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Future Opportunities to Utilize Biocarbon for Steel Production

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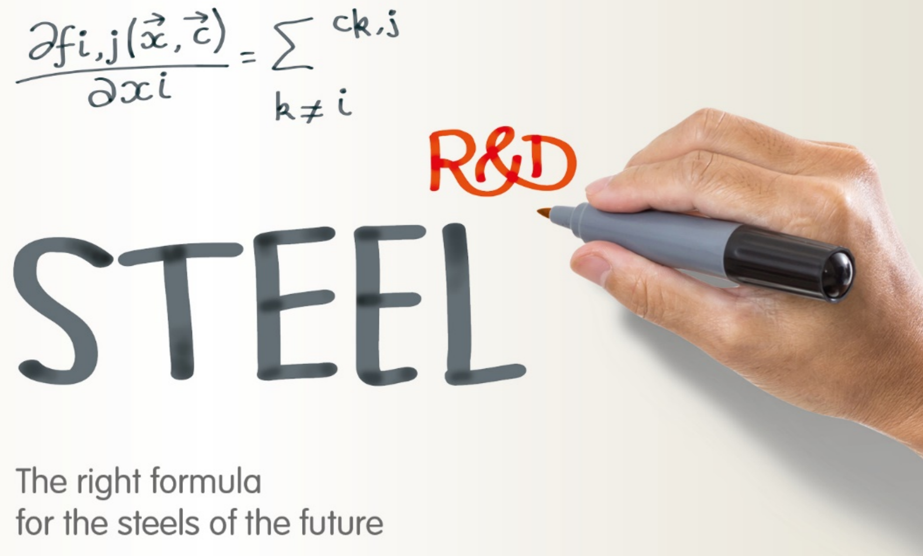
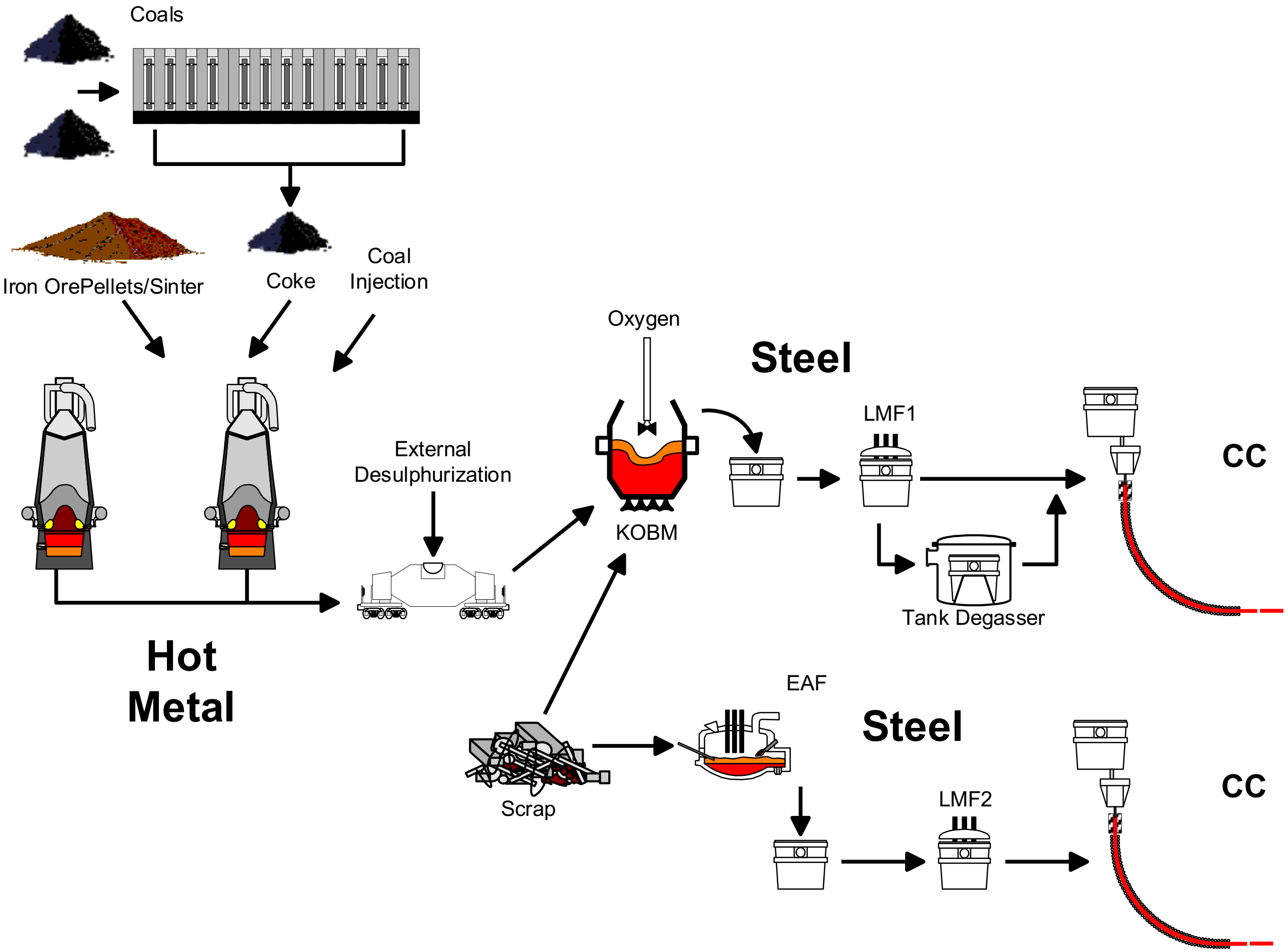


September 1, 2020

Overview

- Steel industry is either BF-BOF route or DRI/Scrap – EAF route



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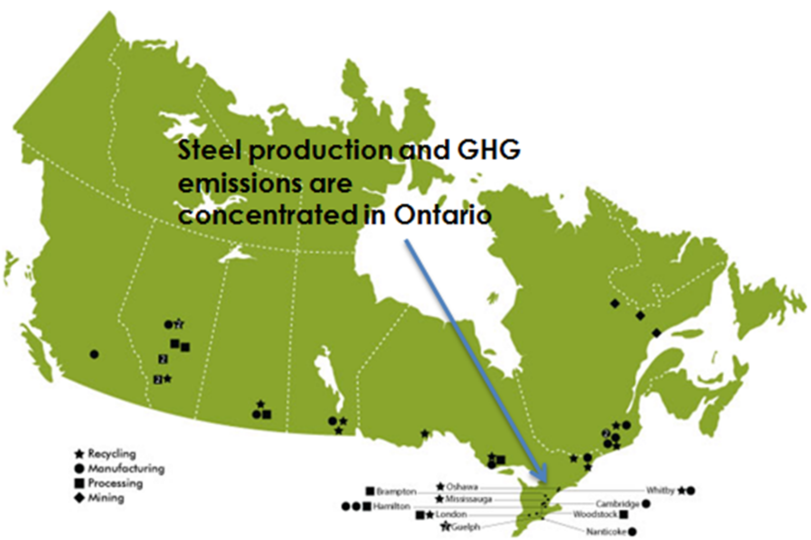
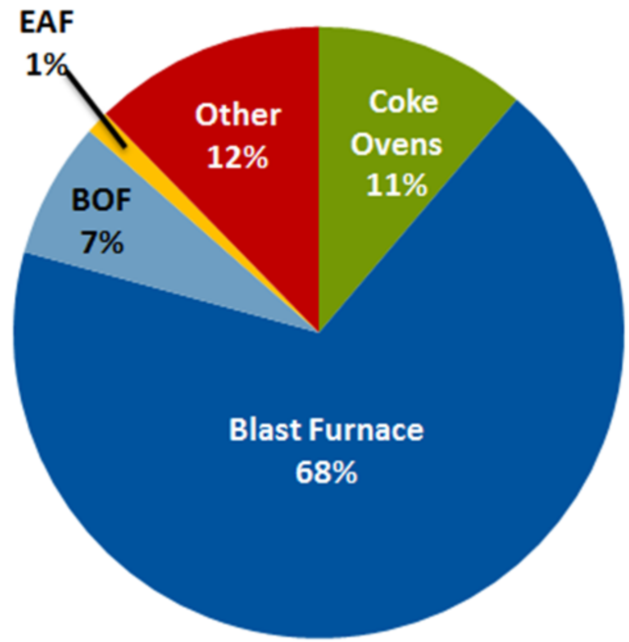
Canadian Overview

- Integrated:
  - Blast Furnace Iron: 9 Mt
  - Coke consumption: ~4 Mt
  - CO_2 emission: ~14 Mt
- EAF:
  - EAF Iron: 6 Mt
  - CO_2: ~ 1 Mt





(CSPA Presentation March 30, 2016)

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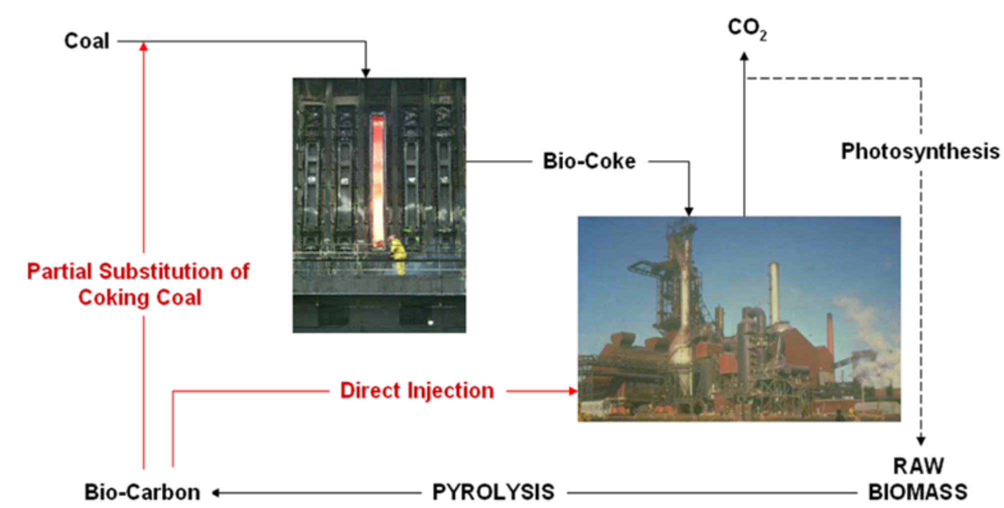
What can we do to replace fossil fuel carbon?

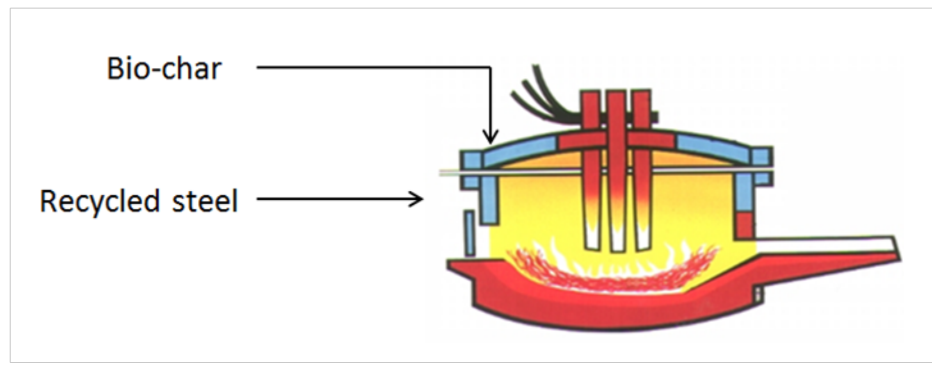


Role of Coke in Blast Furnace

- Source of Reducing Gas
- Source of Heat
- Burden Support
- Gas Distribution

Hot and cold strength of particular coke determines its suitability for blast furnace ironmaking

- Coal replacement in coal blend which makes coke for BF
- Nut coke replacement
- Coal replacement for PCI applications
- Fossil carbon replacement in EAF



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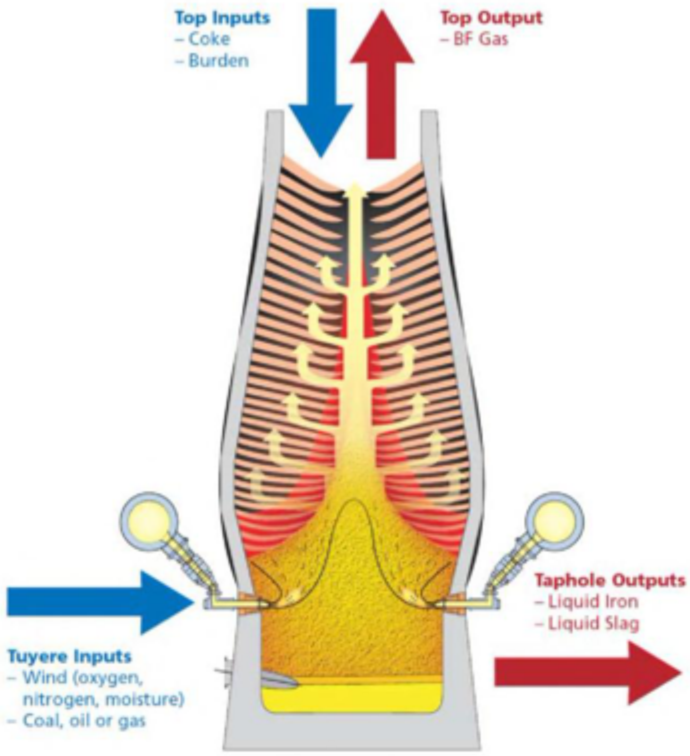
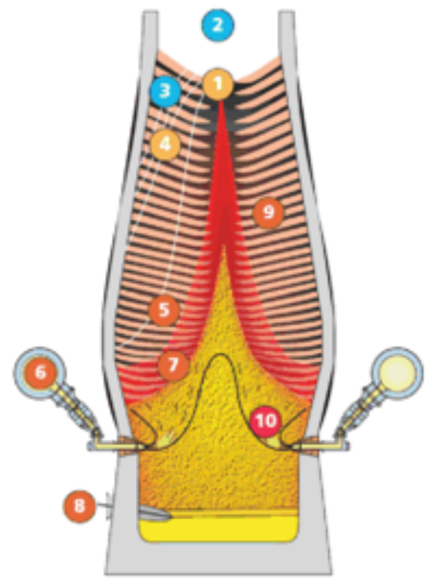
Blast Furnace – A counter current reactor





1	Centre Coke	600–900 °C
2	Top Gas	110 °C
3	Evaporation of water	100 °C
4	Reactions start	500–600 °C
5	Start of softening front	1000–1200 °C
6	Hot blast	1050 °C
7	End of cohesive zone	~1400 °C
8	Hot metal cast	1500 °C
9	Granular zone	
10	Raceway Flame	2100–2300 °C

Ore burden starts melting at 1100–1150 °C
Slag fully liquid at approximately 1400 °C

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Biomass carbon compared to fossil fuel carbon

(% in injectant)	Coal	Eucalyptus	Switchgrass	Bio-Oil	Charcoal
Ash	11.21	0.62	5.76	0.00	3.52
→ C	77.71	49.85	47.27	43.21	86.88
N	1.18	0.06	0.51	0.14	0.43
→ O	4.64	43.50	41.59	48.80	6.82
H	4.24	5.86	5.31	7.73	2.30
S	0.68	0.01	0.10	0.03	0.05

Ash Composition (% ash)	Coal	Eucalyptus	Switchgrass	Bio-Oil	Charcoal
Fe_2O_3	4.84	0.00	0.40	N/A	2.47
→ CaO	1.85	26.50	4.80	N/A	45.50
MgO	0.62	7.30	2.60	N/A	5.29
SiO_2	60.14	17.80	69.90	N/A	11.18
Al_2O_3	28.42	7.90	0.40	N/A	2.78
→ P_2O_5	1.13	29.10	2.60	N/A	3.20
→ K_2O	1.24	7.20	15.00	N/A	13.29
→ Na_2O	0.10	5.00	0.10	N/A	1.67
TiO_2	1.65	0.00	0.10	N/A	0.20

Elemental Composition is Critical to Iron and Steelmaking Products

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Biomass conversion technology

		Coal	Bio-char			
		PCI	Fast Pyrolysis	Slow Pyrolysis	Torrefaction	Hydrothermal Carbonization
Proximate	Ash	7.89	9.8	2.18	1.18	0.05
	VM	36.2	4.92	15.71	50.47	51.74
	FC	55.91	85.27	82.12	48.35	48.21
Ultimate	C	77.5	86	87.2	67	71.6
	H	5.15	0.95	2.63	4.45	4.85
	N	1.71	1.27	0.57	0.19	0.18
	S	0.78	0	0.05	0	0.0054
	O	6.98	2.01	7.4	27.2	23.4
Ash Chemistry	SiO2	52.29	54.95	2.38	7.41	2.38
	Al2O3	29.41	0.6	0.48	2.08	0.48
	Fe2O3	6.55	0.72	0.97	3.4	0.97
	CaO	3.25	15.99	61.67	37.17	61.67
	MgO	0.95	9.88	7.28	5.97	7.28
	P2O5	0.117	4.98	4.13	1.99	4.13
	Na2O	0.26	0.2	1.76	0.7	1.76
	K2O	1.64	7.45	8.12	15.59	8.12

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Biocarbon usage in steel sector

Application	Material	Requirements	Typical	Biocarbon
Cokemaking	Coal	Ability to swell and condense into coke when heated to 1000°C	Use LV, MV and HV coals Blend 3-5 coals to a blend VM of 25%-30%	• Inert during cokemaking so lack of bonding • High in oxygen – not good for bonding and swelling • Residuals K, Na, Ca cause poor hot strength in carbon • Biocarbon <5% still is not acceptable in resulting coke • Not so much a cokemaking issue, but a resulting coke issue
BF	Coke	50% of BF volume Solid material inside BF Cold and hot strength Supports counter current reactor Chemical and physical targets	Used at 300-350 kg/thm	• Residuals K, Na, Ca cause poor hot strength in carbon • K, Na hard to remove from BF so limited loading • Cold and hot strength compromised
	PCI Coal	HHV – 30 MJ/kg Low residuals P, Na, K, Cl Typically HV coal and LV coal	Used at 150-200 kg/thm	• 80% min carbon, Ash<5%, VM 15%-20% • High in oxygen • Can be too soft for grinding • Residual loading – Na, K, P will limit usage
	Nut coke	Typically 25 x 6 mm Added to iron ore burden as sacrificial coke to protect large coke Comes from coke screening	Used at 25-50 kg/thm	• Can briquette into right size and shape • High reactivity can be a plus • Residual loading might be an issue but usage is low
EAF	Nut coke Breeze Anthracite	Used to allow the slag to foam to create a heat blanket	3.5 kg/t	• Residuals might be an issue • Inability to wet and foam • Environmental issues with dust generation

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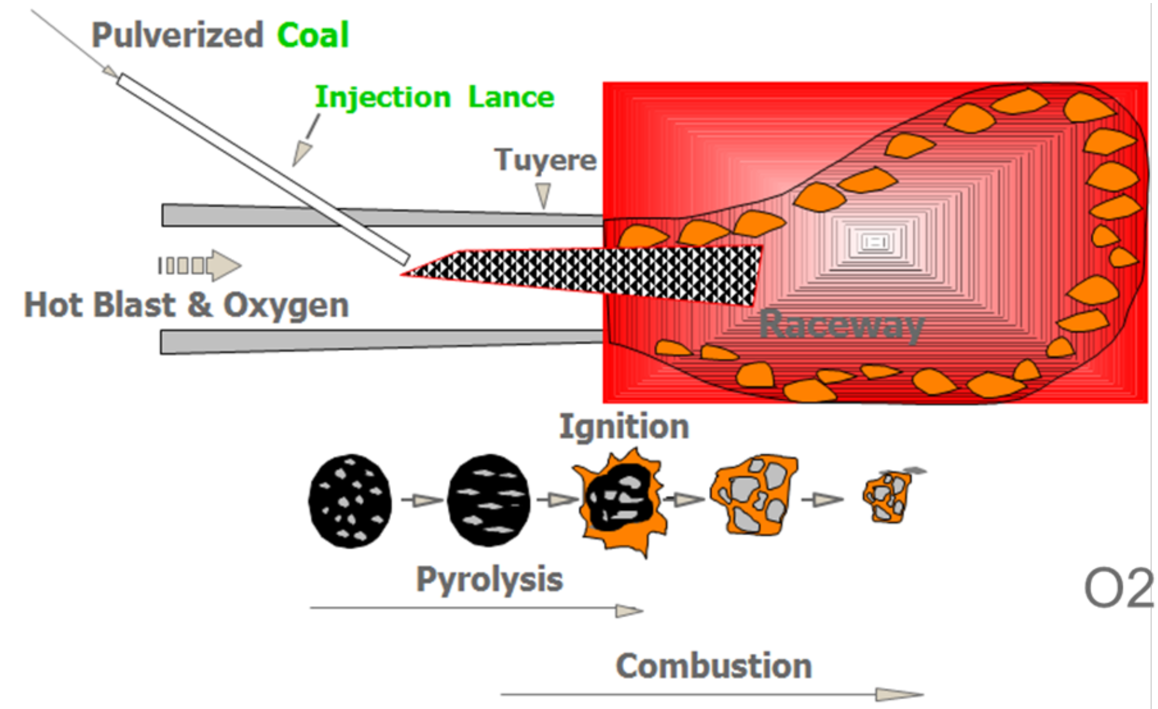
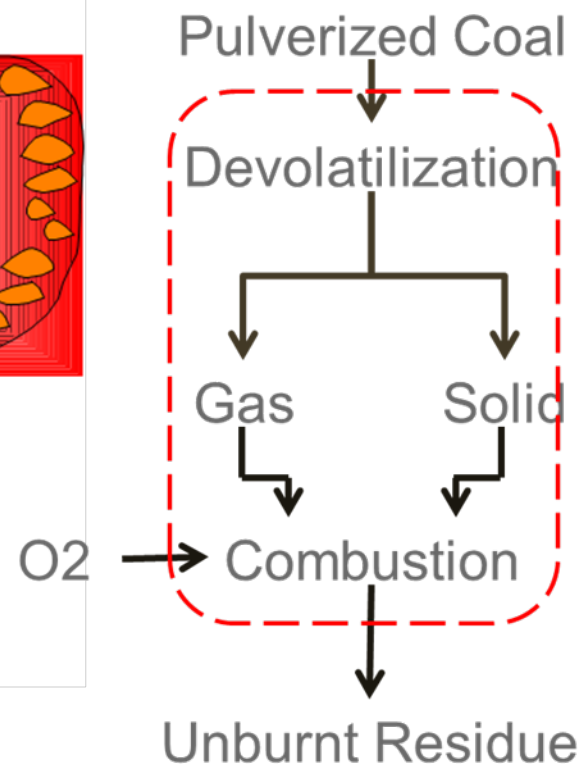
PCI





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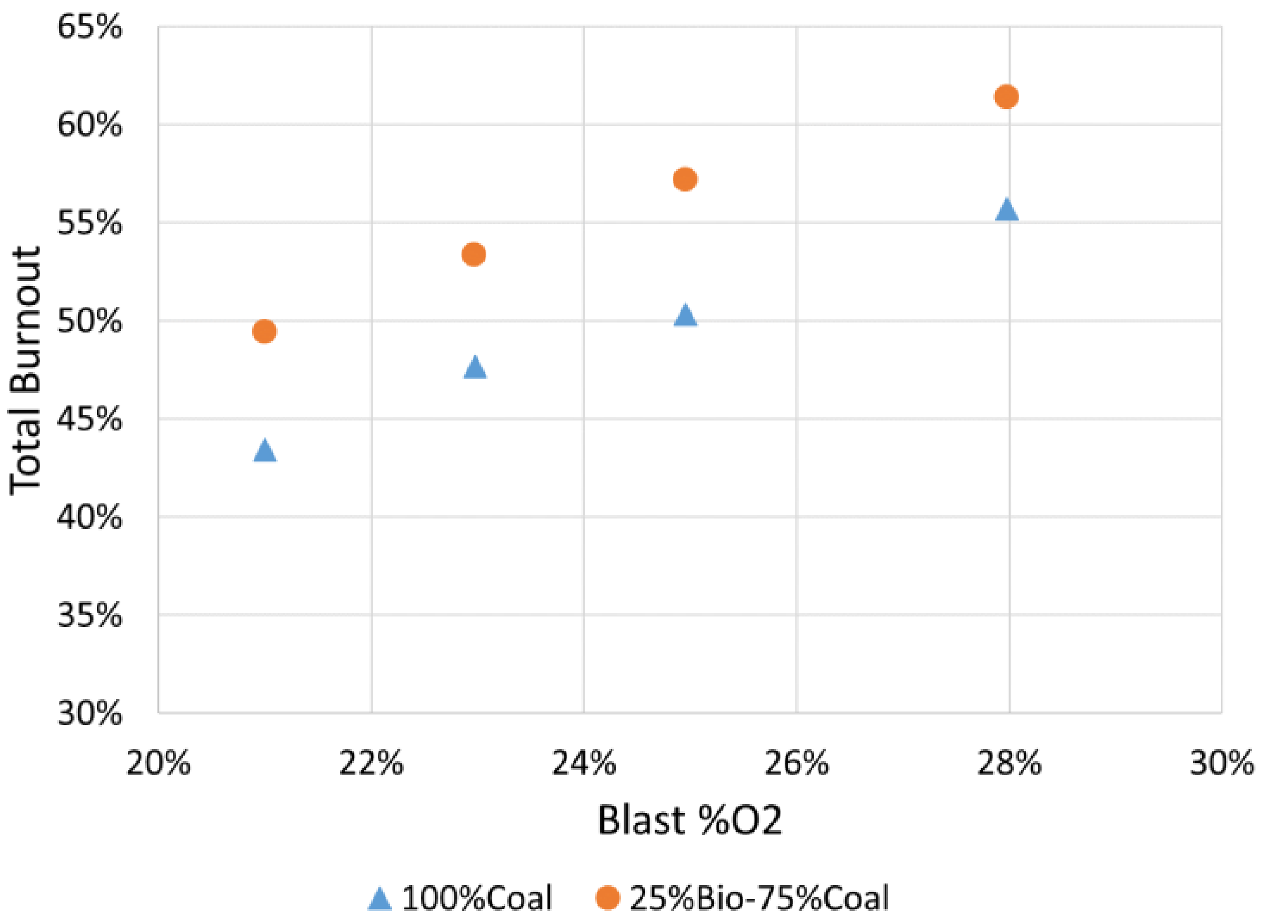
PCI Replacement and burnout



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AM Dofasco Trials for PCI injection

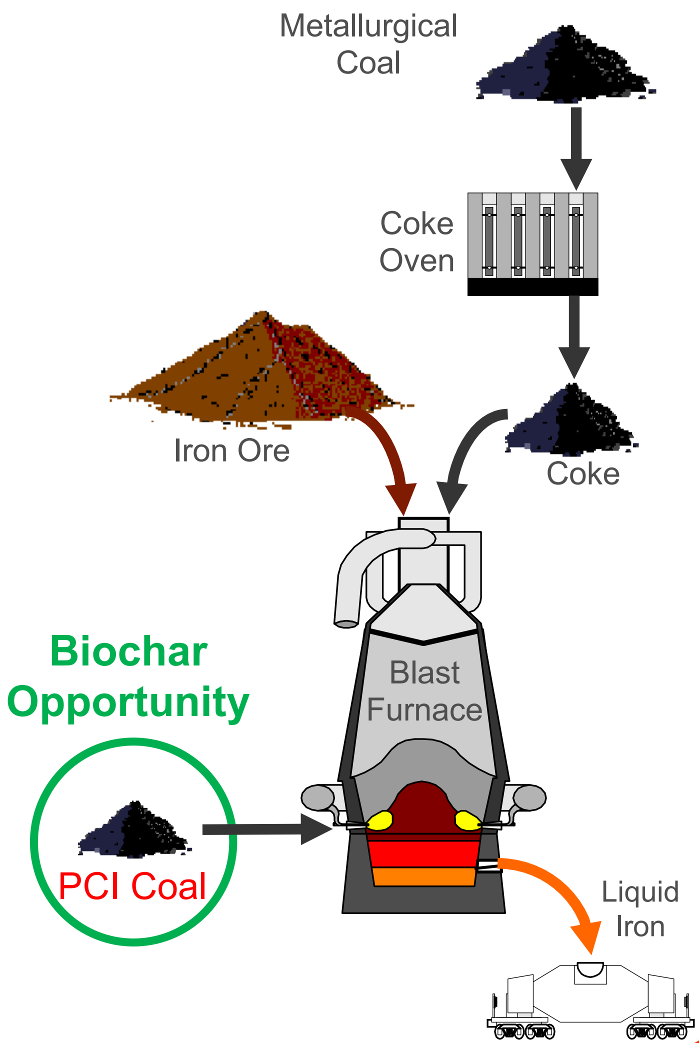
- A blast furnace needs carbon to reduce iron oxide;

$$2\ Fe_2O_3 + 3\ C \rightarrow 4\ Fe + 3\ CO_2$$

- Coke requires physical properties
- PCI (pulverized coal injection) mostly chemical carbon

Therefore, easier to replace PCI with bio-based carbon

- Initial goal to replace ~10% PCI coal (40,000 tpy) with biochar carbon (~120,000 tpy CO_2 reduction)
- Use existing drying and grinding facilities



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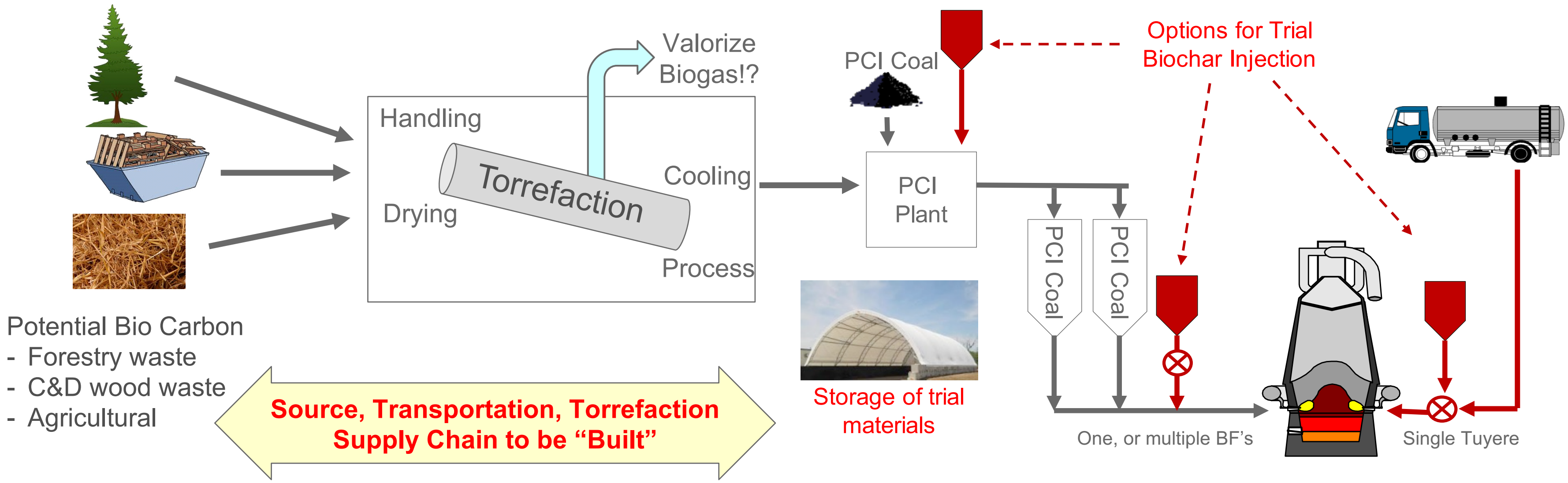
AM Dofasco Trials for PCI injection

Have built and developed network for biocarbon within Canada



Bio Supply
- Domtar (also interested in conversion)
- Walker Industries (also logistics)
- FPInnovations
- Canadian Forest Service
- Lac des Mille Lacs First Nations

Conversion
- Airex, BC Biocarbon, Char Technologies, Elkem
- National Carbon Technology
- CanmetENERGY BioFuels
- ArcelorMittal Gent ↔

Users
- **ArcelorMittal Dofasco**
- Other ArcelorMittal sites globally
- Canadian Steel Producers Association (CSPA)
- ArcelorMittal Gent

Consultants
- Ecostrat
- Cobden Strategies

Evaluation
- CanmetENERGY Met Labs

Government & Agencies
- Ontario Ministry of Natural Resources and Forestry
- Ontario Ministry Food and Rural Affairs
- Ontario MEDJCT – Investment Office
- Ontario Centers of Excellence (OCE)
- Centre for Research & Innovation in the Bioeconomy

Others
- Canadian Carbonization Research Association (CCRA)
- Canadian Biocarbon for Steel Working Group
- Universities

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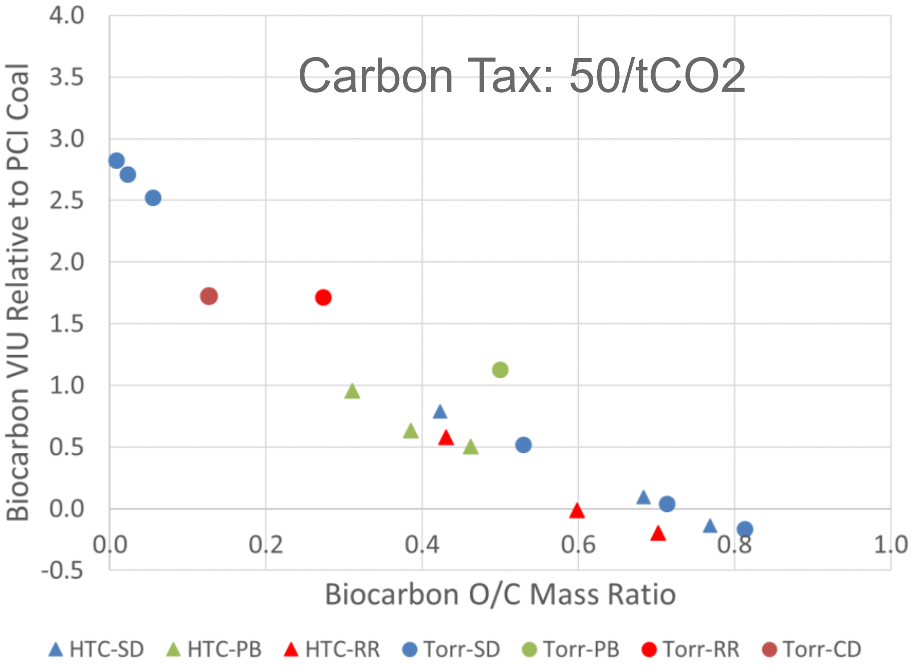
VIU

Biocarbon Injection

- Affect raw materials input (coke,
- O2, etc.
- Affect operating cost
- Decrease GHG emission
- Saving in emission cost

Overall economic impact VIU

- Sensitive to carbon tax
- Depends on chemical composition of biocarbon
- Affect by pyrolysis technology and conditions



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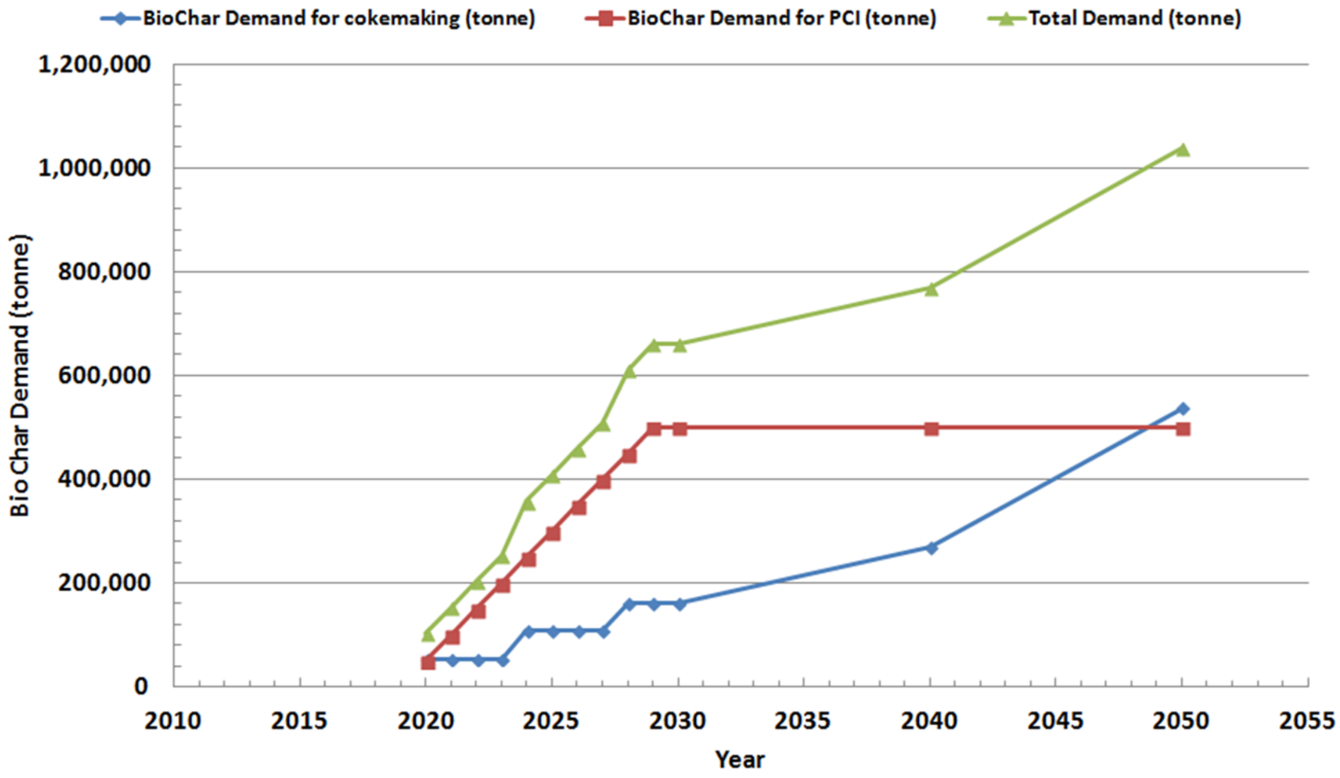
Biocarbon Usage in the Steel

- Substitution of fossil fuel by renewable biocarbon
- Incorporate biocarbon in existing facilities to avoid capital investment
- Goal if 25% GHG reduction



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Biocarbon Usage in the Steel Potential

- Substitution of fossil fuel by renewable biocarbon
- Incorporate biocarbon in existing facilities to avoid capital investment
- Goal of 25% GHG reduction

Goal	Mitigation Impact	Anticipated Technical Challenge	Development Priority
100% replacement of pulverized coal injection in blast furnace ironmaking	High	Low	1
100% replacement of fossil carbon input in EAF steelmaking	Low	Medium	2
100% replacement of small coke by bio-pellet	Low	High	3
10% substitution of coal in cokemaking	Low	High	4

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