Feasibility Study of Hydrogen Co-firing in TransAlta Natural Gas Plants

Ryan Bartel, Sadhiq Nazeer, Rakib Uddin & Rakil Ahmed
Advisor: Dr. Sean McCoy
Schulich School of Engineering, University of Calgary

Abstract

Natural gas electricity generation is ubiquitous in Alberta, with it accounting for around 60% of total provincial generation [1]. Given the high carbon emissions intensity of natural gas combustion, hydrogen co-firing has been proposed as a potential solution.

Co-firing is the use of a fuel mixture—in this case, hydrogen and natural gas—during combustion to achieve desired burning characteristics.

In this project, TransAlta Corporation tasked us with:

1. Evaluating the feasibility of hydrogen co-firing in three of their natural gas plants.
2. Selecting the best plant for co-firing implementation.
3. Determining all expenditures associated with co-firing (Levelized Cost of Energy).

Introduction

Keephills 2 (KPH2)	0.87 tonnes/hr CO_2e
Keephills 3 (KPH3)	0.31 tonnes/hr CO_2e
Sundance 6 (SD6)	0.61 tonnes/hr CO_2e

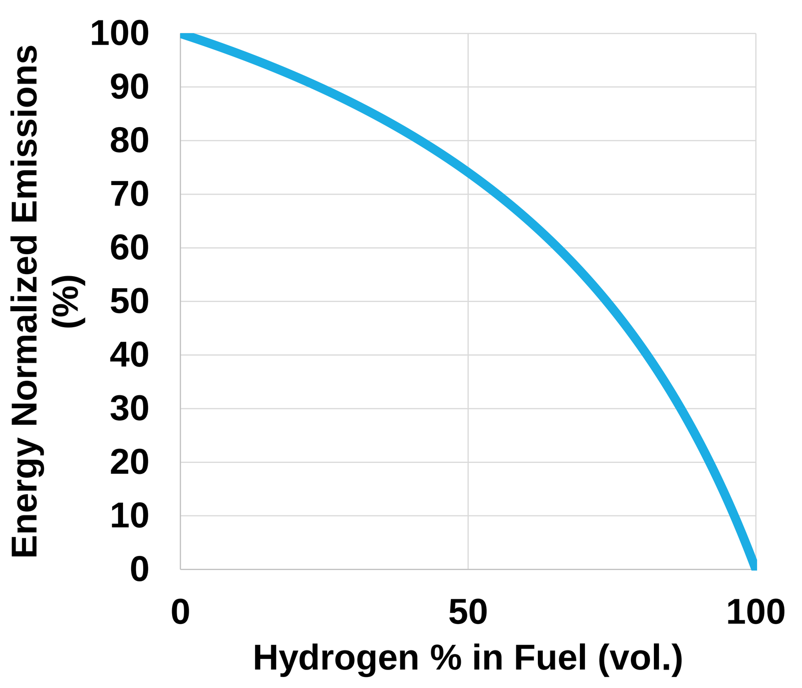


Figure 1. KPH2 Emissions shown as a percentage of emissions at 100% natural gas.

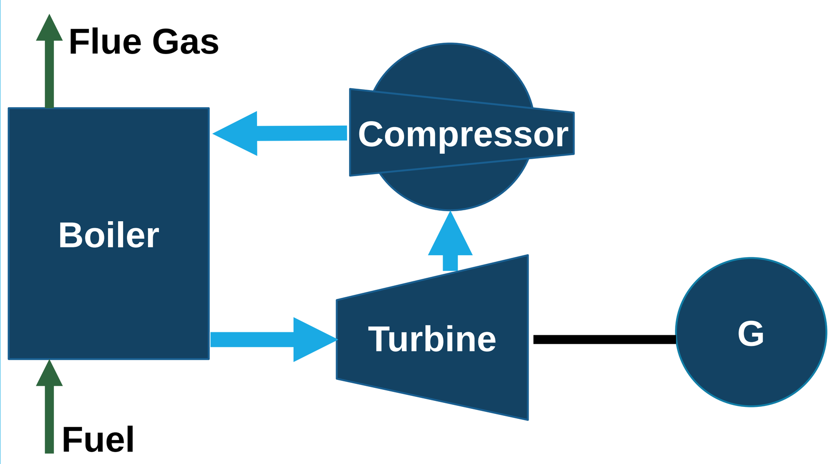


Figure 2. Simplified Schematic of a Natural Gas Plant.

Methods

- Site Selection
- Literature Review
- Technical Assessments
- Levelized Cost of Energy (LCOE)

Site Selection

Selection Criteria	Weighting	KPH 2	KPH 3	SD 6
Site Specific Technology	15	6	9	6
Existing Site emissions	15	8.75	6	8.75
Design Complexity	10	7	4.25	6.5
Capacity Factor	10	7.25	5	6.75
Total Score (out of 10)		7.28	6.35	7.08

Technical Assessments

Hydrogen Embrittlement

Embrittlement occurs when hydrogen atoms penetrate pipe steel, causing it to become brittle and more susceptible to cracking or failure.

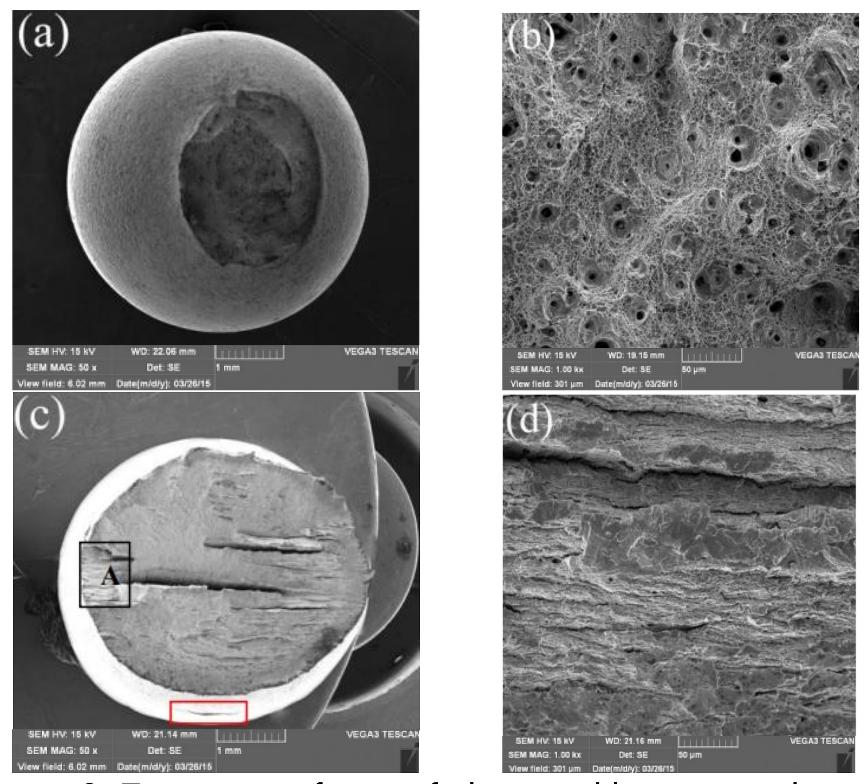


Figure 3. Fracture surfaces of pipe steel in pure methane (a,b) and in 20% vol hydrogen blend (c,d) [2].

Table 1. Elongation as a function of added hydrogen.

Added hydrogen (vol %)	0	5	10	20	50
E_I (%)	0	3.39	4.32	15.88	16.77

Maximum allowable hydrogen in current TransAlta facility piping is determined to be 15%

NOx Emissions

NOx is a pollutant that is known to increase significantly with hydrogen co-firing [3]. We created a **computation fluid dynamics** model to simulate NO_x output at Keephills 2.

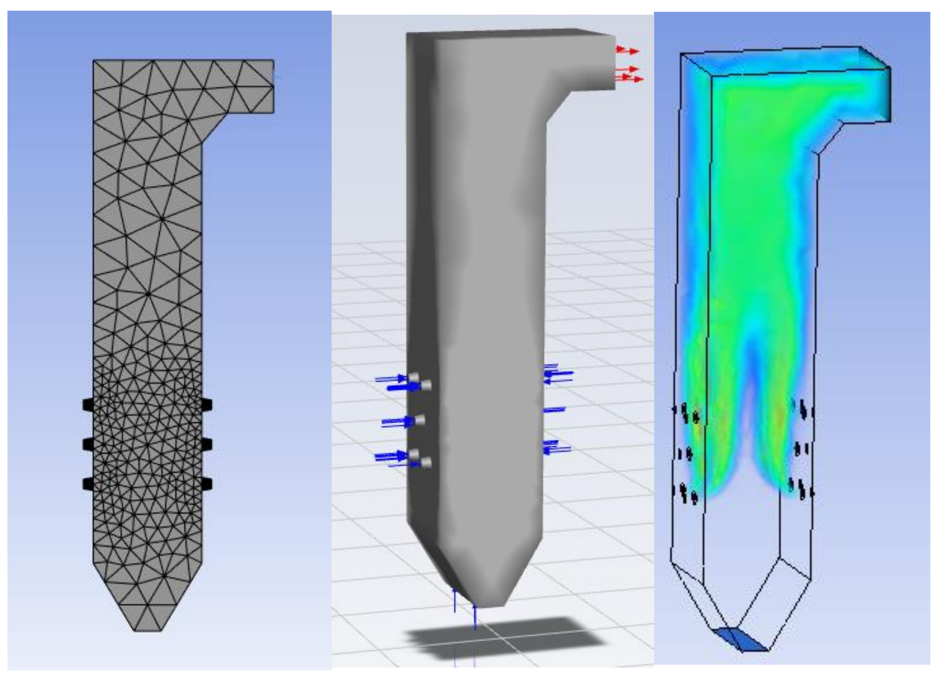


Figure 4. (left to right) mesh of boiler model, fuel & air inlets/outlets, CFD simulation.

The trend shows that increasing the H_2 blend % increases the NO_x emission significantly.

NOx Emissions

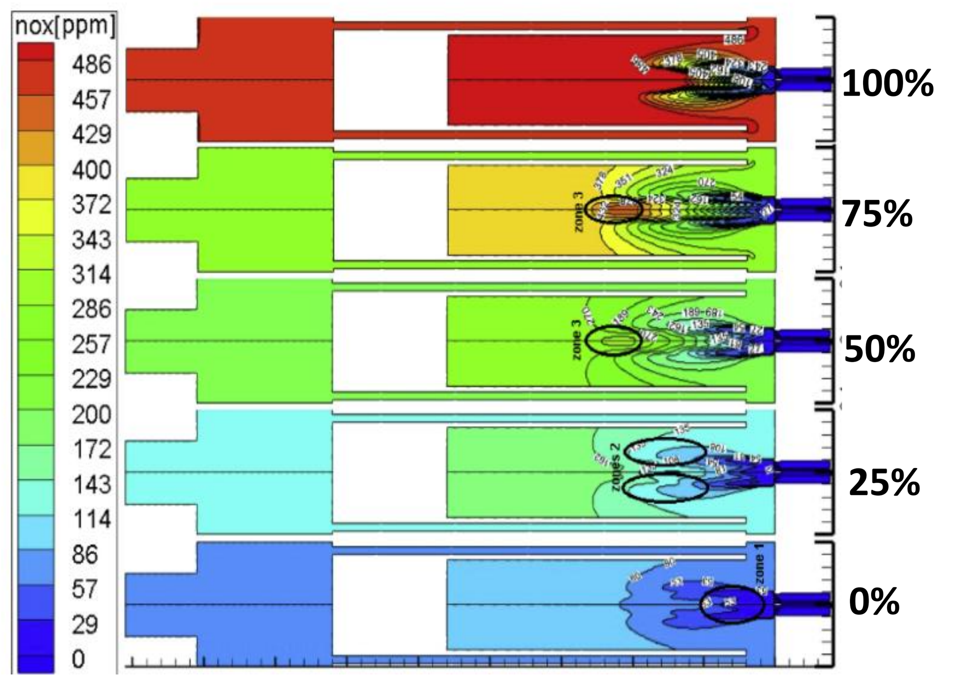
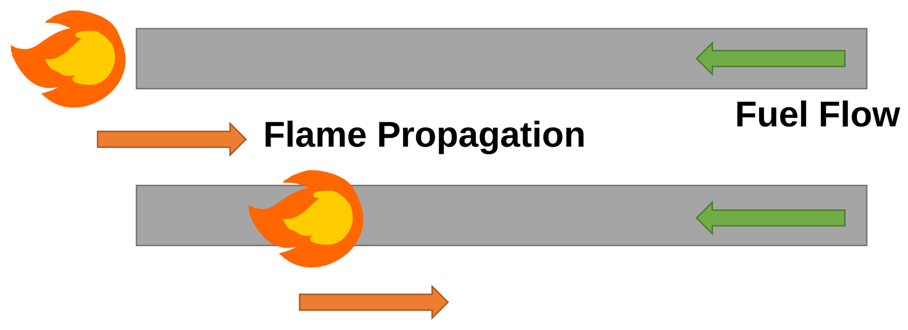


Figure 5. Literature CFD results showing NOx concentration with increasing hydrogen [3]. Burner radius is 0.4m and burner length is 4.5m.

Flashback

Flashback is a phenomenon where the flame travels upstream of its intended combustion area. This poses a safety and hardware damage risk. We evaluated boundary layer flashback risk.



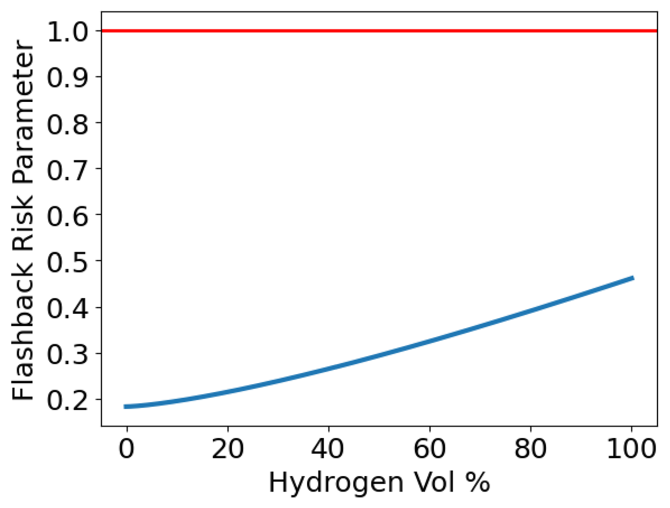


Figure 6. Predictive flashback model for laminar methane-hydrogen flames. Under this model, flashback occurs when the risk parameter exceeds 1.

Financial Assessment

Our financial model was based on a plant lifespan of 15 years. The key selected sensitivities were the pricing of hydrogen, carbon tax escalation rate, TIER reduction rate, and the subsidy received for CAPEX.

Table 2. Adjusted Sensitivities for the financial model

Sensitivities	Best Case	Baseline	Worst Case
Hydrogen Price ($/kg) [4]	1.5	2.5	3
Carbon Tax Escalation ($/yr)	30	15	7.5
TIER Reduction Rate (% per yr)	4	2	2
Subsidy %	70	30	0

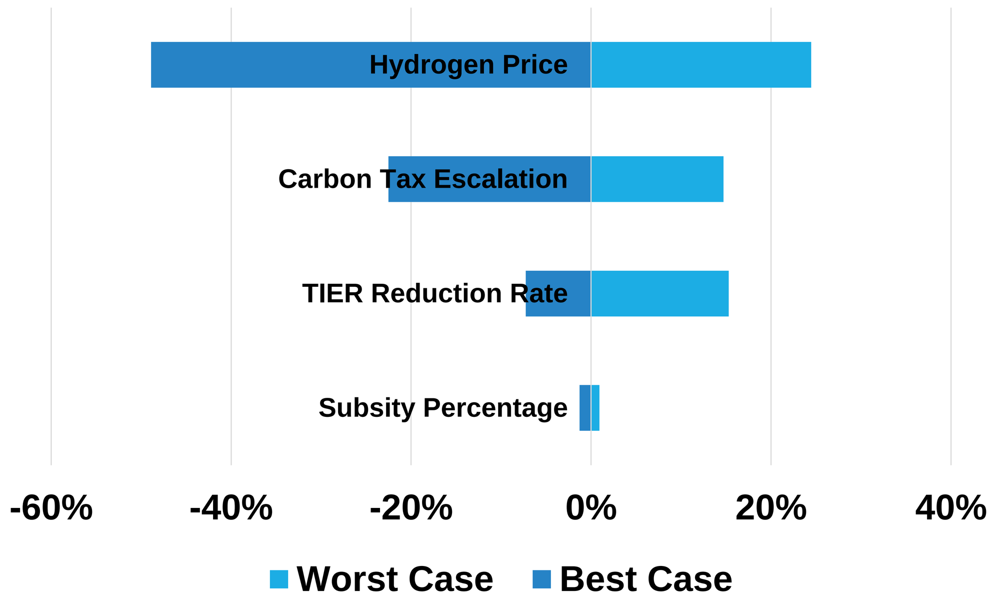


Figure 7. Price Change Tornado Chart for 70% Blend Hydrogen

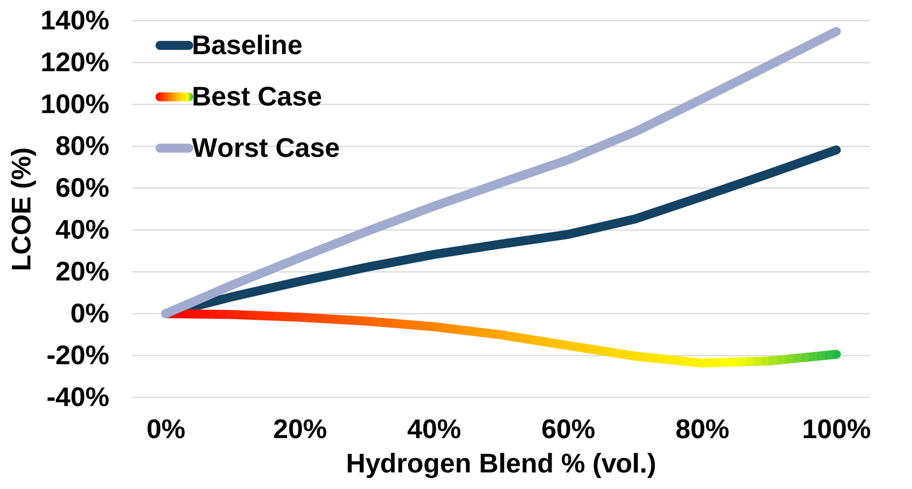


Figure 8. LCOE comparison for Hydrogen under for all cases. Expressed as percent of LCOE for 0% hydrogen.

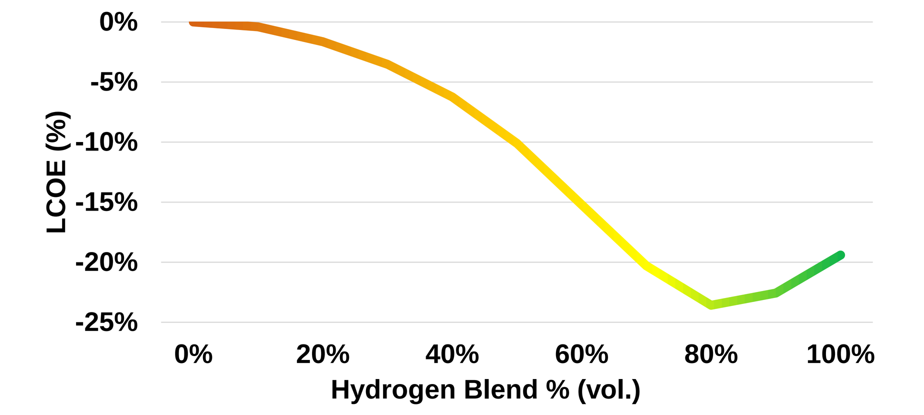


Figure 9. LCOE comparison for Hydrogen under the best case.

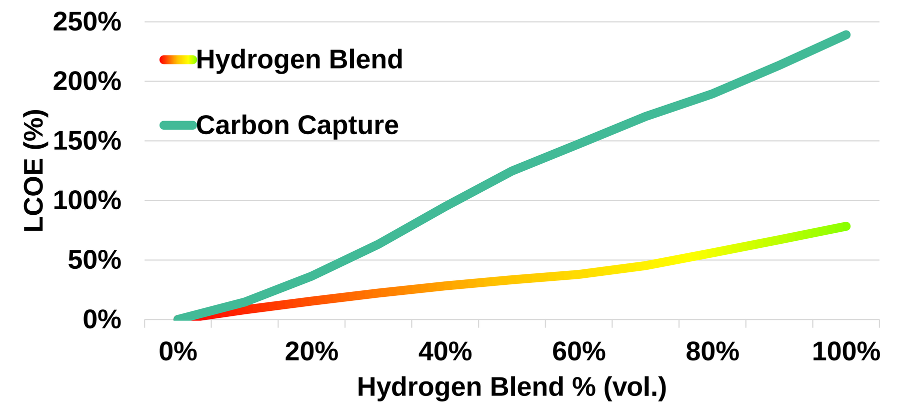


Figure 10. LCOE comparison for Hydrogen and Carbon Capture. Carbon Capture data is matched to same emissions reduction as the corresponding hydrogen blend.

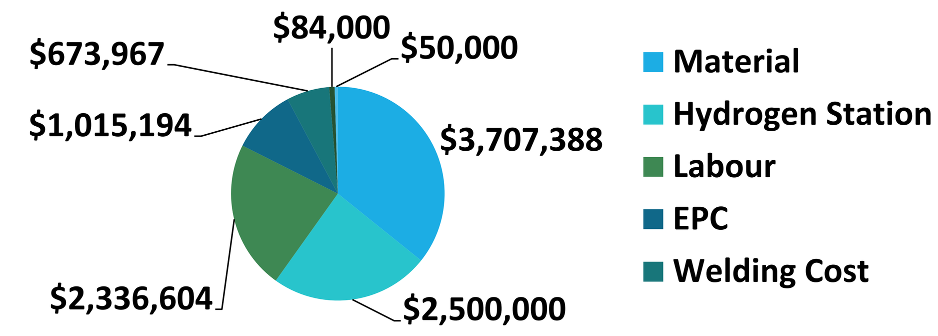


Figure 11. CAPEX Cost Categories.

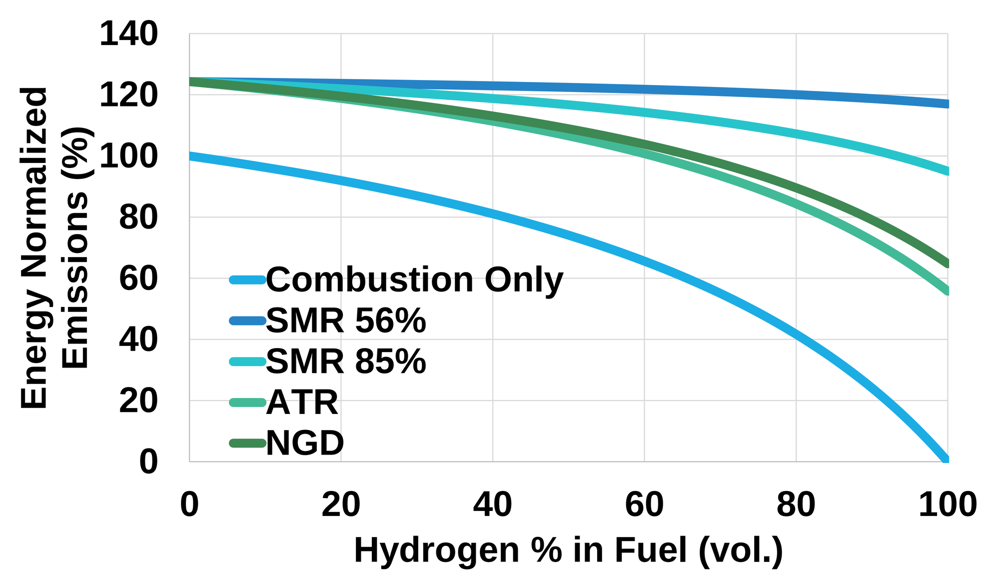


Figure 12. Blue hydrogen co-firing life cycle emissions. Emissions normalized by 0% hydrogen values for the Combustion Only case.

Conclusions

Hydrogen co-firing is **not feasible** at KPH2 for our baseline and worst-case scenarios; however, it is feasible in our best-case scenario. Based on the sensitivity analysis hydrogen pricing is the most important factor that affects feasibility.

References

[1] "Canada's Energy Future 2021," p. 98, 2021.
[2] B. Meng *et al.*, "Hydrogen effects on X80 pipeline steel in high-pressure natural gas/hydrogen mixtures," *International Journal of Hydrogen Energy*, vol. 42, no. 11, pp. 7404–7412, Mar. 2017, doi: 10.1016/j.ijhydene.2016.05.145.
[3] "Investigations on performance and emission characteristics of an industrial low swirl burner while burning natural gas, methane, hydrogen-enriched natural gas and hydrogen as fuels", doi: https://doi-org.ezproxy.lib.ucalgary.ca/10.1016/j.ijhydene.2017.05.107.
[4] A. O. Oni, K. Anaya, T. Giwa, G. Di Lullo, and A. Kumar, "Comparative assessment of blue hydrogen from steam methane reforming, autothermal reforming, and natural gas decomposition technologies for natural gas-producing regions," *Energy Conversion and Management*, vol. 254, p. 115245, Feb. 2022, doi: 10.1016/j.enconman.2022.115245.

Acknowledgements

Dr. Leo Fang

Dr. Arief Budiman

Meghdad Ghias

Contacts:

Ryan Bartel
Email: Ryan.Bartel@ucalgary.ca
Phone: (403) -978-1032

Sadhiq Nazeer
Email: sadhiq.nazeer@ucalgary.ca
Phone: (587)-973-3364

Rakib Uddin
Email: rakib.uddin1@ucalgary.ca
Phone: (403) -970-5744

Rakil Ahmed
Email: rakil.ahmed1@ucalgary.ca
Phone: (587)-500-8953