Using Pulsed Methane Pyrolysis to Create a Clean Hydrogen Hub in Alberta

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ABSTRACT

Hydrogen has significant potential to advance the energy transition in Canada. This research project is a technoeconomic analysis of a proposed hydrogen hub in Alberta, Canada deploying low emission Pulsed Methane Pyrolysis. This hub could meet future clean hydrogen demand from nearby gas fired electricity generating facilities and heavy-duty trucks equipped with fuel cells. The solid carbon co-product could address existing industrial demands or be expanded to new applications. This study relies on primary and secondary data to develop technical, cost, and market assumptions to understand the delivered cost of hydrogen from Pulsed Methane Pyrolysis at different deployment scales versus the cost of the incumbent fuel. Larger scale production offers the lowest costs, and the economics of providing hydrogen to heavy-duty transportation currently appears to be more favorable than for electricity generation. Policies and incentives supportive of clean hydrogen from methane pyrolysis will be important to advance this technology's deployment.

RESEARCH QUESTION

What is the commercial potential for the hydrogen and solid carbon produced by the deployment of Pulsed Methane Pyrolysis in Grande Prairie, Alberta?

Inter-disciplinary study

This project integrates the three disciplines of **energy**, the **environment**, and **economics**.

This project addresses two U.N. Sustainable Development Goals (SDP) #7 and #9.

Source: (UNDP, 2023)

BACKGROUND

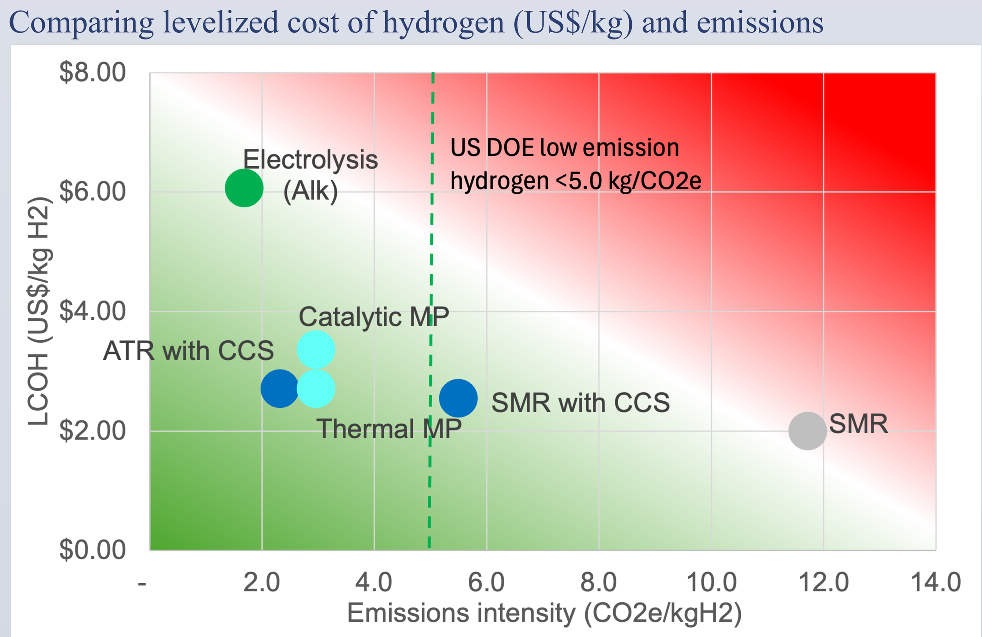
Hydrogen production types

Methane pyrolysis is called "turquoise" hydrogen as it shares some elements of both blue and green hydrogen; it utilizes natural gas as a feedstock, yet it does not require CCS and it is a low emissions production process (IEA, 2023).

Color	Energy source	Mode of production
White	Natural geologic formations	Fracking
Brown/Black	Coal (lignite / bituminous)	Gasification
Gray	Natural gas	SMR
Purple/Pink	Nuclear	Water electrolysis
Green	Renewable energy	Water electrolysis
Blue	Natural gas	SMR / ATR + CCS
Turquoise	Natural gas	Pyrolysis

Source: Adapted from (Fernandez et al., n.d.)

Comparing levelized cost of hydrogen (US$/kg) and emissions



Sources: (CICE, 2023, 2024; IEA 2023; DOE, 2023)

Pyrolysis of Methane

Pyrolysis involves the decomposition of methane at high temperatures to produce hydrogen and solid carbon. Methane pyrolysis is more energy efficient than water electrolysis, as it requires 37.5 kJ to produce 1 mol of H_2 as compared to 286 kJ per mol of H_2 for electrolysis. Methane pyrolysis produces approximately 3 kg of solid carbon (C) for every kilogram of H_2 (Timmerberg et al., 2020)

$$CH_4 \leftrightarrow C + 2H_2 \quad \Delta H^o 75.6\ kJ\ mol^{-1}$$

BACKGROUND (CONTINUED)

Pulsed Methane Pyrolysis

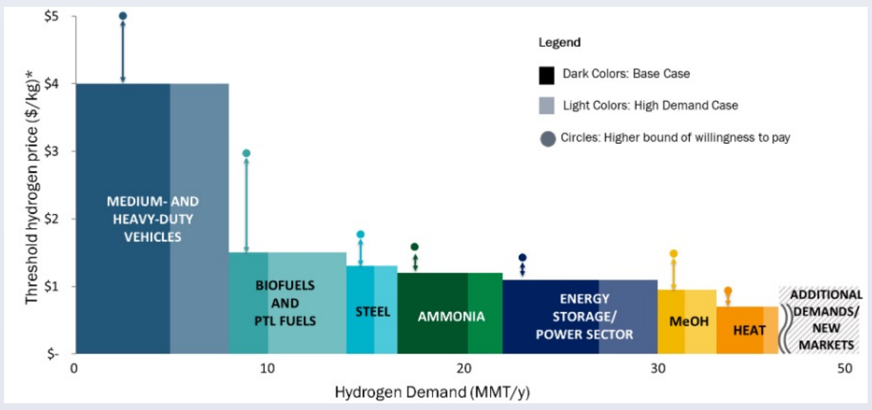
Ekona's Pulsed Methane Pyrolysis (PMP) uses no catalyst and is a variation of thermal pyrolysis. Ekona's novel xCaliber™ pyrolysis reactor design increases the temperature and pressure inside the reactor volume by directly injecting hot products of combustion and allowing rapid mixing in the feedstock chamber. Preheated methane feedstock is delivered to the reactor and an air separation unit provides onsite oxygen supply. Product gases are discharged from the reactor to downstream purification equipment, and the process is repeated. Discharging the pressurized pyrolysis products from the reactor minimizes "carbon fouling" in the reactor and drives solid carbon to the downstream carbon separator.

Process Yield	
H2	72%
C	93%
Inputs	**/kgH2**
NG (kg)	5.6
Electricity (kWh)	3.7
O2 (kg)	3.2
Outputs	**/kgH2**
Carbon (kg)	4.0
Water (kg)	2.8
CO2 (kg)	1.0

Source: (Kendrick, 2024)

Potential clean hydrogen demand by sector

The U.S. DOE estimates that early adopters such as medium/heavy duty trucking and buses have the highest willingness to pay approximately US$4.00 - $5.00 / kg for clean hydrogen to displace diesel.



Source: (DOE, 2023)

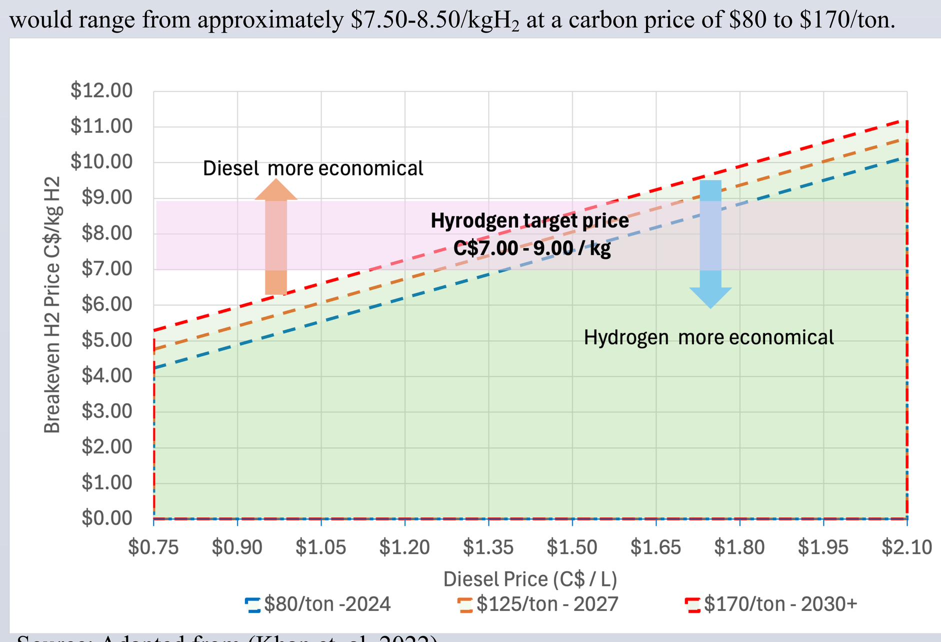
Electricity generation

Gas turbine systems are the backbone of Alberta's electricity grid. In the short term, existing assets and infrastructure could utilize hydrogen to partially decarbonize this important form of dispatchable energy. Higher blend proportions (beyond 60% H_2) are required to deliver significant emissions reductions which will require the potential retrofit or replacement of existing turbine systems. Even considering carbon emissions pricing, natural gas is a low-cost fuel for electricity generation. Low hydrogen production costs are required to displace it.

Heavy duty trucking

Battery Electric Vehicles (BEV) are a viable alternative for light duty passenger cars but are not as well suited to the heavy payloads, short duration refueling requirements, longer range journeys, and long service times in cold weather that heavy-duty trucking requires. Heavy duty trucks equipped with hydrogen fuel cells (FCEV), or hybrid diesel/FCEV are better suited to meet these requirements (DOE, 2023).

Hydrogen is more economical than diesel in the green shaded area, and higher carbon prices increase hydrogen's competitiveness as a fuel. For example, at a diesel price of $1.50/L in Grande Prairie, and a relative J_{H2}/J_{Diesel} efficiency of 0.86, the equivalent price of hydrogen would range from approximately $7.50-8.50/kgH$_2$ at a carbon price of $80 to $170/ton.



Source: Adapted from (Khan et. al, 2022)

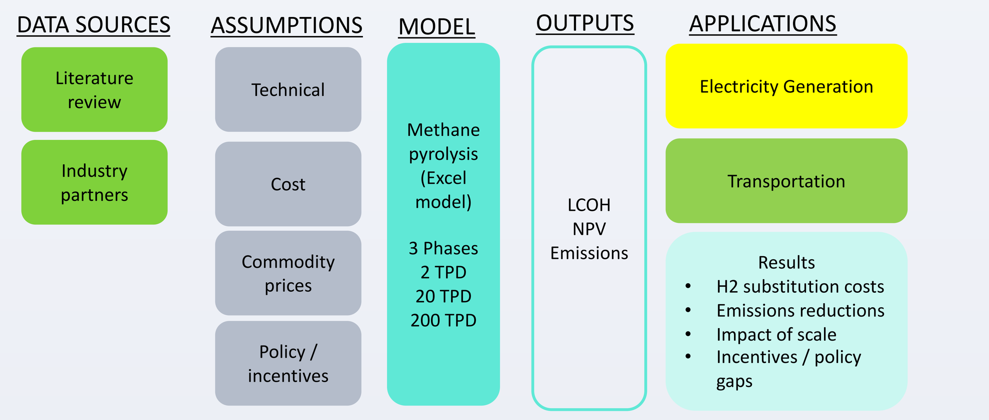
Carbon black

The solid carbon co-product of methane pyrolysis presents both opportunities and obstacles to the process and economics of this technology. Carbon black is formed at higher temperature reactions, without employing a catalyst, and this is the type of co-product yielded from Ekona's PMP. The formation and removal of solid carbon can be an issue for cost-effective pyrolysis but optimizing the carbon stream and performing additional processing and verification can create increased value and would decarbonize another emissions-intensive industrial product. Carbon black is primarily used to strengthen rubber, particularly in tire manufacturing. Obtaining new markets for carbon black, in agriculture, cement, or asphalt could support higher levels of production. Creating value for carbon black is important to the economics of methane pyrolysis and also allows the allocation of emissions to each of the hydrogen and solid carbon co-products.

ANALYSIS

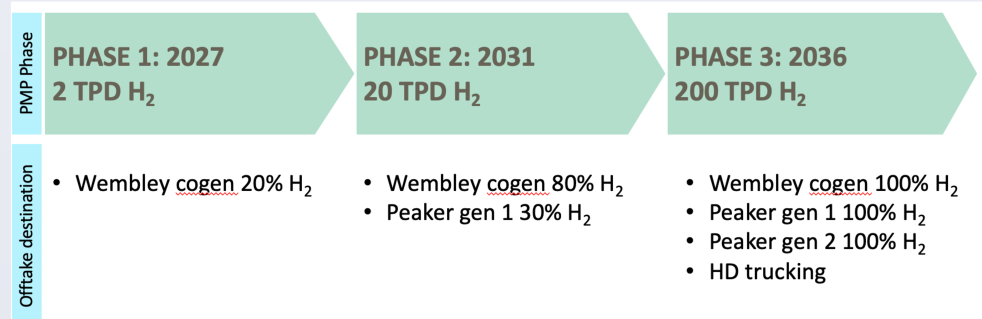
Methodology

The conceptual framework for the technoeconomic analysis is presented below.



Phased development plan

Deployment of PMP takes place over three phases to manage capital resources, mitigate risk, and allow learnings to be incorporated in the next larger phase of development. The production capacity of each phase is synchronized with anticipated hydrogen demand and align with a 2035 net zero ambition.



Key assumptions

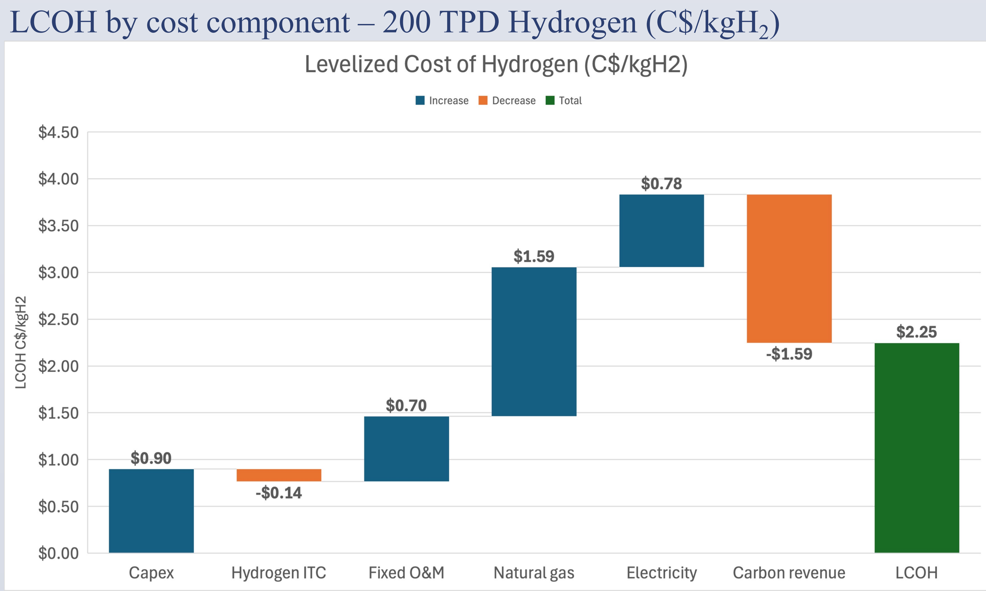
Phase and Capacity (TPD H_2)	Phase 1 2 TPD	Phase 2 20 TPD	Phase 3 200 TPD
In-service (year)	2027	2031	2035
Production life (#years)	20	20	20
Capital expenditure (C$M)	$40	$110	$620
O&M (% of capital)	5.0%	5.0%	5.0%

Assumption		Assumption	
Hydrogen (C$/kg$H_2$) - 2024	$5.00	Inflation (per year)	2.0%
Carbon Black (US$/ton) - 2024	$200	Tax rate (Fed. + Alberta)	23%
		Discount rate	10.00%
AECO gas (C$/GJ) – 2027	$3.70	Capital recovery factor*	10.58%
Electricity (C$/MWh) - 2027	$70	Discount date	2024-06-30

Source: Ekona – Hydrogen, carbon black, discount rate. (EDC, 2024) - natural gas, electricity.

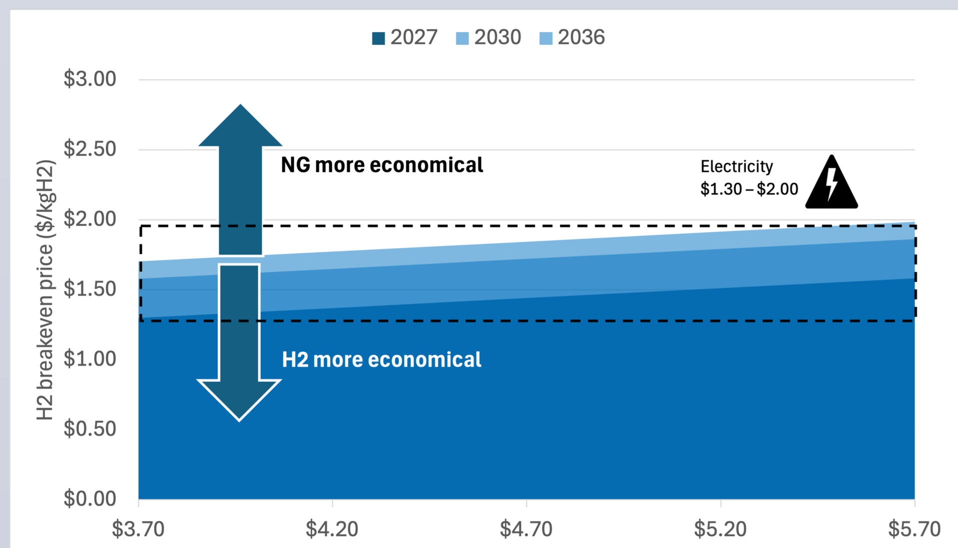
Phase and H2 capacity (T H_2/day) (In service year)	Phase 1 2 TPD (2027)	Phase 2 20 TPD (2031)	Phase 3 200 TPD (2035)
NPV (ATAX) (C$M)	-$22	$71	$821
IRR (ATAX)	7%	12%	15%
LCOH (C$/kg H_2)	$10.47	$3.28	$2.25

LCOH by cost component – 200 TPD Hydrogen (C$/kg$H_2$)



Hydrogen and natural gas costs in electricity generation

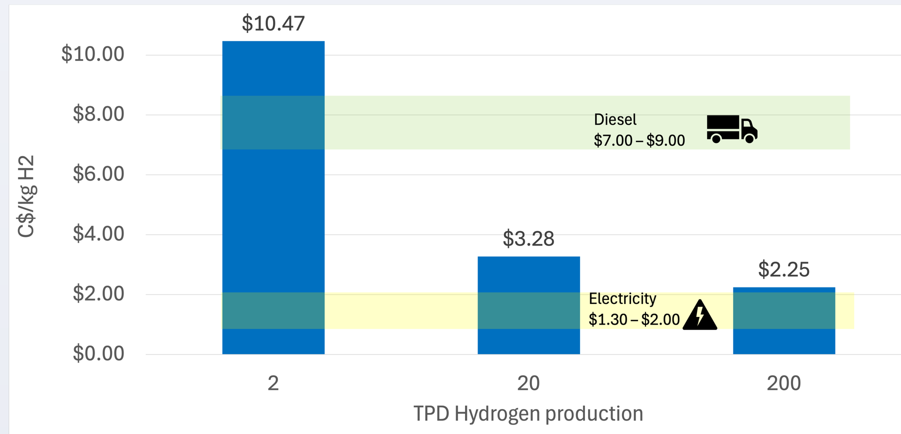
The willingness to pay for hydrogen as fuel in a gas fired turbine on an energy equivalency basis is impacted by the price of natural gas and the cost of related emissions. Natural gas is a comparatively low-cost source of energy. Hydrogen is more economic in the blue shaded areas given a range of underlying natural gas prices. Three different years are used (2027, 2030, and 2036) to show how the breakeven price for hydrogen increases in step with escalating TIER carbon prices and more stringent benchmarks for carbon intensity. The operator of a natural gas fired generation facility would be willing to pay C$1.30 - $2.00 per kilogram of hydrogen under these circumstances, beneath the levelized cost of hydrogen.



CONCLUSIONS

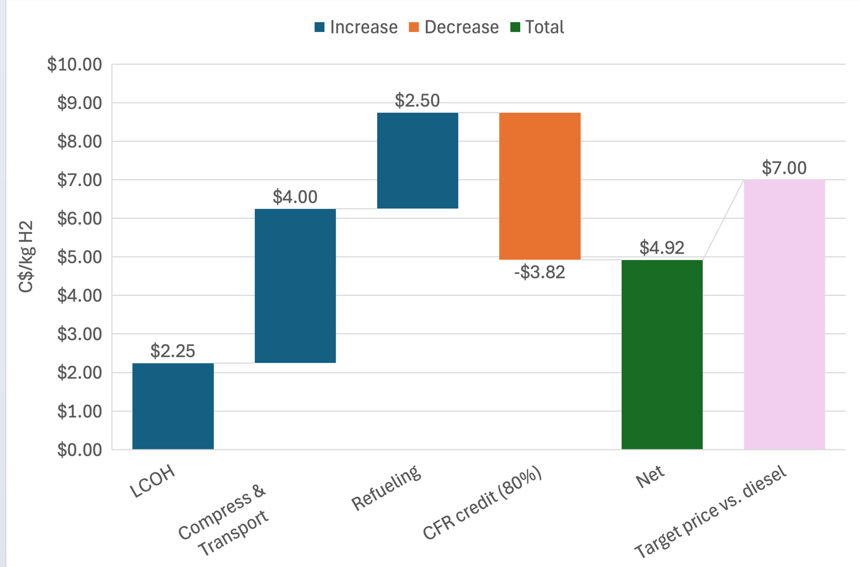
Levelized cost versus willingness to pay for hydrogen

An electricity generator has a relatively low willingness to pay for hydrogen (approximately $1.30 - $2.00 kg$H_2$, which is below the levelized cost of producing hydrogen. Heavy-duty trucking has a higher willingness to pay ($7.00 - $9.00 kg$H_2$) due to the higher cost of diesel fuel and related emissions. It should be noted that additional investment in hydrogen processing and transportation is necessary to deliver hydrogen to refueling points which is not included in the LCOH of hydrogen in the chart below.



Additional refueling costs could be offset by low carbon fuels credits

The Transition Accelerator (Khan et. al, 2022) estimated an additional $4.00/kg for compression and transportation and $2.50/kg in refueling cost to deliver hydrogen, which can vary based on distance and scale. This adds significant cost to hydrogen production costs but can be offset by the market value of credits obtained under Canada's proposed *Clean Fuels Regulation*. Assuming an 80% tradeable value of the $250/ton$CO_2$e penalty, a credit value of approximately $3.80/kg could reduce the delivered cost of hydrogen to under $5/kg, which would be below a diesel consumer's willingness to pay.



Concluding messages

1. Scale up / accelerate 20 TPD
2. Electricity requires low cost H_2
3. Prioritize H_2 for Transportation
4. Refueling infrastructure is costly
5. Solid carbon markets are key
6. Methane pyrolysis – policy gaps

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Thank you for your interest!

My LinkedIn profile