Natural Resources Canada

The Transition Accelerator | L'Accélérateur de transition

Hydrogen and the Decarbonization of Steel Production in Canada

ERH2 PRESENTATION - DEC 14, 2023

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CSPA ACPA
Canadian Steel Producers Association

Who's who?

Funding

Natural Resources Canada

Funding Recipient & Steering Committee

CSPA ACPA
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Content Creation

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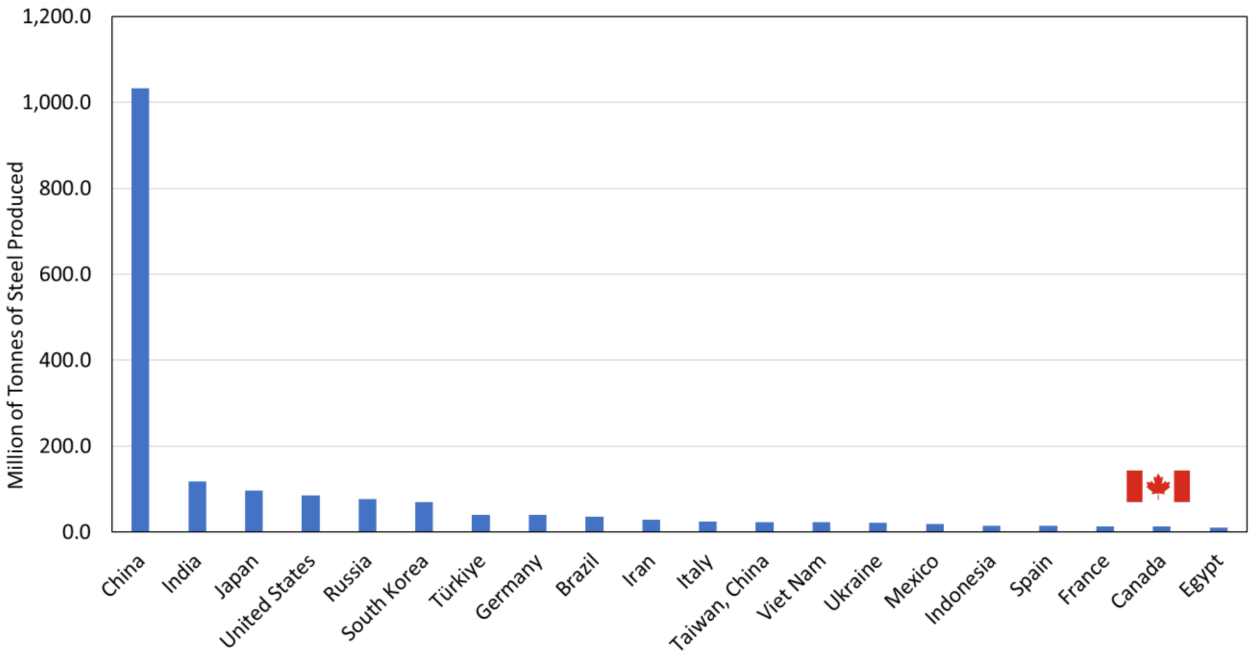
Presentation Outline

1. Steelmaking in Canada
2. Study Context and Objectives
3. Steel Production: Energy use & emissions
4. A case study of H_2 DRI-EAF in the Hamilton Region
5. The steel industry as an anchor tenant in a larger Ontario H_2 economy
6. Recommendations

STEELMAKING IN CANADA AND CURRENT DECARBONIZATION MEASURES

Steelmaking in Canada

- ❑Steel is deep rooted in our society: Construction, Industry, Health, Transportation etc.
- ❑Canada's 15 billion $ steel industry: 13 Mt steel products (Top 20); Directly/Indirectly employing over a 100,000 people.
- ❑Steel will also be an integral ingredient for the energy transition, with solar panels, wind turbines, dams and electric vehicles all depending on it to varying degrees



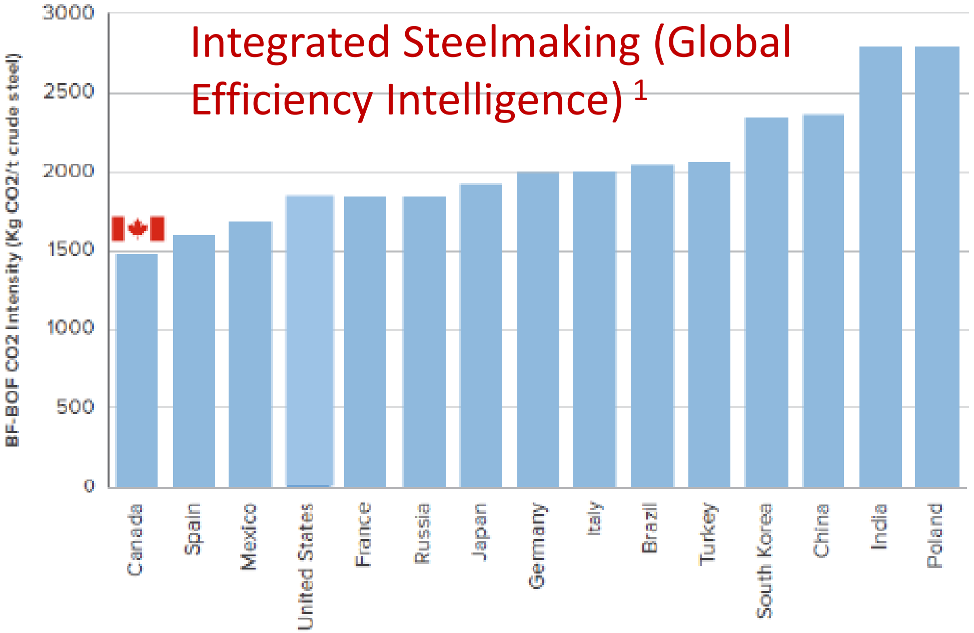
1) Canadian Steel Industry Energy & Greenhouse Gas Emissions Intensity, Technology and Carbon Reduction Roadmap, Golder Associates

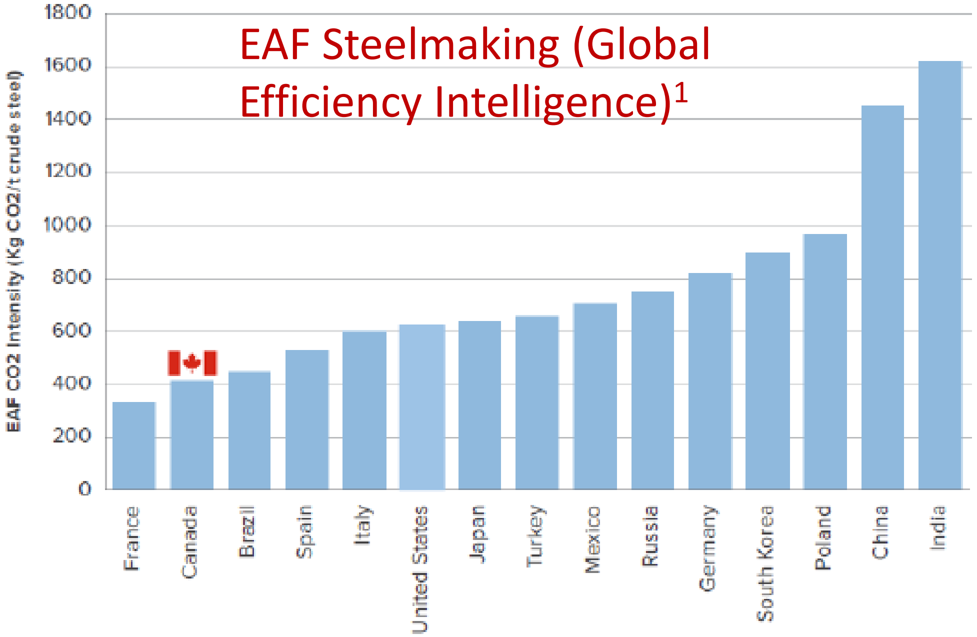
Steelmaking in Canada

- Total emissions from steelmaking in Canada are ~15 Mt-CO_2eq annually

- Since 1990, the Canadian steel industry has voluntarily invested to reduce energy consumption and emissions, achieving a 31.5% reduction in absolute GHG emissions by 2016

- One of the lowest GHG intensity globally for steelmaking.[1]





1) Canadian Steel Industry Energy & Greenhouse Gas Emissions Intensity, Technology and Carbon Reduction Roadmap, Golder Associates

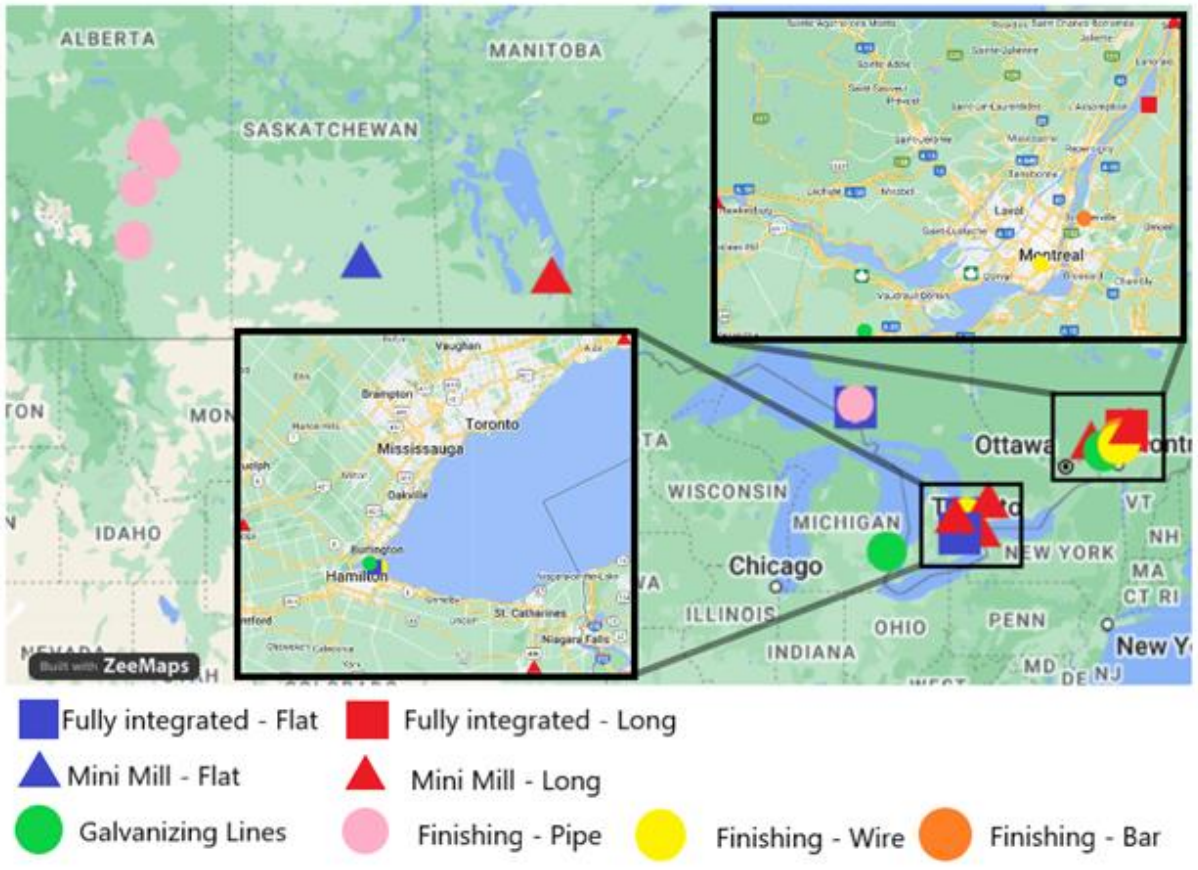
Where do we produce Steel in Canada

- ❑ 3 Integrated plants for Primary Steel making – Blast Furnace/Basic Oxygen Furnace in Southern Ontario

- ❑ 7 EAF plants for secondary steelmaking located throughout Canada

- ❑72% of Canadian steelmaking is concentrated in Ontario alone

- ❑ 1 DRI plant in Quebec



Export of Canadian Steel

- Canada exports steel to over 130 countries and territories.
- The United States and Mexico represent the top markets for Canada’s exports of steel, receiving more than 350 thousand metric tons each.

Canada's Exports of Steel Mill Products-YTD 2019 (Top Ten in Blue)

https://legacy.trade.gov/steel/countries/pdfs/exports-Canada.pdf

Key Announcements

- Algoma Steel is transitioning from BF-BOF to full EAF mode by 2026
- ArcelorMittal Dofasco invested in a 2.5 Mt "hydrogen-ready" natural-gas DRI furnace to replace current integrated mill by 2028
- In 2022, ArcelorMittal DRI facility in Quebec successfully tested partial replacement of natural gas with hydrogen
- Each organization's approach to decarbonization and pursuing carbon-reducing technologies will be unique and depends on several factors

Steel production is forging a new future in Hamilton as it shifts from being a large contributor to climate change to being an important solution.[1]

1) https://hamiltoncitymagazine.ca/steel-goes-green/

STUDY CONTEXT

Study Context & Objectives

- In alignment with the Canadian Steel Producers Association (CSPA) new **Climate Vision** - to achieve net zero carbon dioxide emissions by 2050.[1]
- Slowly developing market for low-GHG steel as different industries look to decarbonize
- Various options for decarbonizing steel production being investigated - likely path forward will be a combination of several solutions
- ArcelorMittal Dofasco plant in Hamilton has committed to transition to natural gas (NG DRI-EAF) - The technology has the potential to transition to zero-emission hydrogen fuel (H_2 DRI-EAF) in the future.
- Options beyond hydrogen adoption are not discussed in any depth in this report but should be considered as integral in the steel sector's decarbonization strategy.

Purpose of this report:

To explore the potential for hydrogen to decarbonize the Canadian steel industry, with a focus on possible sources of low-GHG hydrogen and the costs to deliver it at the scale needed to the Dofasco plant in the Hamilton region.

1) https://www.canadiansteel.ca/media/release/2020/03/canadas-steel-producers-set-a-goal-to-achieve-net-zero-co2-emissions-by-2050

ENERGY USE & EMISSIONS ASSOCIATED WITH CANADIAN STEEL PRODUCTION

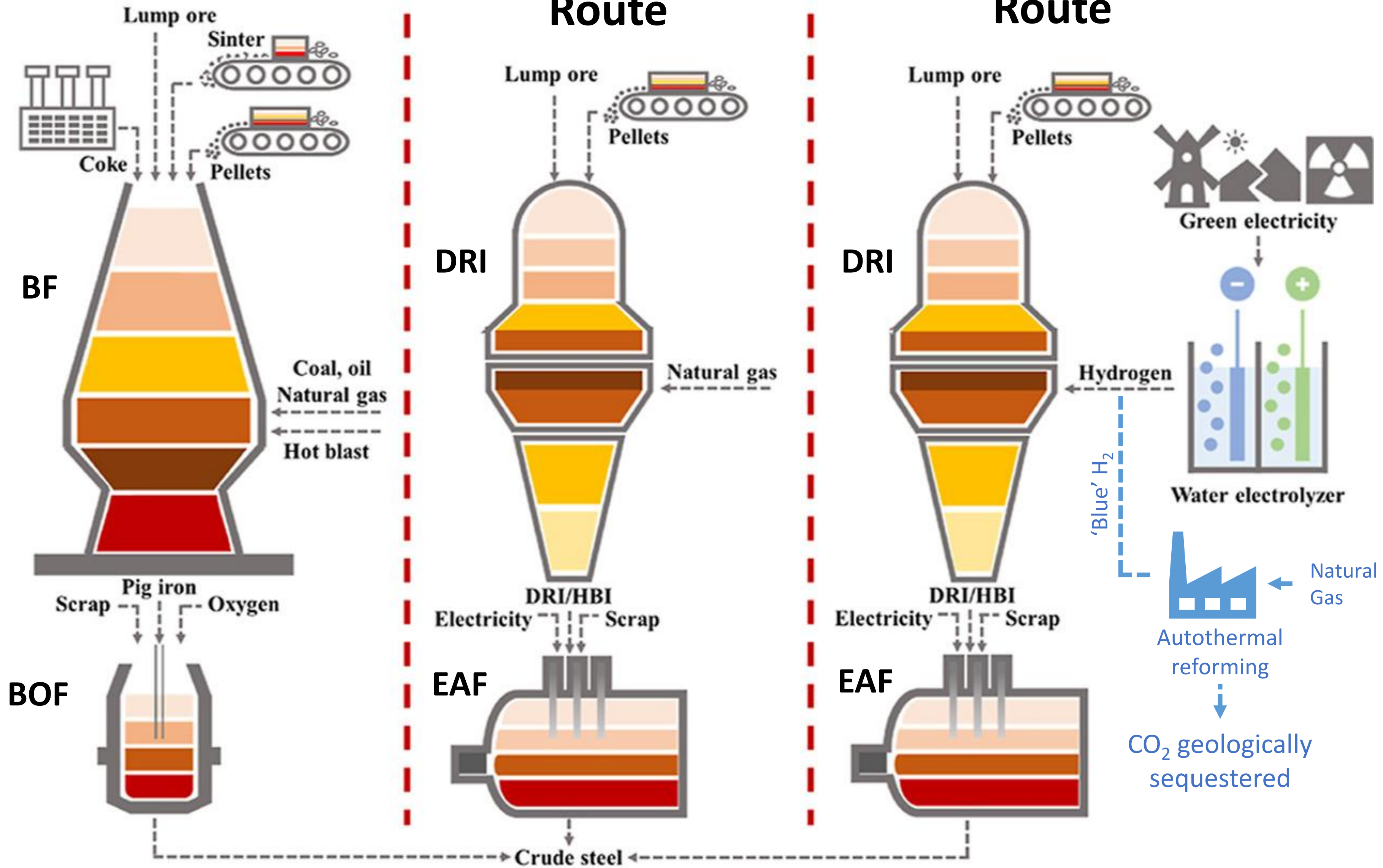
Primary Steel Production (from Iron Ore)

[typically also includes some recycled steel]

BF-BOF Route

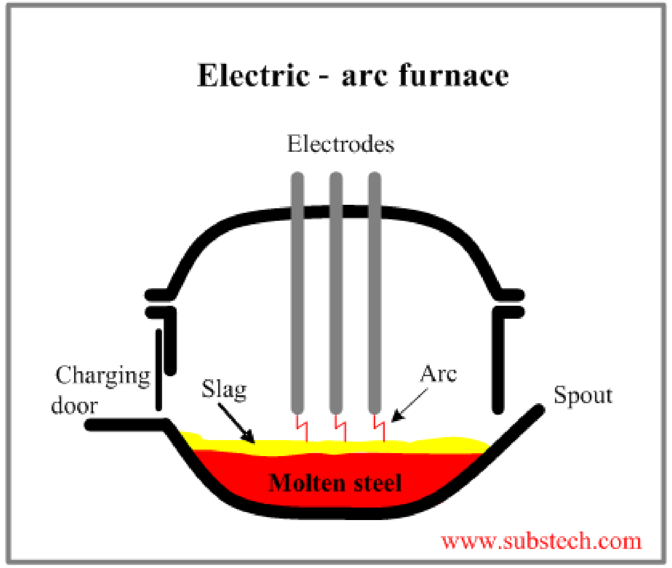
NG DRI-EAF Route

H_2 DRI-EAF Route



Recycled Steel

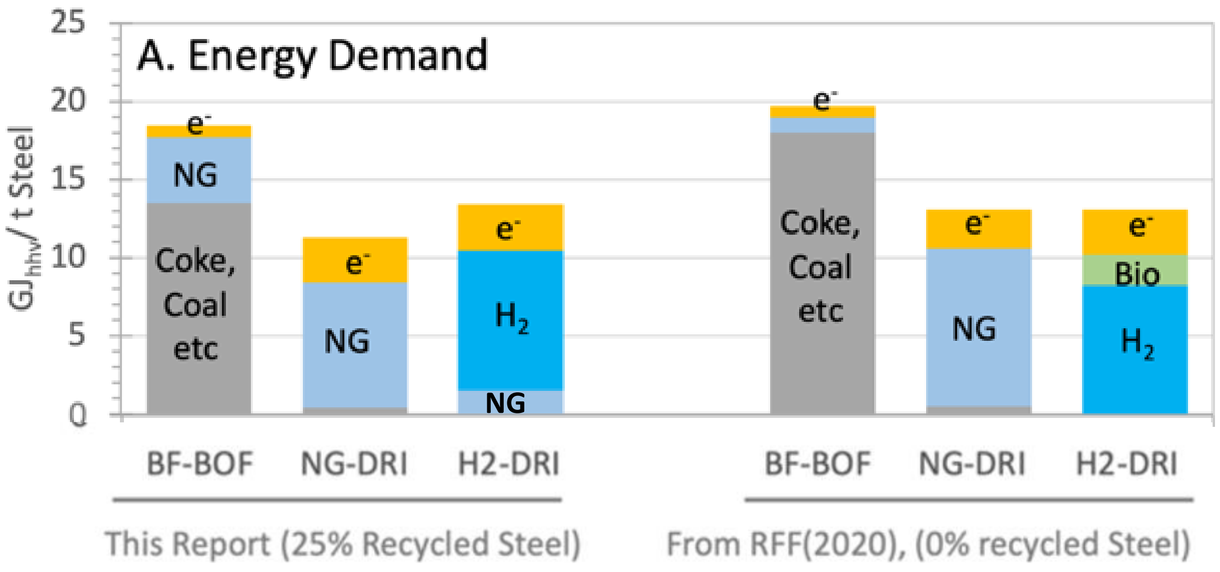
EAF (mini-mill)



Abbreviations

BF – Blast Furnace
BOF – Basic Oxygen Furnace
DRI – Direct Reduction of Iron
EAF – Electric Arc Furnace
NG – Natural Gas
H_2 - Hydrogen

Energy Use & Emissions with Primary Steel Production



Data from Thorn & Associates

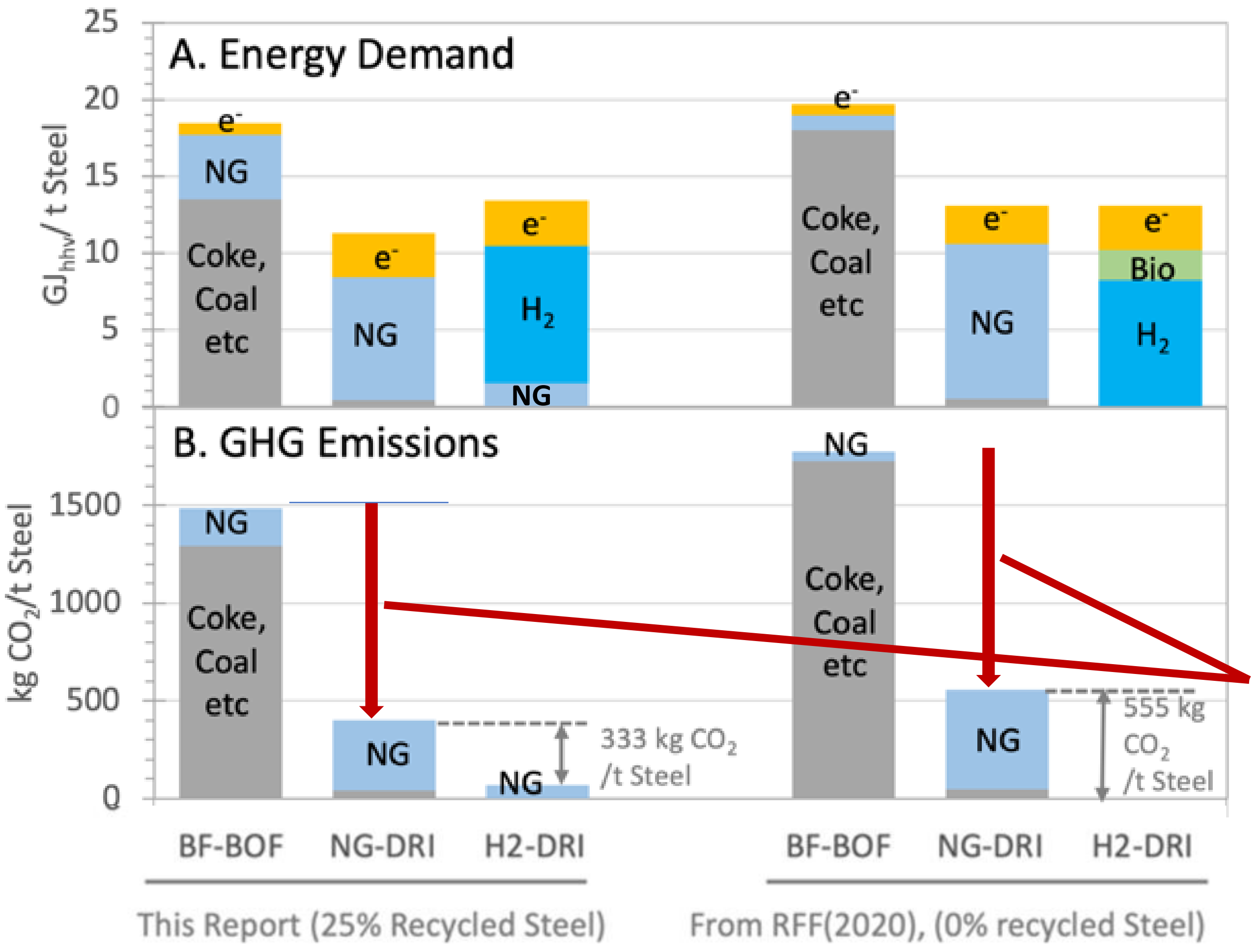
Resources for the Future Study

NOTES RE ENERGY USE:

- ❑ DRI is more energy efficient than BF-BOF.
- ❑ DRI can be fueled with either NG or H_2 (similar energy demand in GJ/t Steel)

https://www.rff.org/publications/reports/decarbonizing-hydrogen-us-power-and-industrial-sectors/

Energy use and GHG Emissions in Steel Making



Data from Thorn & Associates

Resources for the Future Study

Note re Energy Use:

- ❑ DRI is more energy efficient than BF-BOF.
- ❑ DRI can be fueled with either NG or H_2 (similar energy demand in GJ/t Steel)
- ❑ Assuming NG price of ~C$5.50/GJ (no C tax); & best H_2 price will be C$14 to C$28/GJ **($2-$4/kg H_2)**
- ❑ So fuel energy price is going to be 2.5 to 5 X more with H2 DRI-EAF than with NG DRI-EAF
- ❑ ***Minimizing the cost of H_2 supply will be critical!***

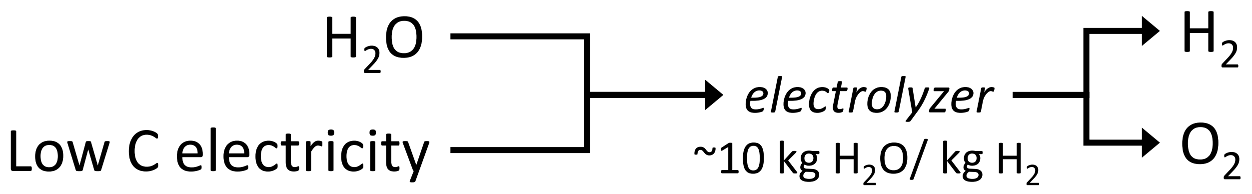
Note re GHG Emissions:

- ❑ Compared to BF-BOF, on site (Scope 1) emissions for DRI with NG is reduced by ~70%
- ❑ ...but must add upstream (Scope 2) emissions for electricity generation and NG production so reduction would be ~50-60% of BF-BOF
- ❑ H_2 DRI-EAF can reduce Scope 1 GHG emissions to zero or near zero.

https://www.rff.org/publications/reports/decarbonizing-hydrogen-us-power-and-industrial-sectors/

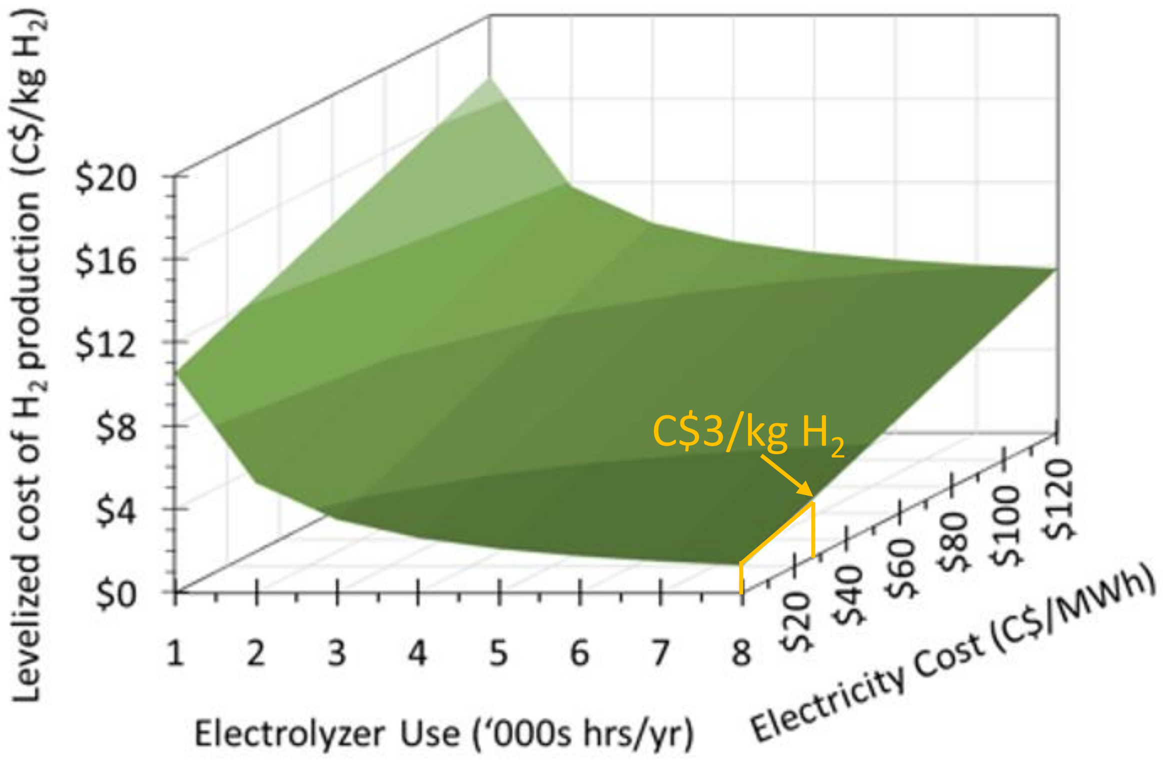
The Technologies and Cost of Low C H_2 Production

1. Water Electrolysis:

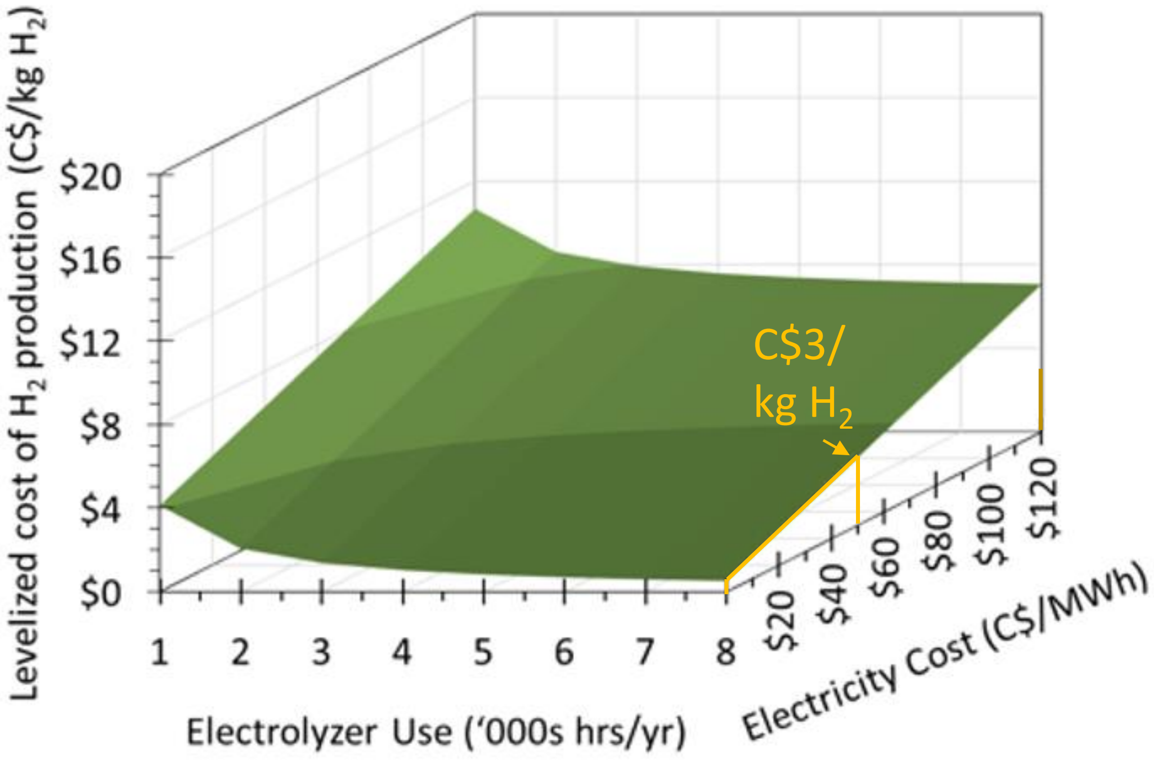


- To deliver H_2 at ~$3/kg H_2, a near-continuous access to electricity @ $30/MWh needed
- In future, even a higher electricity price of $50/MWh would
- *Typical price is $50-$130/MWh*

A. Electrolysis Today (2020)

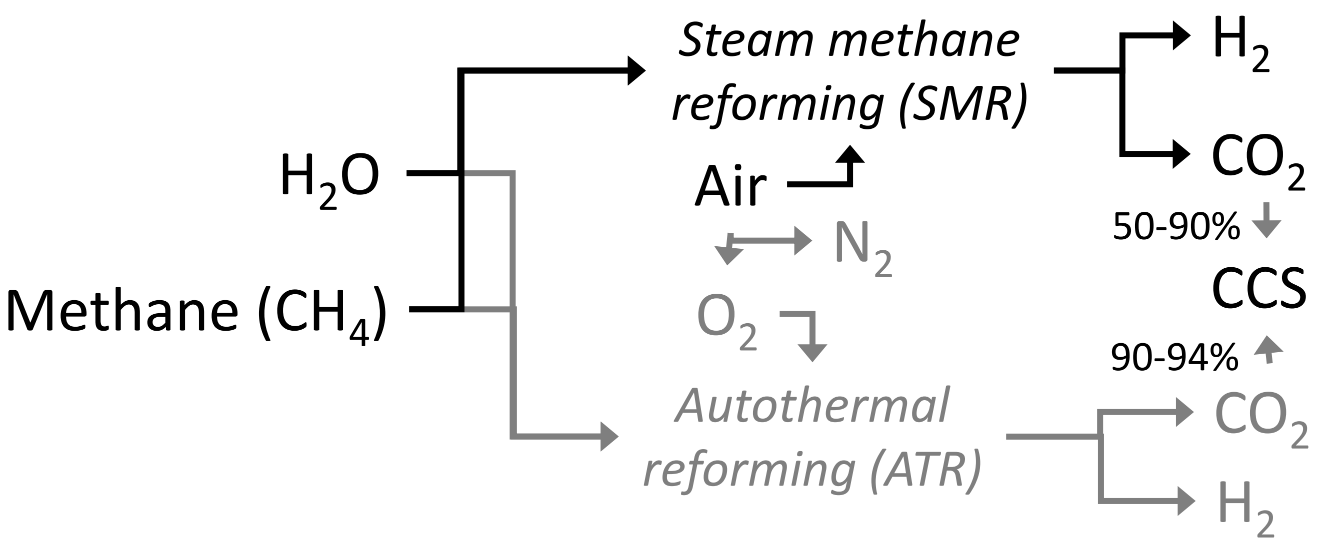


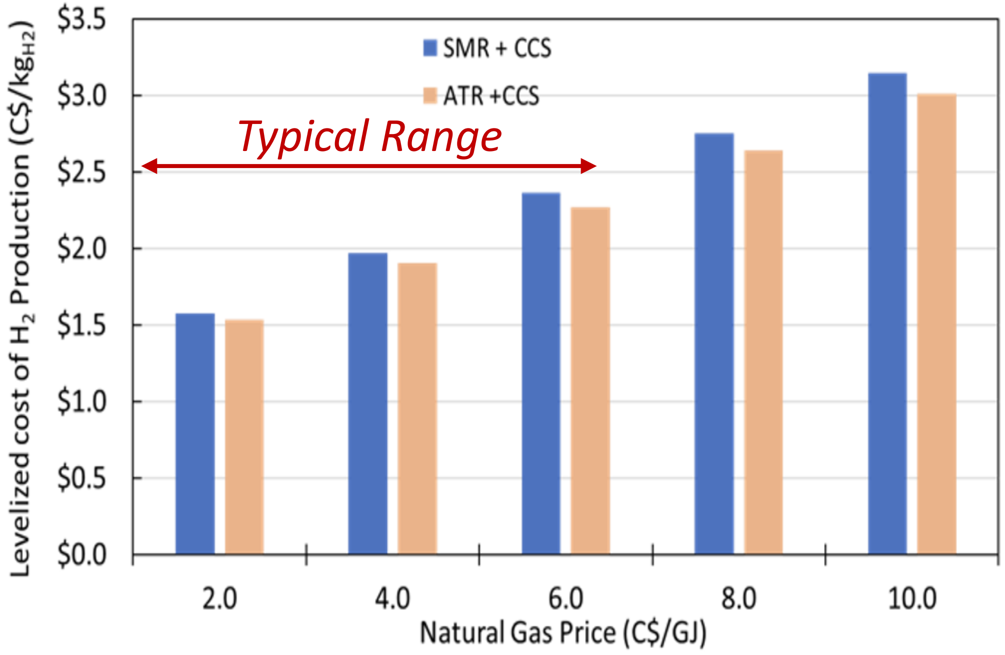
B. Electrolysis Future (2040)



The Technologies and Cost of Low-GHG H_2 Production

2. Natural Gas Reforming





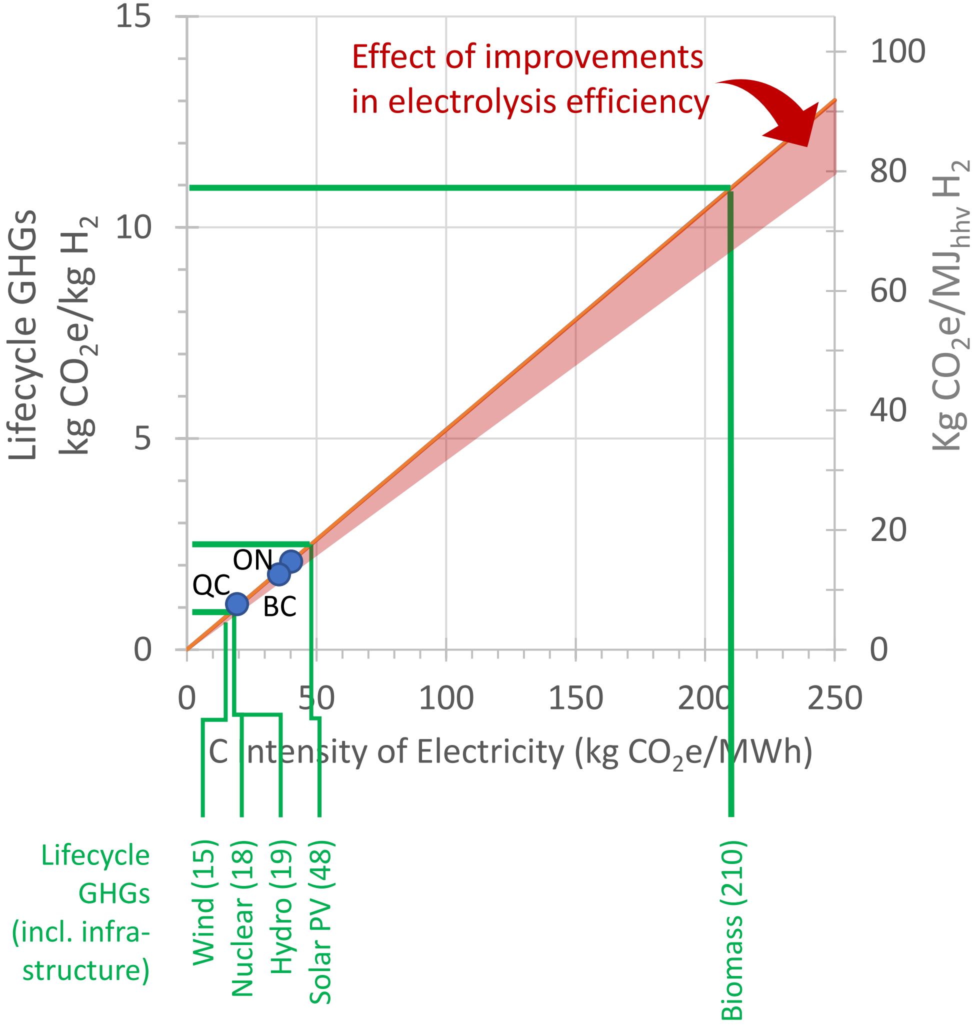
Low-GHG H_2 production from natural gas with CCS (Blue H_2) is lower cost than that from electrolysis (Green H_2), but:

- Blue H_2 requires the geology for permanent CO_2 storage
- Must be done at scale (200+ t H_2/day)

But what about CO_2 intensity of production?....

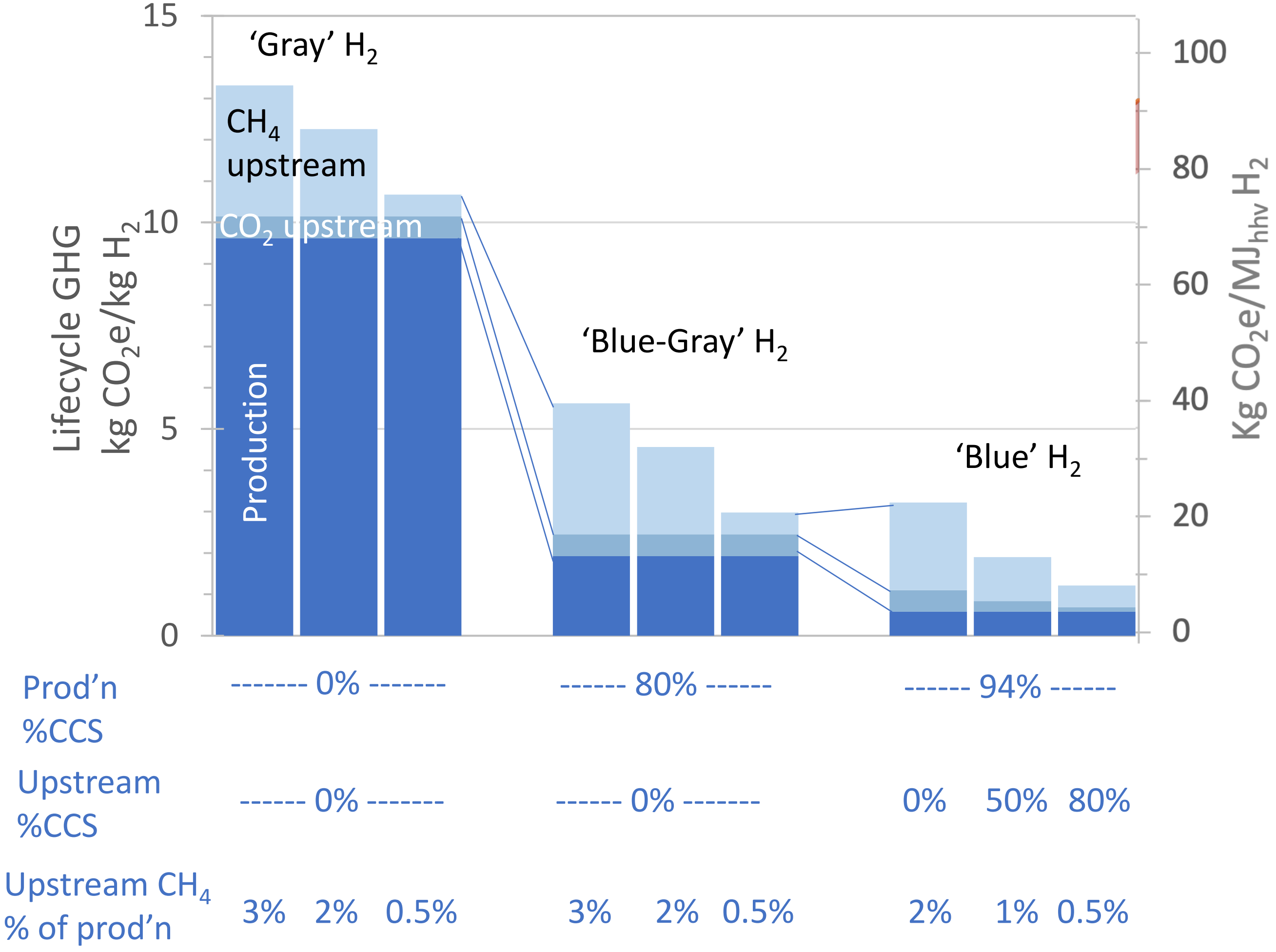
The GHG Intensity of Hydrogen Production

Hydrogen from Water Electrolysis 'Green' H_2



Life cycle GHG intensities from:
https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf

Hydrogen from Natural Gas 'Gray' and 'Blue' H_2



NOTE: to address climate change, focus must be on both production and upstream emissions of H_2

A CASE STUDY OF H_2 DRI-EAF IN THE HAMILTON REGION

A Case Study for Conversion to H2 DRI-EAF in Ontario

Table 5.1. Steel production facilities in Ontario, Canada.

Source: Adapted from References [69,72].

Number	Location	Name	Technology	Low-C strategy
1	L'Orignal	Ivaco Rolling Mills	Electric Arc Furnace	Use of low-C electricity
2	Sault Ste Marie	Algoma Steel Inc.	Integrated Mill – BF/ BOF	Towards EAF with low-C electricity [73]
3	Cambridge	Gerdau	Electric Arc Furnace (idled)	Use of low-C electricity
4	Whitby	Gerdau	Electric Arc Furnace	Use of low-C electricity
5	Nanticoke	Stelco	Integrated Mill - BF/ BOF	Unannounced
6	Welland	Valbruna ASW Inc	Electric Arc Furnace	Use of low-C electricity
7	**Hamilton**	**ArcelorMittal Dofasco**	**Integrated Mill - BF/BOF + EAF**	**NG-DRI to H2-DRI [74]**

Note: Facility # 7 highlighted in bold text is the one assessed in this study for conversion to H2-DRI-EAF plants.

Dofasco Site:

- ❑ 2.5 Mt DRI/yr capacity
- ❑ Due to availability of public data, we assumed the Midrex H_2 DRI-EAF process.
- ❑ Estimated demand for:
  - **492 t H_2/d**

- ❑ ~6% of Canada's current industrial H_2 production
- ❑ To produce H_2 via electrolysis would require ~27 GWh electricity/d (6.5% of Ontario's current power generation of 153 TWh/y).
- ❑ If electricity delivered to the Dofasco plant is \$126/MWh, the H_2 cost would be \$7.46/kg H_2 (=\$53/GJ)

  …. \$80/MWh, the H_2 cost would be \$5.06/kg H_2 (=\$36/GJ)

NG today is \$5.50/GJ

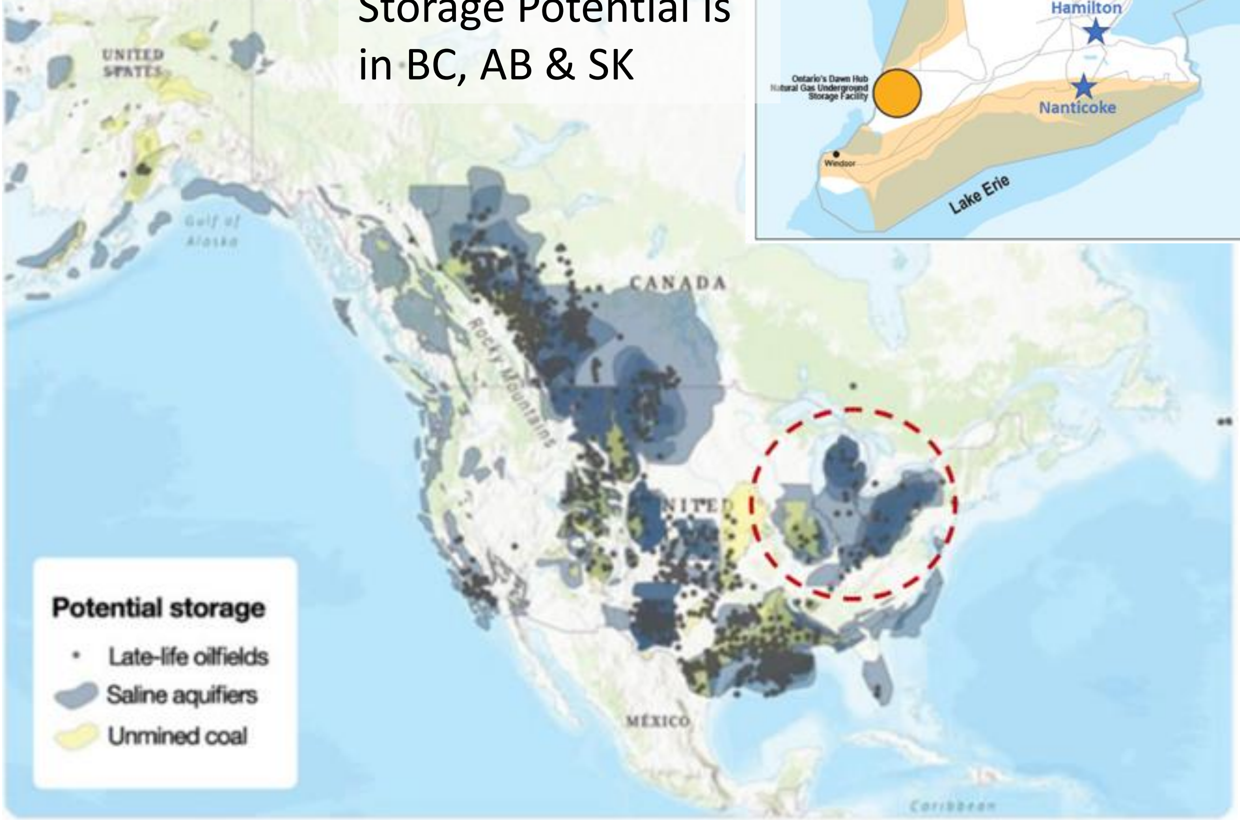
It is difficult to see how 'Green' H_2 produced at the Dofasco site could be a cost-effective solution in the near future. *What about Blue H_2?*

Carbon Storage Potential in North America

How much CCS is needed?

492 tH_2/d X 9 tCO_2/tH_2 X 365 d/yr = **1.6 $MtCO_2$/yr**

Most of Cdn CCS Storage Potential is in BC, AB & SK



ON has some potential, but there will be competition…

Within 400 km of Hamilton is significant CCS potential…

… and these regions produce Nat'l Gas, so the feedstock costs should be less.

Table 5.5. CO_2 storage potential in billion metric tons

Source: Carbon Storage Atlas, 2015 [10].

State	Oil and NG Reservoirs Storage		Unmineable Coal Storage		Saline Formation Storage		Total Storage	
	Low	High	Low	High	Low	High	Low	High
Michigan	0.17	0.32	0	0	31.55	66.2	31.72	66.52
Ohio	0.65	1.97	0.12	0.12	9.91	9.91	10.68	12
Pennsylvania	0.8	2.45	0.27	0.27	17.34	17.34	18.41	20.06
Total	**1.62**	**4.74**	**0.39**	**0.39**	**58.80**	**93.45**	**60.81**	**98.58**

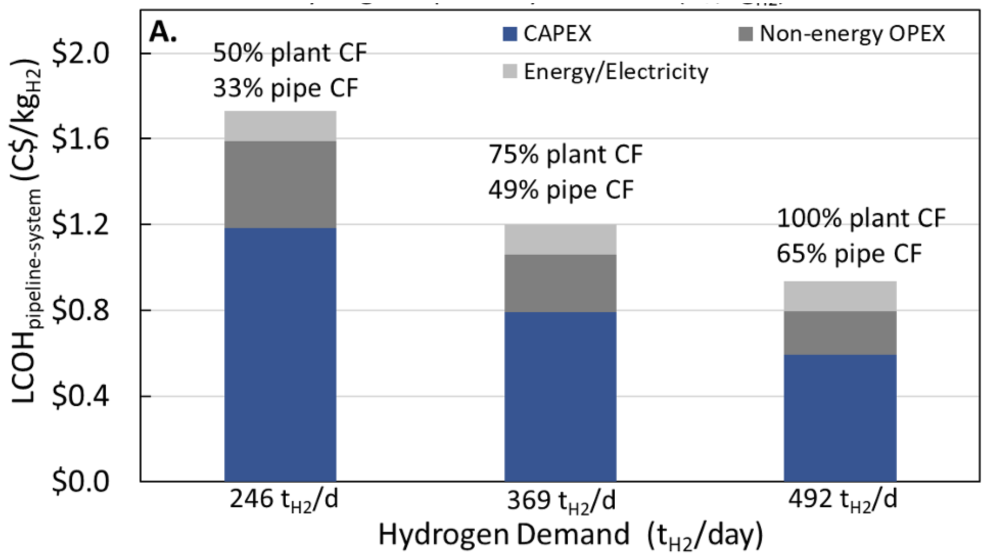
Enough for 38,000 years of CO_2 storage from Dofasco

Cost Estimates for pipeline delivered Hydrogen

Assumptions:

- 400 km, 16 inch pipeline from MI, OH or PA to Hamilton, ON
- Natural gas cost C$4/GJ at source (lower than est. Hamilton price of C$5.5/GJ NG)

Pipeline System Costs (C$/kg H2)



If pipeline sizing is optimized for 492 tH_2/d, the estimated delivered cost is C$3.10/kg H_2 (C$21.88/GJ_{hhv}), about 4X the current C$5.50/$GJ_{hhv}$ NG cost in Hamilton.

The problems with a dedicated, 400 km H_2 pipeline feeding only one company.

- Still a high price for energy supply
- Higher risk, that could drive up costs and reduced project viability
- Less likely to attract public support

Are there other potential markets for low carbon H_2 in ON that could help to reduce costs while addressing climate change?

THE STEEL INDUSTRY AS THE ANCHOR TENANT IN A LARGER ONTARIO H_2 ECONOMY

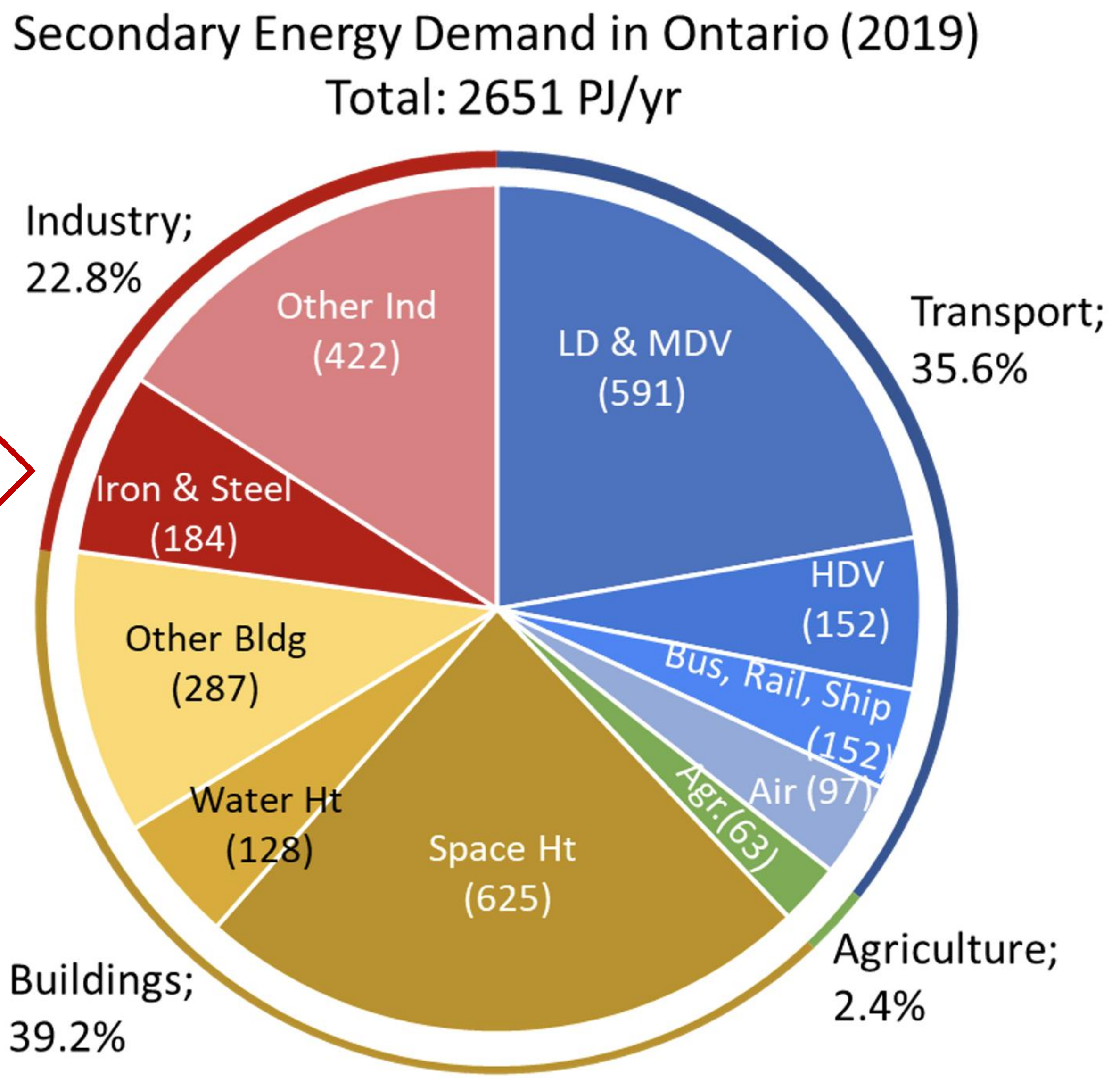
Implications for Ontario of a Net-Zero Transition…

End Use Energy Demand in ON

(not including electricity or O&G prod'n)

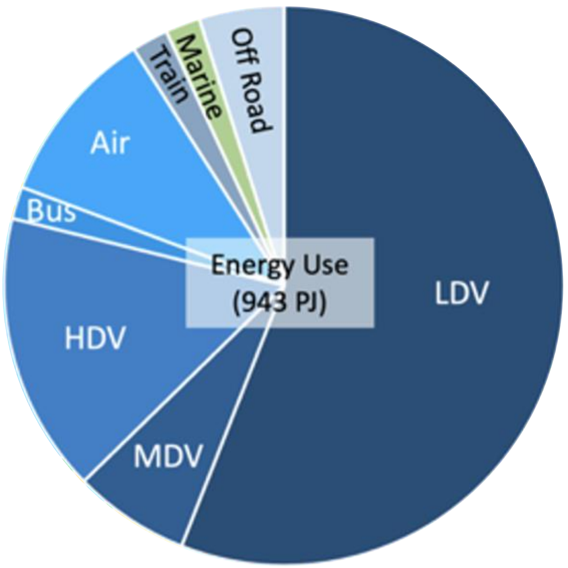
Steel industry is only 7%

What are the most credible/likely net-zero solutions for these sectors?

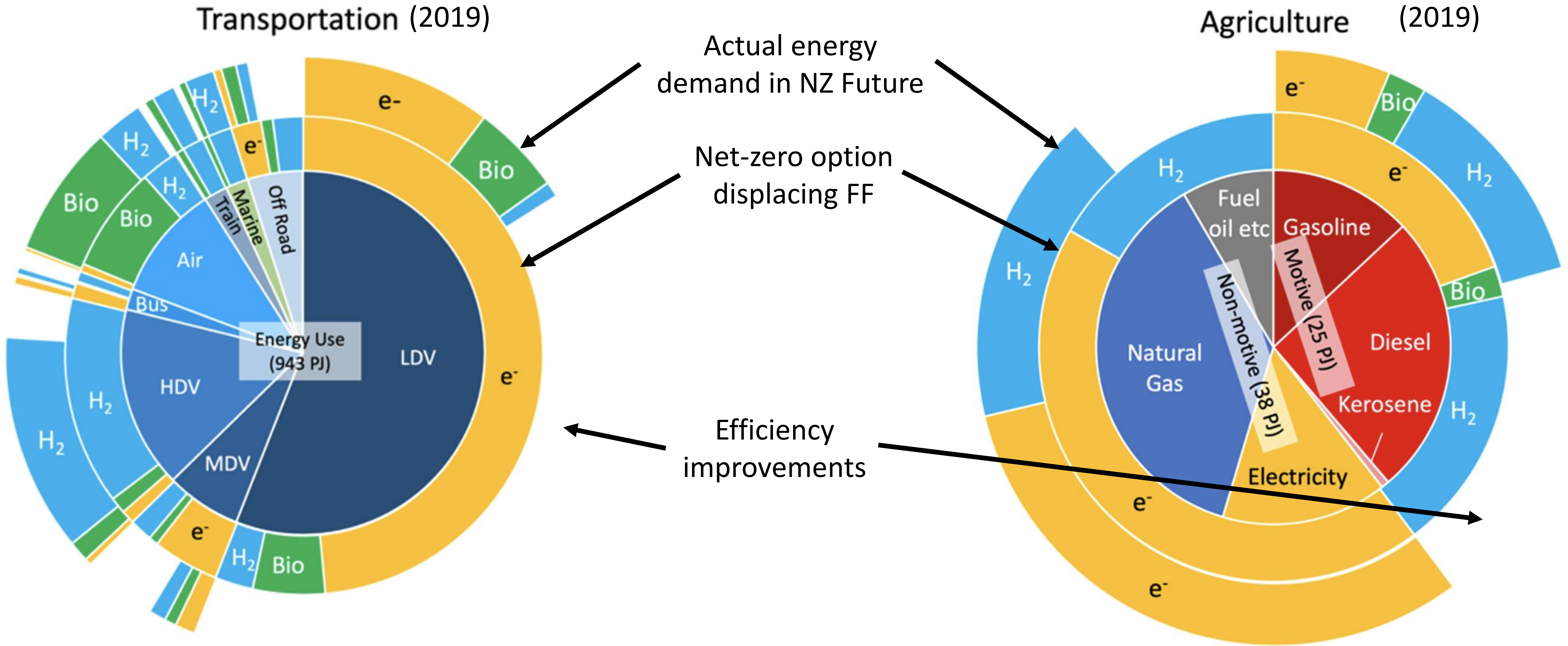


Implications for Ontario of a Net-Zero Transition…

Transportation (2019)

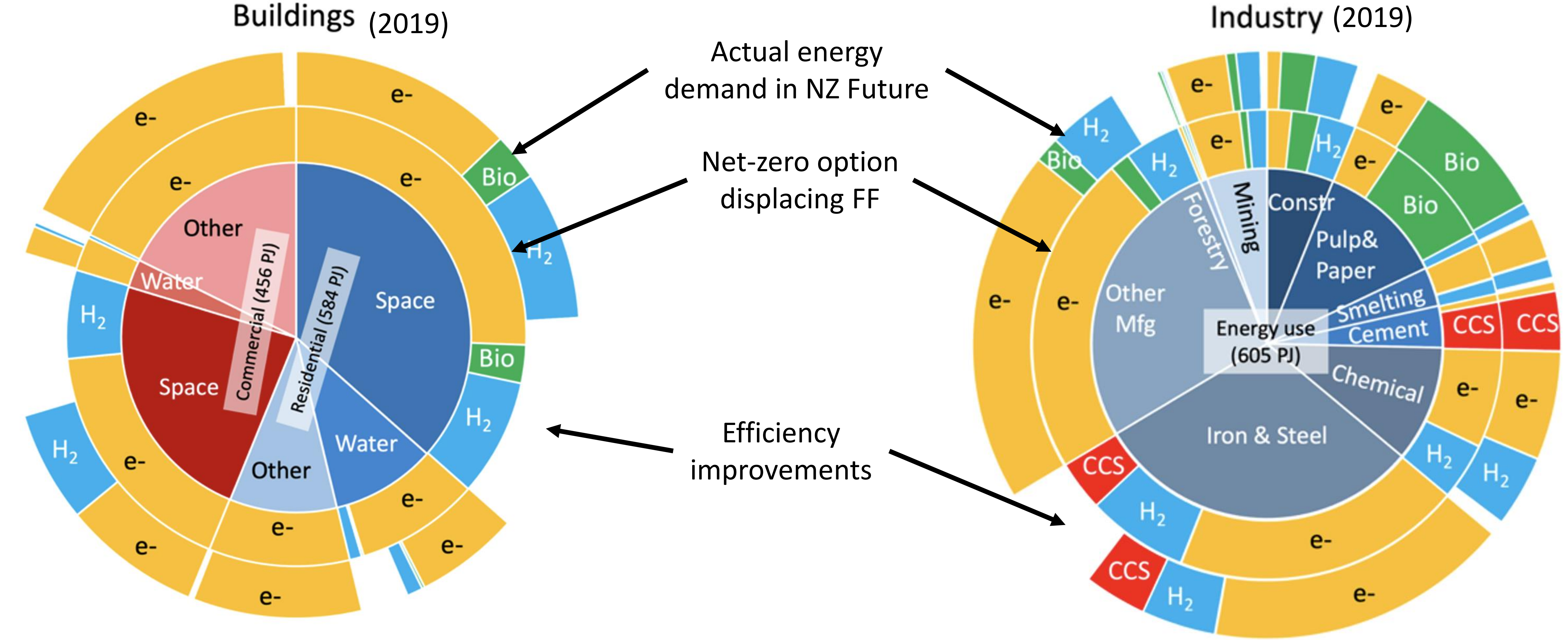


Implications for Ontario of a Net-Zero Transition…



Add'l Demand	**Electricity** (TWh/yr)	**Biofuels** (PJ/yr)	**Hydrogen** (tH_2/d)	**FF with CCS** ($MtCO_2$/yr)
Transportation:	33.9	102	3647	0
Agriculture:	6.5	1.3	353	0

Implications for Ontario of a Net-Zero Transition…



Add'l Demand	**Electricity** (TWh/yr)	**Biofuels** (PJ/yr)	**Hydrogen** (tH_2/d)	**FF with CCS** ($MtCO_2/yr$)
Buildings:	158.3	29.6	3221	0
Industry:	87.9	89.4	2063	3.28

Implications for Ontario of a Net-Zero Transition…

		A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Sector	2019 Energy use					Zero Emission Energy System Delivering Similar Energy Services								
		Electricity		Bioenrgy / fuels	Fossil Fuels	Total	Low GHG Electricity		Bioenergy/fuels		Hydrogen & Ammonia		Fossil Fuels with 90% CCS		TOTAL
		PJ/yr	TWhr/yr	PJ/yr	PJ/yr	PJ/yr	PJ/yr	TWh/yr	PJ/yr	Mt /yr	PJ/yr	t H_2/d	PJ/yr	MT CO_2/yr	PJ/yr
Non-energy Producing	Transportation	1.5	0.4	45.9	896	943	122	33.9	102	12.6	189	3647			412
	Agriculture	9.47	2.6		53	63	23.5	6.53	1.30	0.16	18.2	353			43
	Residential	158	43.9	28.7	397	584	295	82.0	29.61	1.83	98.0	1895			423
	Commercial	192	53.3		264	456	275	76.5			68.6	1326			344
	Industry (non-energy)	135	37.6	42	428	605	316	87.9	89.4	5.55	107	2063	40.8	3.28	553
	Non-Energy TTL:	**496**	**138**	**117**	**2038**	**2651**	**1032**	**287**	**222**	**20**	**480**	**9284**	**40.8**	**3.28**	**1775**

Projected Net-Zero future for Ontario's Energy System:
(based on 2019 data, not counting 36% increase in pop'n growth to 2050)

Doubling in size of public electricity grid with low GHG power.

More than double biomass→ energy demand to 20 Mt/yr

CCS of 3.3 Mt CO_2/yr *(not counting refineries & power gen)*

Implications for Ontario of a Net-Zero Transition…

		A	B	C	D	E	F	G	H	I	J	K	L	M	N
		2019 Energy use					Zero Emission Energy System Delivering Similar Energy Services								
	Sector	Electricity		Bioenrgy / fuels	Fossil Fuels	Total	Low GHG Electricity		Bioenergy/fuels		Hydrogen & Ammonia		Fossil Fuels with 90% CCS		TOTAL
		PJ/yr	TWhr/yr	PJ/yr	PJ/yr	PJ/yr	PJ/yr	TWh/yr	PJ/yr	Mt /yr	PJ/yr	t H_2/d	PJ/yr	MT CO_2/yr	PJ/yr
Non-energy Producing	Transportation	1.5	0.4	45.9	896	943	122	33.9	102	12.6	189	3647			412
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	SW Ont. only*	**346**	**96**	**81**	**1419**	**1846**	**719**	**200**	**155**	**14**	**334**	**6462**	**40.8**	**3.28**	1248
Energy Producing	Refineries											410			
	Peak Power (IESO)											2384			
	Energy TTL:											**2794**			
Ontario Total												**12078**			

* For all but CCS estimates, values calculated as 70% of all Ontario values based on proportion of 2021 population living in Toronto (6.2M), Hamilton (0.78M), Kitchener-Cambridge-Waterloo (0.58M), London (0.54M), St Catherines-Niagara (0.43M), Windsor (0.42M), Oshawa (0.42M), Barrie (0.21M), Guelph (0.17M) and Brantford (0.14M) when the provincial population was 14.2M (https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=9810000101).

Projected Net-Zero future for Ontario's Energy System:
(based on 2019 data, not counting 36% increase in pop'n growth to 2050)

Doubling in size of public electricity grid with low GHG power.

More than double biomass→ energy demand to 20 Mt/yr

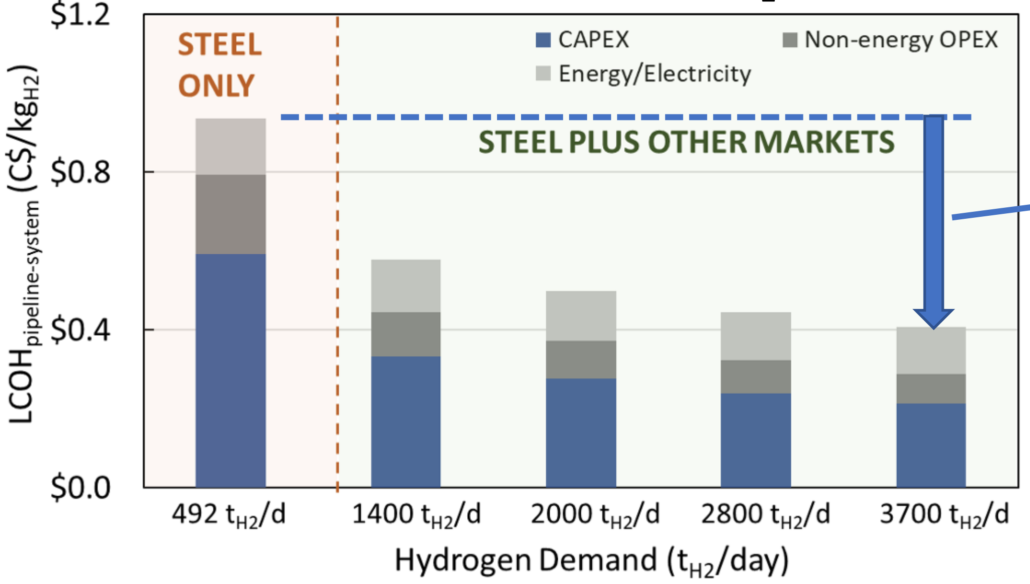
Low GHG H_2 demand of up to 12,000 t H_2 /day (2019 energy system)

CCS of 3.3 Mt CO_2/yr *(not counting refineries & power gen)*

The Effect of Scale on Cost of Pipelining H_2 to Ontario

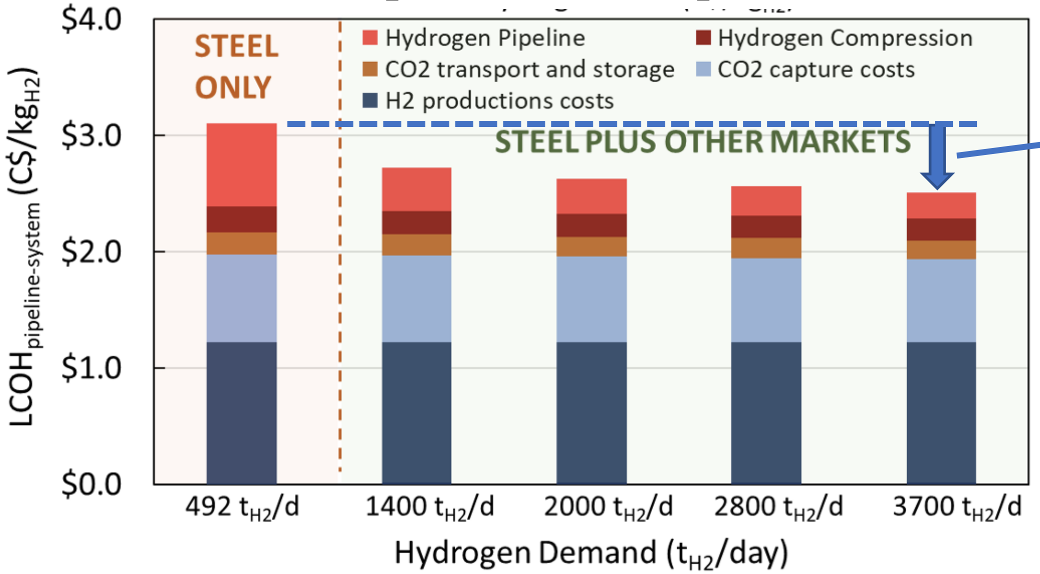
If satisfying the steel industry's H_2 demand (492 t H_2/d) was part of a larger supply strategy for Ontario, what would be the effect on H_2 cost?

Pipeline System Costs (C$/kg H_2)



More than a 50% reduction in the cost of pipelining H_2 400 km

Delivered H_2 Costs (C$/kg H_2)

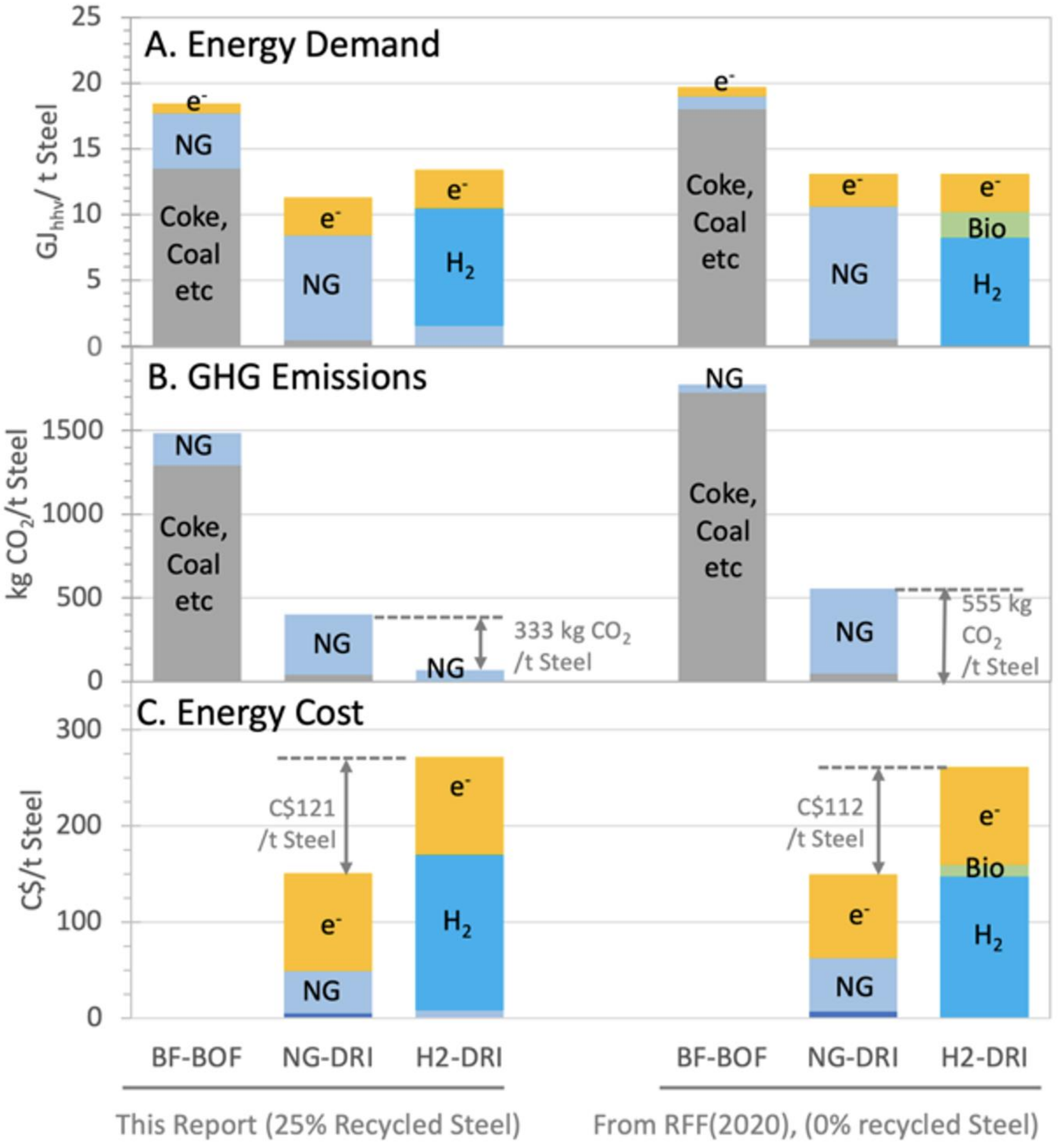


A reduction in the delivered cost of hydrogen from C$3.10/kg H_2 to **C$2.50/kg H_2**

The Economics of Transitioning from NG DRI-EAF to H2 DRI-EAF

Reduces Scope 1 emissions by 333 to 555 kg CO_2/t steel

Increases fuel cost by C$112 to C$121/t Steel



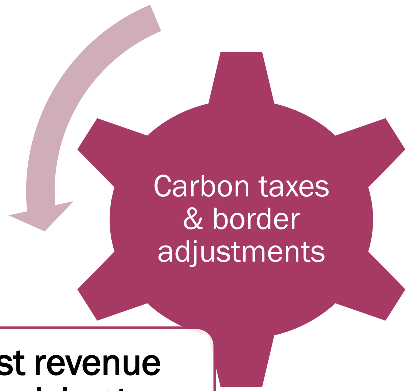
Assumptions:

- NG price in Hamilton C$5.50/GJ; in USA C$4/GJ
- Electricity in Hamilton C$126/MWh
- Biomass: C$100/dry tonne
- H_2: Delivered @CS2.50/kg

Therefore, the effective cost per t CO_2 abated ranges from C$201 to C$364/t CO_2.

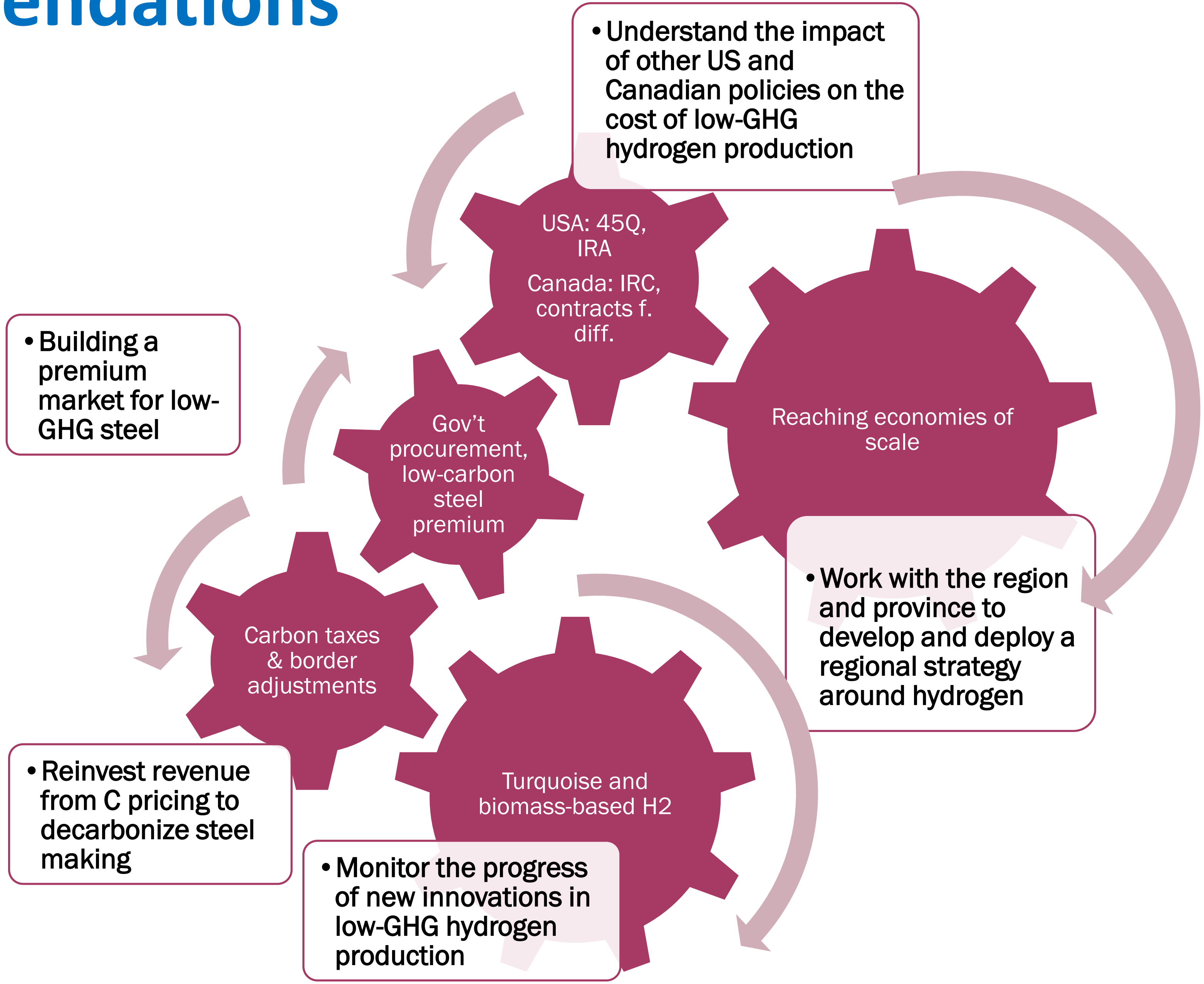
RECOMMENDATIONS

Recommendations



- Reinvest revenue from C pricing to decarbonize steel making

Recommendations



US Invests US$7 Billion in Hydrogen Hubs (Oct 2023)

Pacific NW
- US1B
- Renew. $e^- > H_2$
- HD transport
- Fertilizer prod'n
- Port operations
- Air pollution

California
- US$1.2B
- Renew. $e^- > H_2$
- Biomass > H2
- Buses, HD Trucks. Port Operations
- Air pollution

Midwest
- US$1B
- Nucl. $e^- > H_2$
- Renew. $e^- > H_2$
- NG+CCS > H_2
- Steel & Glass prodn
- Power gen
- HD transport,
- Aviation fuels

Mid-Atlantic
- US$750M
- Nucl. $e^- > H_2$
- Renew. $e^- > H_2$
- O&G Sector
- HD Trucks, buses, street sweepers)
- Combined heat & power

Heartland
- US$925M
- NG+CCS > H_2
- Fertilizer prod'n,
- Power Gen & Space heating

Gulf Coast
- US$1.2B
- NG+CCS > H_2; Renew. $e^- > H_2$; Storage
- O&G sector, Fertilizer Prod'n
- Power Gen & Space heating
- Trucks, marine fuel (methanol0

Appalachian
- US$925M
- NG+CCS > H_2
- H_2 pipelines
- HD vehicles

https://www.energy.gov/oced/regional-clean-hydrogen-hubs-selections-award-negotiations

The Transition Accelerator
L'Accélérateur de transition

THANK YOU