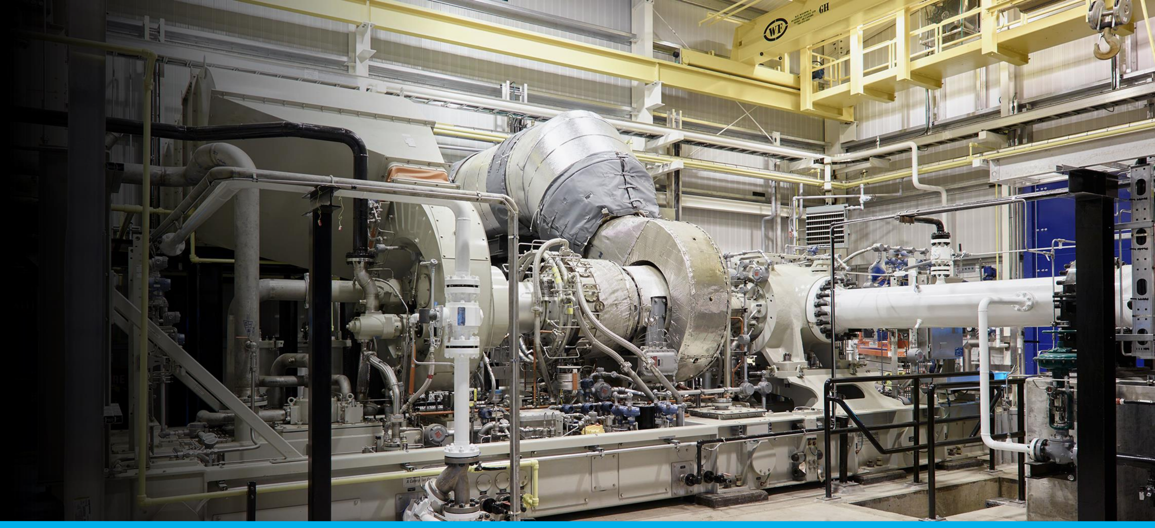
Natural Gas Pyrolysis Applications in Gas Compression



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Abstract

Canada has set an ambitious goal of being net-zero emissions by 2050. This paper explores if hydrogen production from natural gas can be used to provide an economically lower greenhouse gas emitting alternative fuel source. This study reviews the options of pyrolysis methods in the current literature, including emissions of system configurations that apply to plasma pyrolysis; studies by Okeke et al. (2023) and Shokrollahi et al. (2024) provide the basis for the energy, cost, and emissions comparison models. Three system configurations were used for comparison: 30MW Gas Turbine, 30MW H2 Turbine w/Plasma – Electric, and 30MW H2 Turbine w/Plasma – Natural Gas. Plasma pyrolysis was seen as a viable option due to low emissions and high-quality carbon black and hydrogen production . This paper confirmed that a lower greenhouse gas-emitting fuel source can be produced. However, it does not appear to be economically viable.

Research Question

Can natural gas pyrolysis can be utilized at a natural gas compression facility to provide an economically lower greenhouse gas emitting fuel source to drive compression turbines on the natural gas system?

Introduction

The climate in western and central Canada is known for its extreme conditions, requiring an energy system that can withstand temperatures ranging from -40 to +30 degrees Celsius. Natural gas is a critical component of this system, providing essential heating for homes during severe cold spells and ensuring that vital facilities, such as hospitals, have a dependable power and heat supply regardless of weather conditions. Natural gas is distributed via a vast network of pipelines known as the natural gas transmission system, propelled by large compression turbines like jet engines. These turbines, powered by natural gas, circulate the gas throughout the network to end-users.

- With over 93,700km of natural gas pipelines, there are opportunities to reduce emissions.
- Hydrocarbon pyrolysis offers potential opportunities of decarbonization depending on the type of hydrogen produced (reference table 1).
- Turquoise pyrolysis production methods produces approximately 1ton of hydrogen to 3 tons of carbon black.
- Natural gas pyrolysis involved the high-temperature decomposition of methane, either through thermal or catalytic processes.
- Hydrogen produced via methane pyrolysis is typically of higher quality and does not require purification steps, in addition, the carbon black quality higher as well.
- Of the known pyrolysis system configurations, plasma was identified as the choice as it has a high carbon and hydrogen yield with a high conversion of natural gas in a smaller footprint.
- Plasma requires temperatures between 1,000 and 3,500 celsius.
- Early adopters of plasma technology in commercial applications are Monolith Materials, currently able to produce 50 kilotons of hydrogen and 180 kilotons of carbon black at their Olive Creek plant.
- Due to the high output of 3 tons of carbon black to 1 ton of hydrogen from pyrolysis, the hydrogen production is actually a byproduct to the carbon black production.

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Hydrocarbon H2 Production Processes

- Hydrocarbon H2 production reviewed narrowed to three options, as the feedstock must use natural gas.

Table 1 Hydrocarbon Production Processes

Hydrogen Type	Process	Carbon Capture	Primary Product	Secondary Product
Grey	Steam Reforming	None	Hydrogen	N/A
Blue	Steam Reforming	Yes	Hydrogen	N/A
Turquoise	Methane Pyrolysis	Yes	Hydrogen	Carbon Black

Source: *The Hydrogen Colour Spectrum| National Grid Group* (n.d.)

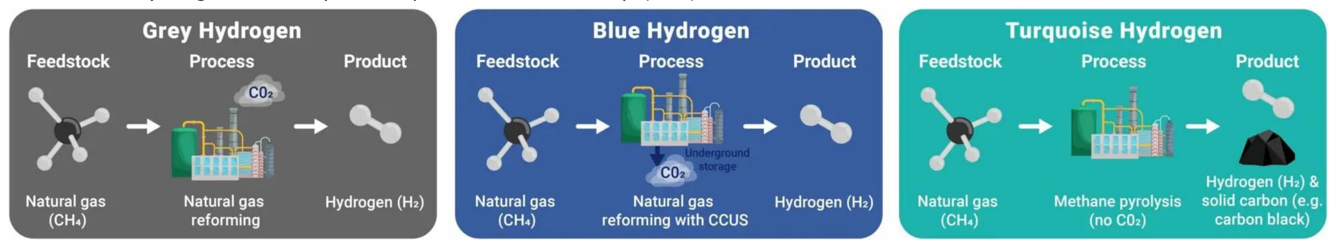

Figure 1: Hydrogen Production Colours
Source: Peel, 2023

System Energy Inputs & Outputs

Table 2 System Energy Input & Outputs

		Description	Current System Natural Gas	Hydrogen Pyrolysis via Electricity	Hydrogen Pyrolysis via Natural Gas
Compressor Energy Requirements		**Compressor Sizing (MW)**	**30**	**30**	**30**
		MWh per year for 30MW Compressor	262,800	262,800	262,800
		Heat Rate (GJ/MWh)	9.6	9.6	9.6
		Annual Energy Input Required	262,800	262,800	262,800
		Utilization	95%	95%	95%
		Load Factor	80%	80%	80%
		Annual Energy Input after Factors (MWh)	**199,728**	**199,728**	**199,728**
		Annual Energy Input (GJs)	**1,917,389**	**1,917,389**	**1,917,389**
Total Energy Input	Input	Gas Input (GJs)	1,917,389	5,585,964	7,021,493
		Gas Input (MWh)	532,608	1,019,049	1,417,807
		Gas Input (m^3)	50,114,791	95,885,550	133,405,982
		Gas Input (Tonnes) Hydrogen	0	15,950	15,950
		Electricity Input (MWh)	0	398,758	0
	Output	Hydrogen Output (Tonnes)	0	15,950	15,950
		Carbon Black Output (Tonnes)	0	47,851	47,851
		Scope 1 CO2 Emissions	106,227	0	79,531
		Scope 2 (Electricity) CO2 Emissions	0	147,541	0

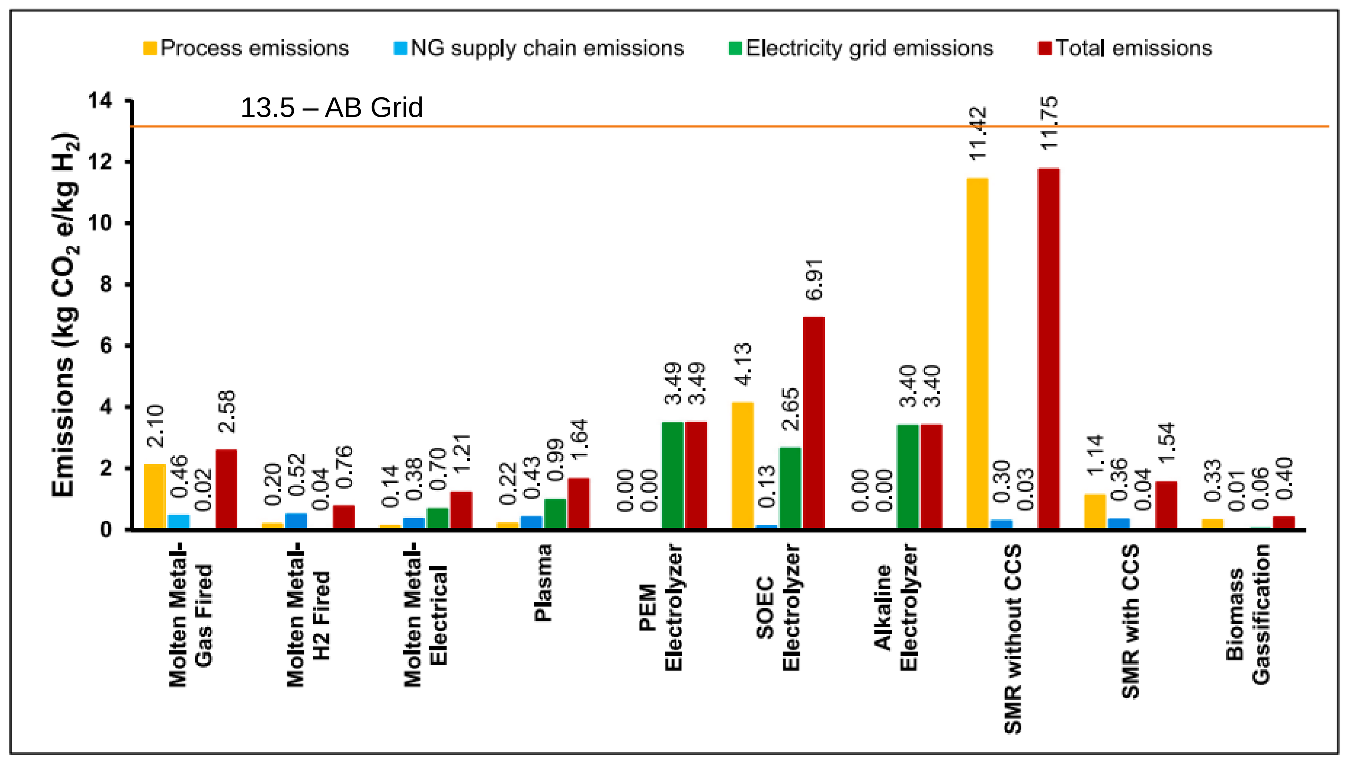

Figure 2: GHG emissions of methane pyrolysis vs alternative H2 production technologies
Source: Shokrollahi et al., 2024

Sensitivity Analysis – LCOE MWh

Sensitivity analysis done using levelized cost of Energy in MWh.

- 2025 – Pricing based on next year, base.
- 2030 – Full carbon pricing at $170/tonne
- Scenario 1 – Henry Hub pricing based on 2022 peak
- Scenario 2 – 2033 Henry Hub Pricing forecast
- Scenario 3 – Carbon Black price collapse
- Scenario 4 – 2-% increase to MWh pricing and CB Price collapse
- Scenario 5 – Worst case, almost 3x NG Pricing, emissions doubles, CB Completely collapses
- Gas Turbine configuration outperforms in all cases where carbon black is below break-even cost.
- Pyrolysis via electricity is not an economically viable method due to the high cost of electrical energy.

Table 3 Sensitivity Scenario Results – LCOE per MWh

Parameter	UoM	2025 Amount	2030 Amount	Scenario 1 2022 Henry Hub Pricing	Scenario 2 2033 Henry Hub	Scenario 3 CB Price Collapse	Scenario 4 20% < Elec	Scenario 5 Worst Case
Hydrogen	MT	$ 6,610.25	$ 6,610.25	$ 6,610.25	$ 6,610.25	$ 6,610.25	$ 6,610.25	$ 6,610.25
Natural Gas	GJ	$ 2.74	$ 2.74	$ 5.10	$ 4.20	$ 6.00	$ 2.74	$ 6.00
Electricity	MWh	$ 135.95	$ 135.95	$ 135.95	$ 135.95	$ 135.95	$ 163.14	$ 163.14
AB TIER Pricing	tCO2e	$ 95.00	$ 170.00	$ 170.00	$ 170.00	$ 170.00	$ 170.00	$ 340.00
Carbon Black	MT	$ 2,561.90	$ 2,561.90	$ 2,561.90	$ 2,561.90	$ 512.38	$ 512.38	$ 256.19
FX $1 USD to CAD	CDN	$ 1.37	$ 1.37	$ 1.37	$ 1.37	$ 1.37	$ 1.37	$ 1.37

Parameters			Scenario 2025	2030	1	2	3	4	5
Gas Turbine	MWh-$	MWh	$ 26.30	$ 26.30	$ 48.96	$ 40.32	$ 57.60	$ 26.30	$ 57.60
		w/Carbon Sales	$ 26.30	$ 26.30	$ 48.96	$ 40.32	$ 57.60	$ 26.30	$ 57.60
		w/Emissions	$ 76.83	$ 116.72	$ 139.38	$ 130.74	$ 148.02	$ 116.72	$ 238.43
NG-Pyro-E	MWh-$	MWh	$ 458.33	$ 458.33	$ 501.68	$ 485.15	$ 518.21	$ 512.62	$ 572.50
		w/Carbon Sales	-$ 155.45	-$ 155.45	-$ 112.10	-$ 128.63	$ 395.46	$ 389.86	$ 511.12
		w/Emissions	-$ 85.27	-$ 29.87	$ 13.48	-$ 3.05	$ 521.04	$ 515.44	$ 762.28
NG-Pyro-NG	MWh-$	MWh	$ 206.60	$ 206.60	$ 266.91	$ 243.91	$ 289.91	$ 206.60	$ 289.91
		w/Carbon Sales	-$ 407.18	-$ 407.18	-$ 346.87	-$ 369.87	$ 167.15	$ 83.84	$ 228.53
		w/Emissions	-$ 369.35	-$ 339.49	-$ 279.18	-$ 302.18	$ 234.85	$ 151.54	$ 296.23

Conclusion

- Study's results indicated that a lower GHG fuel can be produced but is not economically viable.
- Capital cost of the pyrolysis facility, in addition to the high energy inputs to produce hydrogen, is not competitive with a natural gas turbine compressor.
- Referring to scenario five in Table 3, even with the high carbon tax cost through Alberta's TIER system, the gas turbine is still cheaper per LCOE MWh.
- In all comparison scenarios, minimum selling price of $479.43/t carbon black is required to break even on CAPEX cost.
- Current market outlook indicates increasing hydrogen production and thus, more carbon black, further eroding the selling price of carbon black.

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