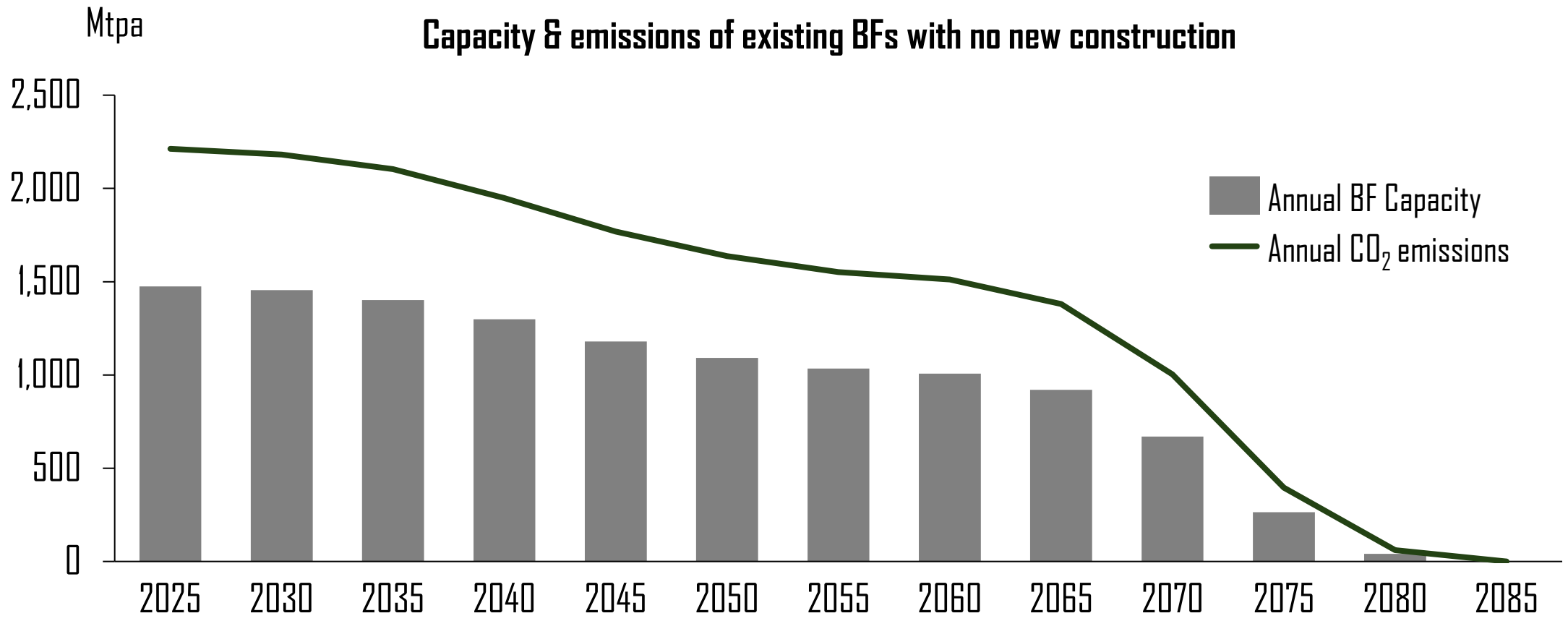
# Profitable Decarbonization of the Ironmaking Furnace

## "eTGR": A New Approach to Top Gas Recycling

Evan Haas | Helix Carbon

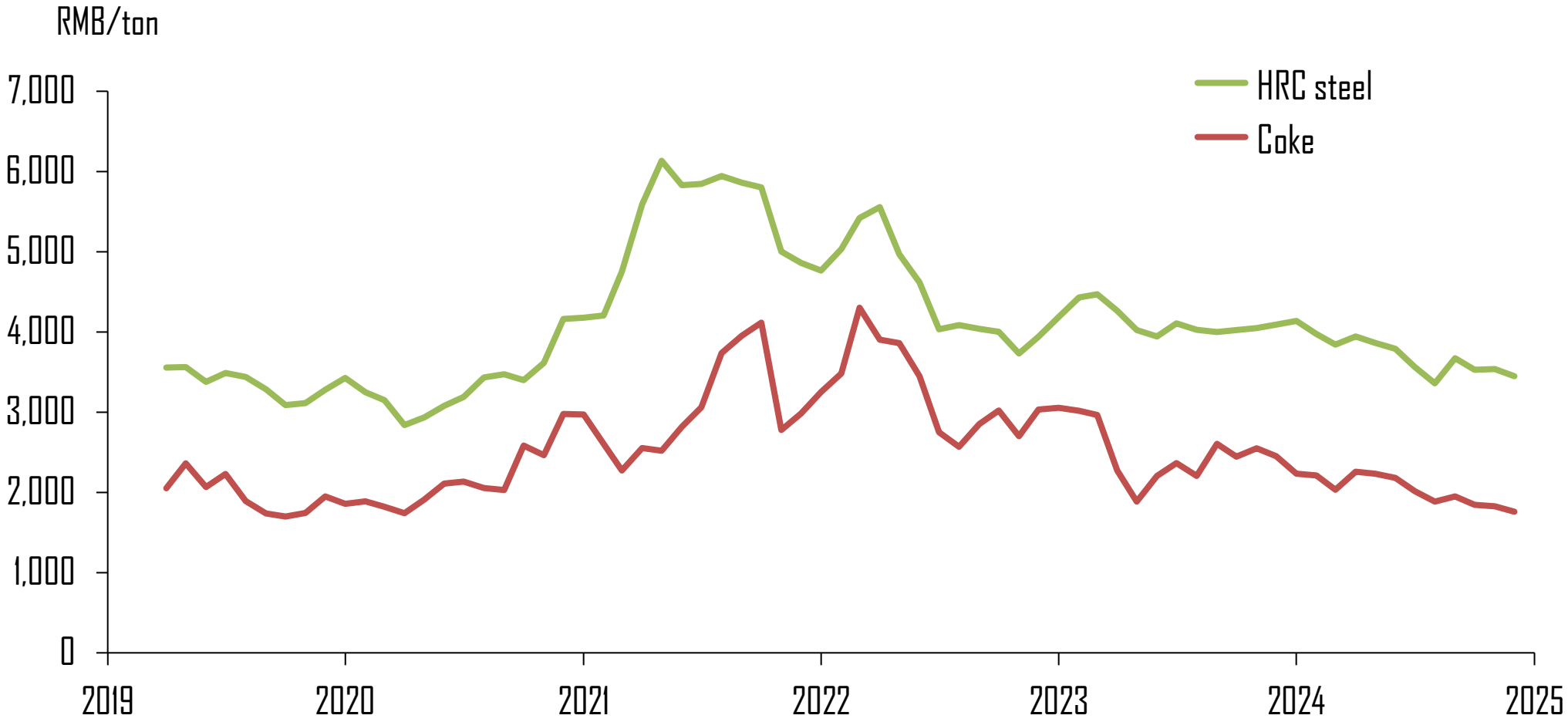
Helix
Closing the carbon cycle.

# Just today's blast furnaces lock in emissions through 2070



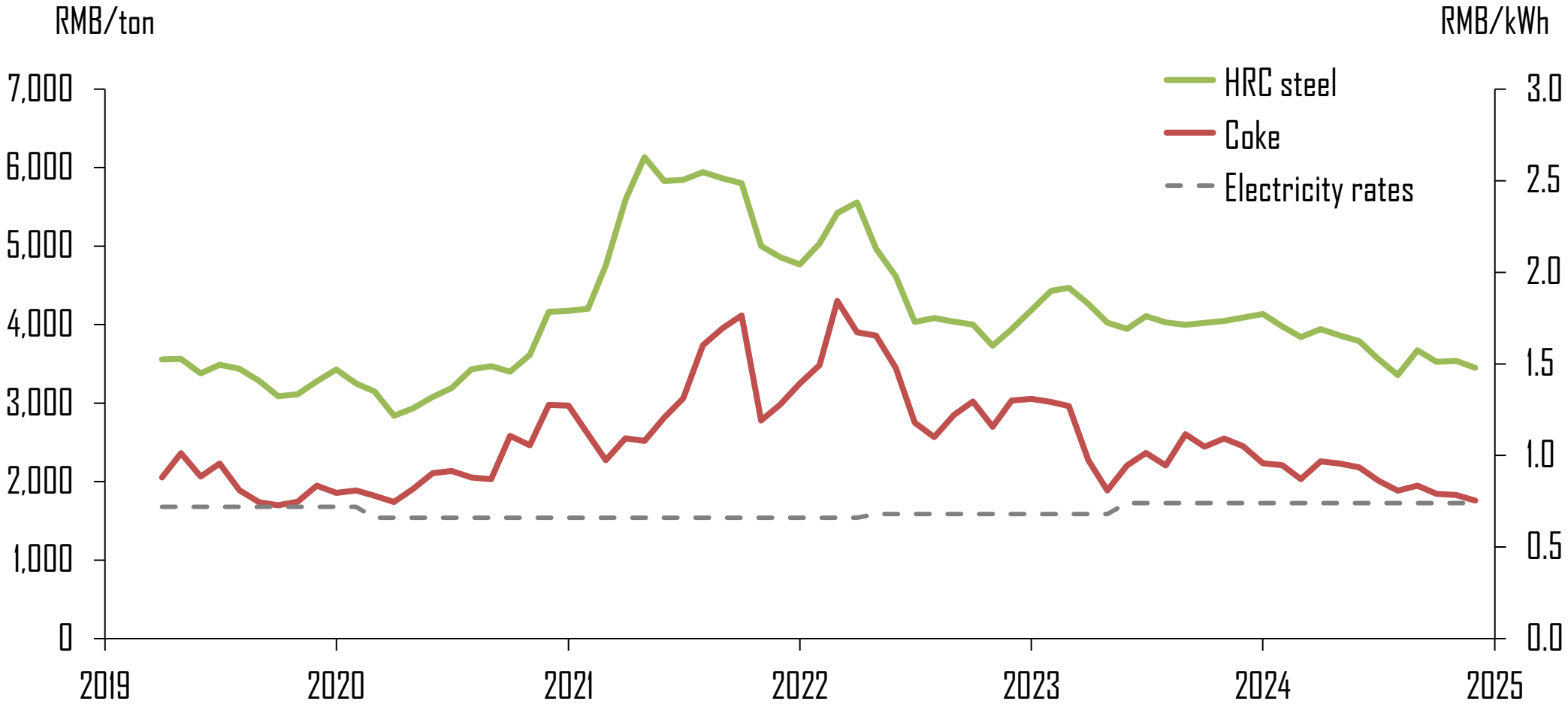

Source: Projected emissions based on Global Energy Monitor blast furnace age distributions, assuming 60-year natural lifespans of furnaces (construction + 2 relines).

# And are uniquely exposed to volatile energy markets



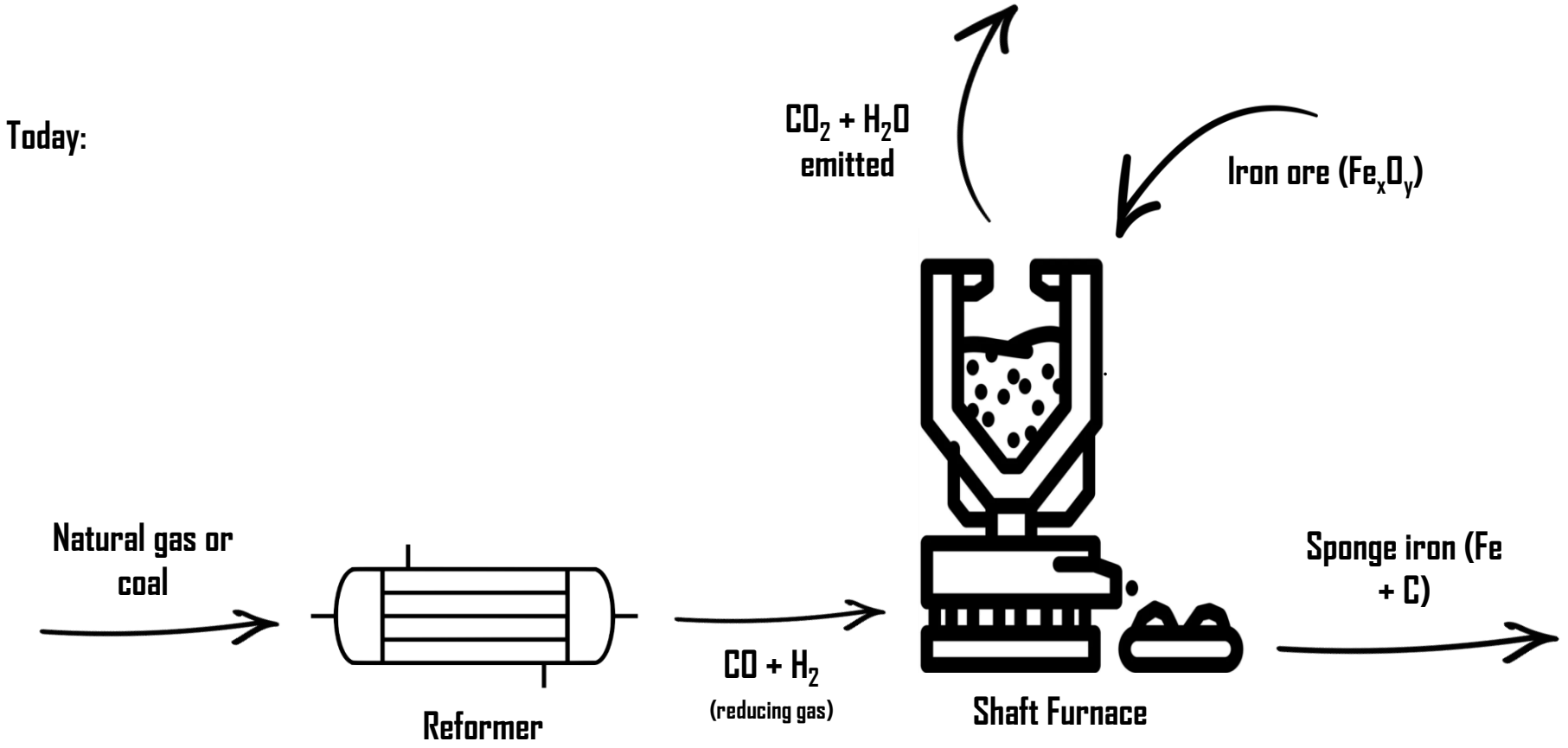

Source: China FOB Futures pricing. Electricity for Jiangsu province.

# While electricity is relatively stable

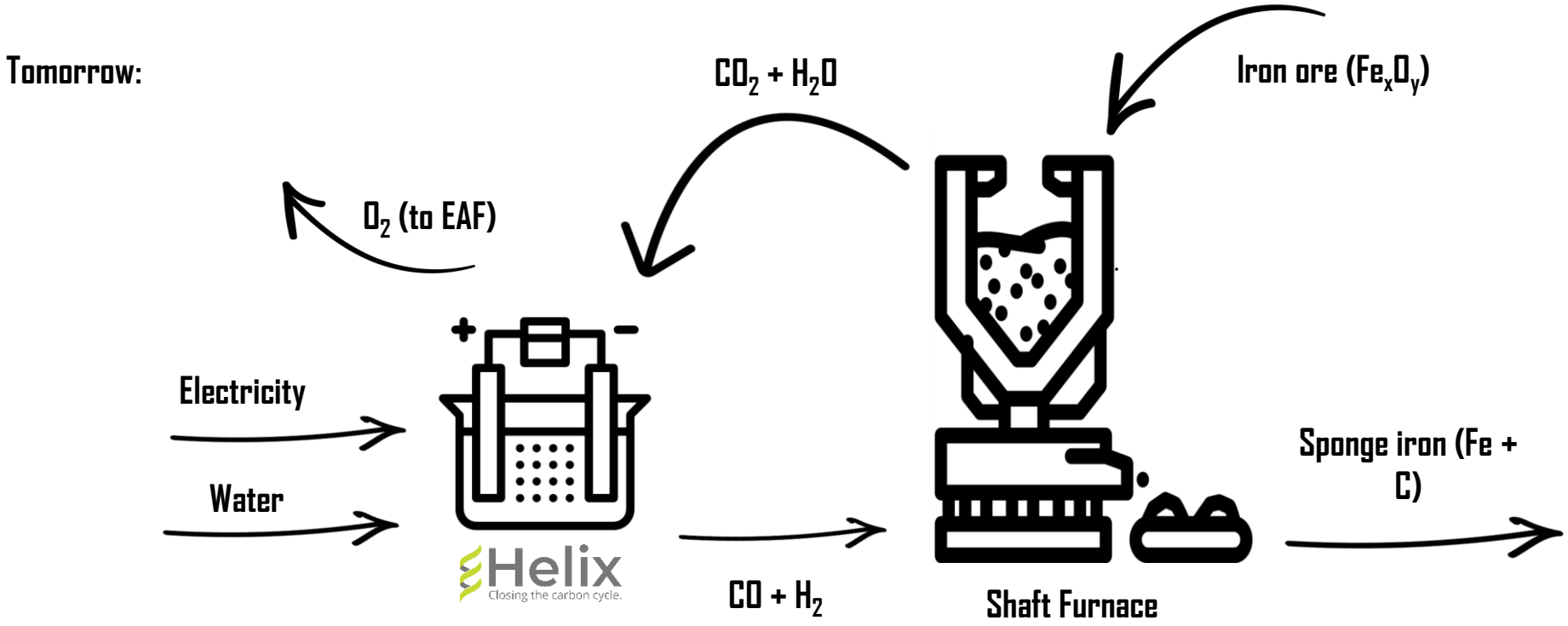



Source: China FOB Futures pricing. Electricity for Changsha, CEICData.

# Today's ironmakers use syngas as a chemical reagent, emitting the $CO_2$ and $H_2O$



# Helix's approach: **Closed-loop ironmaking**




Note: this electrochemical looping concept is wholly-owned Helix IP. We acknowledge some liberties with "closed-loop" as there is carbon exiting via the sponge/pig iron and the system may not operate in 100% fossil replacement in most scenarios.

# Helix's technology:
## "Electrochemical reforming"

*Cathodic reactions*

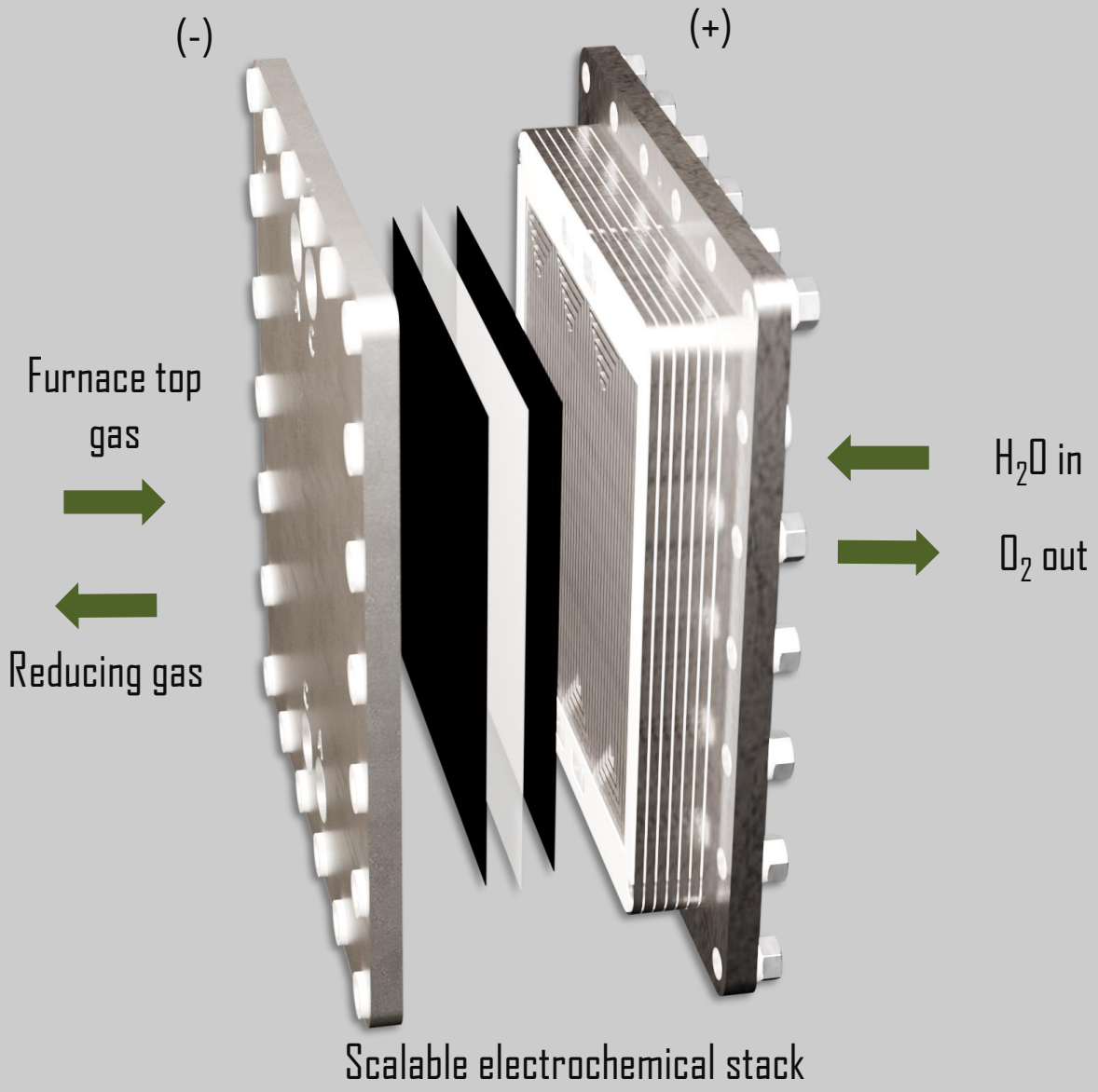
$CO_2 \rightarrow CO$

$H_2O \rightarrow H_2$

$CO, H_2, CH_4 \rightarrow$ **recycled to improve energy efficiency**

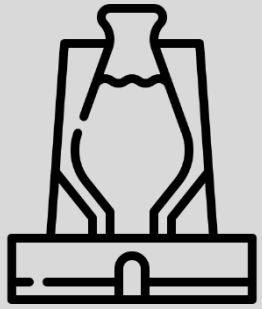
*Anodic reaction*

$H_2O \rightarrow O_2$



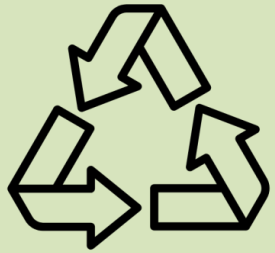
# The first electrolyzer to directly convert top gas

**Top gas presents challenges for today's systems**



- **Dilute $CO_2$**: Today's electrolyzers stall under impure carbon dioxide
- **Variable Conditions**: Changing pressure, flow, and gas compositions
- **Contamination:** Sulfur and particulates poison catalysts

**Helix: Direct carbon recycling for the first time**

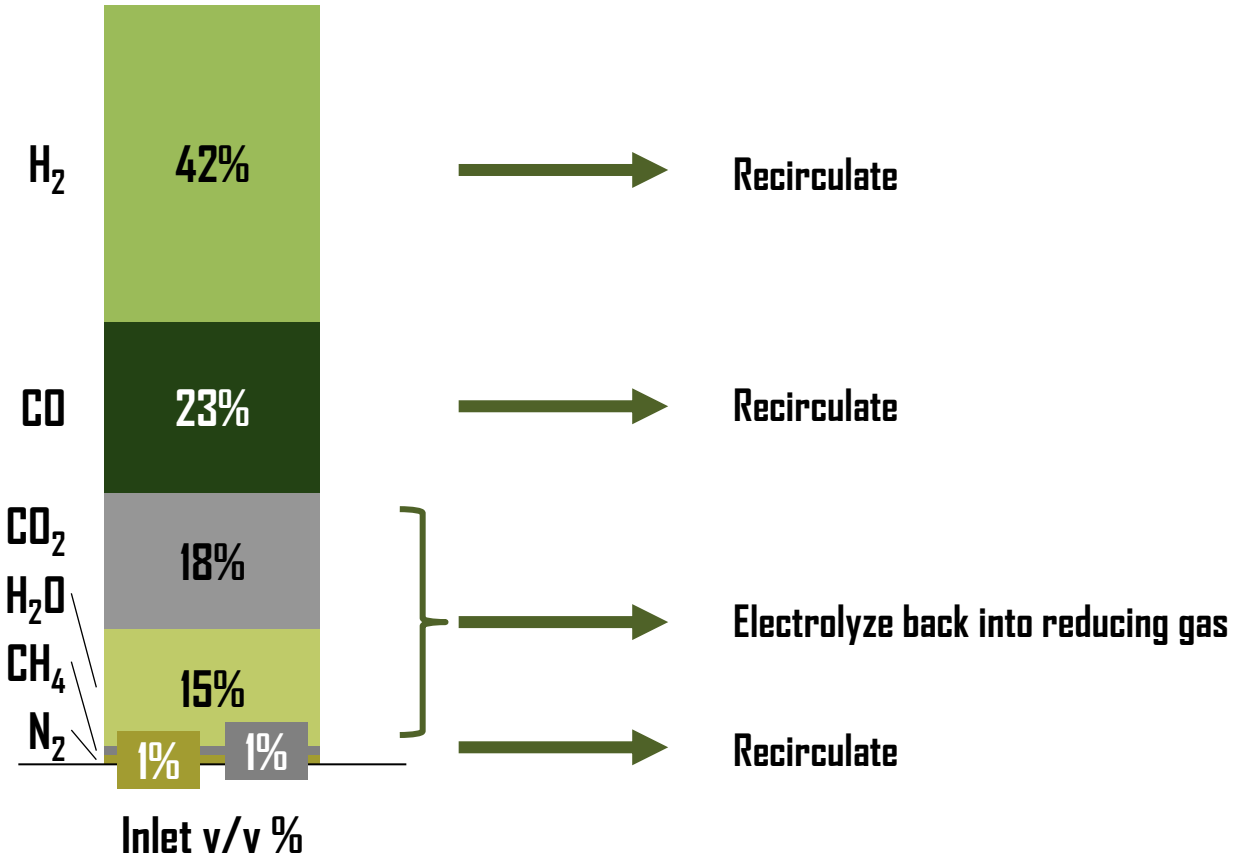


- **Direct Conversion:** The first electrochemical system built ground-up to handle top gas, including <30% $CO_2$, up to 200 ppm sulfur, and particulates
- **Zero Risk:** Redundant cells operate in parallel with closed-loop dynamic control

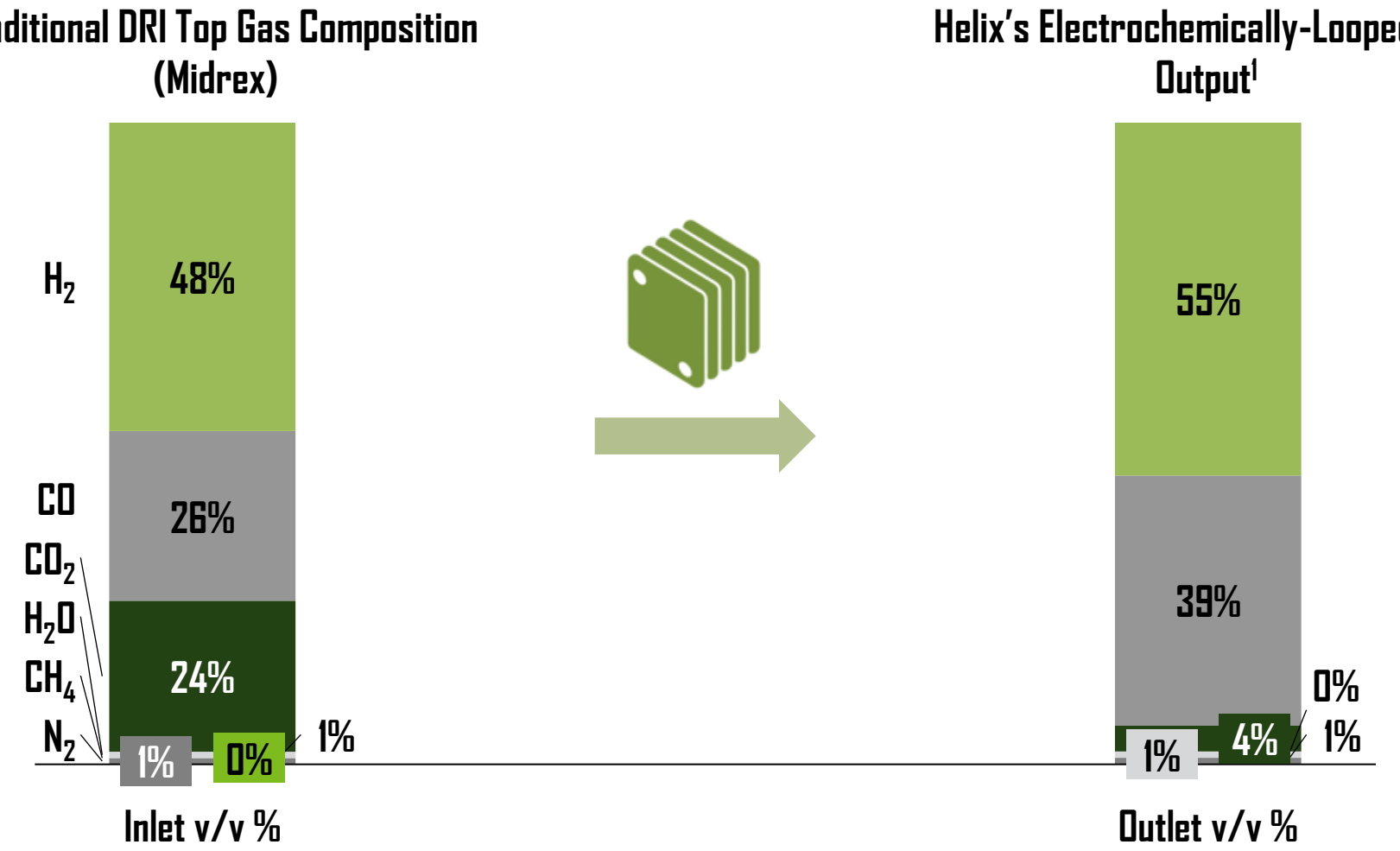
**Meaning drop-in operational savings at today's furnaces**

- **Drop-In:** Uses existing BFG process lines and lances for reinjection
- **Gas Compatibility:** Can match existing reducing gas compositions 1:1
- **Scalability:** Small systems can be installed for instant impact, then scaled

# Traditional DRI Top Gas Composition (Midrex)



# An identical DRI reducing gas means drop-in compatibility



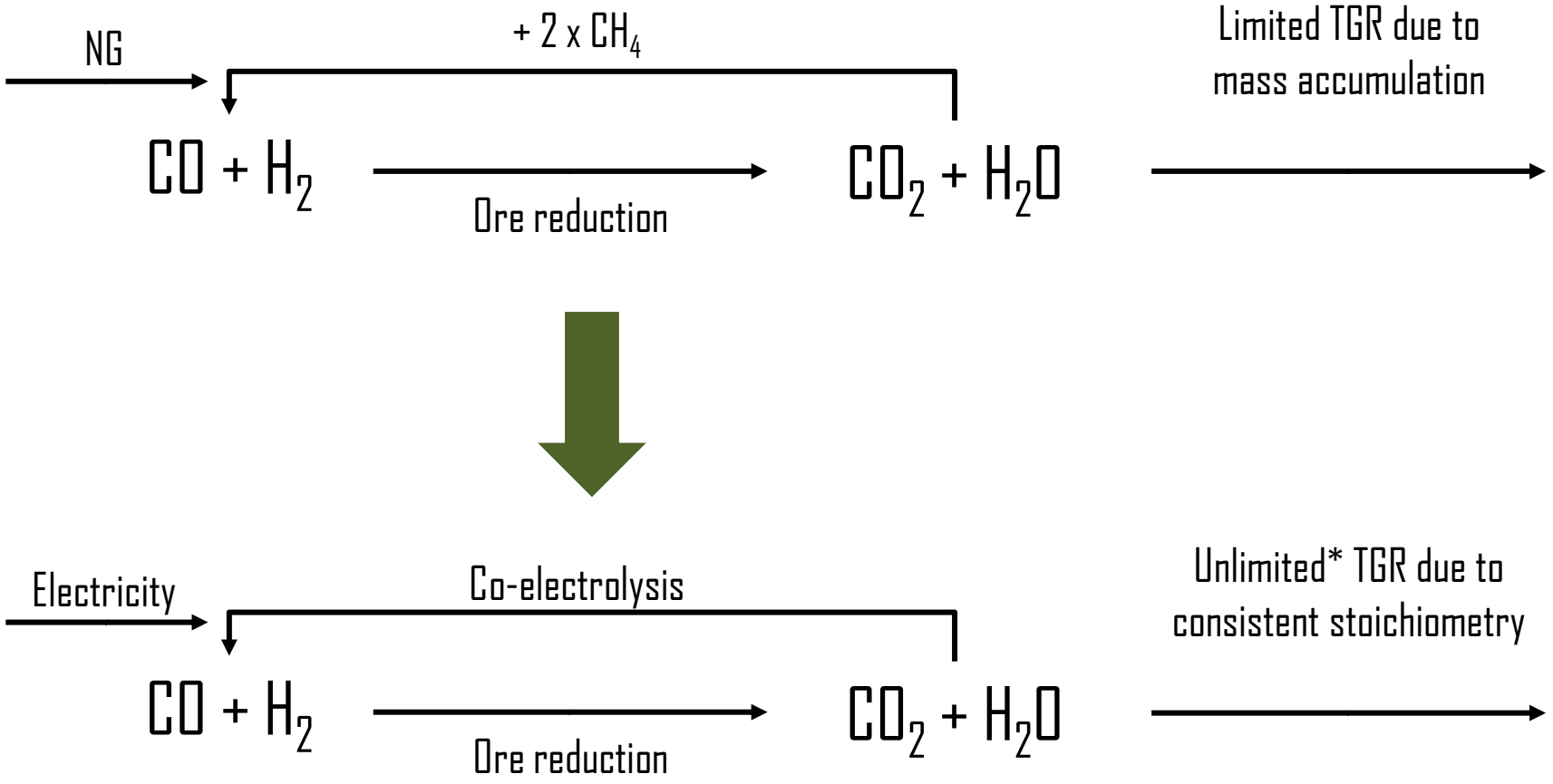



1: Gas composition is tunable based on desired $H_2$:CO ratio.

NG Feedstock → $CH_4$ —Reforming→ $CO + H_2$ —Ore reduction→ $CO_2 + H_2O$ → Emission

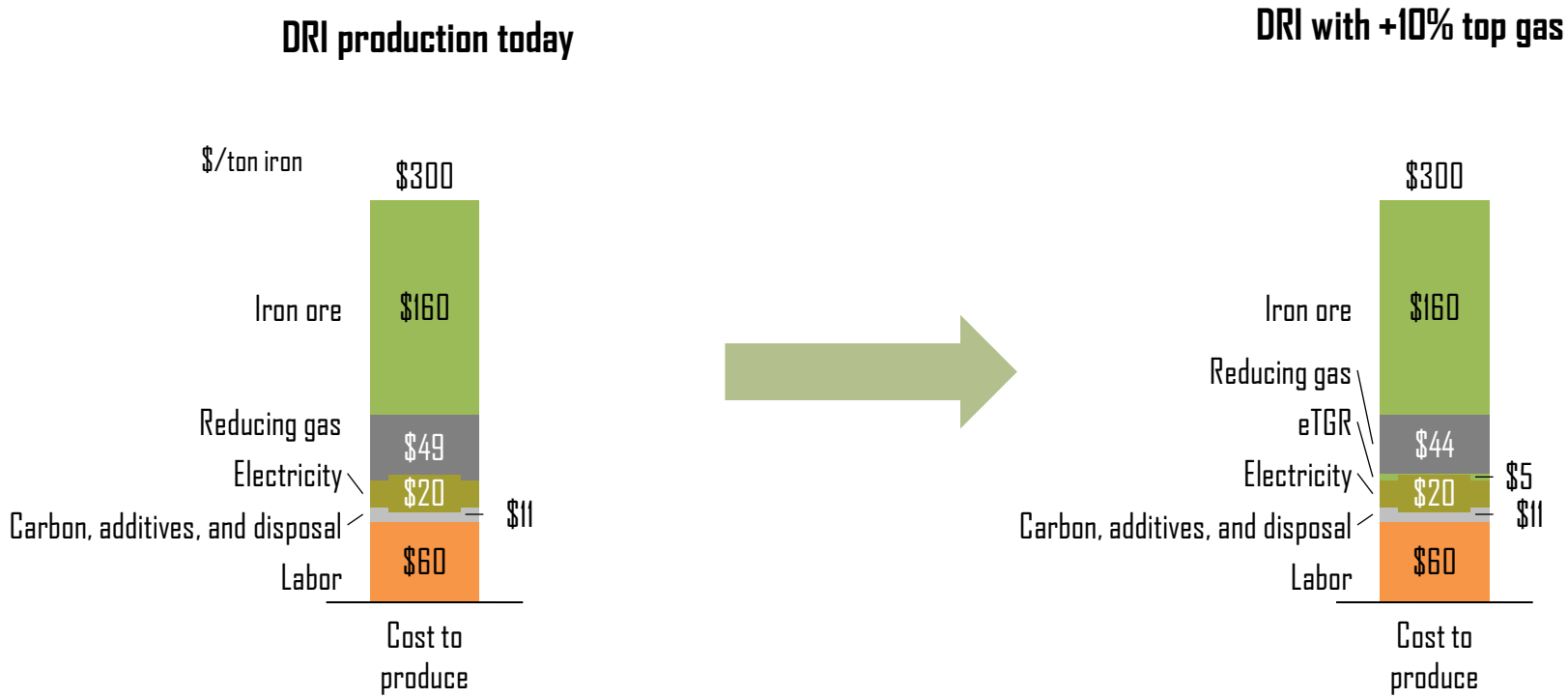
Electricity → $CO + H_2$ —Ore reduction→ $CO_2 + H_2O$, with Co-electrolysis returning $CO_2 + H_2O$ to $CO + H_2$

# Increased top gas recycling can increase furnace efficiency



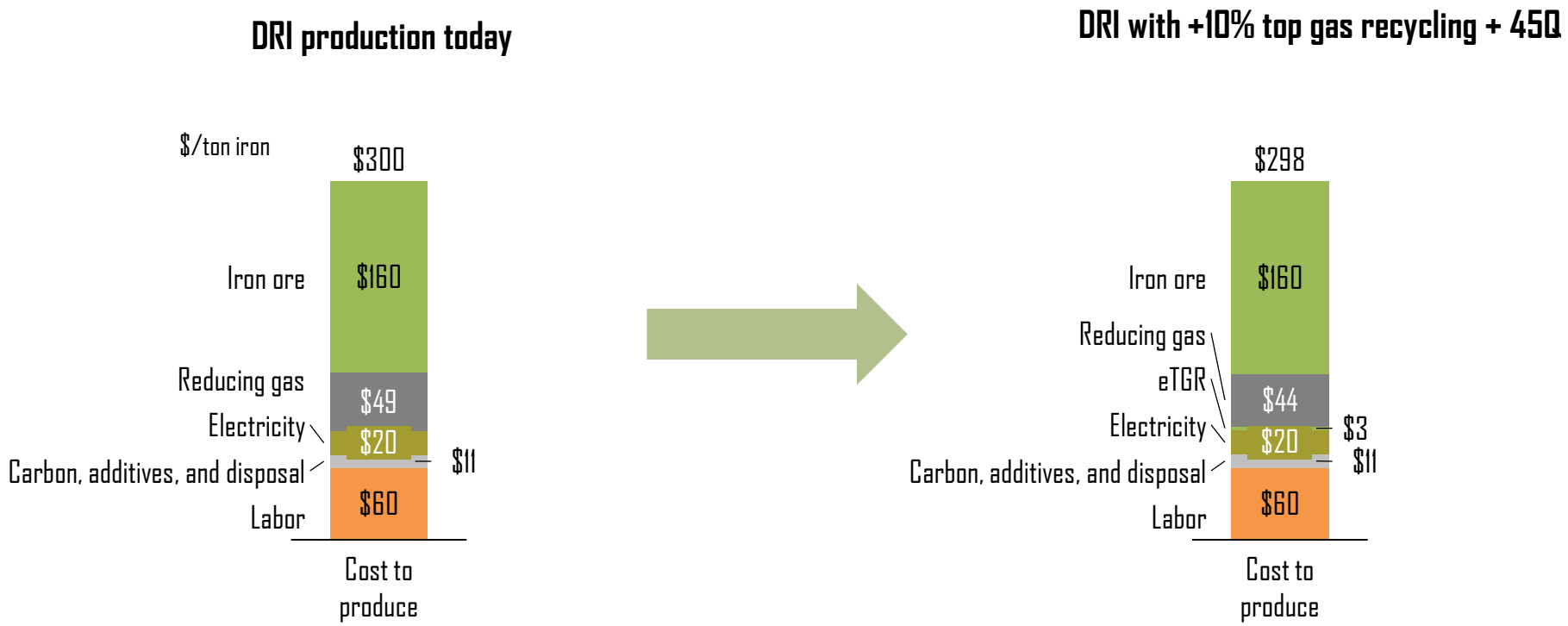

*95%+ possible, some gas bleeding is necessary to remove buildup of trace gases

# System can work alongside existing reformer while displacing NG



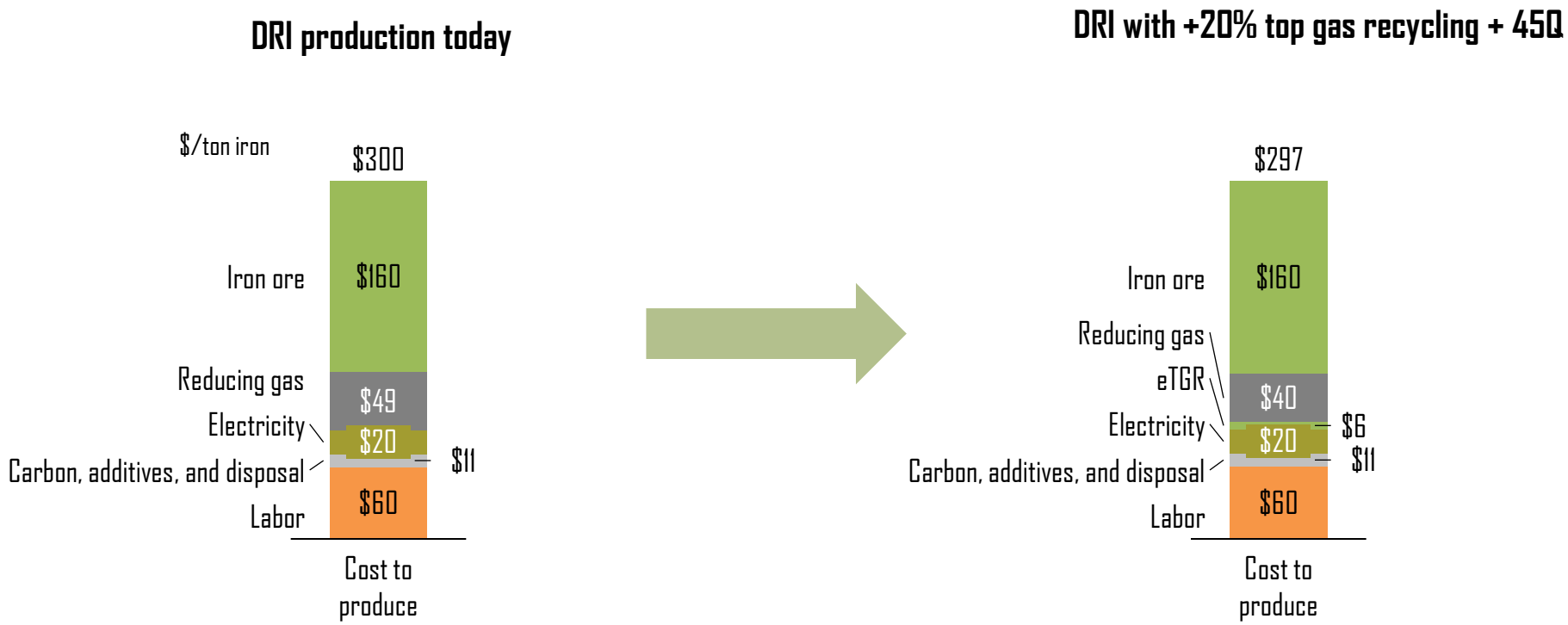

System injects reducing gas through existing tuyeres while blending excess oxygen into the hot air blast. Does not include performance gains from oxygen injection or cost savings from on-site oxygen by-production, which can further enhance profitability. Economics use 10.5 GJ/THM with gas at $5/MMBtu, corresponding to roughly $49/THM in NG costs.

# System can work alongside existing reformer while displacing NG




System injects reducing gas through existing tuyeres while blending excess oxygen into the hot air blast. Does not include performance gains from oxygen injection or cost savings from on-site oxygen by-production, which can further enhance profitability. Economics use 10.5 GJ/THM with gas at $5/MMBtu, corresponding to roughly $49/THM in NG costs.

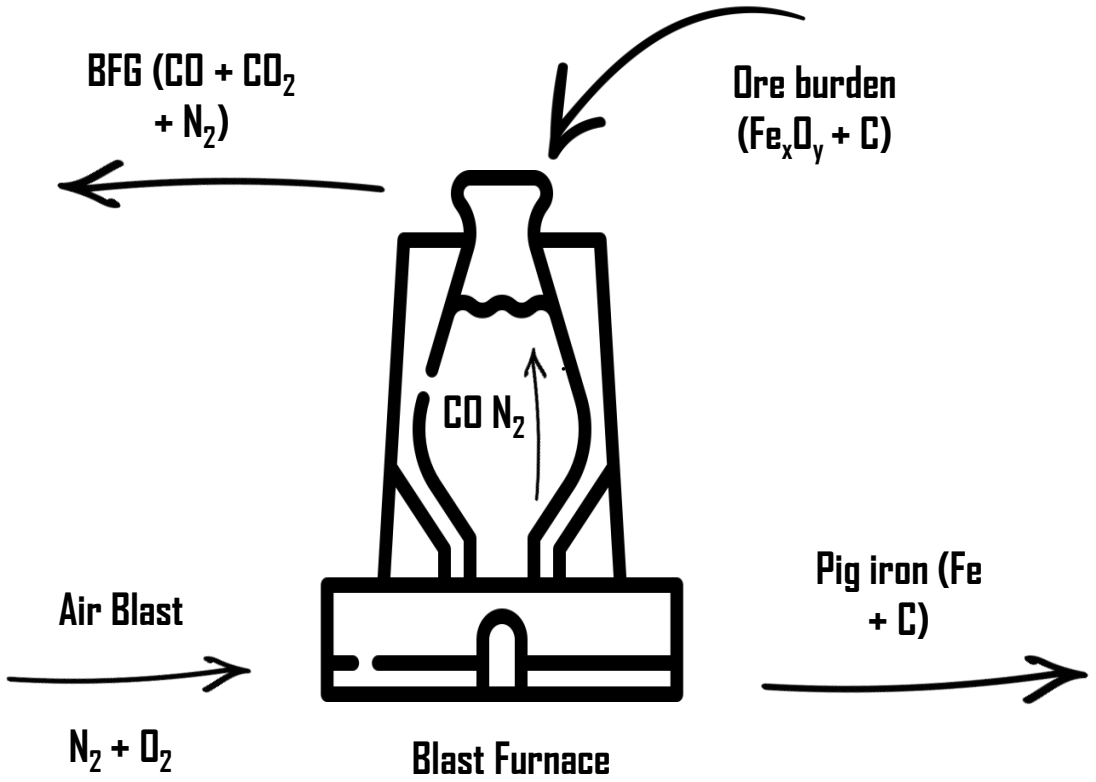
# System can work alongside existing reformer while displacing NG



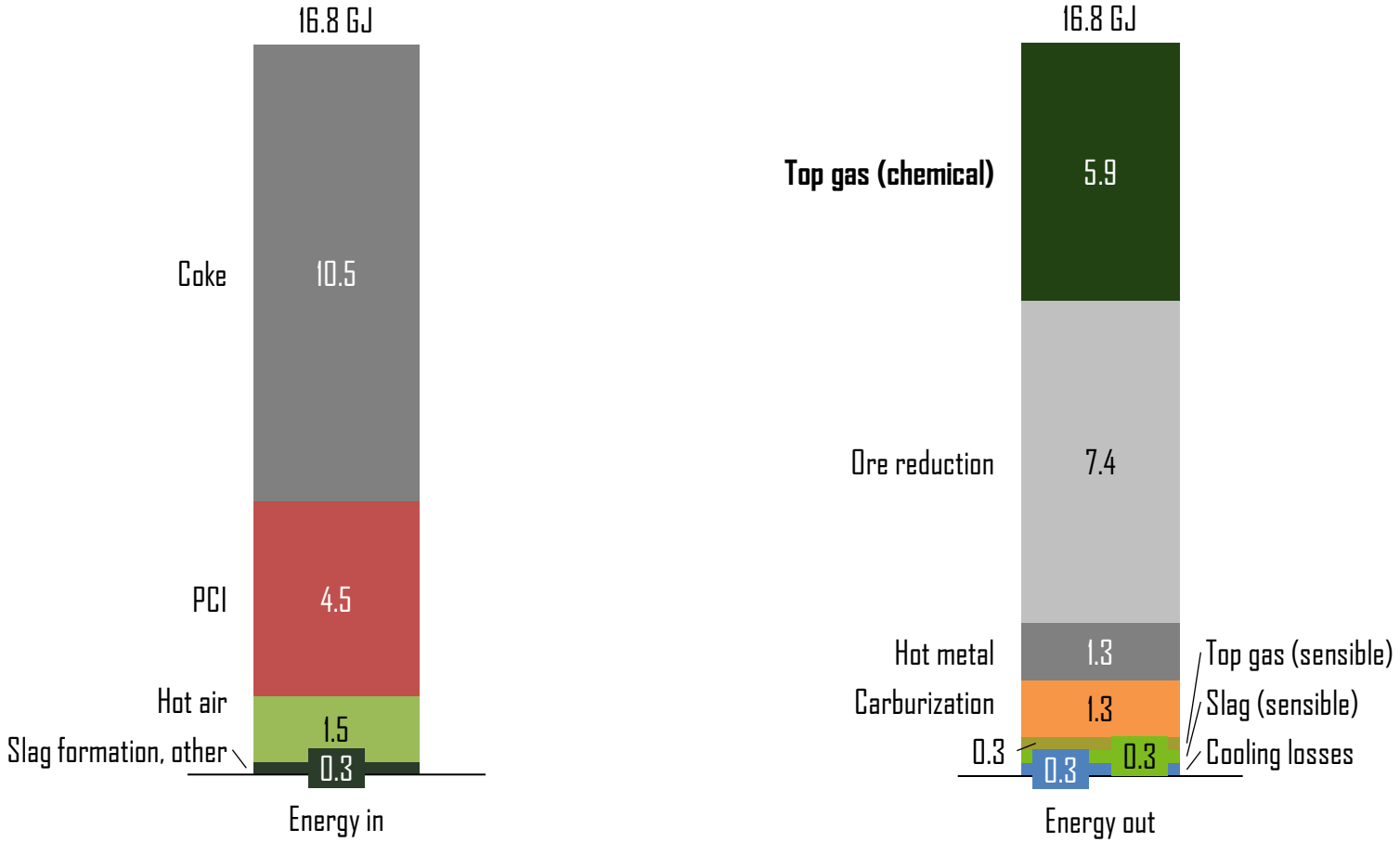

System injects reducing gas through existing tuyeres while blending excess oxygen into the hot air blast. Does not include performance gains from oxygen injection or cost savings from on-site oxygen by-production, which can further enhance profitability. Economics use 10.5 GJ/THM with gas at $5/MMBtu, corresponding to roughly $49/THM in NG costs.

# BFs primarily operate on indirect reduction via CO

Today:

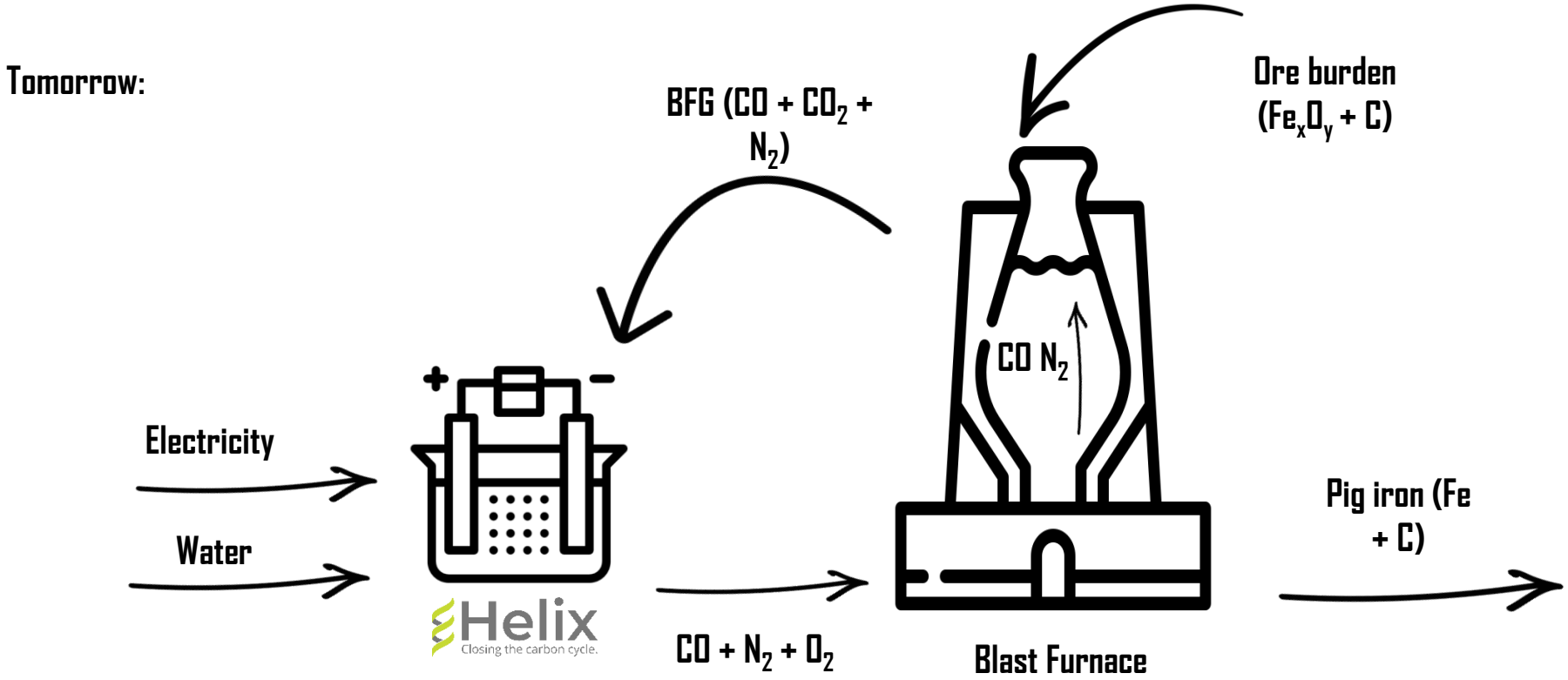


# Major portion of BF energy lost as top gas chemical energy

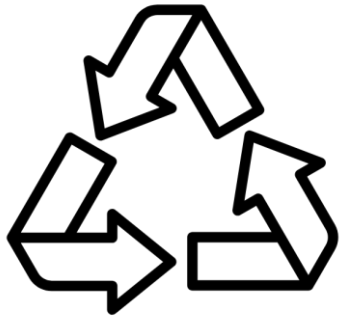



Source: Coking rate of 350 kg/THM, PCI rate of 150 kg/THM. Worrell et al. (2010), Nogami et al. (2006), De Ras et al. (2019), Lu et al. (2019), Musial (2019), DoE (2015), and IEA (2007).

# "eTGR": Top gas recycling compatible with existing furnaces

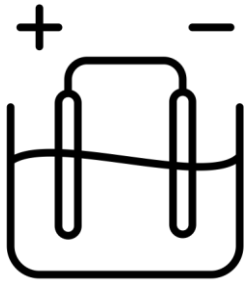


# Single electrolysis system plays three roles



**Top gas recycling**

Electrolyzer enables full re-utilization of blast furnace gas through tuyeres, reducing coke costs



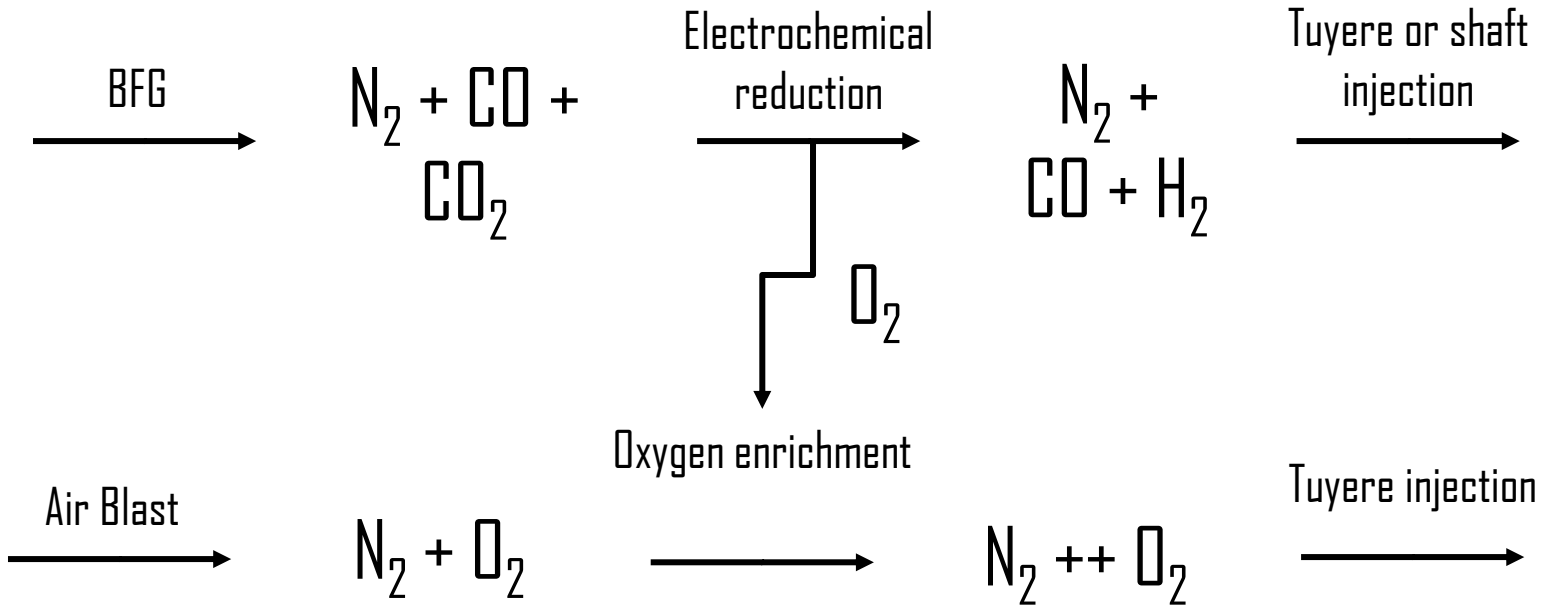

**$CO_2$ conversion & syngas injection**

Electrolyzer converts $CO_2$ back into CO, supplementing recycled syngas with a "carbon loop"

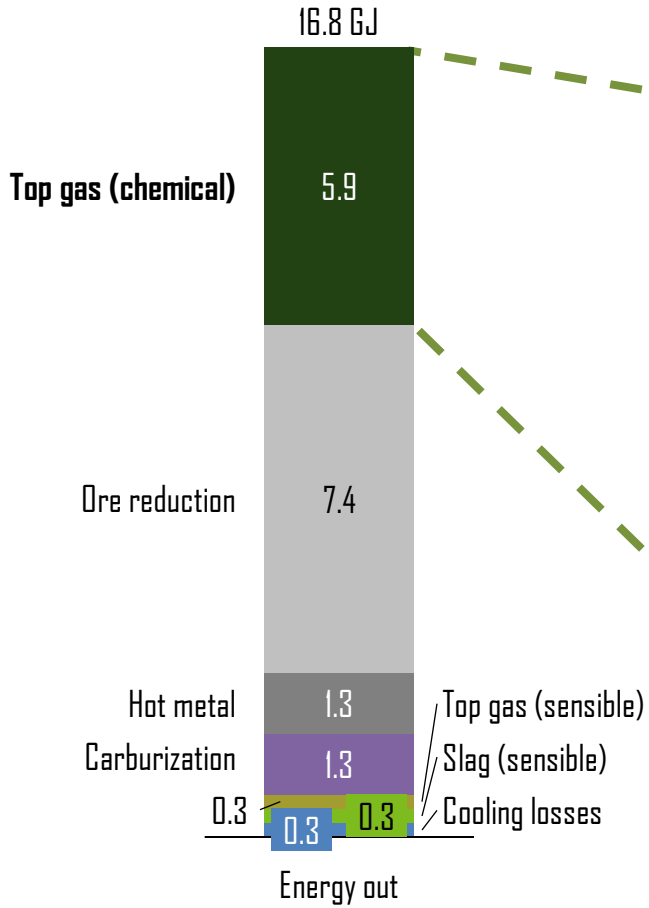
**Oxygen enrichment**

Byproduct $O_2$ enriches air blast for improved furnace productivity

***All with minimal footprint and no carbon capture or gas separation required***


BFG
$N_2 + CO + CO_2$
Electrochemical reduction
$N_2 + CO + H_2$
Tuyere or shaft injection
$O_2$
Oxygen enrichment
Air Blast
$N_2 + O_2$
$N_2 ++ O_2$
Tuyere injection

# Lost BFG energy can be recovered through e-chem recycling




**Energy consumption of system with 30% coking rate reduction**

**60**
**Wh/mol syngas**

**0.9**
**MWh/THM**

**- 30%**
**potential emissions**

*Preliminary*

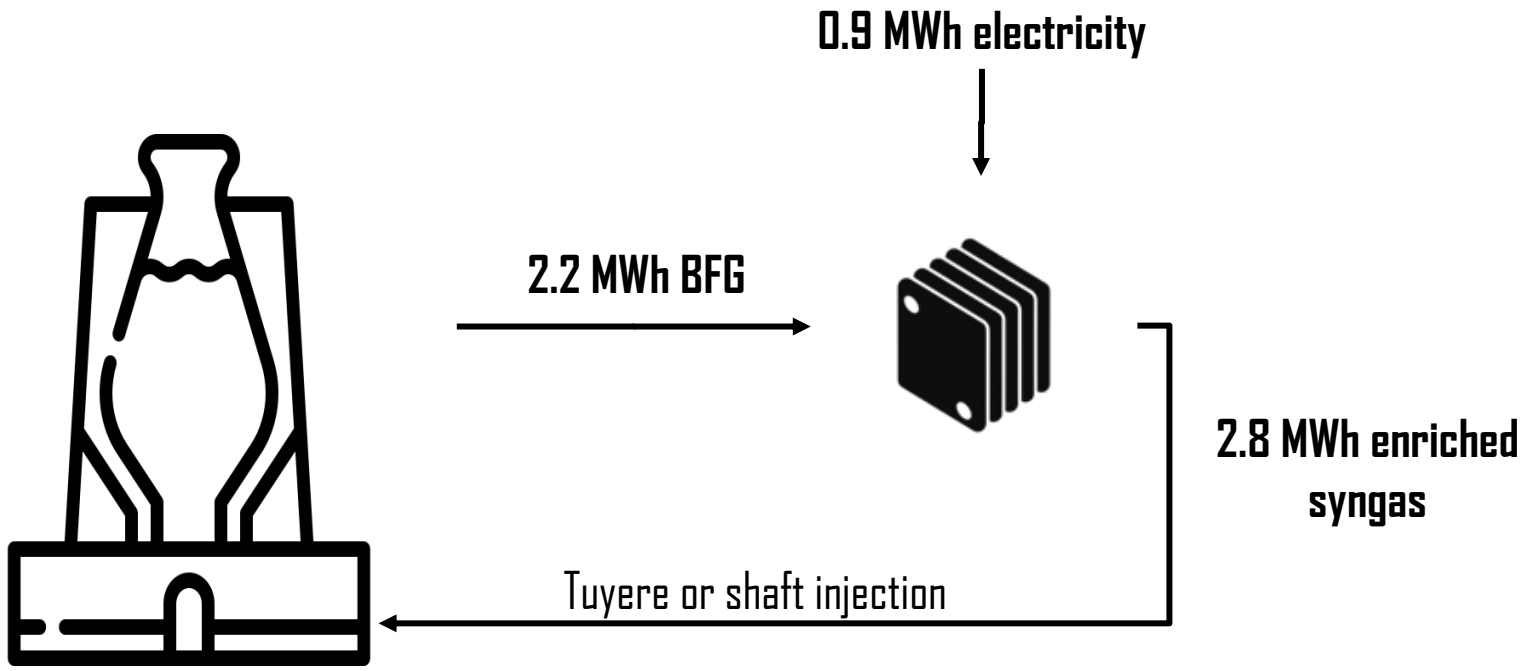
Source: Coking rate of 350 kg/THM, PCI rate of 130 kg/THM. Worrell, E., et al. (2010), Lu et al. (2019), and IEA (2007). MWh/ THM is inclusive of gas reheat energy.

# Energy inputs with eTGR maintain overall LHVs


*Preliminary*

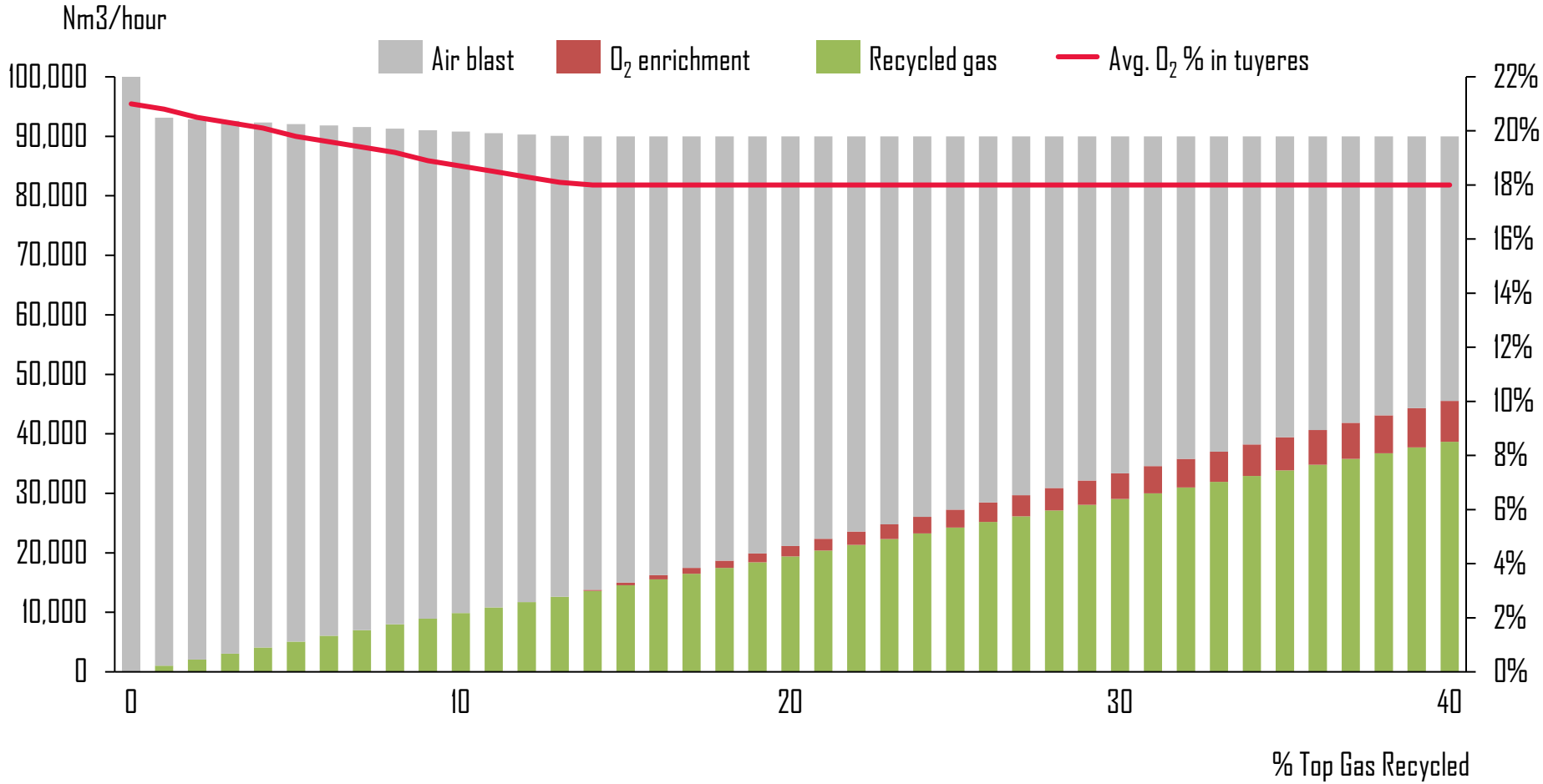
eTGR = electrochemical top gas recycling. Energy calculated using LHV of various fuels.

# 0.9 MWh/THM electrical unlocks 2.8 MWh in syngas




*Preliminary*

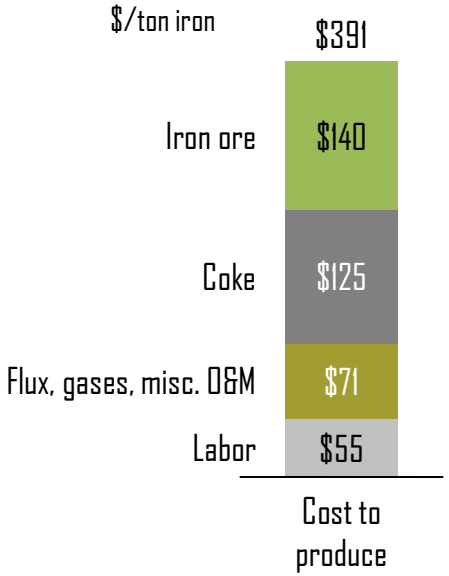
# Gas velocity, $N_2$ flow, and $O_2$ can be maintained with enrichment



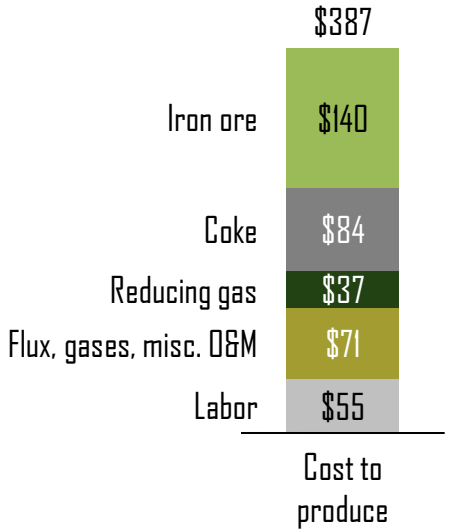

Internal modeling of 900 kt/year BF. Model constraints include 18% floor for $O_2$ concentration in air blast, maintained gas velocity through the furnace to manage sensible heat, and a starting condition of 1000 $Nm^3$/THM of air blast, 50% $N_2$, 22% $CO_2$, 23% CO, 5% $H_2$ initial BFG composition.

# In BF, system can competitively displace coke & emissions

**BF production today**



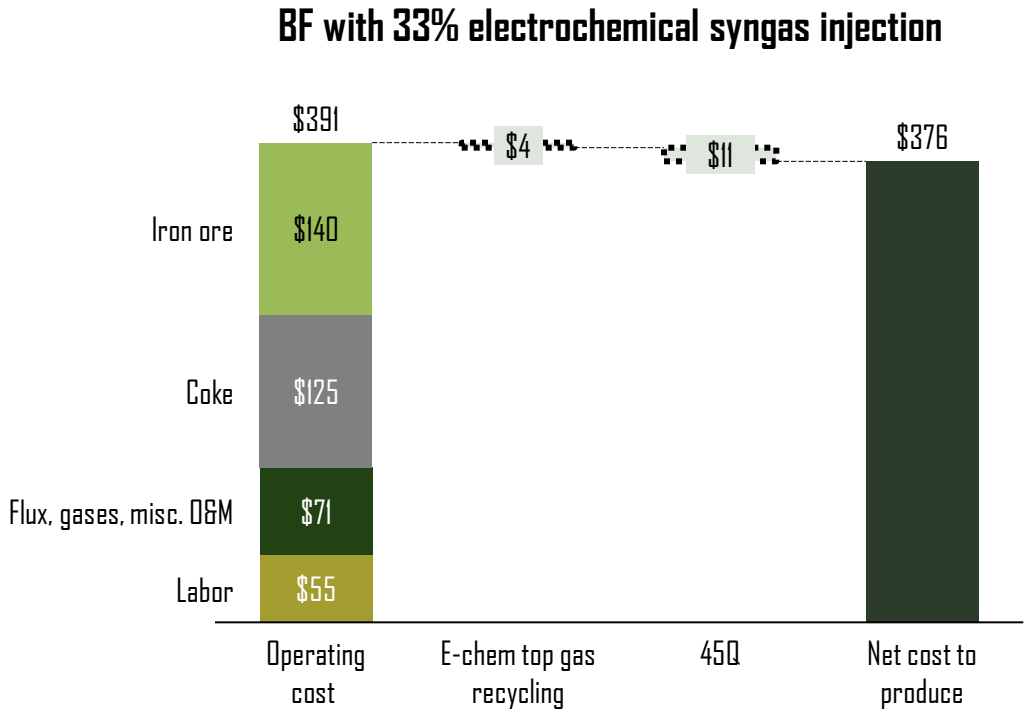

**BF with 33% electrochemical syngas injection**




*Preliminary*

System injects reducing gas through existing tuyeres while blending excess oxygen into the hot air blast. Does not include performance gains from oxygen injection or cost savings from on-site oxygen by-production, which can further enhance profitability. BF-based economics use 24/7, $0.05/kWh electricity pricing. Based on a BF with 490 kg/THM fuel rate.

# With 45Q or EU's CBAM, margin expands further



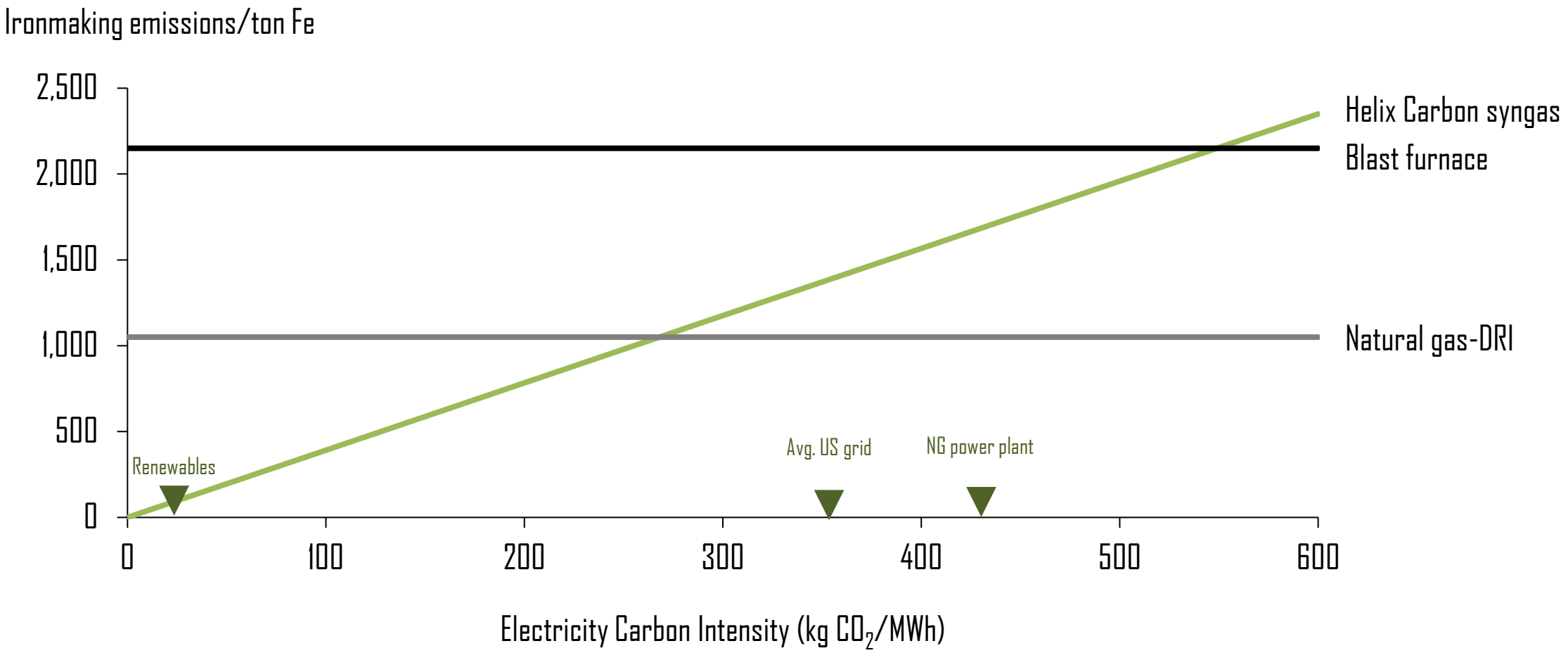

**2-4%**

**reduction in production cost, equivalent to a "carbon price" of -$5-10/$tCO_2$**

*Preliminary*

System injects reducing gas through existing tuyeres while blending excess oxygen into the hot air blast. Does not include performance gains from oxygen injection or cost savings from on-site oxygen by-production, which can further enhance profitability. BF-based economics use 24/7, $0.05/kWh electricity pricing. Based on a BF with 390 kg/THM coking rate and does not consider additional PCI savings.

# Emissions savings can remain, even with fossil electricity




Sources: U.S. EIA; IPCC, averages median lifecycle emissions values for wind, utility-scale solar, nuclear, and hydropower

# Future questions

- Full validation of coke replacement rate
- Full impact of this mixture on RAFT and TGT
- Viability of mid-shaft injection and improved thermodynamics
- % $O_2$ enrichment necessary to enable high levels of eTGR
- "Coke replacement curve" of injections at high volumes and whether syngas utilization in the furnace will be impacted
- Scale of benefit to furnace productivity in THM/hr
- Marginal "cost" of BFG given tiered uses of gas on-site and replacement options
- Optimal $CO/H_2$ ratio in product syngas for RAFT & reduction kinetics

Helix
Closing the carbon cycle.

# Thank you

Let’s close the carbon cycle together.

Evan Haas | CEO

evan@helixcarbon.co

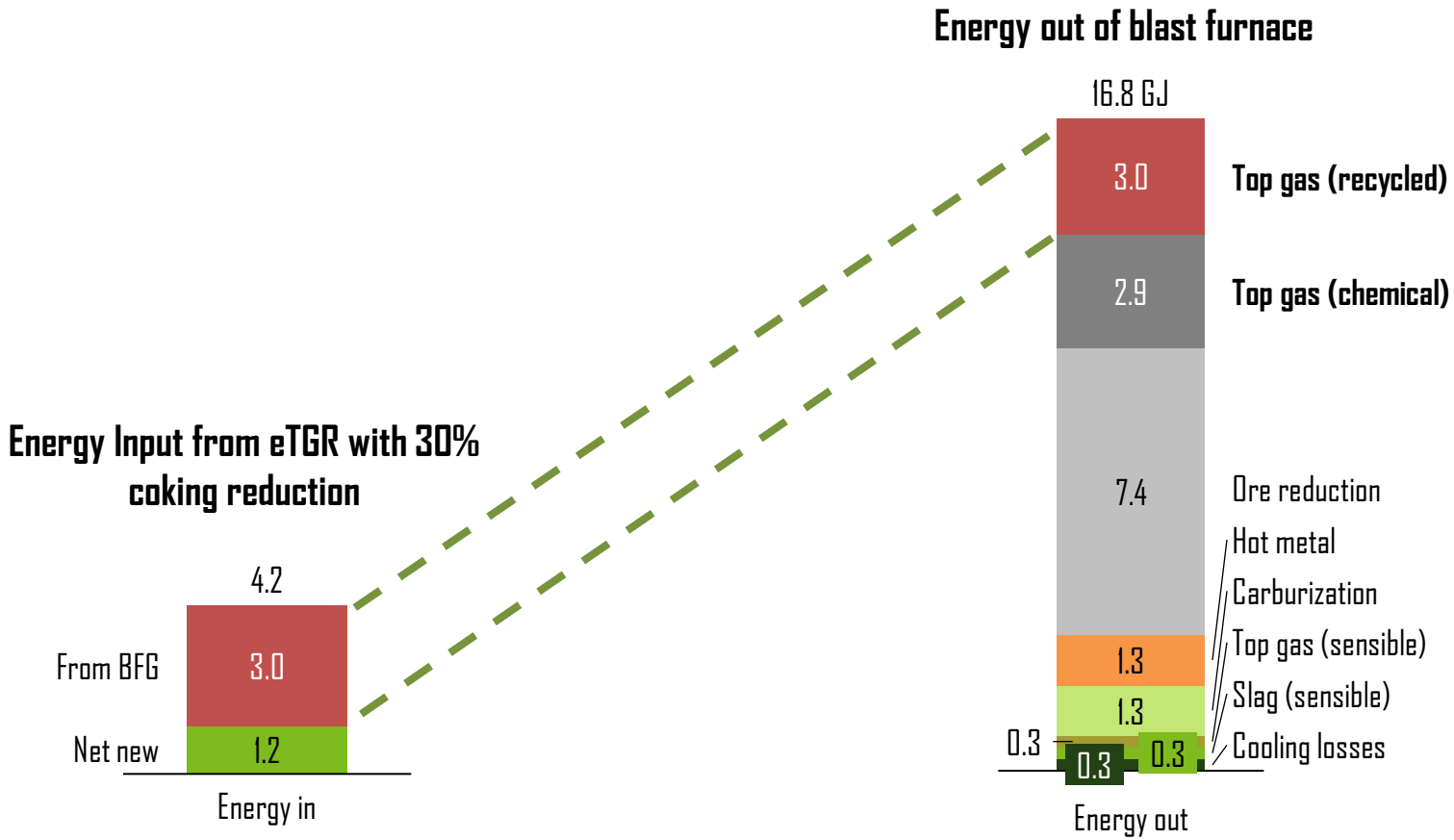
Helix

Closing the carbon cycle.

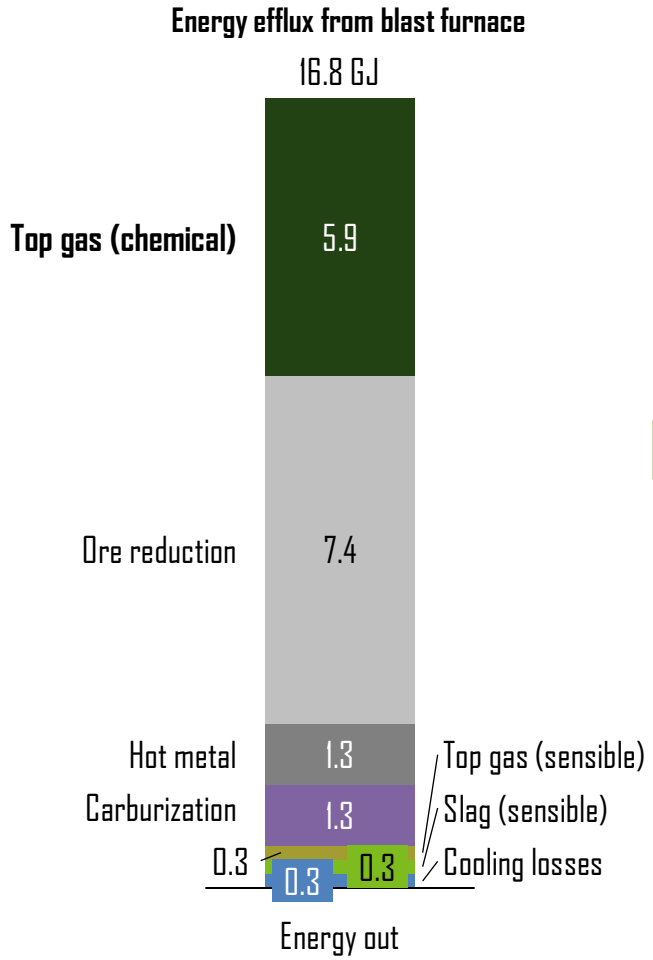
# Appendix

Let’s close the carbon cycle together.

# In max coking reduction via eTGR, system utilizes ~50% BFG

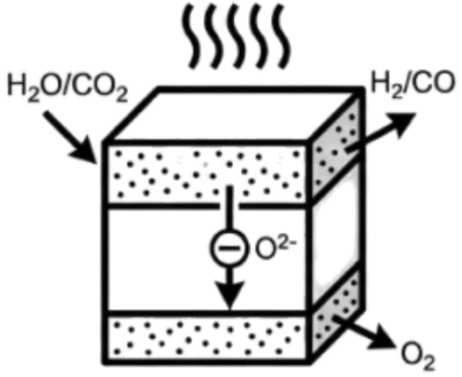


# Why low-temperature electrolysis (LTE)?



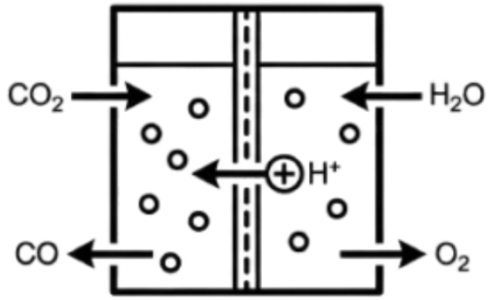

In a well-tuned blast furnace, BFG is only **100-140 °C**, well below SOEC operating temperatures and limiting the energy loss from cooling to 80 °C LTE temperatures

# Why low-temperature electrolysis (LTE)?




**SOEC**

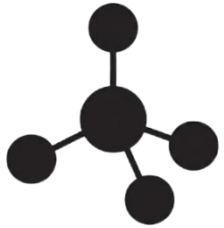
- Coking from Boudouard clogs cell at high CO levels, limiting conversion to <40%
- No at-scale manufacturing of SOECs
- Challenging thermal integration
- Unresponsive to power fluctuations




**LTE**

- High single-pass $CO_2$ conversion
- Leverages existing GW-scale PEM manufacturing capacity
- Minimal balance-of-plant requirements
- Tolerance to intermittent operation, enabling peak shaving or power-price matching in DRI applications

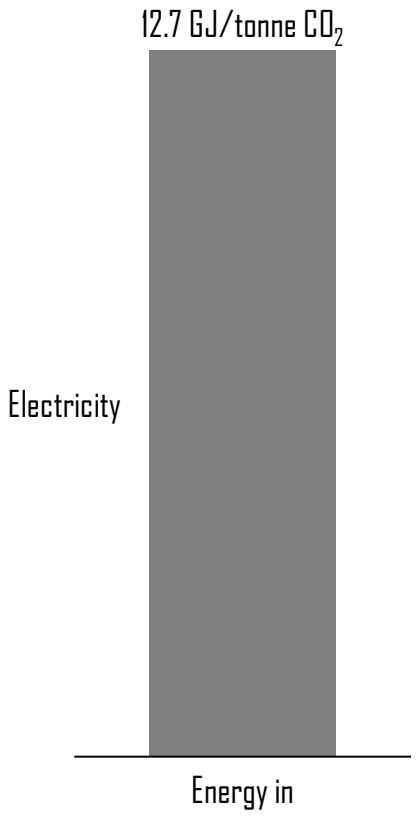
# Supplements NG injection to displace additional coke



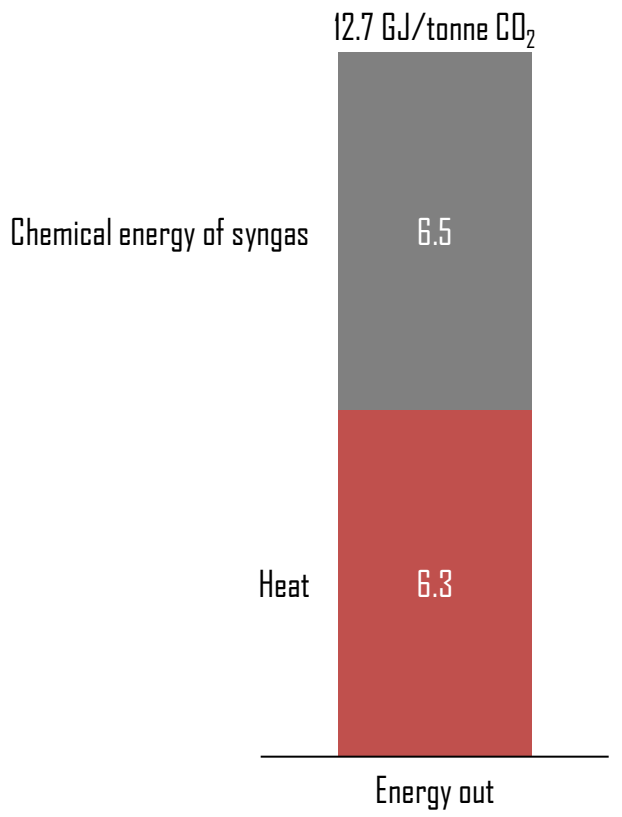
| | Natural Gas | Recycled CO-Rich Gas |
|---|---|---|
| **Raceway Impact** | Significant cooling due to methane cracking | Mild cooling (sensible heat only) |
| **Coke Replacement** | High per kg (due to $H_2$) | Lower per kg (due to lower energy density from CO) |
| **Furnace energy consumption** | Minor reduction | Significant reduction from TGR |
| **Benefits** | Cost reduction, emissions | Cost reduction, add. emissions |
| **Injection Limit** | **Limited** by RAFT (approx. 150 kg/tHM) | **Higher** due to maintained sensible heat flow and RAFT, enabling injection alongside NG |

# Energy balance of electrolyzer itself, net new syngas only

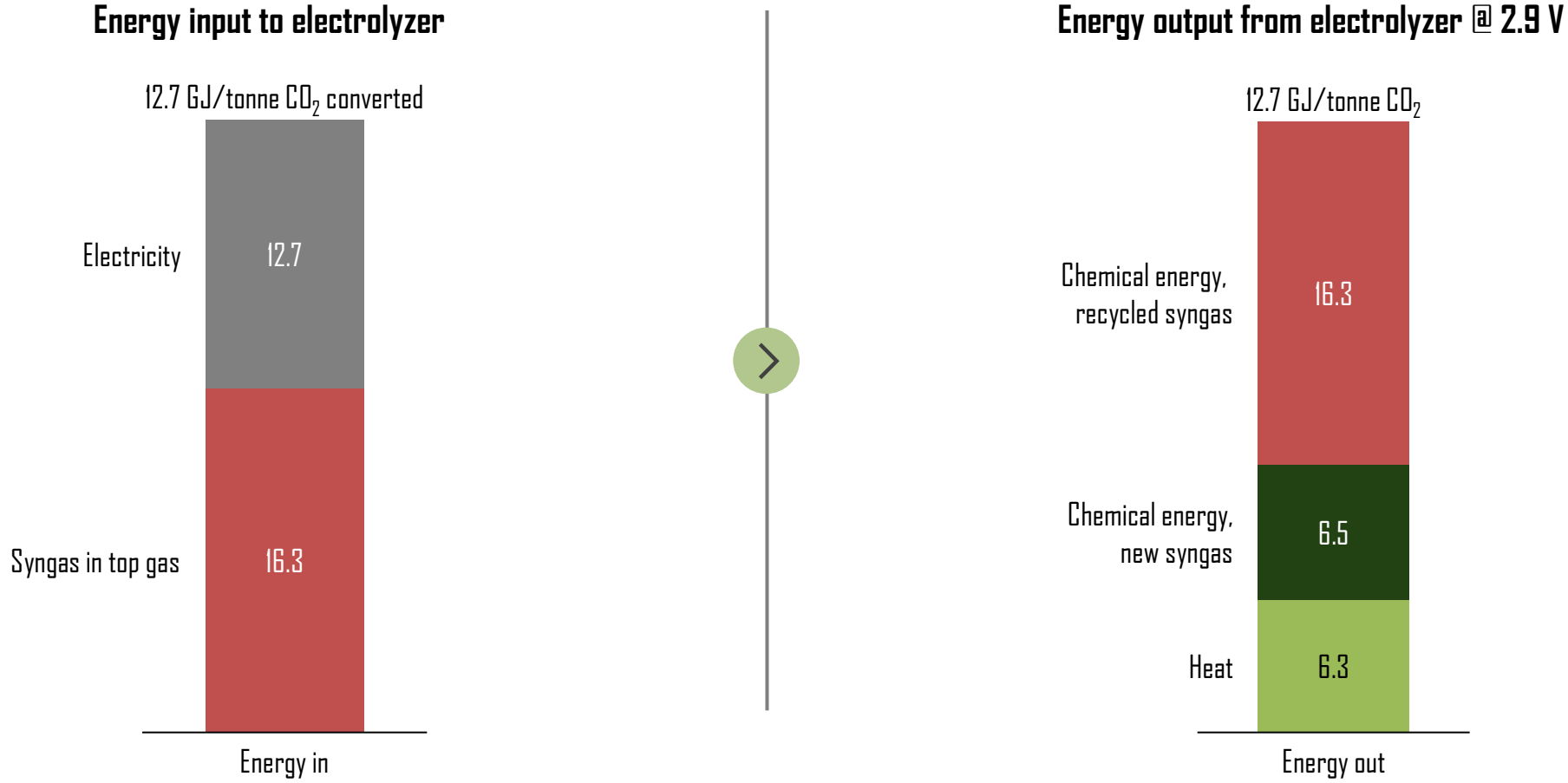
**Energy input to electrolyzer**



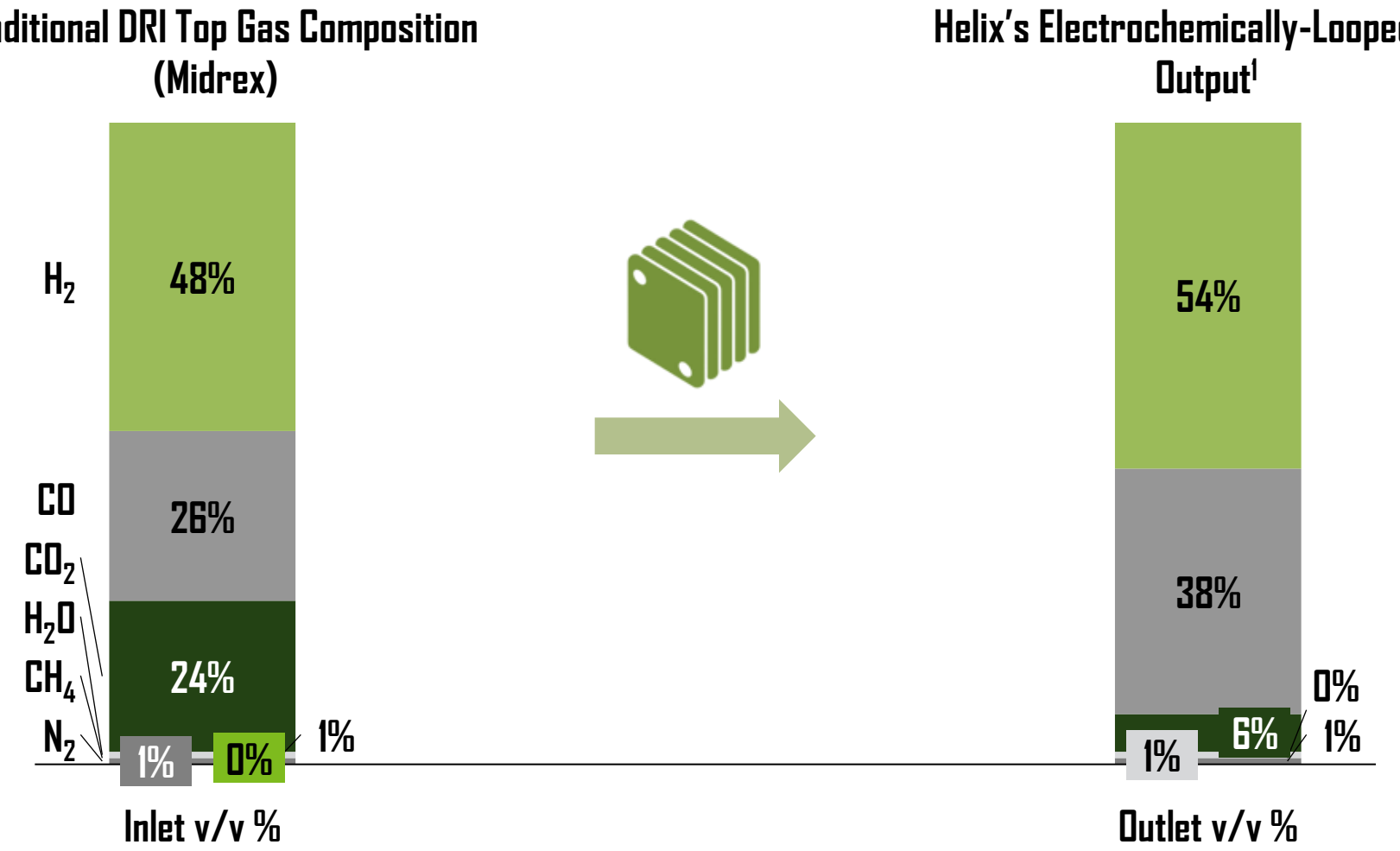

**Energy output from electrolyzer @ 2.9 V**



# Energy balance of electrolyzer itself, including gas recycling



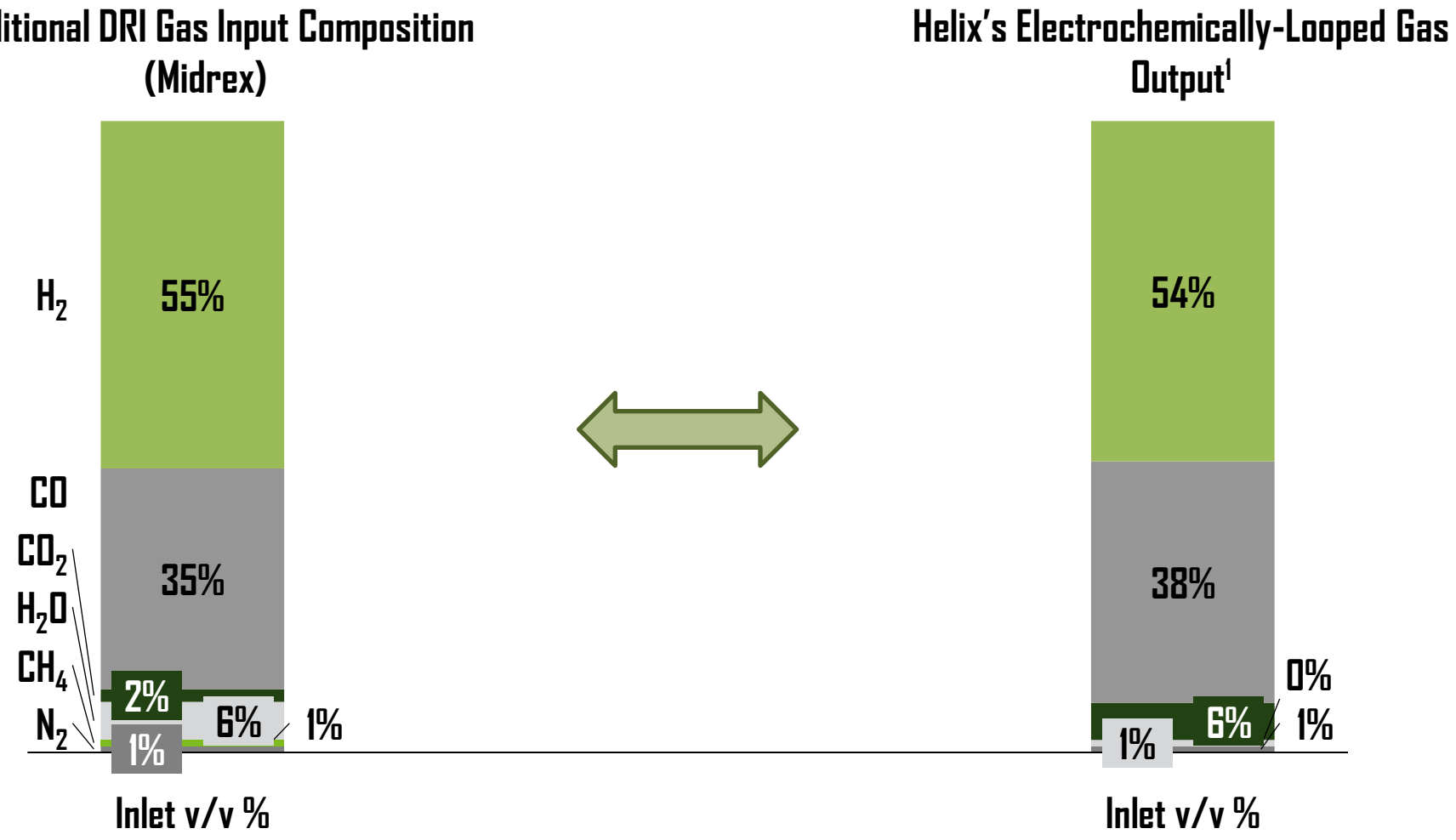
# An identical DRI reducing gas means drop-in compatibility






1: Gas composition is tunable based on desired $H_2$:CO ratio.

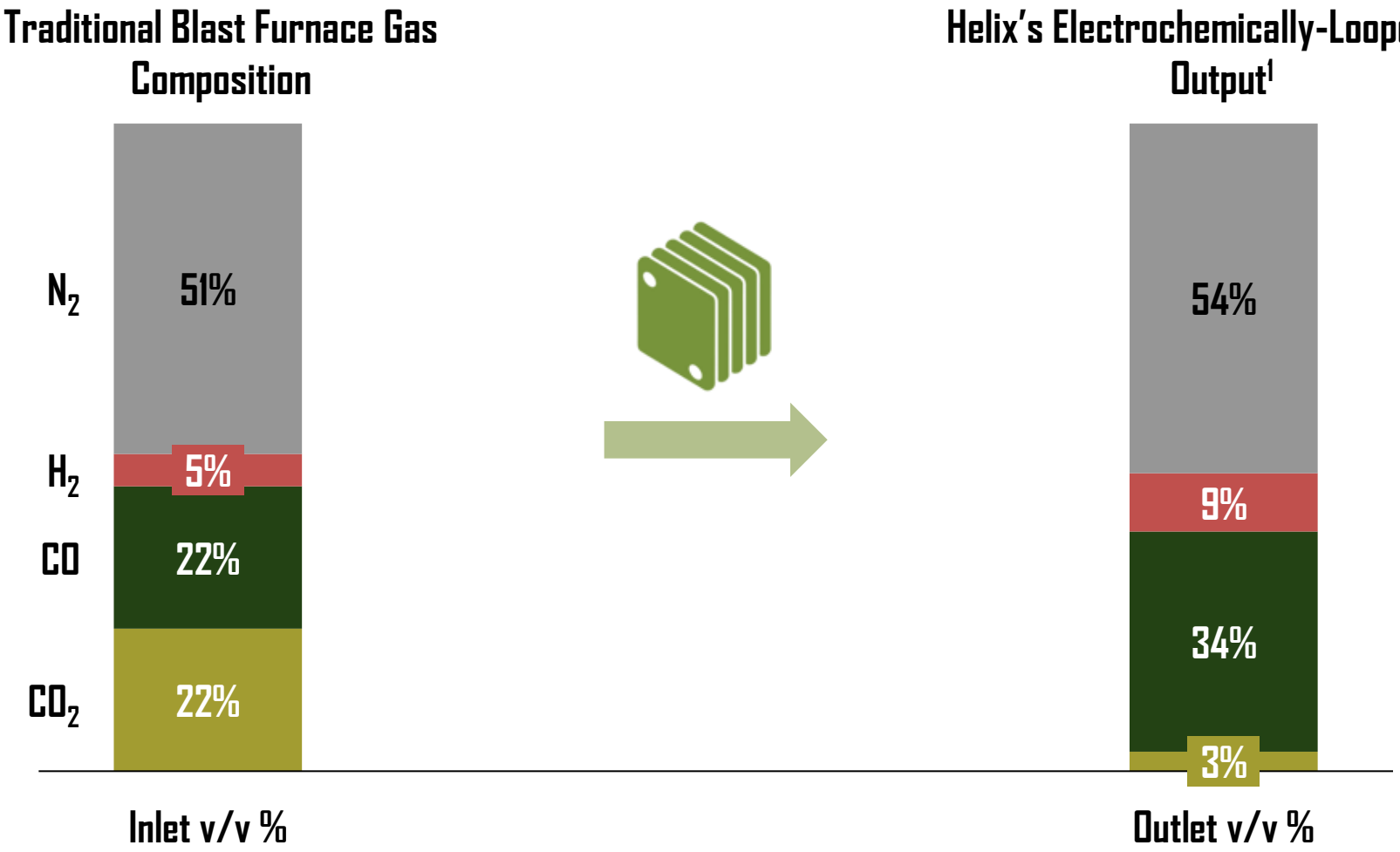
# An identical DRI reducing gas means drop-in compatibility






1: Gas composition is tunable based on desired $H_2$:CO ratio

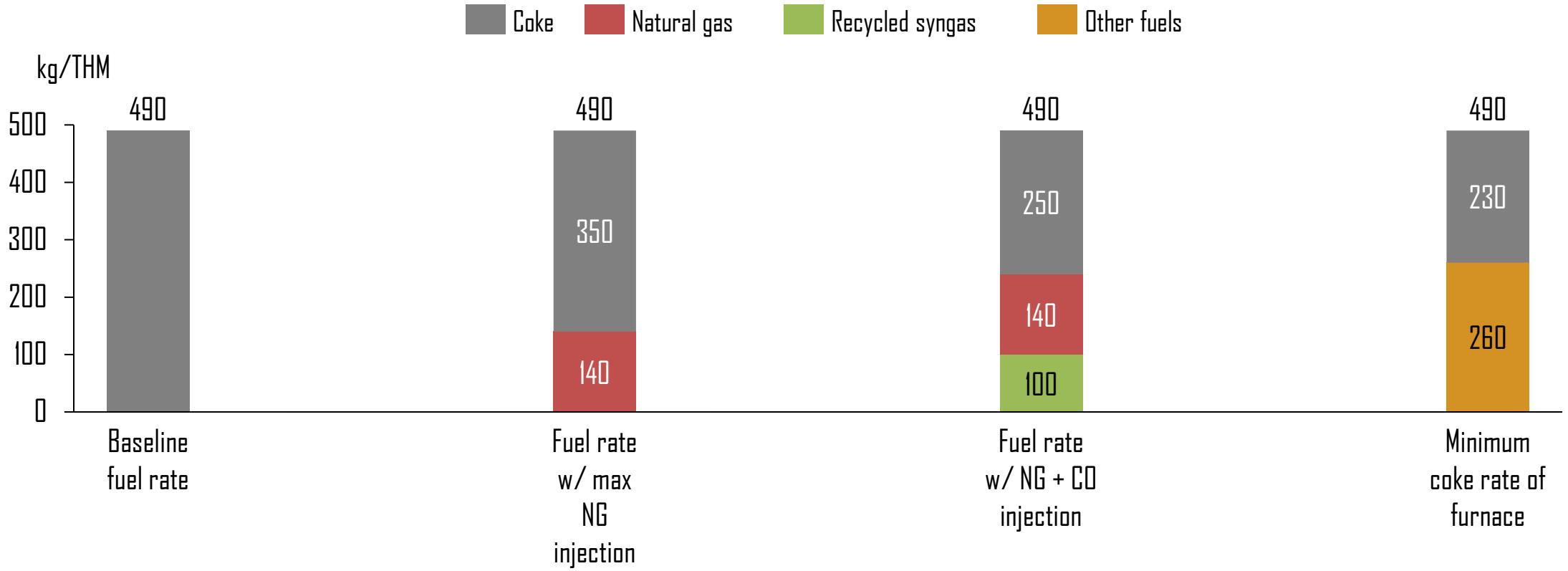
# At blast furnaces, upgrading of top gas enables recycling






1: Gas composition is tunable based on desired $H_2$:CO ratio

# Injection maintains RAFT, can displace add'l coke above NG




Baseline furnace fuel rate. Overall consumption remains constant regardless of fuel.

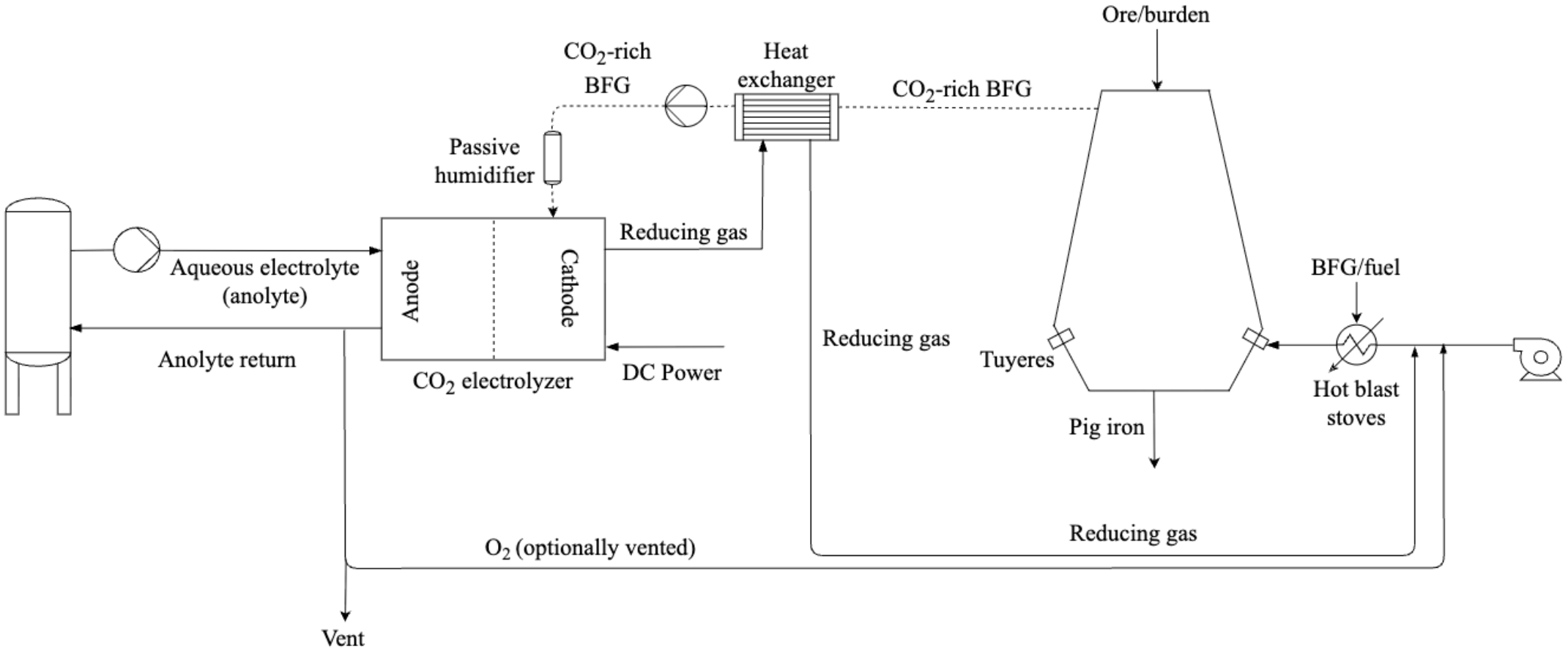
NG displaces coke up to a point, limited by dropping RAFT

Recycled syngas can avoid cracking penalty, further dropping coke rate

Minimum coke rate of blast furnace as defined by porosity/structural integrity

Sources: Okusun et al. (2019), Guo et al. (2013), Ariyama et al. (2016)

# Example: PFD of blast furnace integration



# Example: PFD of DRI (Midrex) integration