EDMONTON REGION Hydrogen HUB

The Transition Accelerator | L'Accélérateur de transition

Building a Fuel Hydrogen Value Chain for Heavy Transport in a Net Zero Future

Mohd Adnan Khan, PhD (Energy Systems Analyst)
David. B. Layzell, PhD, FRSC (Energy Systems Architect)
Mark Lea Wilson, MBA (Hydrogen Lead)

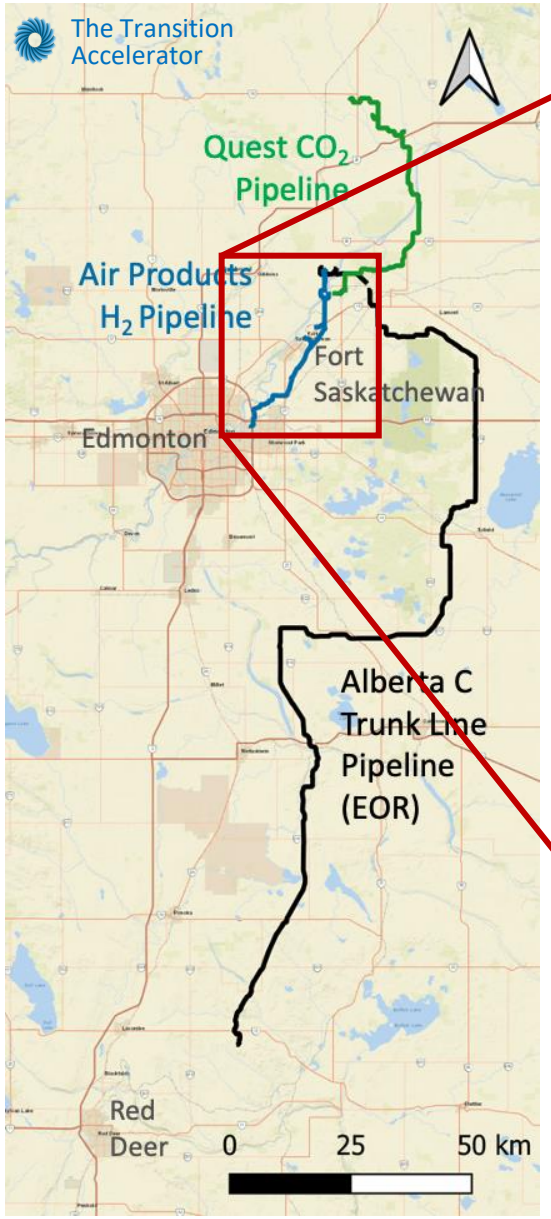
Context: Growing a Hydrogen Economy in Edmonton Region

- **Why: Edmonton/Alberta Industrial Heartland Region ?**
  - Strategically positioned to be a global H_2 leader in NetZero future
  - Produces 1/4th of Canada's H_2
  - Low-cost NG leading to very low cost H_2 production
  - Ideal geology for permanent storage of CO_2
  - World class infrastructure (pipelines) and technical expertise

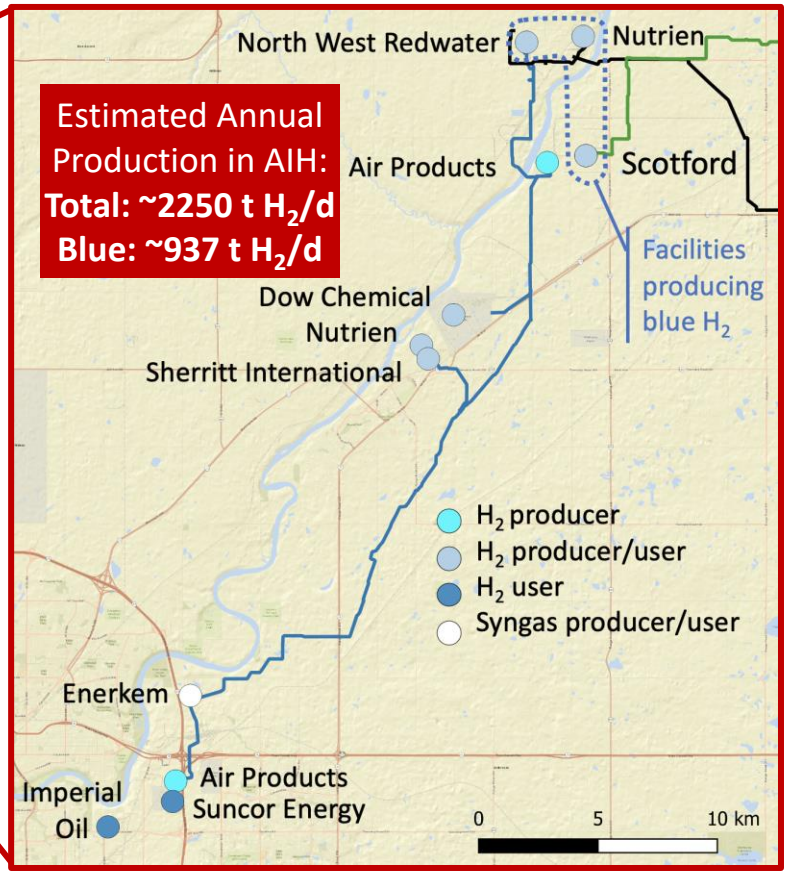
HOW ?

EDMONTON REGION Hydrogen HUB

The Transition Accelerator | L'Accélérateur de transition



The Alberta Industrial Heartland



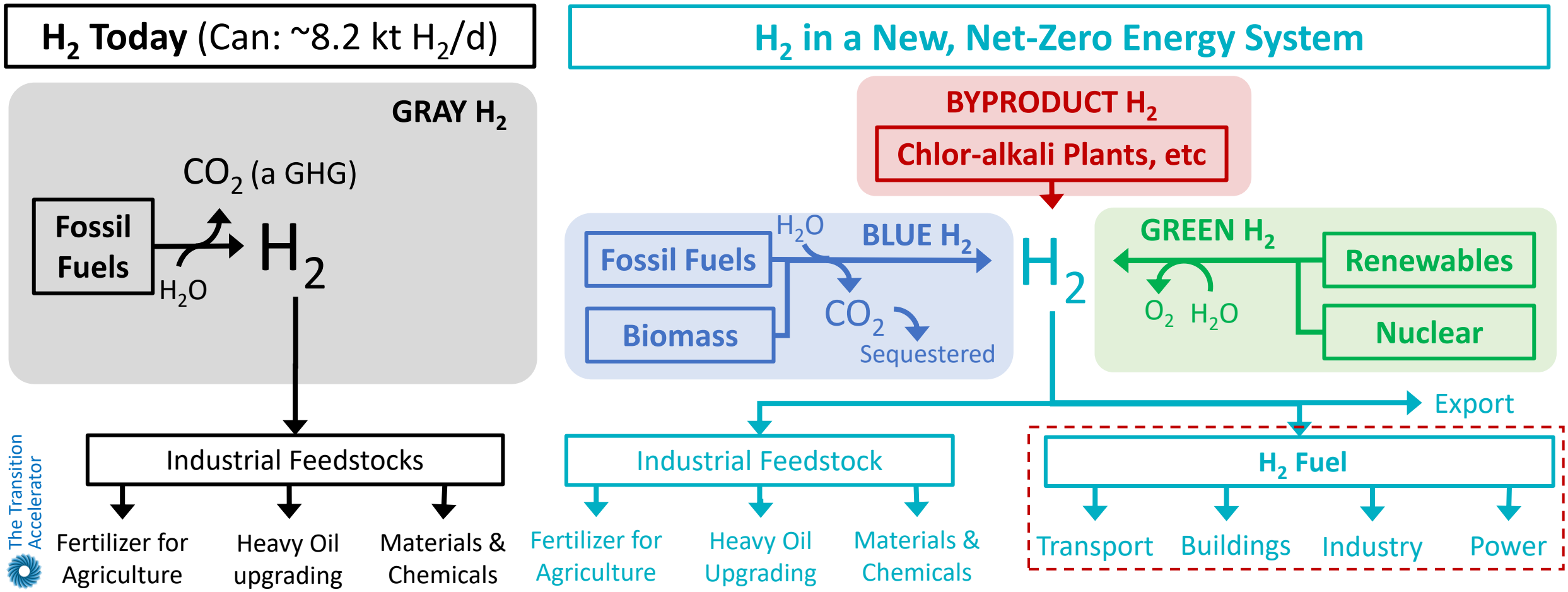
New Blue H_2 initiatives

May 2021: Suncor/ATCO for ~2027
June 2021: Air Products for ~2024
July 2021: Scotford CO_2 infrastructure
Aug 2021: Petronas-Itochu H_2/NH_3 export
Sept 2021: Mitsubishi-Shell Canada H_2/NH_3
Nov. 2021: Northern Petrochem. Corp. H_2/NH_3

OUTLINE

1. Net-Zero Energy System: Role of Hydrogen and Market Assessment
2. Building a Fuel Hydrogen Value Chain for Heavy Transport in a Net Zero Future
3. Techno-economic Analysis: Results
4. Growing a Hydrogen Economy in Edmonton Region
5. Key Messages

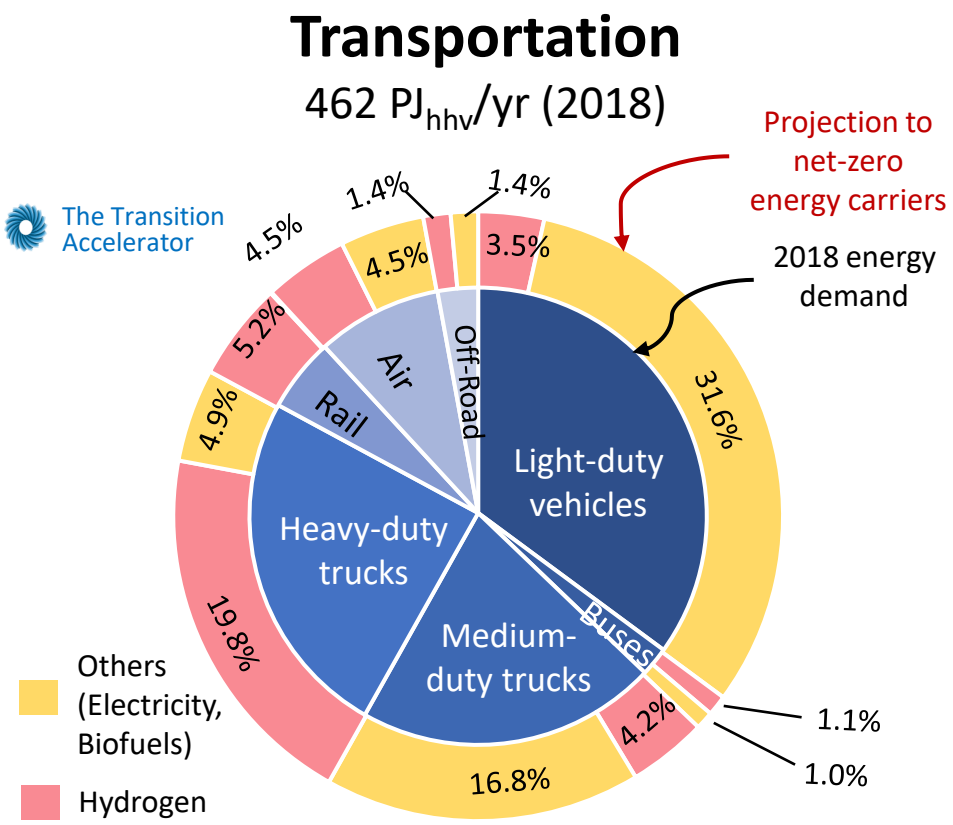
Current Hydrogen Economy and Role in Net-Zero



- *Currently served by C based fuels*
- *Design of a new value chain to deliver H2 ?*
- *Potential market for H_2 ?*

From
Layzell et al. 2020

Est. of H_2 Demand from 2018 Provincial Data: Transport



Potential of hydrogen as fuel in Alberta						
Sector	End use	PJ(FF)/yr (2018)	PJ(FF)/yr (2018) allocated to transition to H2	Relative efficiency (PJ(H2)/PJ(FF))	All Alberta	
					PJ(H2)/yr	t(H2)/day
Transport	LD vehicles	162.6	10% cars; 10% light trucks; 0% motorcycles	0.40	6.5	125
	Buses	9.4	20% school ; 60% transit and 80% inter-city	0.59	3.0	57
	MD trucks	97.1	20% of medium duty trucks	0.86	16.7	323
	HD trucks	114.5	80% of heavy duty trucks	0.86	78.8	1523
	Rail	24.4	50% passenger rail; 100% freight rail	0.55	13.2	256
	Airplanes	41.5	50% passenger air; 50% freight air	1.0	20.8	401
	Off road	13.4	50% of off-road vehicles	0.86	5.8	111
Total for transport					145	2797

Assump-tions:

- H_2 fueled ground vehicles to fuel cell electric with drive train benefits
- Air transport to liquid H_2 jet engine

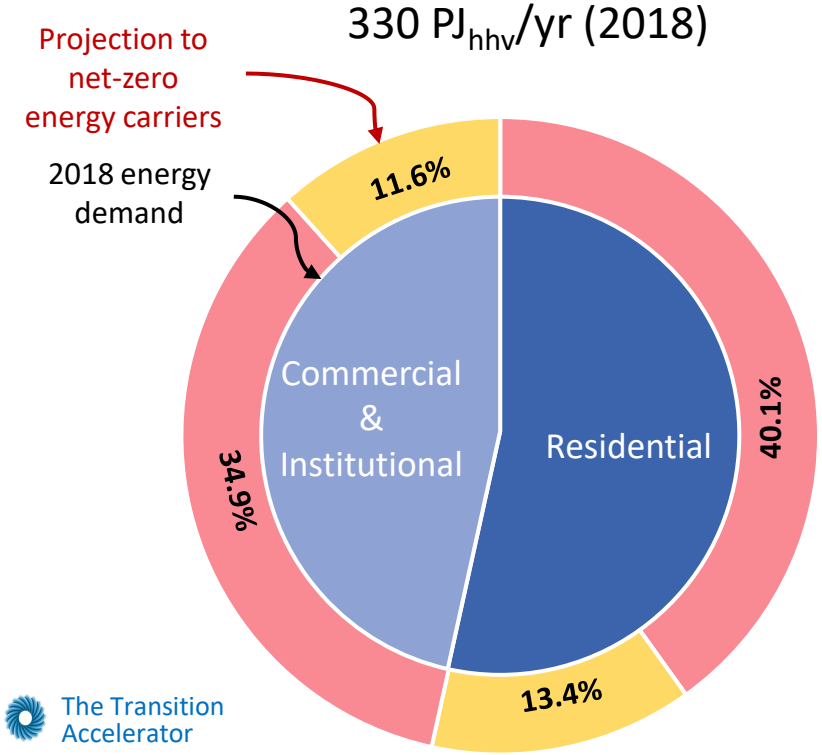
$t\ H_2/d$

Alberta: 2797

Est. of H_2 Demand from 2018 Provincial Data: Buildings

Buildings (from Nat'l Gas)

330 PJ_{hhv}/yr (2018)



Potential of hydrogen as fuel in Alberta						
Sector	End use	PJ(FF)/yr (2018)	PJ(FF)/yr (2018) allocated to transition to H2	Relative efficiency (PJ(H2)/PJ(FF))	All Alberta	
					PJ(H2)/yr	t(H2)/day
Heat	Residential space and water heating	176.3	75% of natural gas use	1.07	141	2724
	Commercial space and water heating	153.5	75% of natural gas use	1.07	123	2371
Total for heat					263	5094

- H_2 fueled building heat uses combustion in furnaces, water heaters and boilers

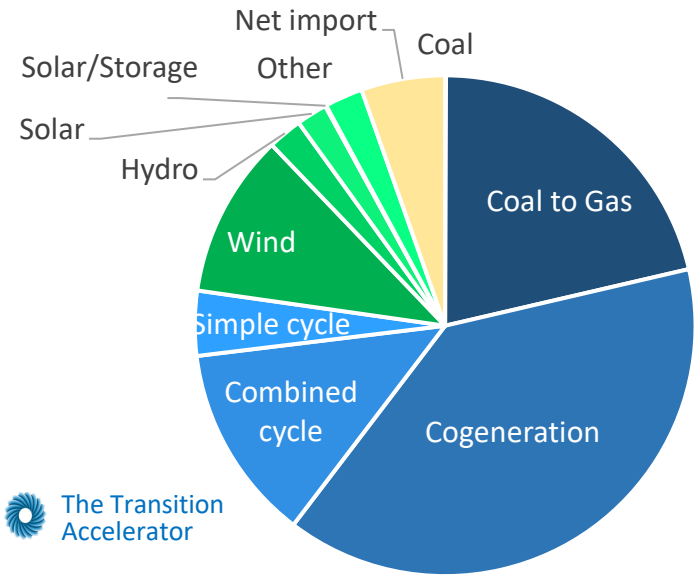
t H_2/d

Alberta: 5094

Est. of H_2 Demand from 2018 Provincial Data: Electricity

Electricity Generation

310 PJ/yr or 86,158 GWh/yr (2021)



Potential of hydrogen as fuel in Alberta						
Sector	End use	PJ(FF)/yr (2018)	PJ(FF)/yr (2018) allocated to transition to H2	Relative efficiency (PJ(H2)/PJ(FF))	All Alberta	
					PJ(H2)/yr	t(H2)/day
Electricity generation	Peaking to firm intermittent renewables	31.0	10% of all generation	3.00	93	1799
	Co-generation	62.0	20% of all generation	3.00	186	3598
Total for electricity generation					279	5397

- Backup for renewables (10% of Ann Gen)
- Industrial Cogeneration (20% of Ann Gen)
- H_2 → electricity via single cycle turbines

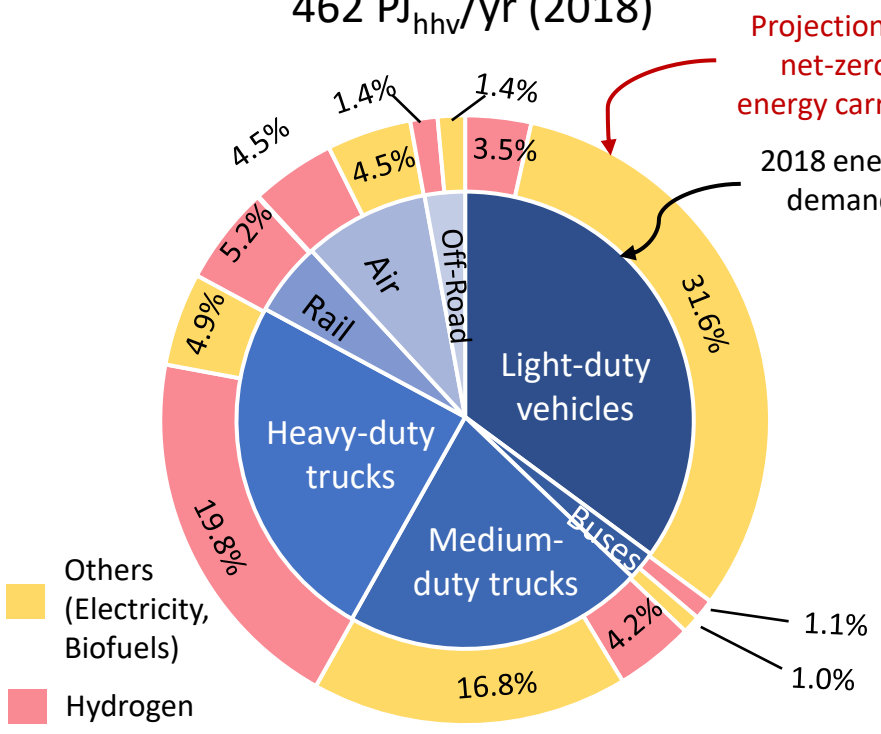
t H_2/d

Alberta: 5397

Hydrogen Fuel Market Opportunity

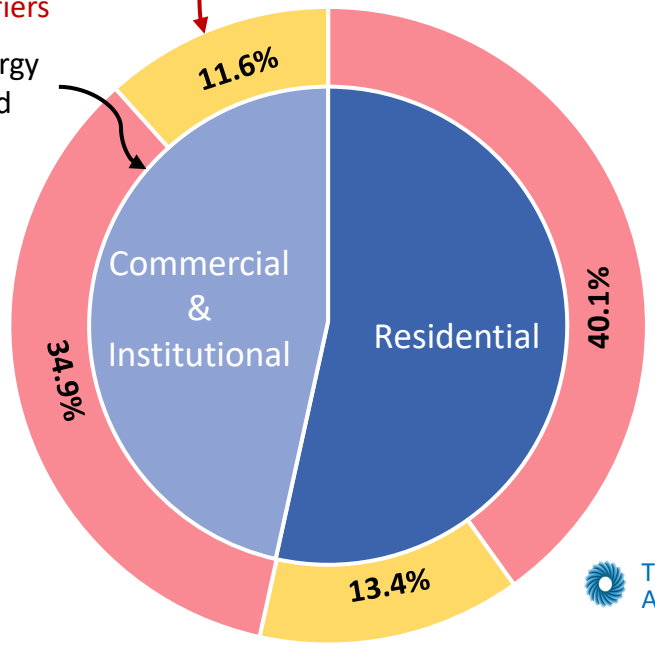
Transportation

462 PJ_{hhv}/yr (2018)



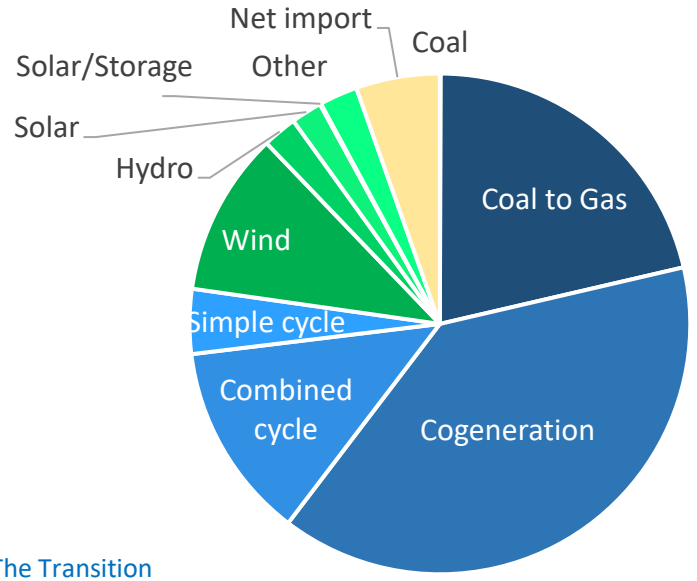
Buildings (from Nat'l Gas)

330 PJ_{hhv}/yr (2018)



Electricity Generation

310 PJ/yr or 86,158 GWh/yr (2021)



The Transition Accelerator

About 2.4X current industrial H_2 production in AB. At $2/kg = $9.7B/year.

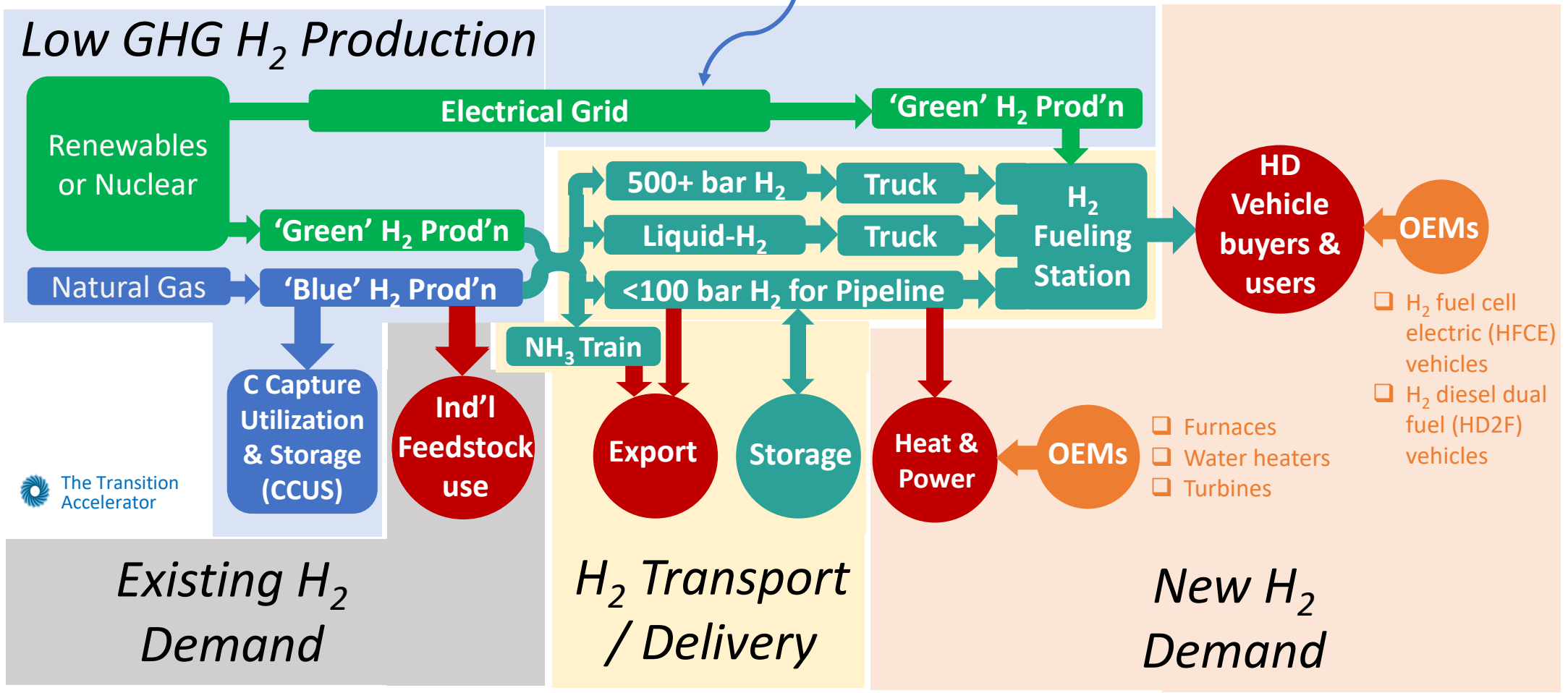
Assumptions:

- ❑ H_2 fueled ground vehicles to fuel cell electric with drive train benefits
- ❑ Air transport to liquid H_2 jet engine
- ❑ H_2 fueled building heat uses combustion in furnaces, water heaters and boilers
- ❑ Backup for renewables (10% of Ann Gen)
- ❑ Industrial Cogeneration (20% of Ann Gen)
- ❑ H_2 → electricity via single cycle turbines

t H_2/d	Transportation	Buildings	Electricity	Total
Alberta:	**2797**	**5094**	**5397**	**13,289**

Design of New Hydrogen Value Chain in NetZero Future

Electrical grid costs add $30-$50/MWh, or $1.60-$2.60/ kg H_2



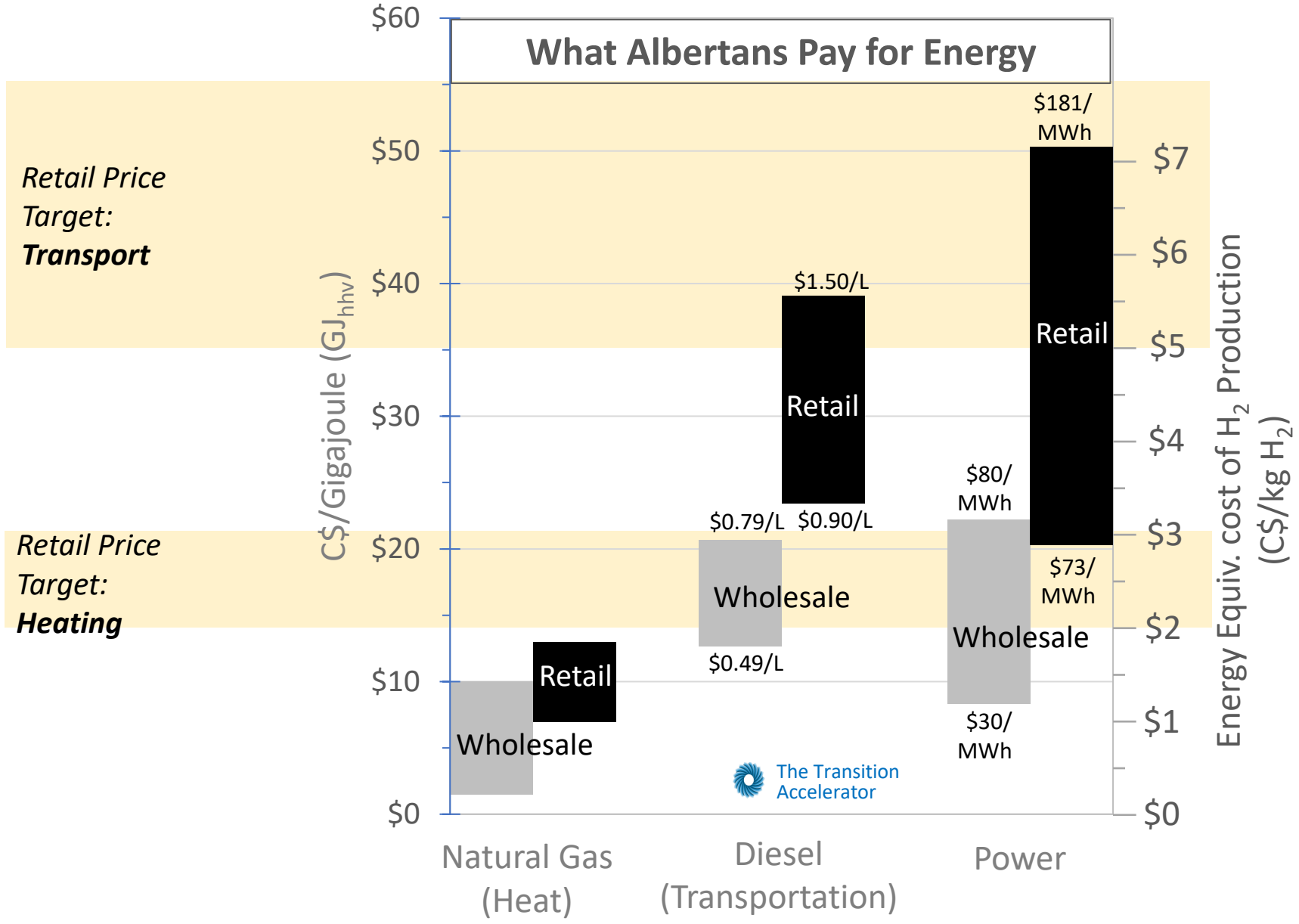
In this study we have focused on CENTRALIZED H_2 production and transport to markets.

What Markets for Hydrogen are Most Promising?…

Current Economics

Per unit of energy, Albertans pay more for transportation fuels than for heating fuels.

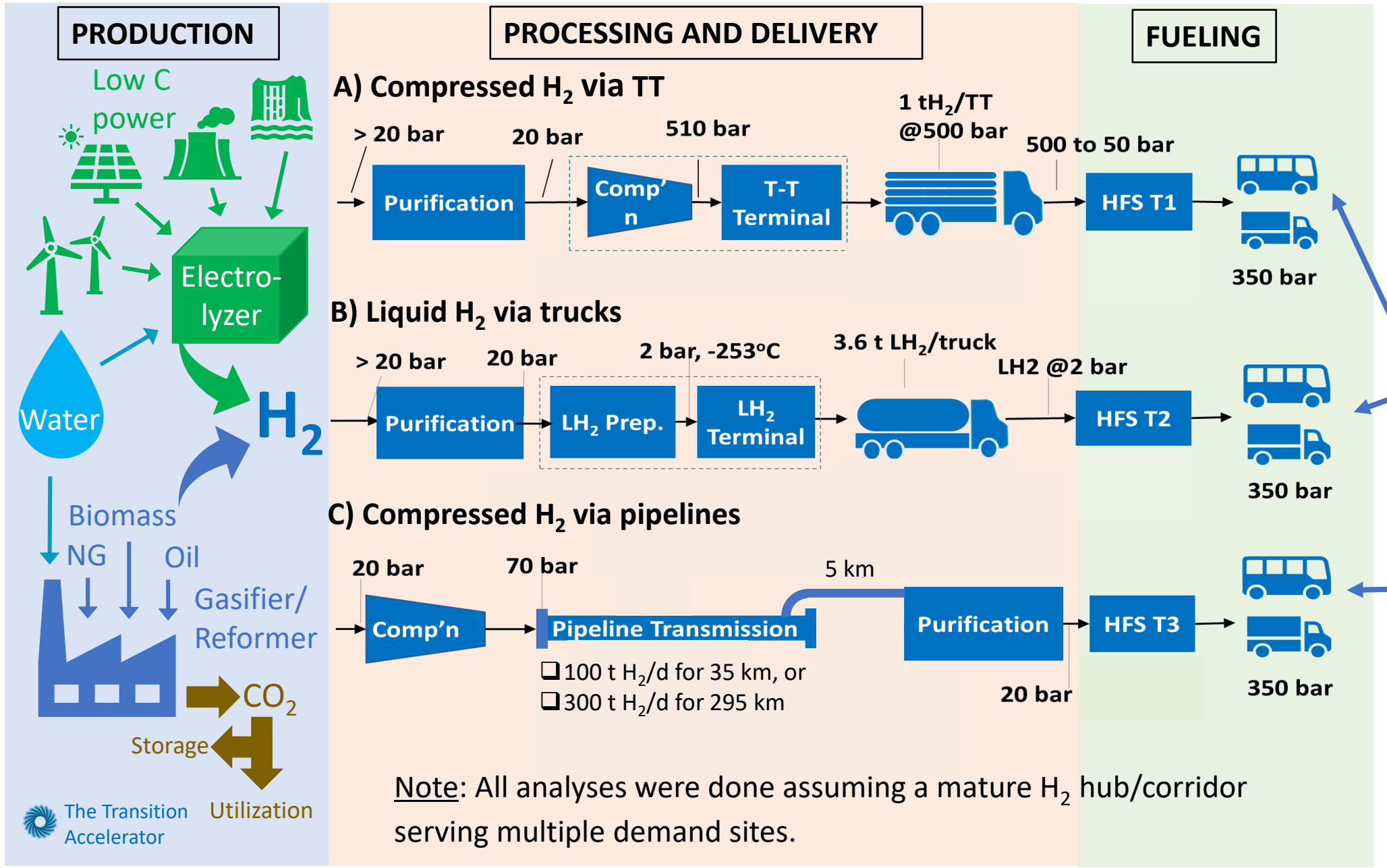
… so today, the **economics for H_2 is more promising for the transportation than the heating sector.**



OUTLINE

1. Net-Zero Energy System: Role of Hydrogen and Market Assessment
2. Building a Fuel Hydrogen Value Chain for Heavy Transport in a Net Zero Future
3. Techno-economic analysis: Results
4. Growing a hydrogen economy in Edmonton Region
5. Key messages

Hydrogen Supply Chains for Heavy-duty Transport



Note: All analyses were done assuming a mature H_2 hub/corridor serving multiple demand sites.

Other Assumptions

Different delivery distances: **5, 40 and 300 km**

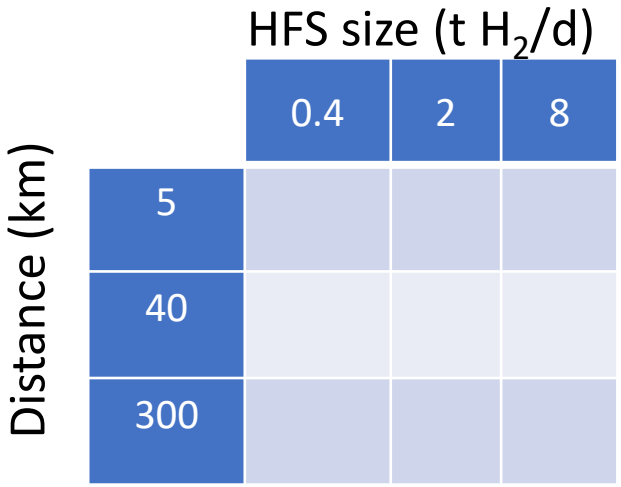
Different HFS size: 0.4, 2 and 8 t_{H2}/d

Large (100 t H_2/d) central terminal for compression or liquefaction

5 km dedicated pipe off 100 t/d or 300 t/d trunk line (for 40 km or 300 km distance, respectively)

Scenarios and costs

Scenarios



H_2 retail cost for HDV =

Production cost + Processing & Delivery cost + Fueling (HFS) cost

Economic assumptions

8 % Return on Capital Investment

All numbers in Canadian $ (2019)

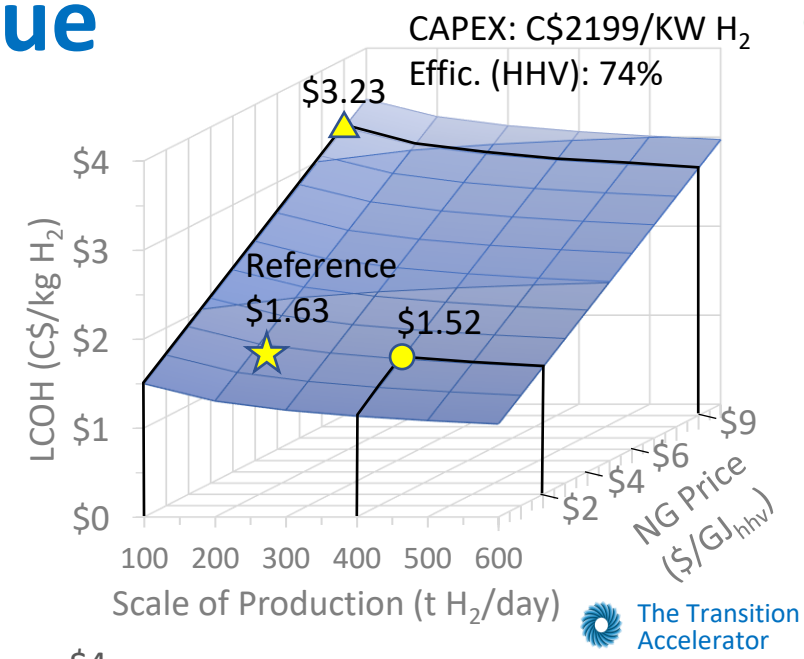
OUTLINE

1. Net-Zero Energy System: Role of Hydrogen and Market Assessment
2. Building a Fuel Hydrogen Value Chain for Heavy Transport in a Net Zero Future
3. Techno-economic Analysis: Results
4. Growing a Hydrogen Economy in Edmonton Region
5. Key Messages

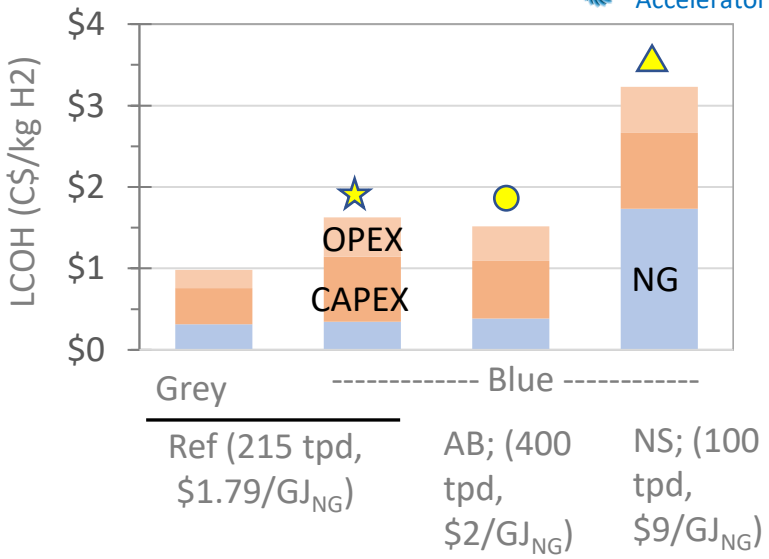
Hydrogen Production Costs - Current

Blue

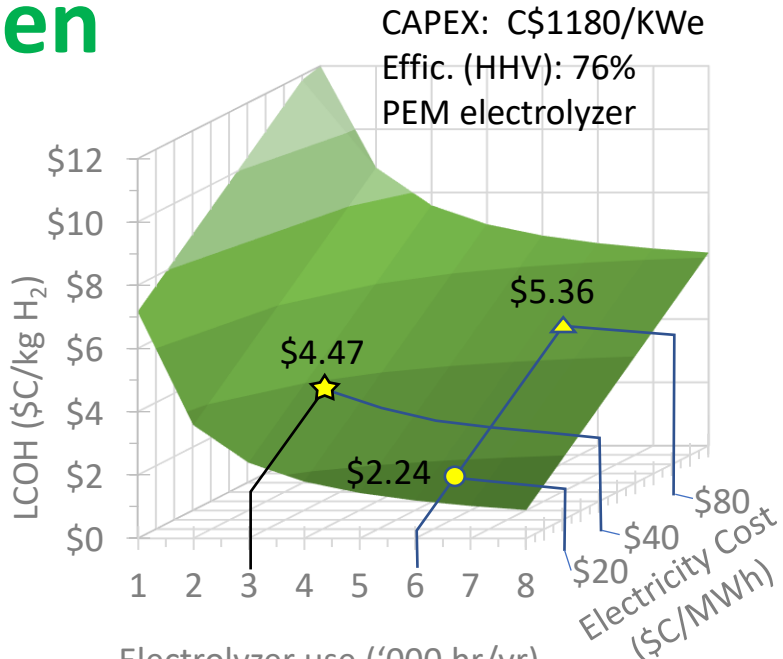
- IEA Model
- SMR + CCS (90% C Capture)
- 100-600 t_{H2}/d



- 1.5-3 C/kg_{H2}
- Major role of NG price
- CCS cost of $C74.37/t_{CO2}$

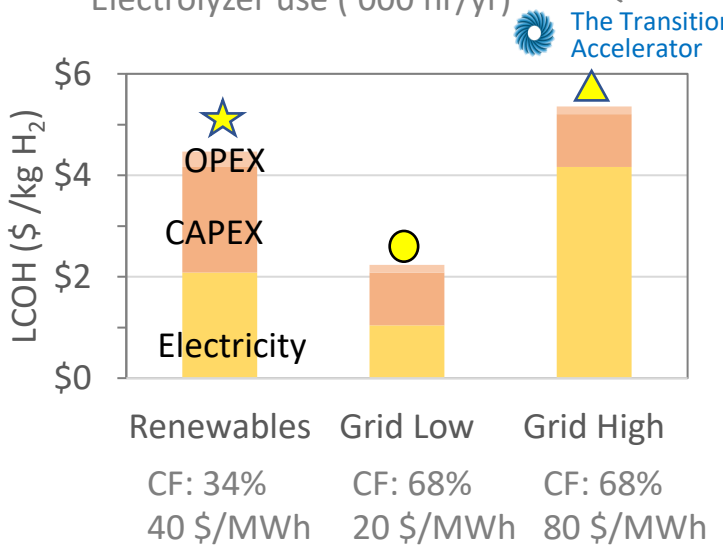


Green

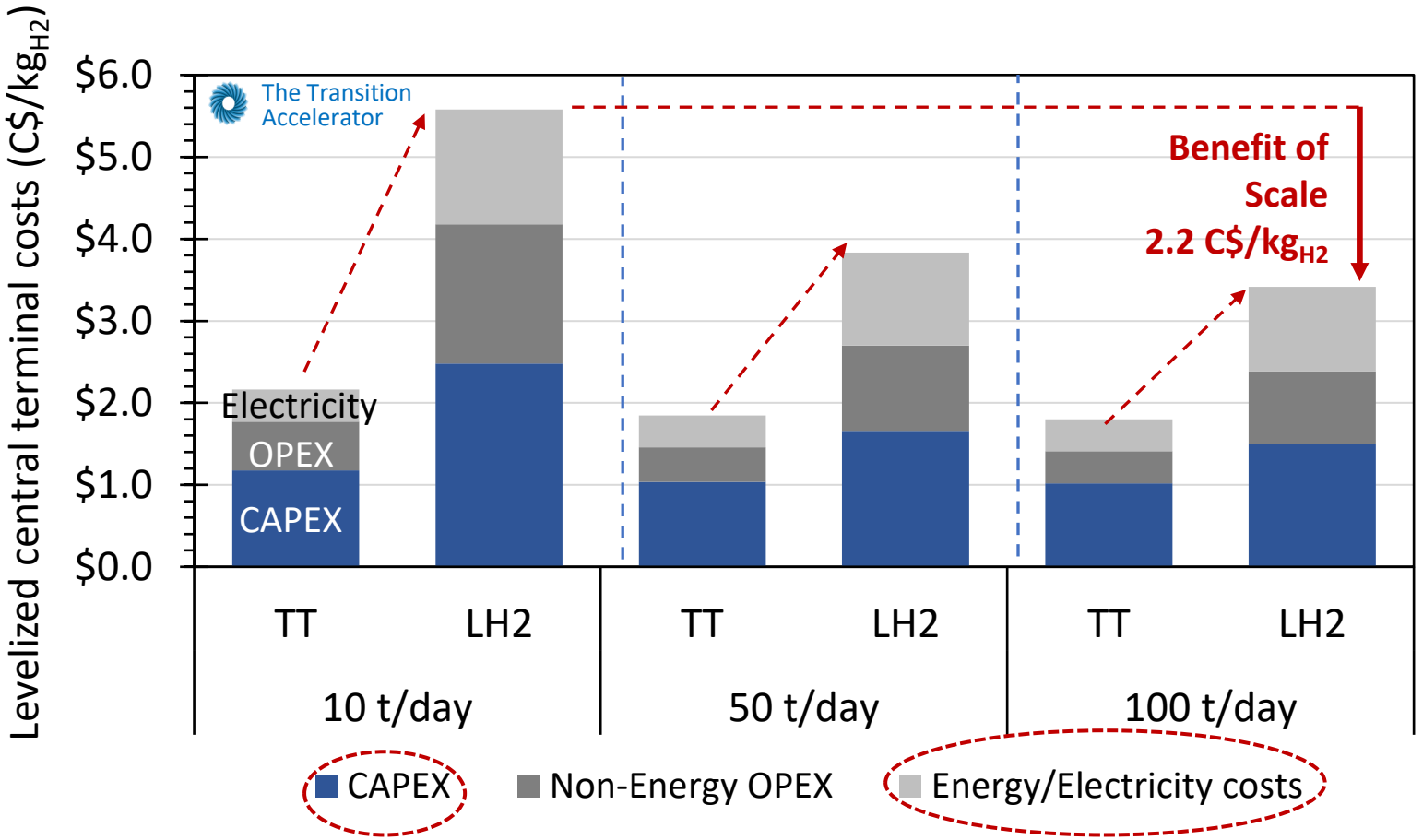


- IEA model
- 4.2 MW PEM Electrolyzer
- 0.22-1.77 t_{H2}/d

- 4-6 C/kg_{H2}
- Major role of electricity price and CF
- <3 C/kg_{H2} possible with continuous low cost electricity (< 30 C$/MWh)



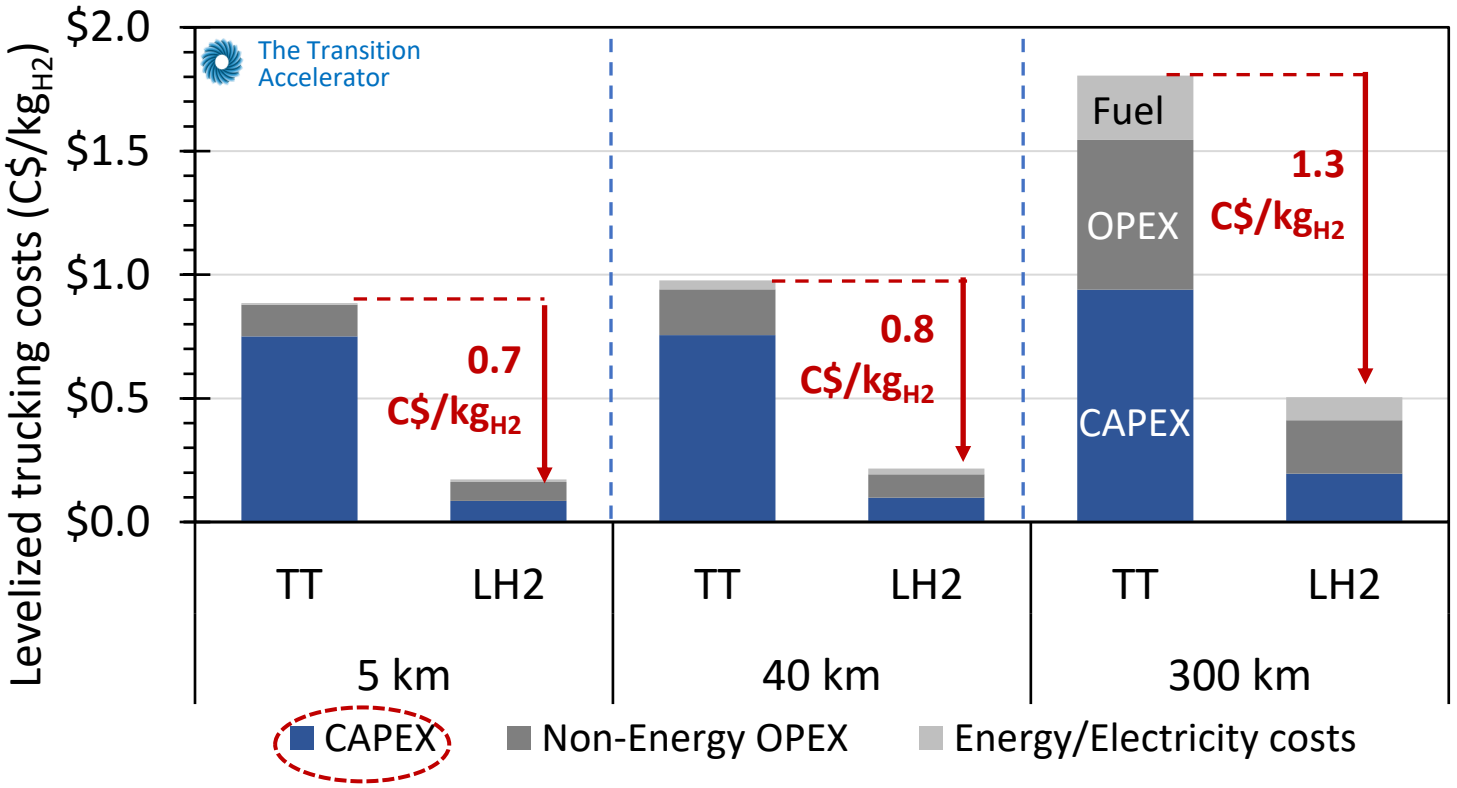
Central Terminal Costs



- Terminal facility → CAPEX dominated
  - High cost of compressors and liquefier units
- Liquefaction is more costly than compression
  - Higher capital & operating costs: (~2X higher than compression)
  - High energy costs of liquefaction: 8.5-11 kWh/kg$_{H2}$ (~3X higher than compression)
- Liquefaction has higher benefit of operating at large scale

Central Terminal costs are significant; Liquefaction is more costly versus compression; However economy of scale can drive down costs

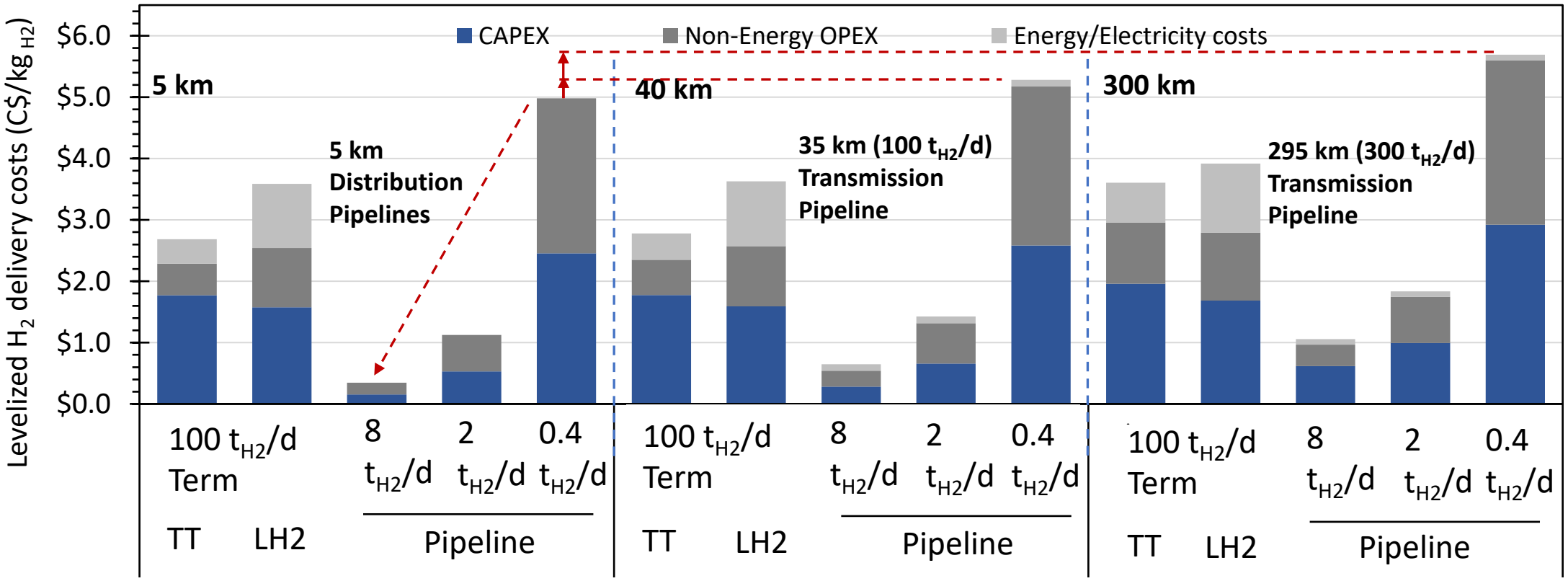
Trucking Costs



- Trucking also dominated by capital costs of the cabs, tube trailers/LH_2 tanks,
  - Other components: driving distance, labor cost, fuel cost, and O&M costs
- Trucking via LH_2 trucks is cheaper versus TT, particularly for longer distances (< 1 C$/kg$_{H2}$).

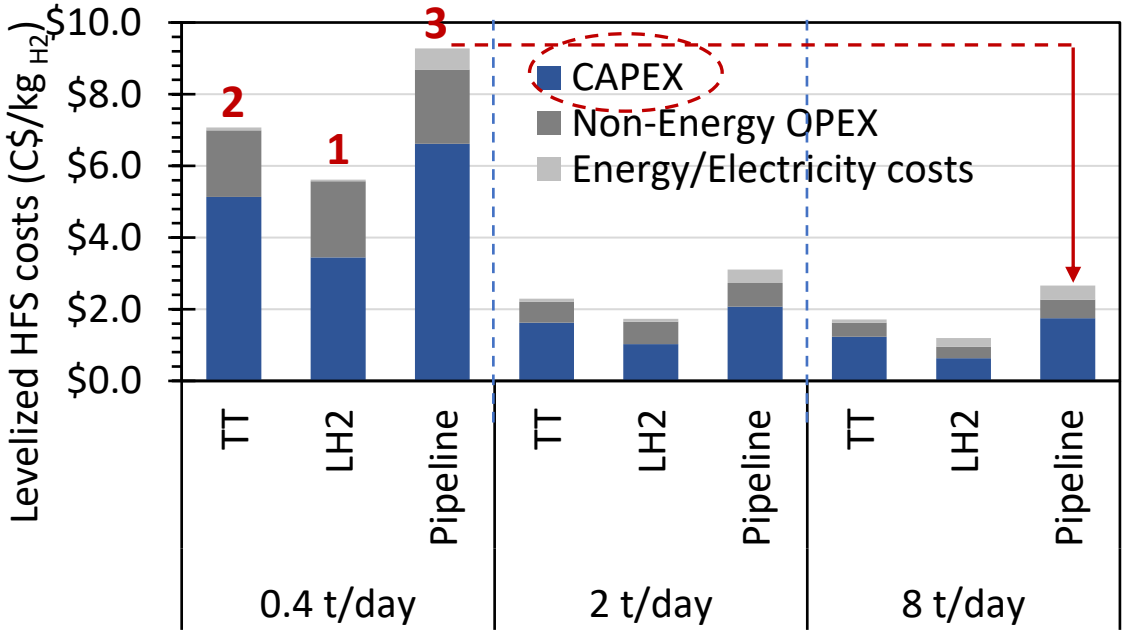
Trucking via LH2 is cheaper than TT; More beneficial for longer distances

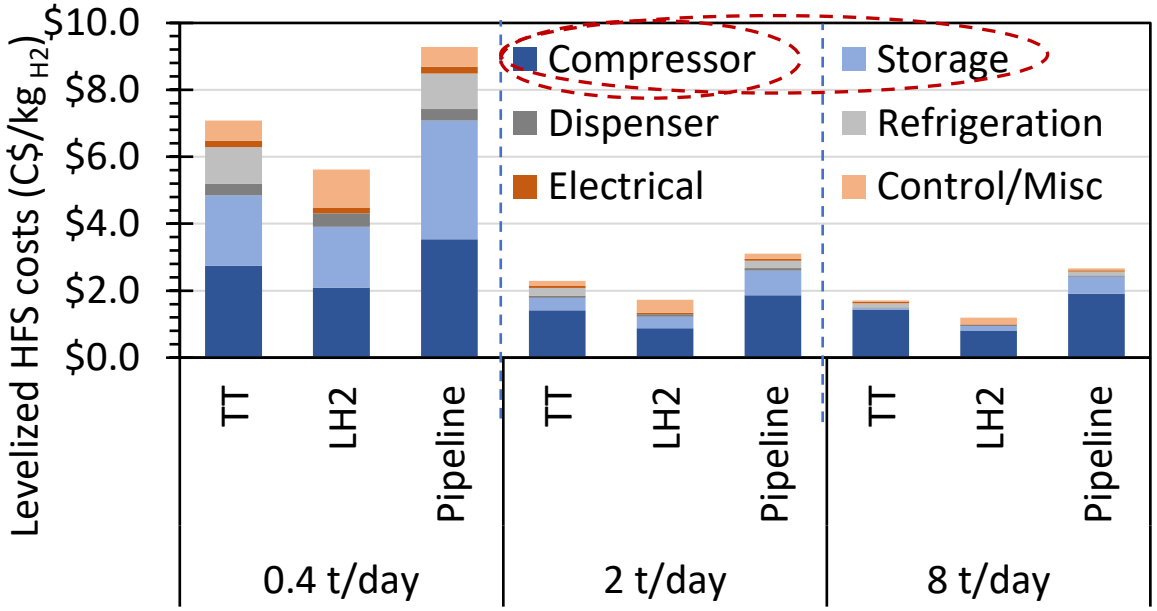
Hydrogen Delivery Costs (Terminal + Trucking)



- Delivery via TT is cheaper but LH2 attractive for long distances
- Dedicated distribution pipelines: Only feasible to large heavy-duty HFS's that are dispensing ≥ 2 t_{H2}/d.
- Transmission pipeline delivery of H_2: Low cost when done at scale (**Demand ~1 t_{H2}/day per km of pipeline to drive economic viability**)

Hydrogen Fueling Station Costs

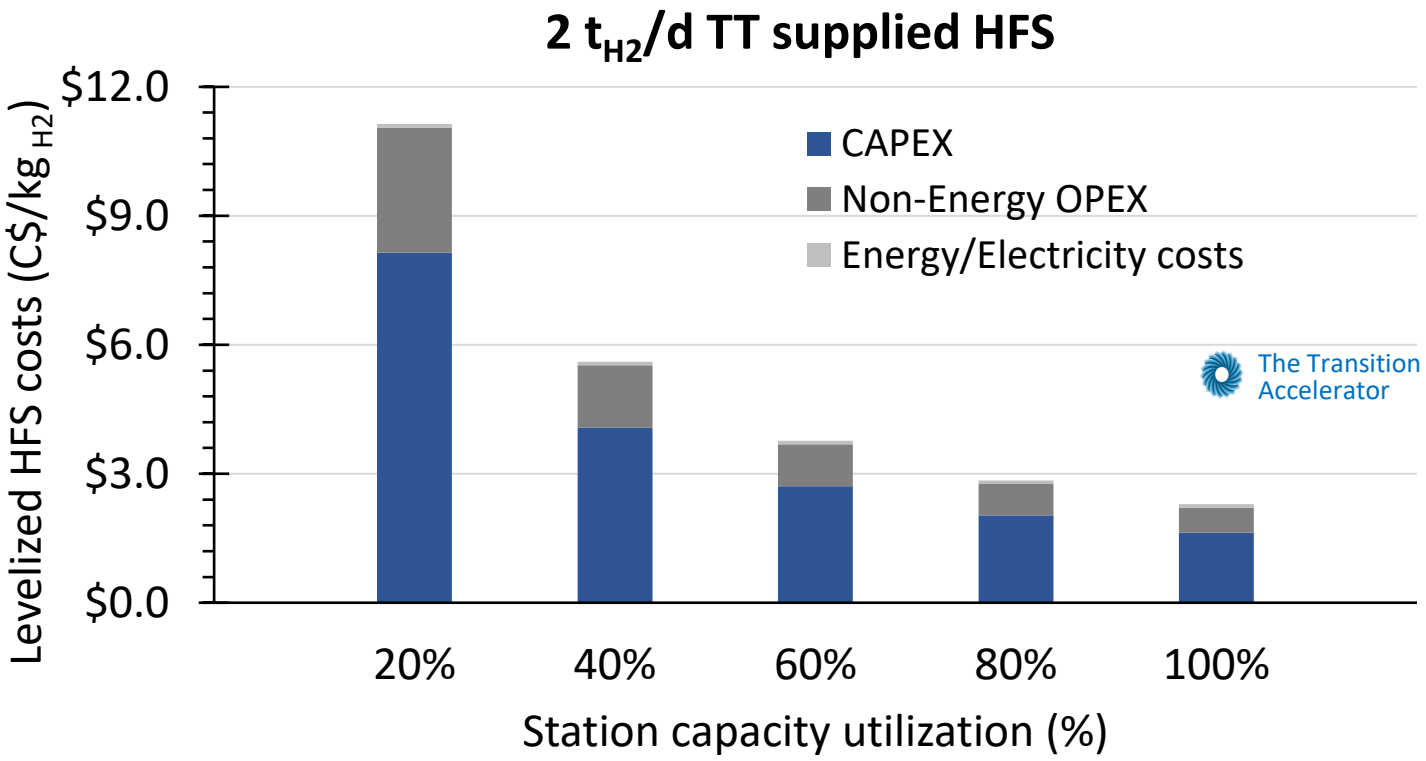




- Big impact of scale ; Small HFS not feasible
- LH2 < TT < Pipeline supplied
- Costs are dominated by CAPEX

- Small scale: Compression and storage are costly
- Large scale: Compression – Most expensive unit in HFS

Impact of utilization/demand on fueling station costs



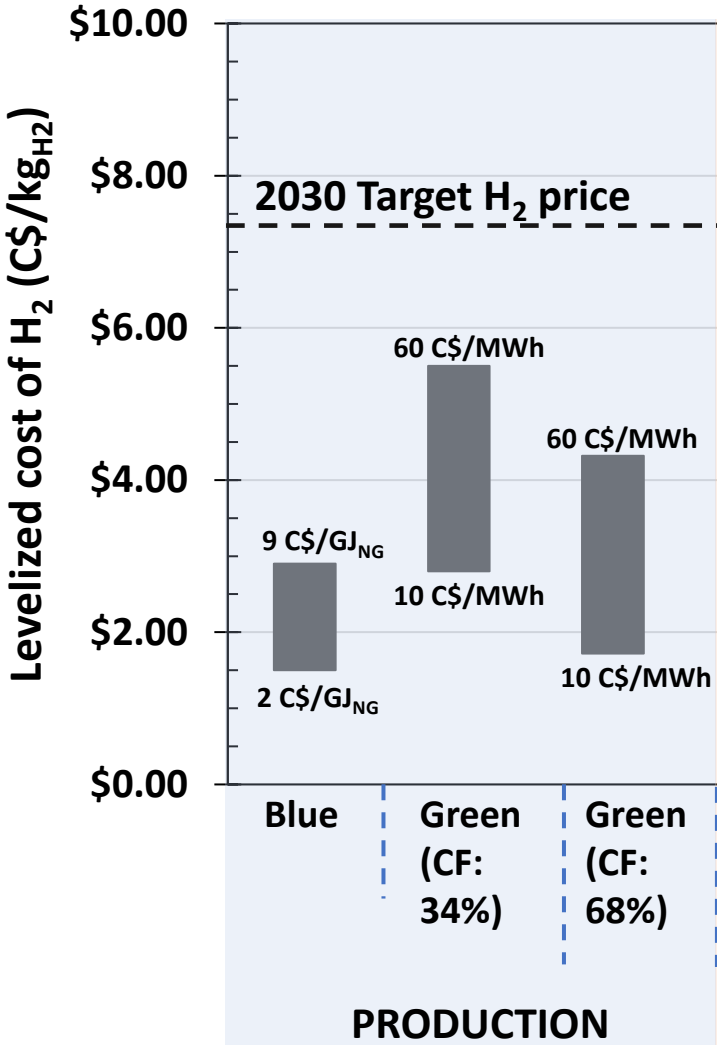
2 t_{H2}/d TT supplied HFS

Full use requires:

- ❑ 80 transit buses using 25 kg H2/d
- ❑ 40 Class 8 trucks using 50 kg H2/d
- ❑ 25 locomotive using 80 kg H2/d
- ❑ 2000 cars using Avg 1 kg H2/d

- ❑ Early market, we expect majority of the HFS's to be underutilized where the demand is low
- ❑ **Support demand creation → Supply will follow**; Various tools and policies needed to support build out of fueling stations

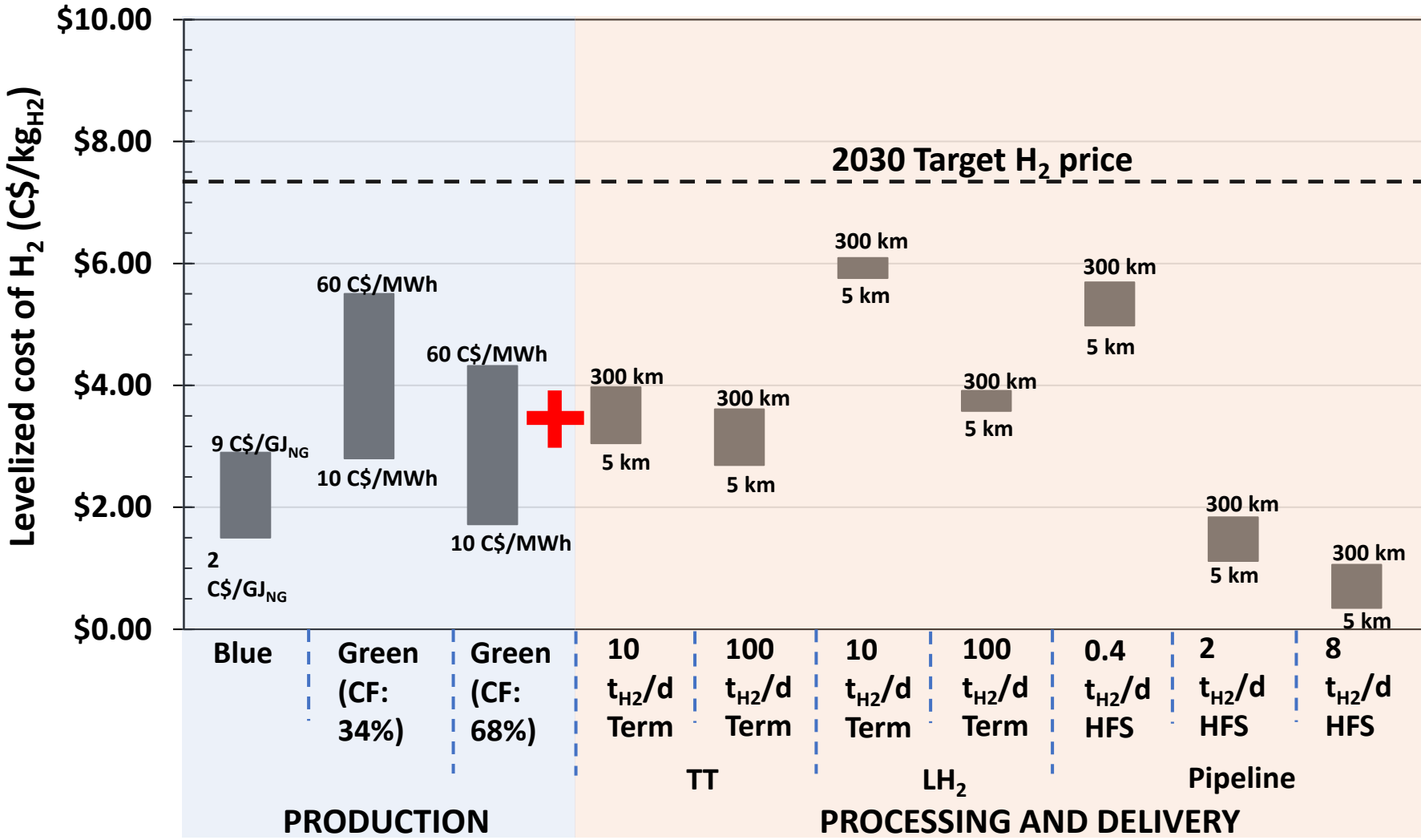
Summary: Levelized Refueling Cost of Hydrogen



NOTES:

- ❑ Centralized blue H_2: Cheapest option when produced at scale. But only at sites where geology exists for carbon capture and storage (CCS). Ex: AB; Advantage of Scale
- ❑ Centralized green H_2: If excess low-carbon grid electricity is available, H_2 could be made at a competitive cost.

Summary: Levelized Refueling Cost of Hydrogen



NOTES:

- As a low density gas, processing & transport costs for H_2 are high;
- For smaller demand and short distances: TT is best. Long distances: LH_2 better
- TT and LH_2 uneconomic for heating
- At larger scale of demand: pipelines

Scale drives economics

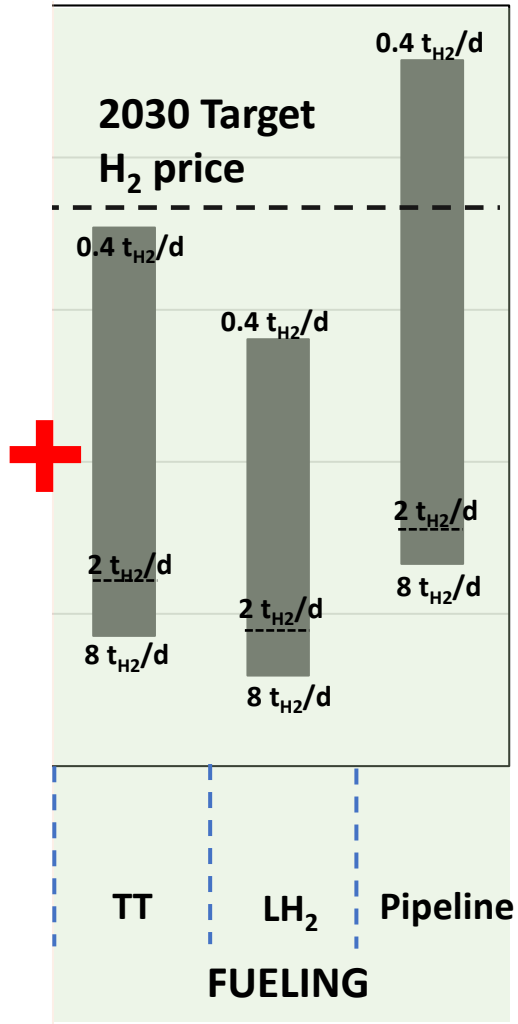
Notes:

- **The 35 km and 295 km transmission pipelines were designed and analyzed with a demand of 100 t_{H2}/d and 300 t_{H2}/d respectively**

Summary: Levelized Refueling Cost of Hydrogen

NOTES:

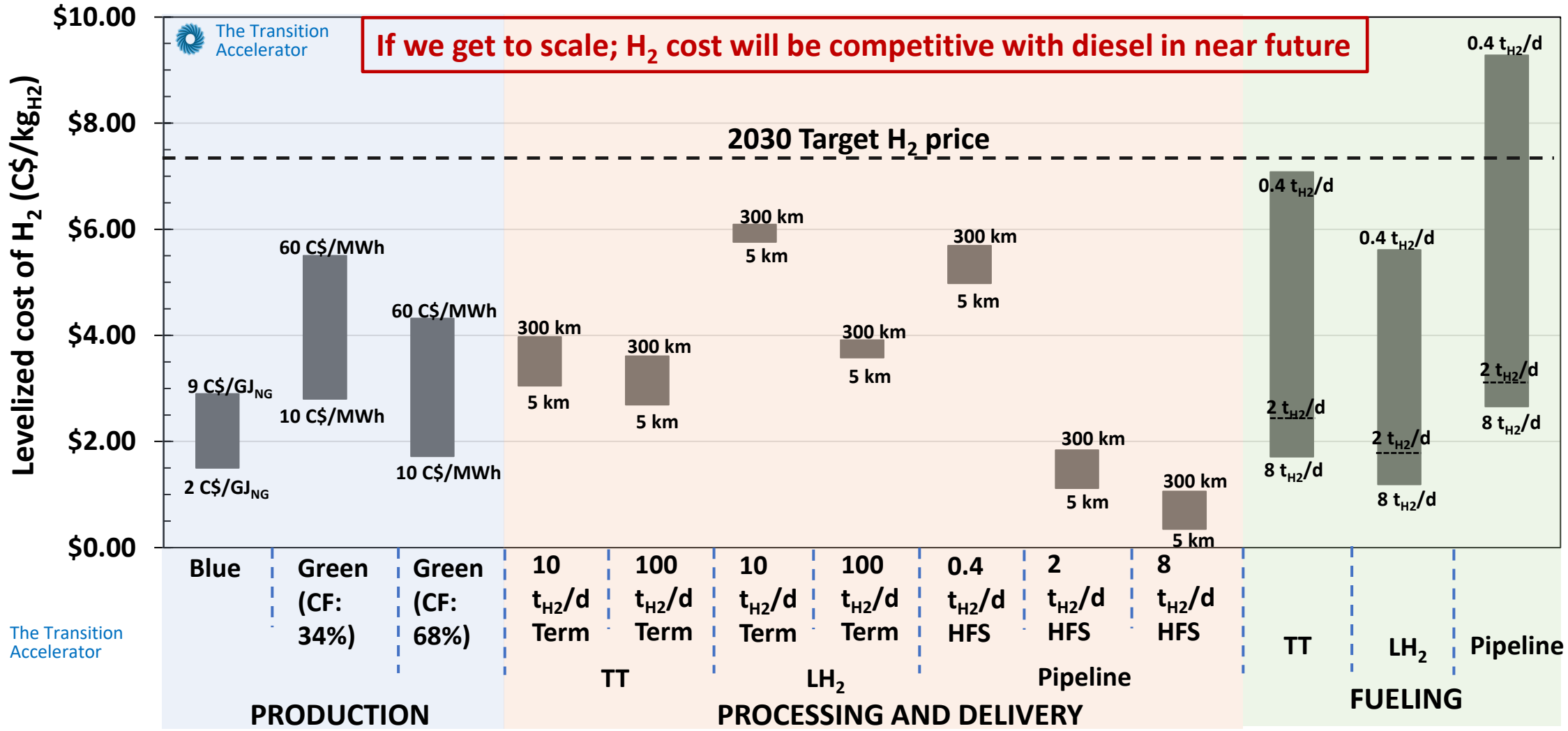
- How H_2 arrives at fueling station significantly impacts cost.
- But in all cases, the larger the fueling station, the better the economics.
  - Min. economic viability is ~2 t H_2/day (80 buses, 40 large trucks, 20-30 trains, 2000+ cars)
- This is tied to the H_2 demand; HFS utilization is critical to lowering fueling costs.



Notes:

- **HFS costs are fully utilized.**

Levelized Refueling Cost of Hydrogen



The Transition Accelerator

Notes:

- The 35 km and 295 km transmission pipelines were designed and analyzed with a demand of 100 t_{H2}/d and 300 tH2/d respectively. HFS costs are fully utilized.

OUTLINE

1. Net-Zero Energy System: Role of Hydrogen and Market Assessment
2. Building a Fuel Hydrogen Value Chain for Heavy Transport in a Net Zero Future
3. Techno-economic Analysis: Results
4. Growing a Hydrogen Economy in Edmonton Region
5. Key Messages

What does the TEA tell us ?

Analysis reveals scale of challenge

Will take coordinated effort between different stakeholders (Hub Concept)

EDMONTON REGION Hydrogen HUB

Analysis also reveals importance of quickly get to scale to drive down costs

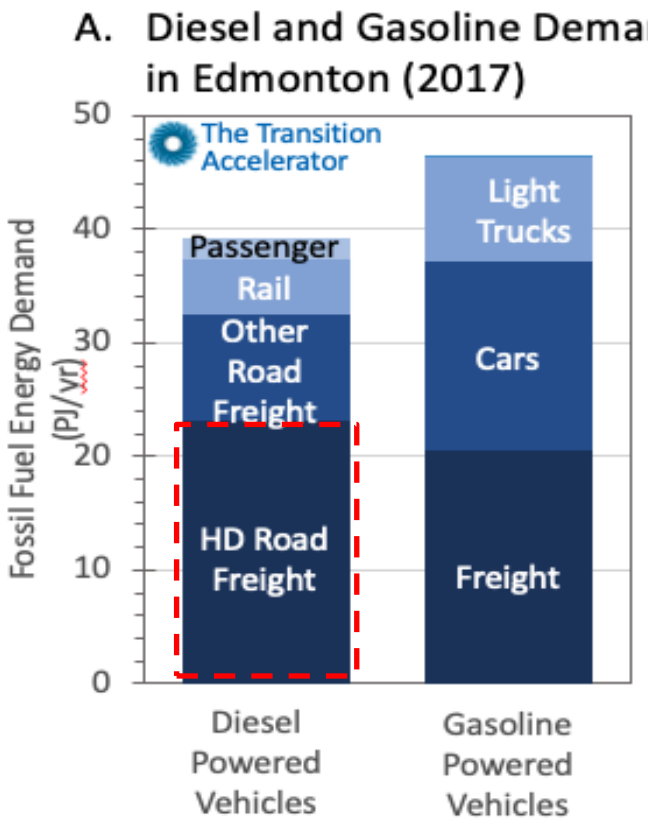
Need to build on economic corridors that connect supply & demand to minimizes barriers

EDMONTON REGION Hydrogen HUB

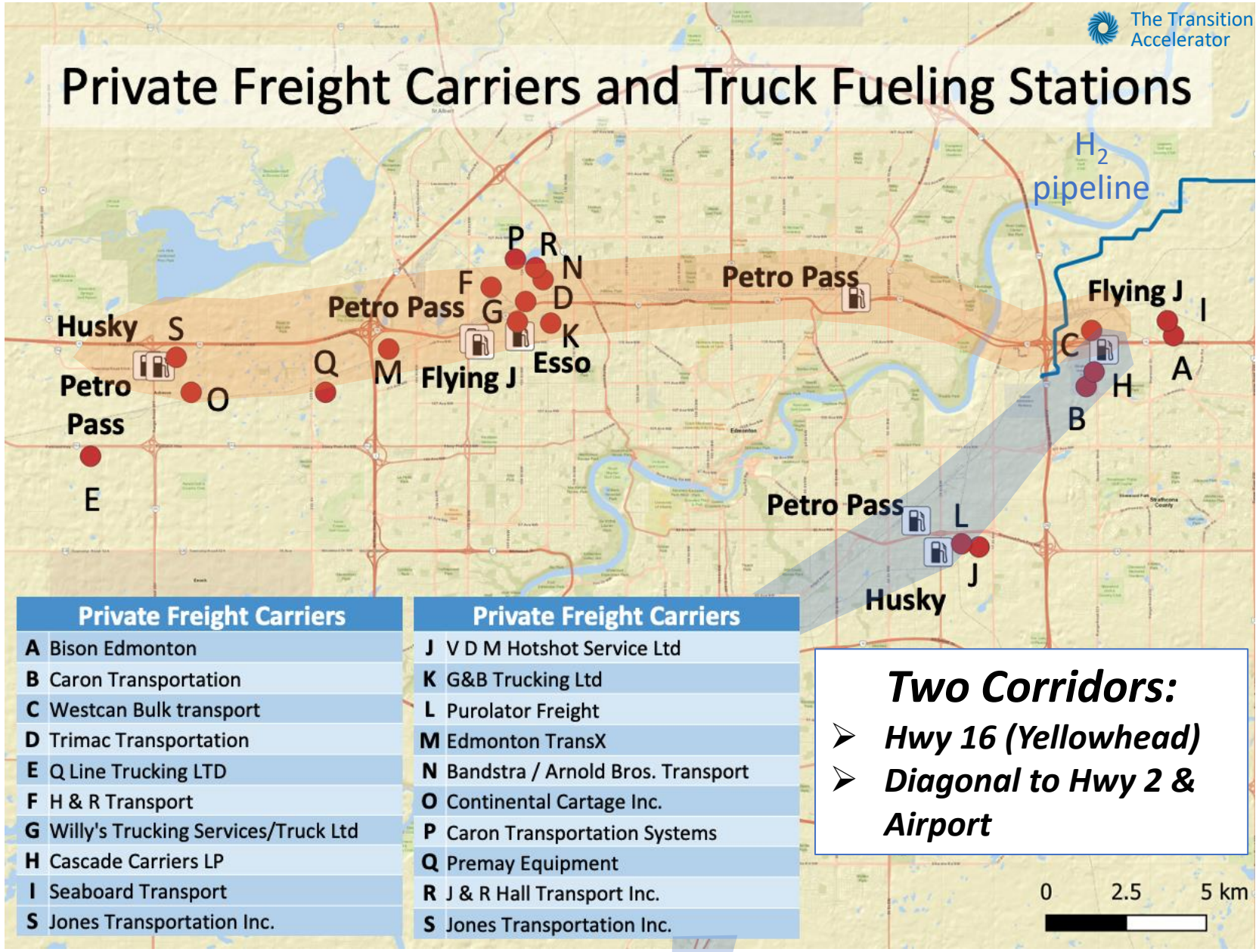
The Transition Accelerator | L'Accélérateur de transition

BASE CASE

Fueling Locations for Private Freight Carriers



23 PJ_{diesel}/yr →382 t_{H2}/day
(DTE: 0.86 PJ_{H2}/Pj_{diesel})



Private Freight Carriers	
A	Bison Edmonton
B	Caron Transportation
C	Westcan Bulk transport
D	Trimac Transportation
E	Q Line Trucking LTD
F	H & R Transport
G	Willy's Trucking Services/Truck Ltd
H	Cascade Carriers LP
I	Seaboard Transport
S	Jones Transportation Inc.

Private Freight Carriers	
J	V D M Hotshot Service Ltd
K	G&B Trucking Ltd
L	Purolator Freight
M	Edmonton TransX
N	Bandstra / Arnold Bros. Transport
O	Continental Cartage Inc.
P	Caron Transportation Systems
Q	Premay Equipment
R	J & R Hall Transport Inc.
S	Jones Transportation Inc.

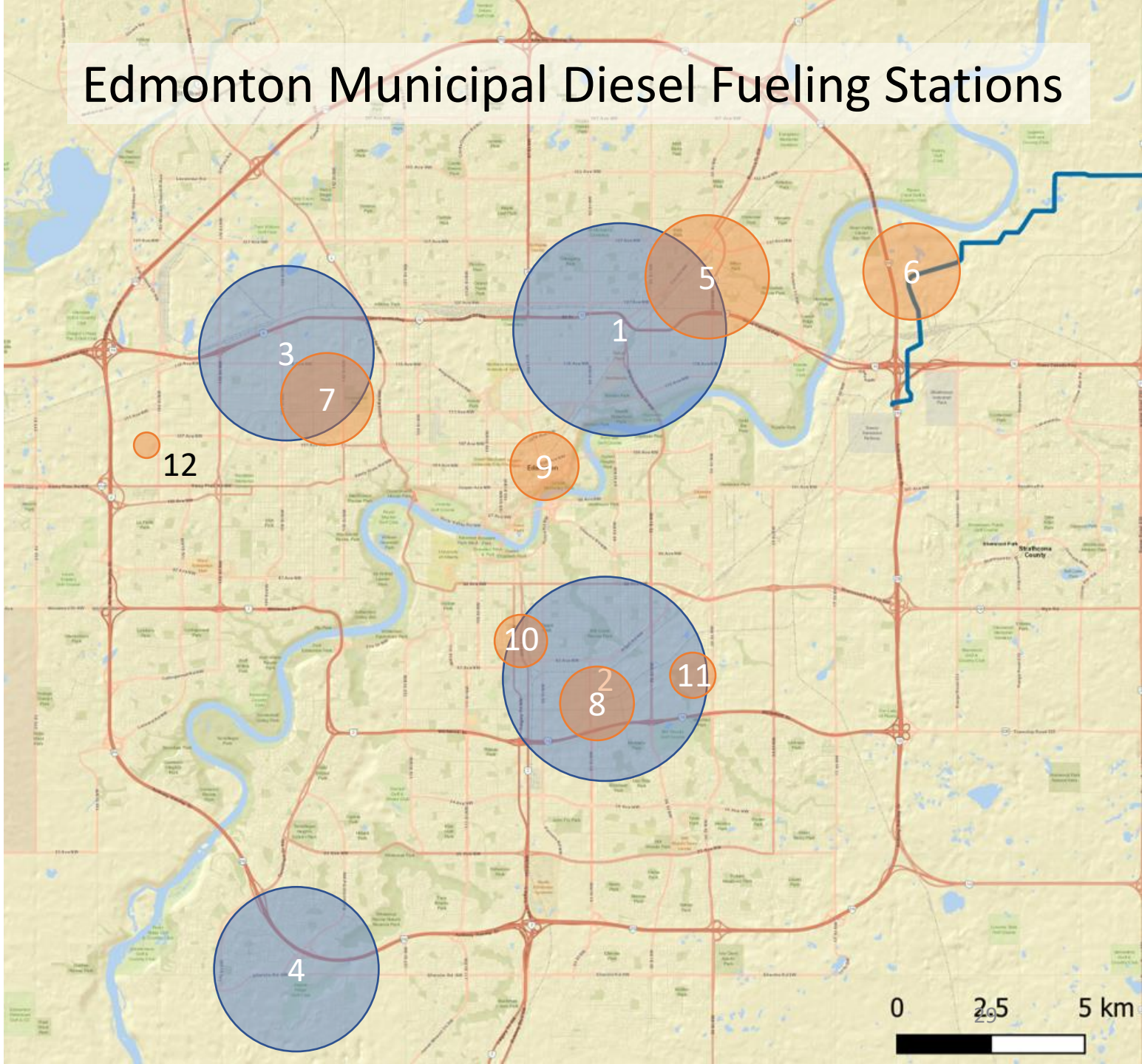
Two Corridors:

- ***Hwy 16 (Yellowhead)***
- ***Diagonal to Hwy 2 & Airport***

Edmonton's Municipal Fleets & Refueling are in the Same Corridors

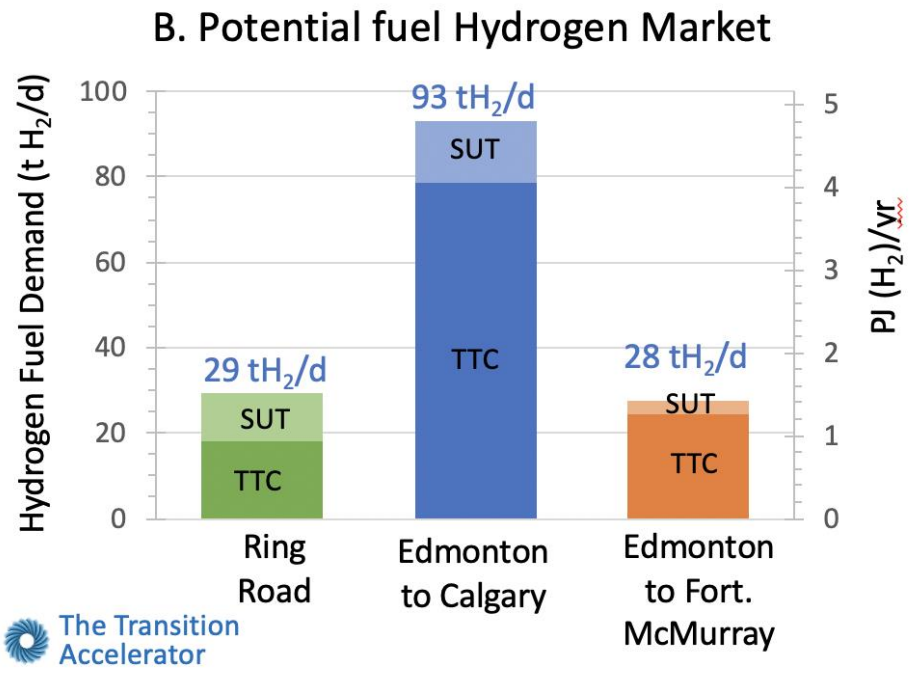
Edmonton Municipal Diesel Fueling Stations	kL diesel/yr	TJ_{hhv} diesel/yr	kt H2/yr	t H2/d
Public Transit	**23,704**	**915**	**5.55**	**15.21**
1 Kathleen Edwards	7,414	286	1.74	4.76
2 Ferrier	6,822	263	1.60	4.38
3 Mitchell	5,027	194	1.18	3.23
4 Centennial	4,442	171	1.04	2.85
Other Municipal Fleets	**8,257**	**319**	**1.93**	**5.30**
5 Kennedale	2,486	96	0.58	1.60
6 EWMC	1,526	59	0.36	0.98
7 West End	1,407	54	0.33	0.90
8 Davis	876	34	0.21	0.56
9 Main Central	757	29	0.18	0.49
10 SE Transportation yard	764	30	0.18	0.49
11 SE Transportation yard	331	13	0.08	0.21
12 Fire Service Center	111	4	0.03	0.07
TOTAL	31,962	1,234	7.5	20.5

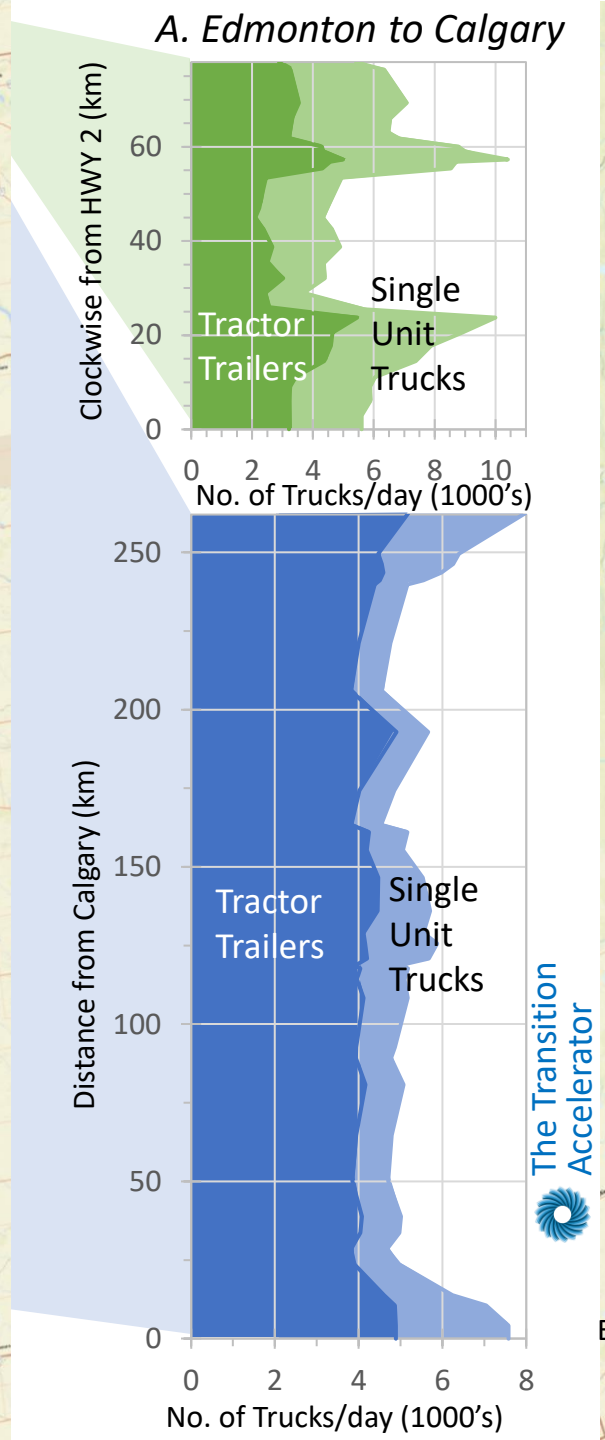
3.1% of all diesel demand in Edmonton

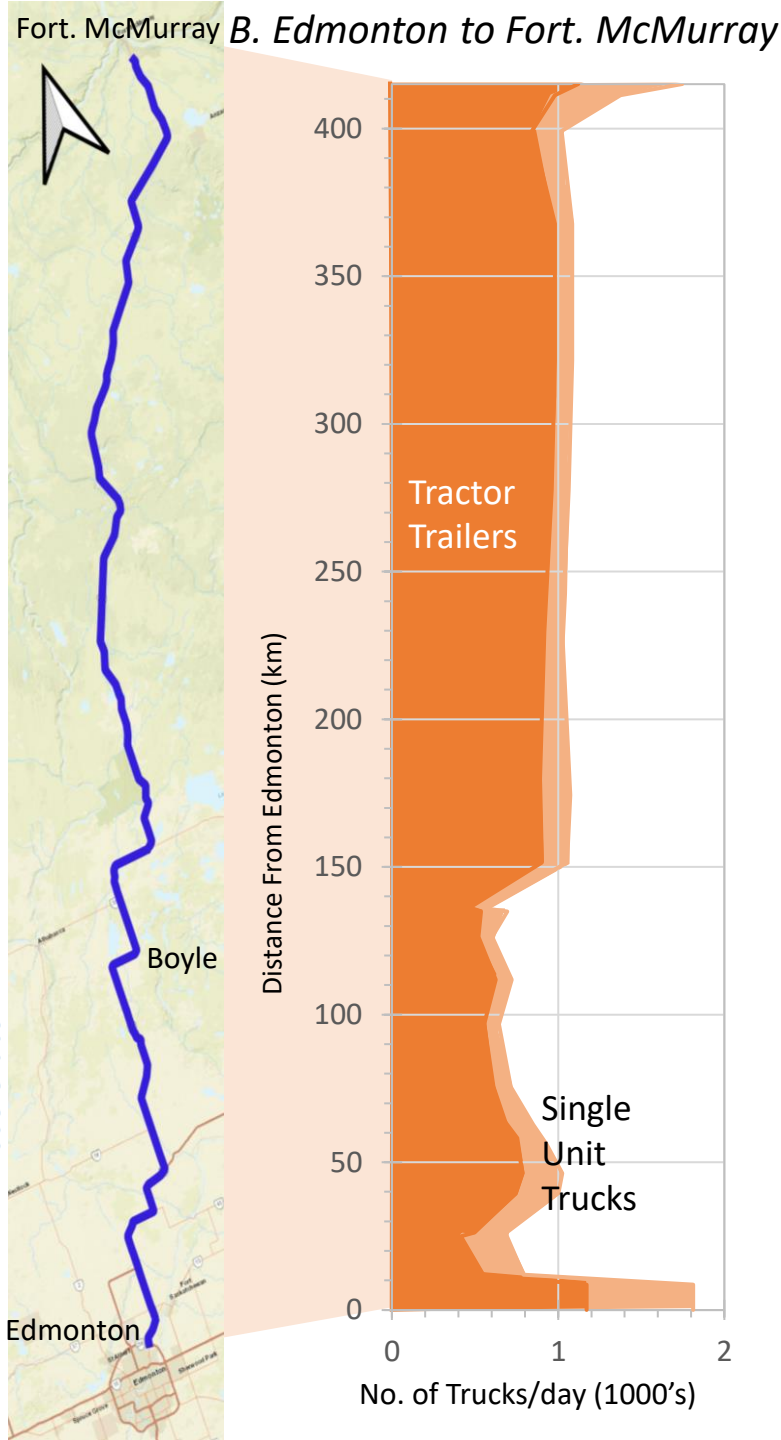


Daily Truck Traffic on Alberta's Major Transport Corridors

[Data extracted from Alberta Transport Models]

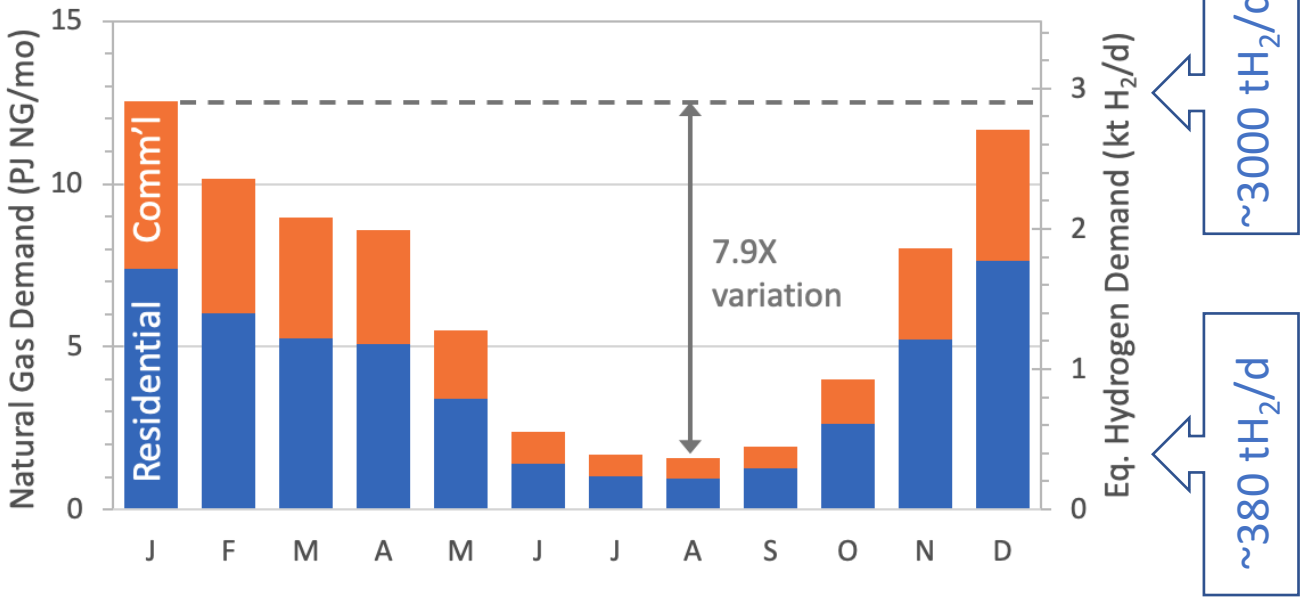


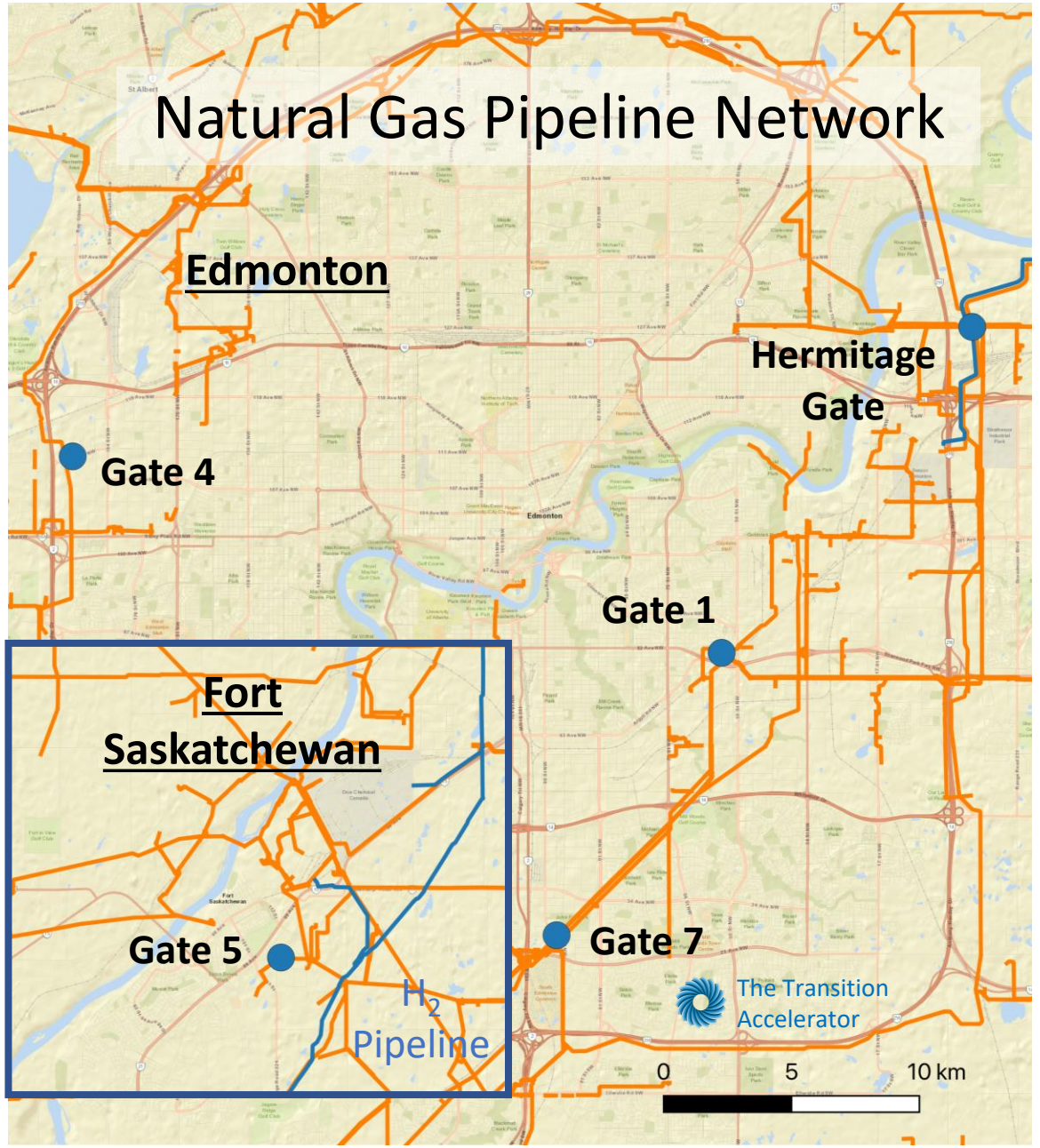




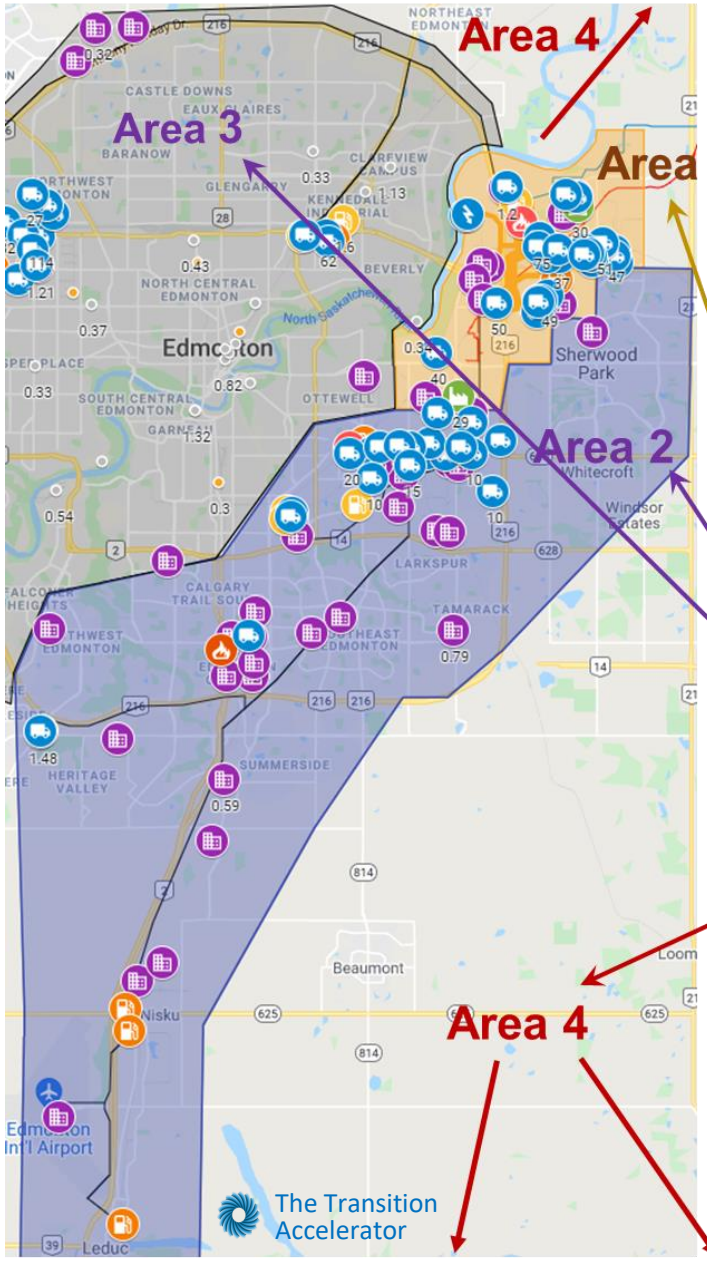
Locations to Inject H_2 into Residential and Commercial Heating are on the Same Corridors

Seasonal Variability in Natural Gas Demand in Edmonton





Creating economic corridors: BASE CASE



Fuel demand companies

Heat & power sites

Fueling stations

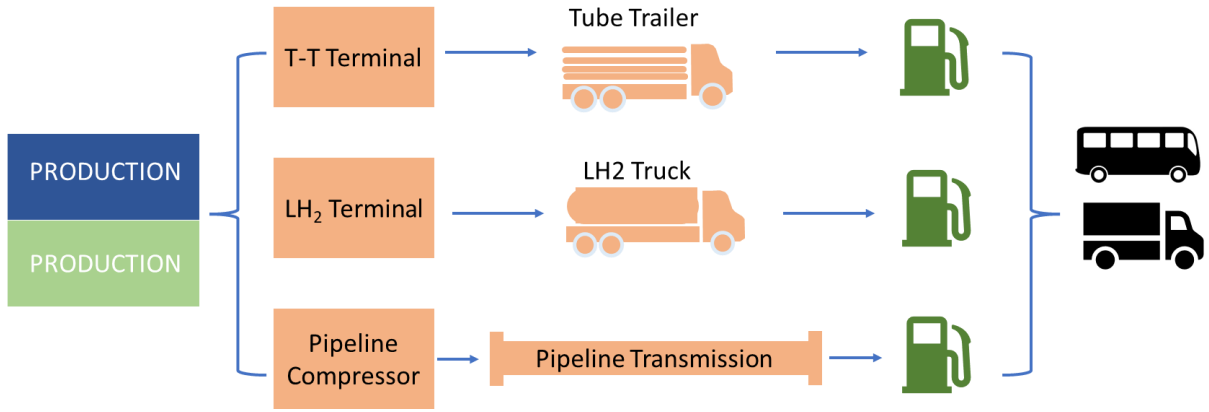
Area 1: 5 km to HFS

Areas 2 and 3: 40 km to HFS

Area 4 (To Calgary and other regions): 300 km to HFS

Base Case: Build-out of H_2 infrastructure in **four key zones/Economic corridors**: To improve coordination, connect supply to demand and quickly get to scale.

5 , 40 and 300 km



TEA was designed for the base case i.e., in these key economic corridors

OUTLINE

1. Net-Zero Energy System: Role of Hydrogen and Market Assessment
2. Building a Fuel Hydrogen Value Chain for Heavy Transport in a Net Zero Future
3. Techno-economic Analysis: Results
4. Growing a Hydrogen Economy in Edmonton Region
5. Key Messages

Key Take Away Messages

- **Scale/Demand is critical:**
  - Significant cost advantage by employing economies of scale. GO BIG OR GO HOME !
  - Incentives for purchasing / leasing H2 fueled HD vehicles. Support DEMAND CREATION

- **Regional Hydrogen Hubs will be key**: To improve coordination and minimize barriers.

- **Support for pilots and R&D:**
  - Support innovative companies to attract funding to launch pilots, demonstration & commercialization projects.
  - R&D that increases efficiency, reliability & lifetime of compression or liquefaction will be critical.

- **Provide support for fueling stations:** Small HFS will need capital support and other tools to support buildout in early market.

- **Demand will dictate delivery option:** Gaseous H2 via TT**:** Small demand and short distances, LH2 **:** Small to Medium demand and long distances, Gaseous H2 via pipelines**:** High Demand and supplying H2 to large HFS's

- **Pipelines are essential to enable H_2 use in multiple sectors:** Enables opportunities in multiple sectors (transport, heat, power) and realize a scale of supply/demand that justifies the infrastructure investments

- **New value chain is capital intensive:** Various policies and financial instruments will be needed to remove market barriers, mitigate risk, and speed up the transition.

EDMONTON REGION Hydrogen HUB

The Transition Accelerator | L'Accélérateur de transition

THANK YOU