Columbia | SIPA
Center on Global Energy Policy

Low-Carbon Steel Production: Options and Assessment

Zhiyuan Fan, Dr. Julio Friedmann
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Agenda

1. Today's Iron and Steel Production
- BF-BOF dominates 71%
- EAF-scrap 24%, DRI-EAF 5%

2. Decarbonization Approaches
- Hydrogen, Biomass, Zero-Carbon Electricity, CCS

3. Potentials and Costs Summary
- Moving towards net-zero
- \$/ton-HM v.s. \$/ton-CO_2

4. Findings and Suggestions
- Pathways and approaches
- Policy Implications

5. Future Work
- Longer term and more options

Iron and Steel:
Massive global industry
Globally traded, small margin commodity

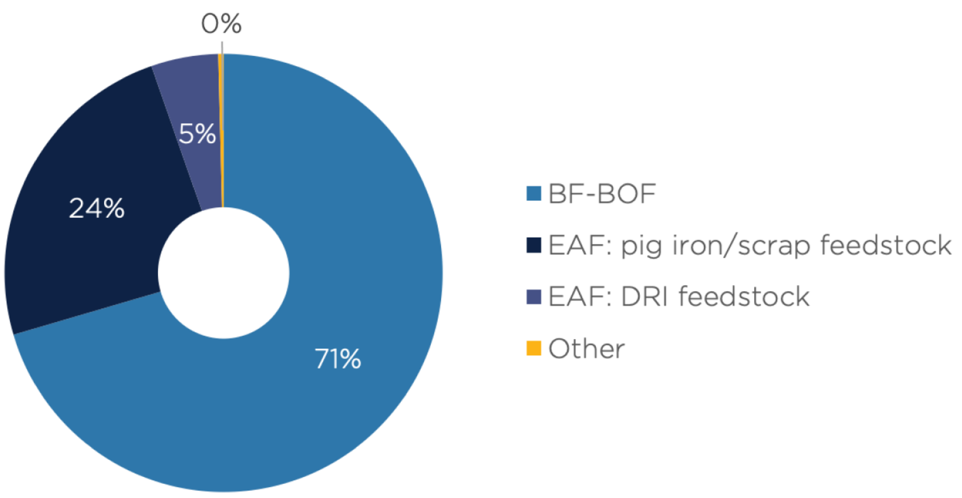
Iron and Steel: 6% of global CO_2-eq emissions *(same as cars)*

In 2018:
1807 Mt/yr hot metal (HM)

1.85 ton-CO_2/ton-HM
$400/ton-HM

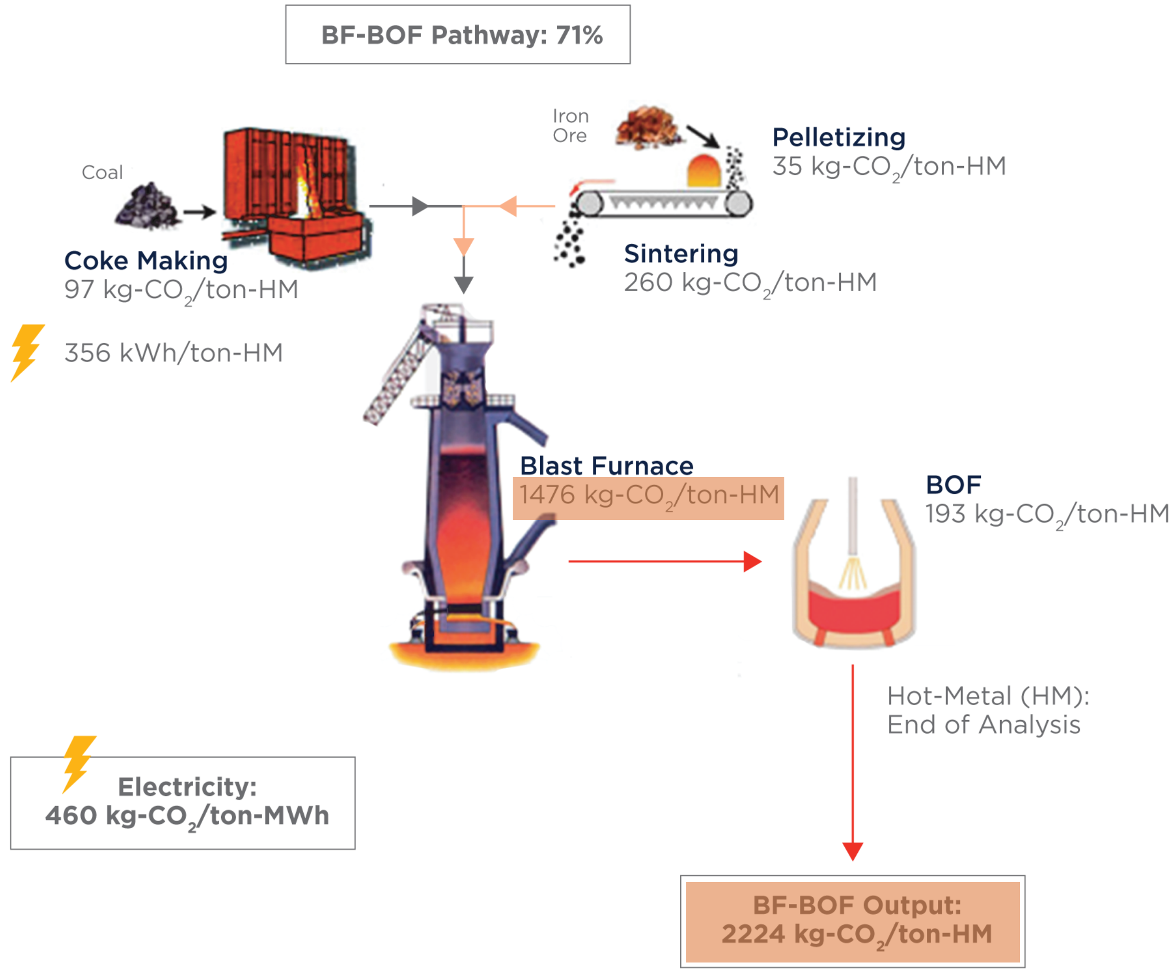
→ 3.34 Gt-CO_2/yr
Source: Worldsteel Association

2018 Global Steel Production by Pathways (Mt/yr)

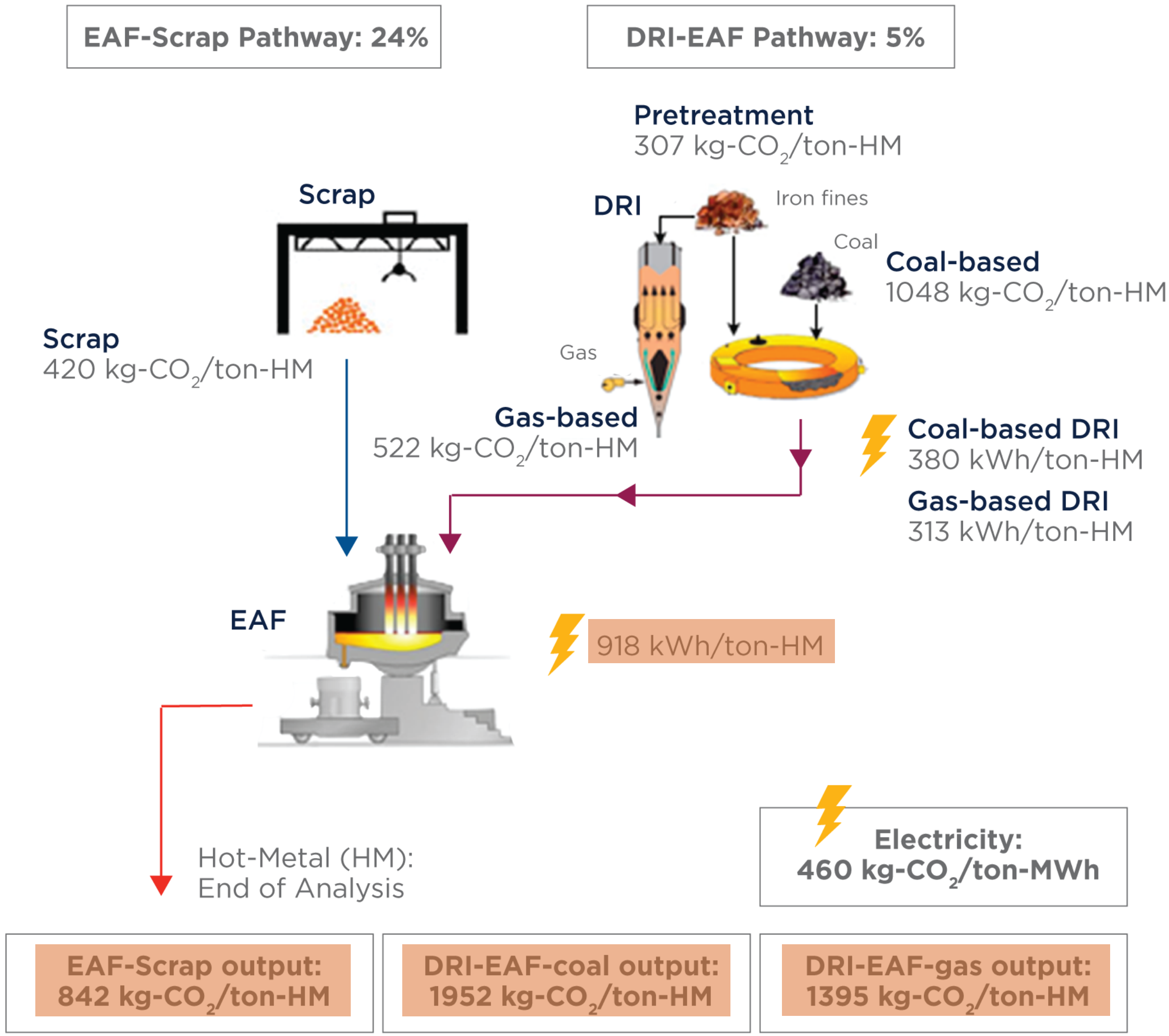


Source: Worldsteel Association

Iron and Steel Production Pathways: Blast Furnace + Basic Oxygen Furnace



Iron and Steel Production Pathways: Electric Arc Furnace & Direct Reduction Iron



Technology Options to Decarbonize Iron & Steel

- Not many options
- All have challenges
- Potential to decarbonize limited

1. **Zero-C Hydrogen injection**
   - Blue (with CCS) & Green (electrolysis) options
   - Fuel injection into furnaces or DRI unit
2. **Biomass substitution**
   - Charcoal, “biocoke”, biogas (not assessed)
   - Life-cycle (LCA) and land use change (LUC) terms dominate
3. **Zero-carbon electricity replacement**
   - No retrofit existing plants on reactors
   - Mostly focused on EAF and DRI
4. **CCS**
   - Retrofits to existing plants with conventional tech
   - Mostly focused on top-gas capture
5. **Combination options**
   - Only way to get deep decarbonization
   - Only one way to make net-negative emissions steel

Hydrogen Injection: ~20% limit for BF-BOF

Decarbonization potential:

DRI > BF

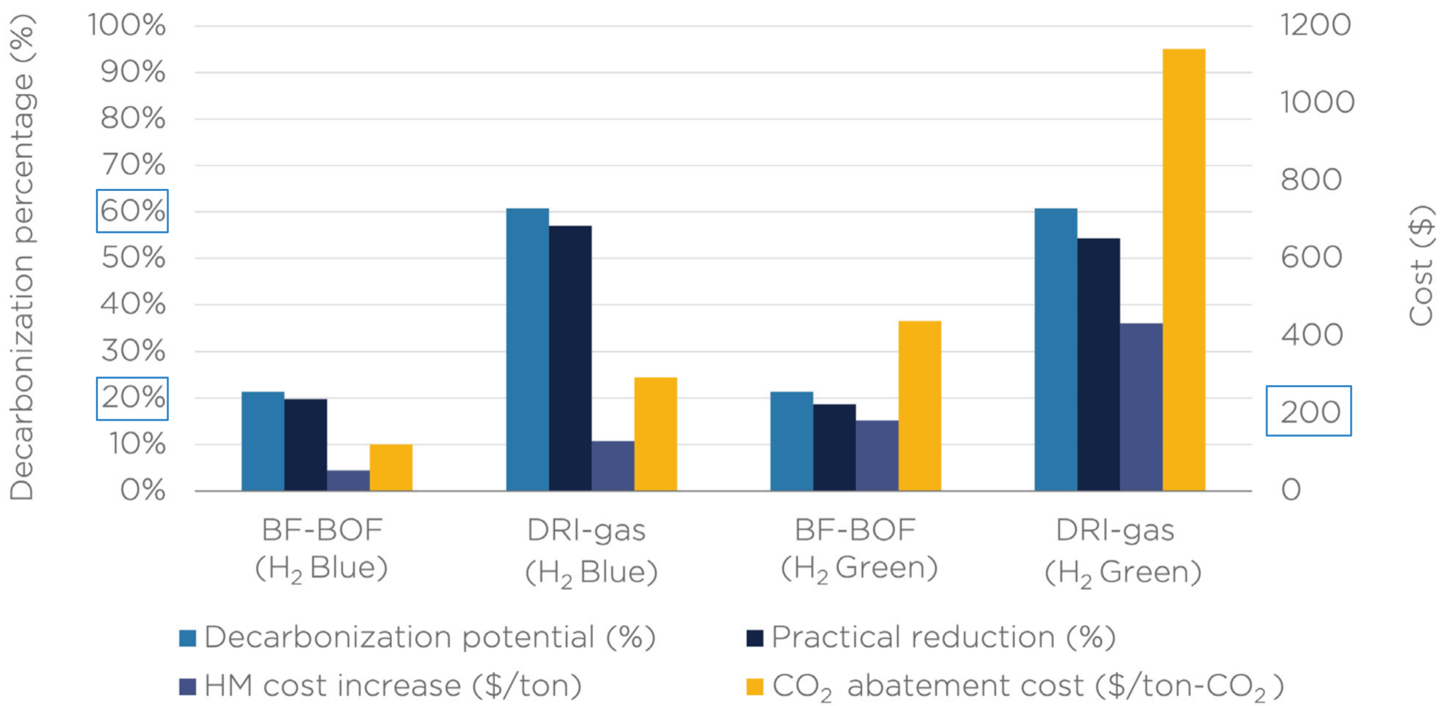
Costs (\$/ton-HM & \$/ton-CO_2):

DRI > BF

Green H_2 > Blue H_2

Hydrogen injection:

Practical reduction close to theoretical limits.



Biomass Substitution with Charcoal: Moderate potential; highly sensitive to LUC

Ideal: No C-footprint

LCA: Life cycle analysis C-footprint

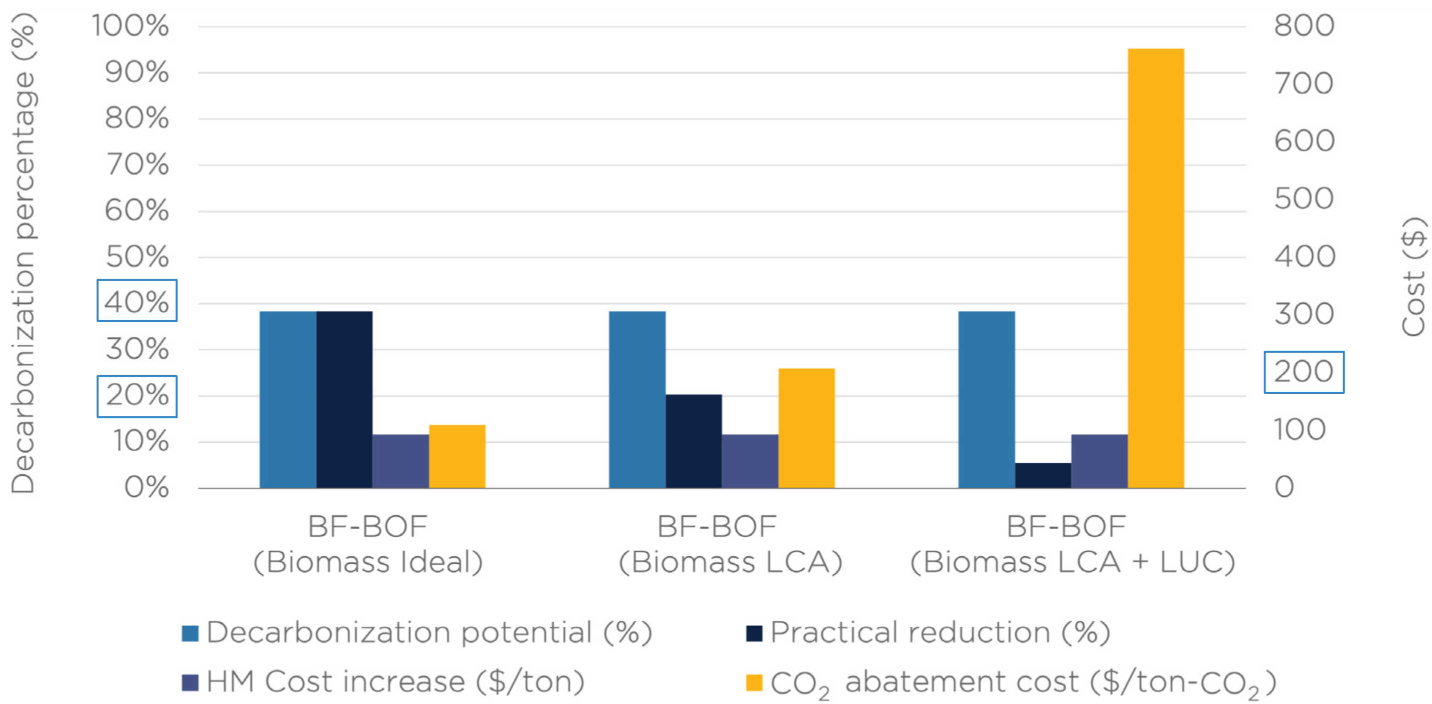
LUC: Land-use change C-footprint

Biomass:

Ideal → Best

Real → Worst

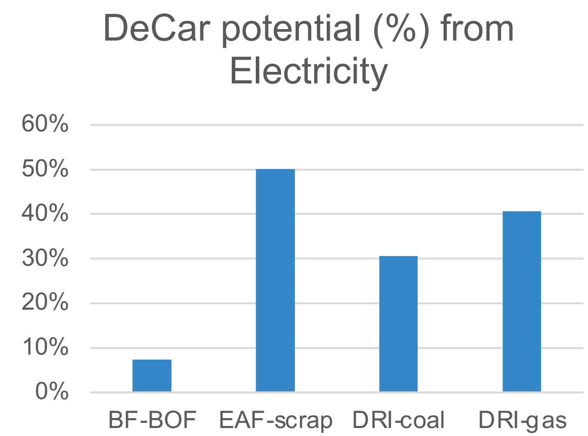
Uncertainty is huge for biomass.



Zero-Carbon Electricity Penetration

Replacing BF with DRI for Electrification and Deep Decarbonization

Iron/steel production pathways and share (%)	Current Baseline	Medium DRI Replacement	High DRI Replacement
BF-BOF	71%	51%	26%
EAF-scrap	24%	24%	24%
DRI-EAF	5%	25%	50%
Weighted average CO2 intensity (kg-CO2/ton-HM)	1857	1713 ↓	1534 ↓
Electricity related CO2 emission (kg-CO2/ton-HM)	246	328 ↑	430 ↑
Non-Elec *CO2 intensity (kg-CO2/ton-HM)*	**1611**	**1385**	**1104**
Added electricity demand (TWh/yr) & capacity (GW)	**N/A**	**449.7 TWh 146.7 GW (35% capacity factor)**	**1011.9 TWh 330.0 GW (35% capacity factor)**



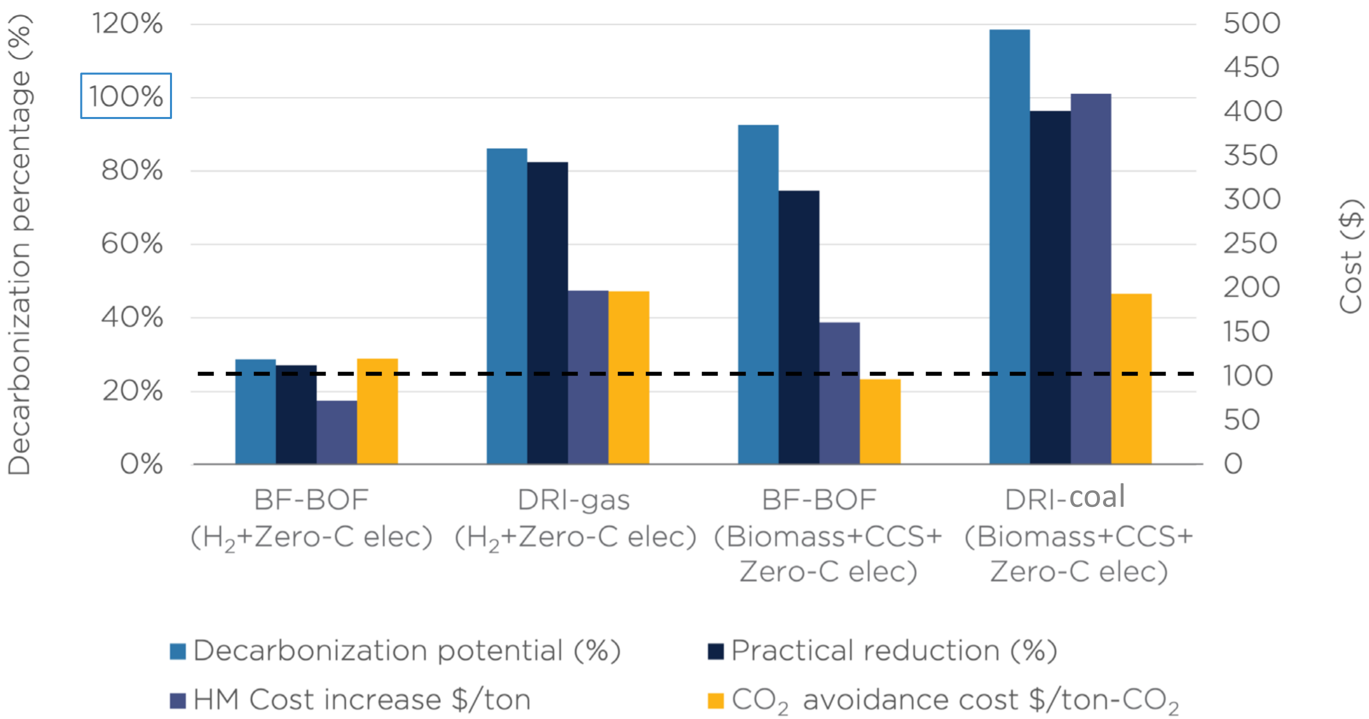
Carbon intensity lower

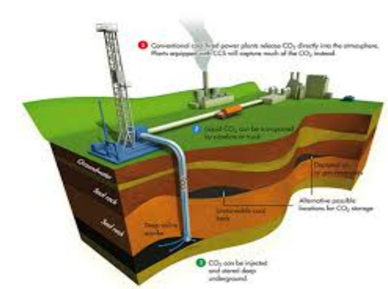
Electricity emission higher

Significant zero-carbon electricity supply required.

Finding 1:

For deep iron/steel decarbonization we need all commercial options in combination





Finding 2:

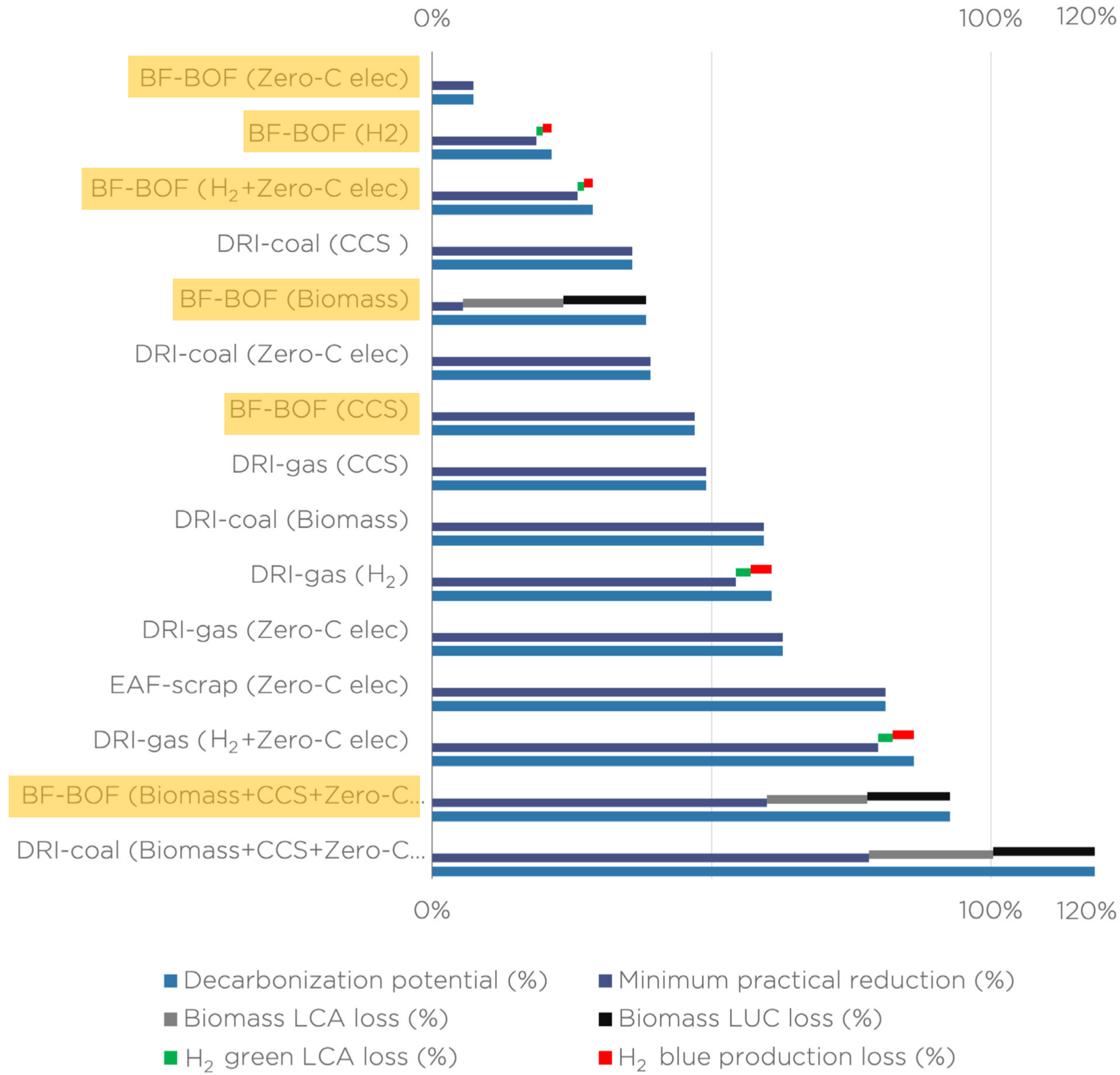
BF-BOF faces deep technical challenges.

1. **BF-BOF has high carbon intensity**
2. **Decarbonization approaches for BF-BOF are limited.**

Deep decarbonization potential better for EAF-Scrap & DRI+EAF systems

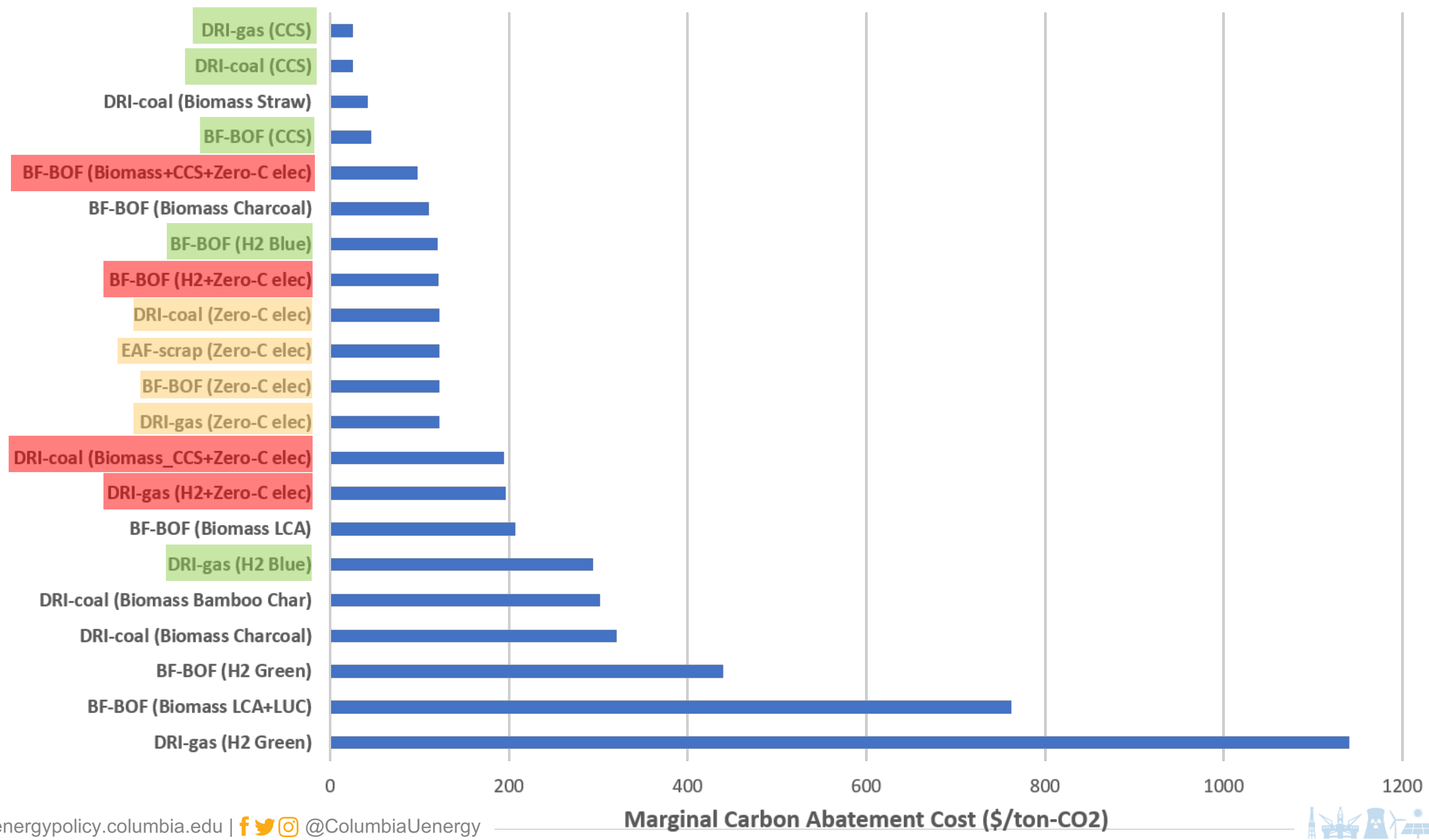
Suggests replacement agenda

Decarbonization potential for different approaches

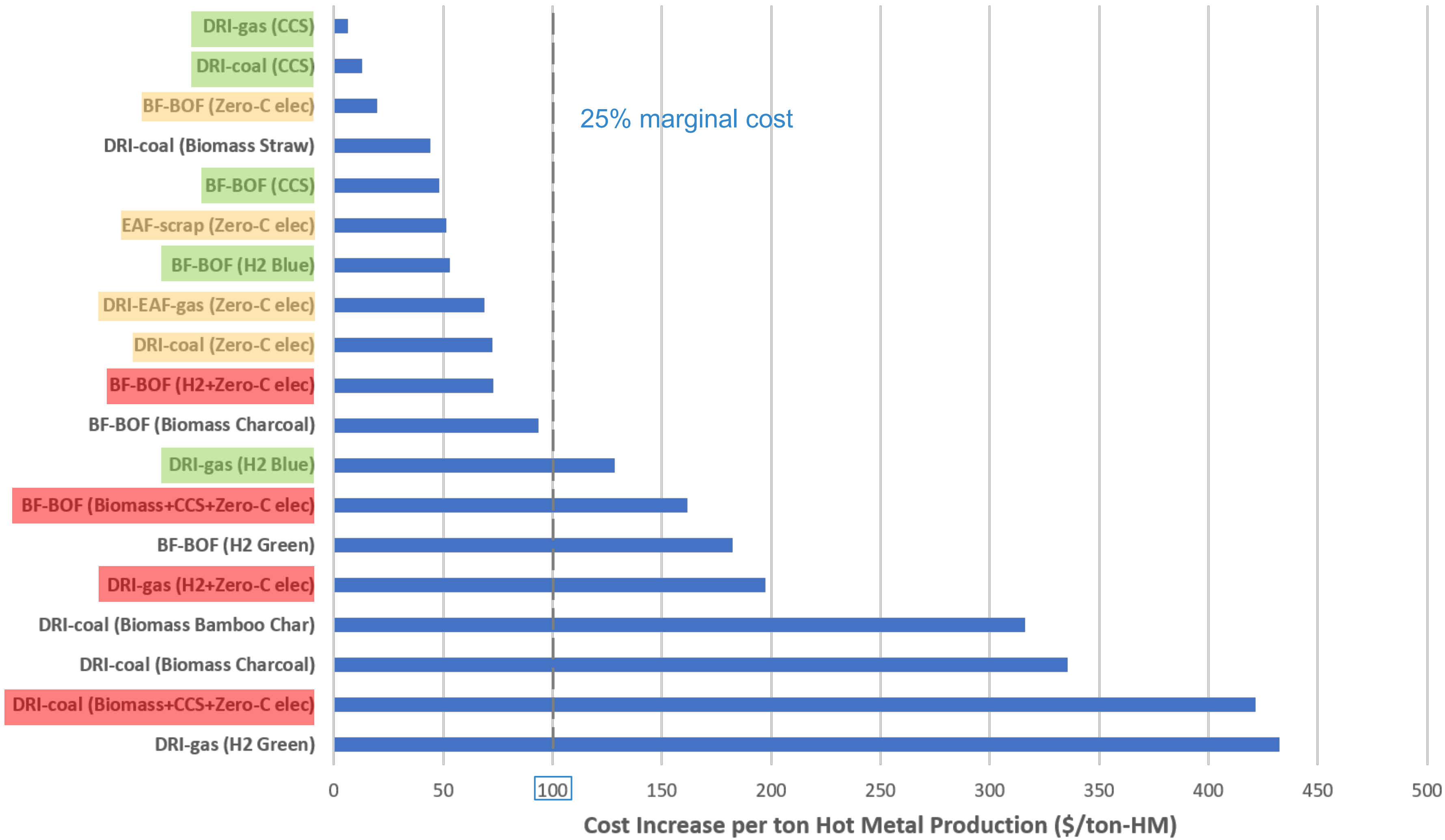


Finding 3: enormous range of costs by option

1. **Lowest cost options (\$/ton CO_2): CCS and Zero-C electricity**
2. **Green H2 and non-ideal biomass are very expensive**



Finding 4: Almost all options result in substantial production cost increases



Policy implications: Hard but important

US Policy

- High abatement costs limit conventional policy value
  - Broad infrastructure (zero-c power & CO_2 pipeline) gets <50%
  - Insensitive to most carbon price policy proposals
  - Border tariffs must be very high
- **Must consider an asset replacement policy strategy**
- Potential policies to assist deployment & cost competitiveness
  - Replacement grants (GND?)
  - Govt. procurement
  - Incentives for early adopters

International Policy

- Most production not in US
  - Will require international standards
  - Will require sectoral participation from companies (including SOEs)
- Not clear what is best model to engage
  - Border tariffs (EU): Unlikely to deliver abatement
  - **Proactive club of nations & companies**
  - Sectoral effort parallel to Paris & G20
- Innovation agenda (possible Mission Innovation target)

Towards a Low-Carbon Future

Future for Iron/Steel

- Policies needed to assist deployment & cost competitiveness.
- Local decarbonization:
  - Design around local geography, economies, infrastructure, etc.
  - Engage local labor, communities, lawmakers, etc.
- Long-term future (>15 years) heavy on innovation agenda:
  - Overcoming technical challenges
  - MOE (electricity energy only)
  - HIsarna (<50% C-intense of BF)

Future for CaMRI Team

- Working on Iron/Steel
  - Specific geography cases (China, India)
  - More novel approaches (e.g., LanzaTech, new CCS)
  - More detailed analysis (e.g., ASPEN model)
- Component of broader on Industrial Decarbonization
  - Hydrogen production
  - Ammonia, Chemicals,
  - Cement & concrete
  - Etc……

Thank You