CarbSteeler.jl

An Optimization Model for Long-Term Planning of Steel Industry Decarbonization

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PSR

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Agenda

1. Introduction
2. Data Collections
3. Planning Decisions
4. Case Study
5. Conclusions

Introduction

Motivation

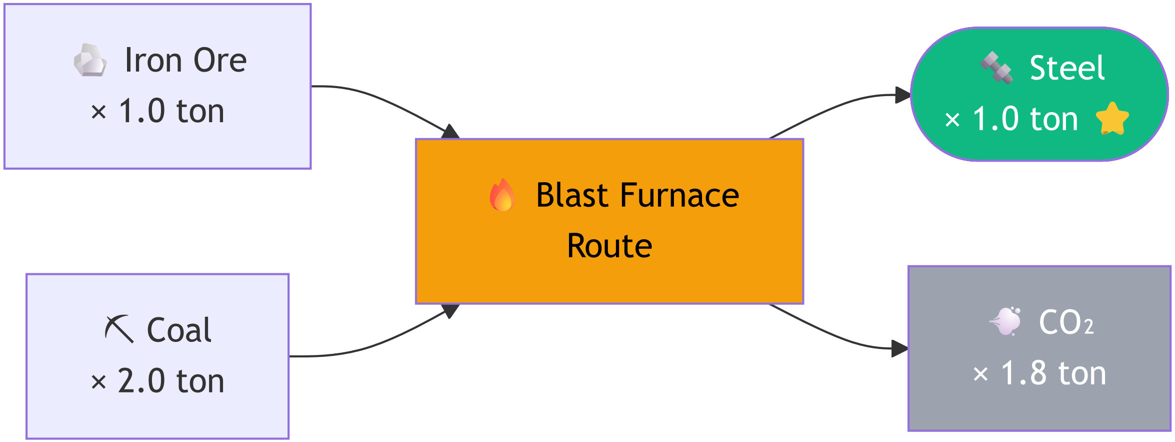
- The iron and steel industry accounts for approximately **7% of global CO_2 emissions**, making its decarbonization a critical challenge for climate policy
- Evaluating transition pathways requires tools capable of capturing the interplay between:
  - Technology selection and investment timing
  - Emission constraints and regulatory frameworks
  - Financial viability across multi-plant industrial systems
- **CarbSteeler.jl** is an optimization model in Julia formulating the steel decarbonization planning problem as a **mixed-integer linear program (MILP)** using JuMP.jl and HiGHS.jl
- It provides a flexible framework for simulating technology transition scenarios, supporting evidence-based policymaking and strategic industrial planning

Data Collections

Route

A **route** defines a conversion recipe: how much of each input is consumed and how much output is produced, per unit of reference product

- Each material has a specific consumption/production ratio and CO_2 intensity
- A route captures a specific operating mode

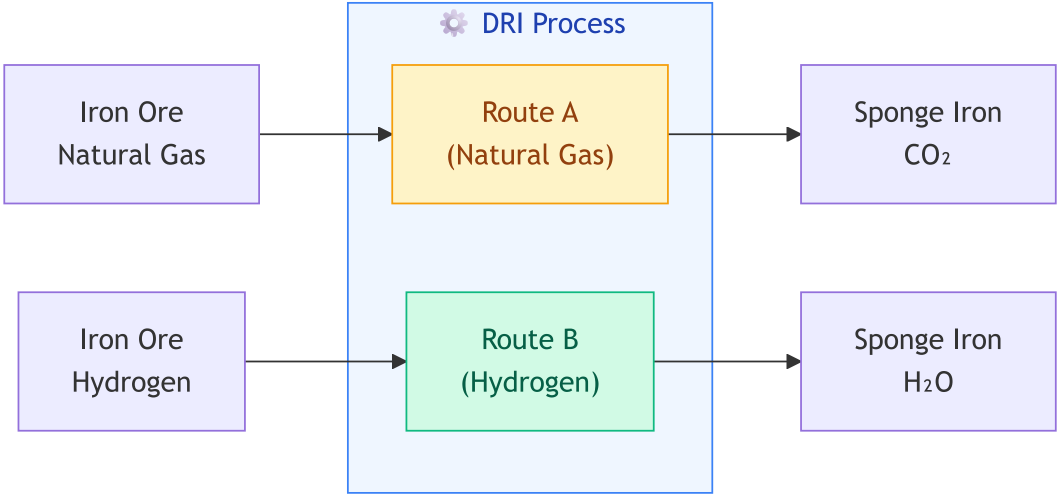


⭐ Reference product — all input/output weights are normalized to 1 unit of this output

Process

A **process** groups multiple routes sharing the same physical technology and capital investment

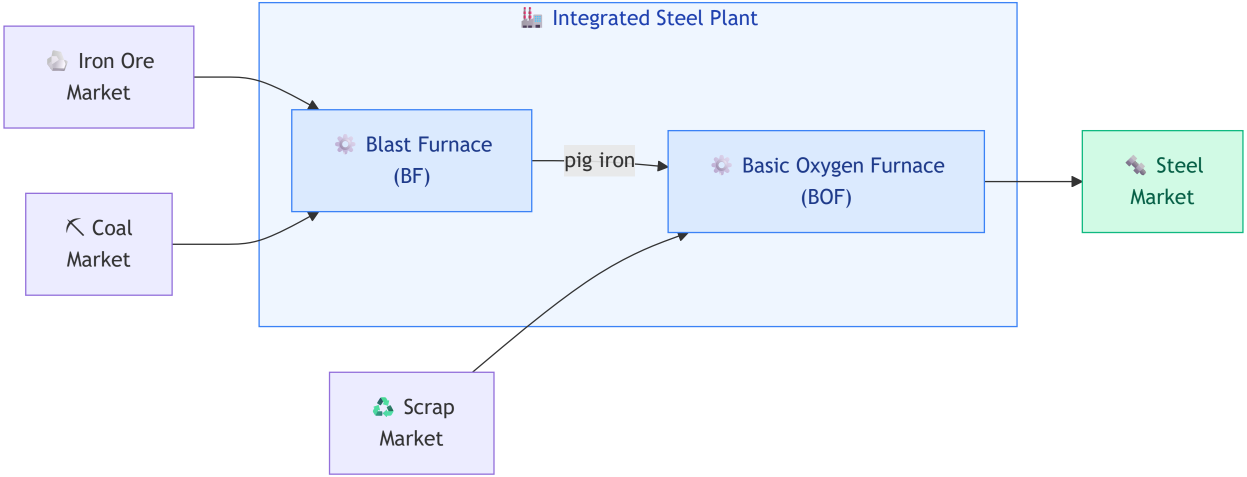
- Multiple routes allow different **operating modes** for the same installed technology
- The optimizer chooses which route combination to activate at each time step



Plant

A **plant** is a physical industrial site that connects processes through material flows

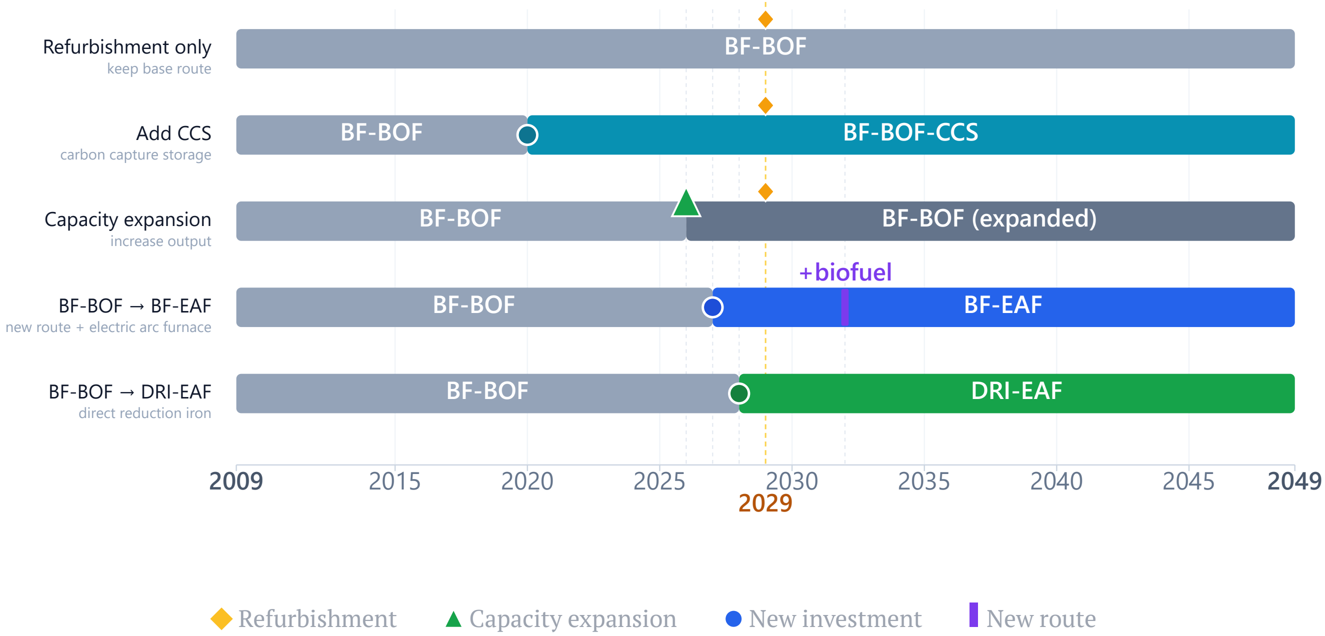
- **Process flow**: graph of process connections within the site
- Intermediate materials flow **between processes** inside the plant
- Local **markets** provide inputs and absorb outputs



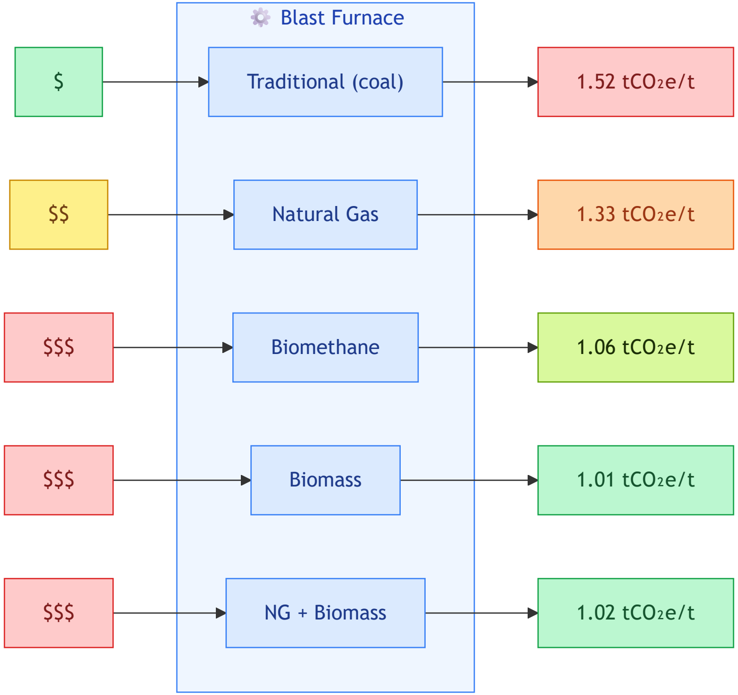
Planning Decisions

Investment Decision

Five transition strategies for an integrated steel mill



Operational Decision



Different **route combinations** can be activated each year for each process, subject to:

- **Production limits** *(regulatory, physical, financial, and contractual)*
- **Global and local resource availability**
- **CO_2 emission limits**
- **CO_2 emission costs**

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Case Study

Brazilian Steel Industry

System scope

- **32 plants** representing 100% of Brazilian steel production
- **8 processes**: BF, Charcoal BF, DRI, BOF (Flat/Long), EAF (Flat/Long), CCS
- **141 process-in-plant** instances: 61 active + 80 candidate
- **18 routes · 23 materials**

Problem size

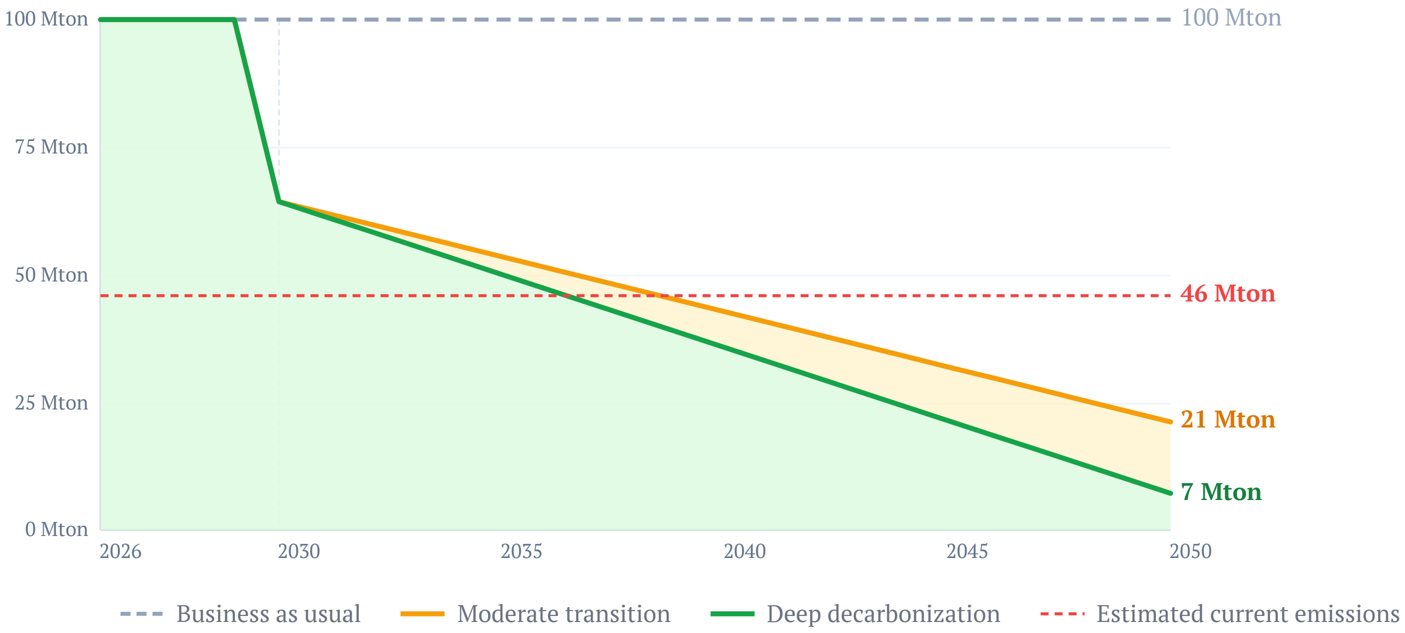
- 195,675 variables (28,425 binary)
- 221,072 constraints

3 scenarios

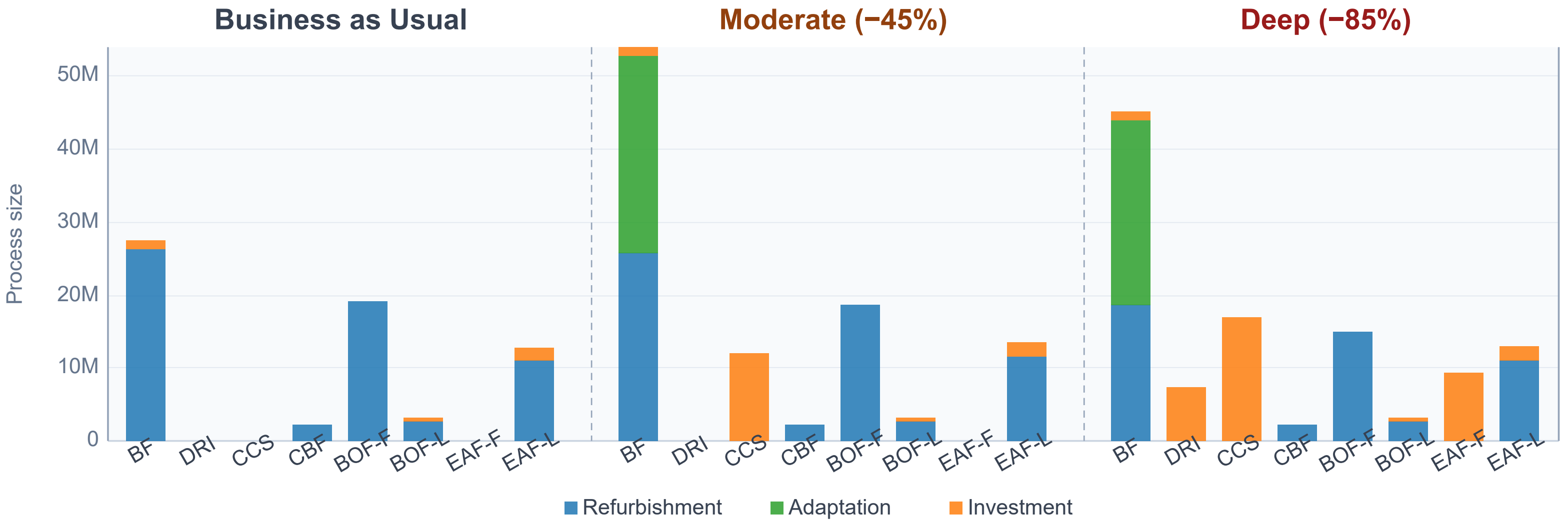
Scenario	CO_2 Target
Business as usual	No limit
Moderate transition	−45% by 2050
Deep decarbonization	−85% by 2050

Both reduction scenarios phased from 2030 onwards.

CO_2 Emission Limits



Investment Trajectory



CBF = Charcoal Blast Furnace
F = Flat Steel
L = Long Steel

Transition Pathways

Business as Usual

No CO_2 limit

- Full refurbishment of existing processes
- Minimal investment in low-CO_2 alternatives
- No structural change required

Moderate Transition

−45% CO_2 by 2050

- Most existing processes refurbished
- BF adapted to use **biomass, biomethane,** and **natural gas**
- Investment in **CCS**

Deep Decarbonization

−85% CO_2 by 2050

- Partial refurbishment only
- BF adaptation with biomass and biomethane
- **Strong CCS** investment
- **DRI-H_2** for sponge iron production

Conclusions

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What we built

- An optimization model (**MILP**) for long-term decarbonization planning of industrial systems
- Provides decision support for **public policy** on energy transition
- Generates insights **aligned with real-world** transition pathways for the iron & steel industry
- General enough to be applied to other sectors: **cement, chemical industry**, and others

Challenges & lessons

- Large instances are difficult to solve with **HiGHS**
- Significant improvement achieved by **scaling the model** based on process capacity magnitudes

Future work

- Decompose the problem using **Dantzig-Wolfe** to improve scalability for large cases
- Use the model to study the decarbonization of **other industrial sectors**

Thank you!

CarbSteeler.jl — A Julia optimization model for steel industry decarbonization

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