Industrial Decarbonization

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TECHNOLOGY OPTIONS FOR DECARBONIZATION AND RESILIENCE
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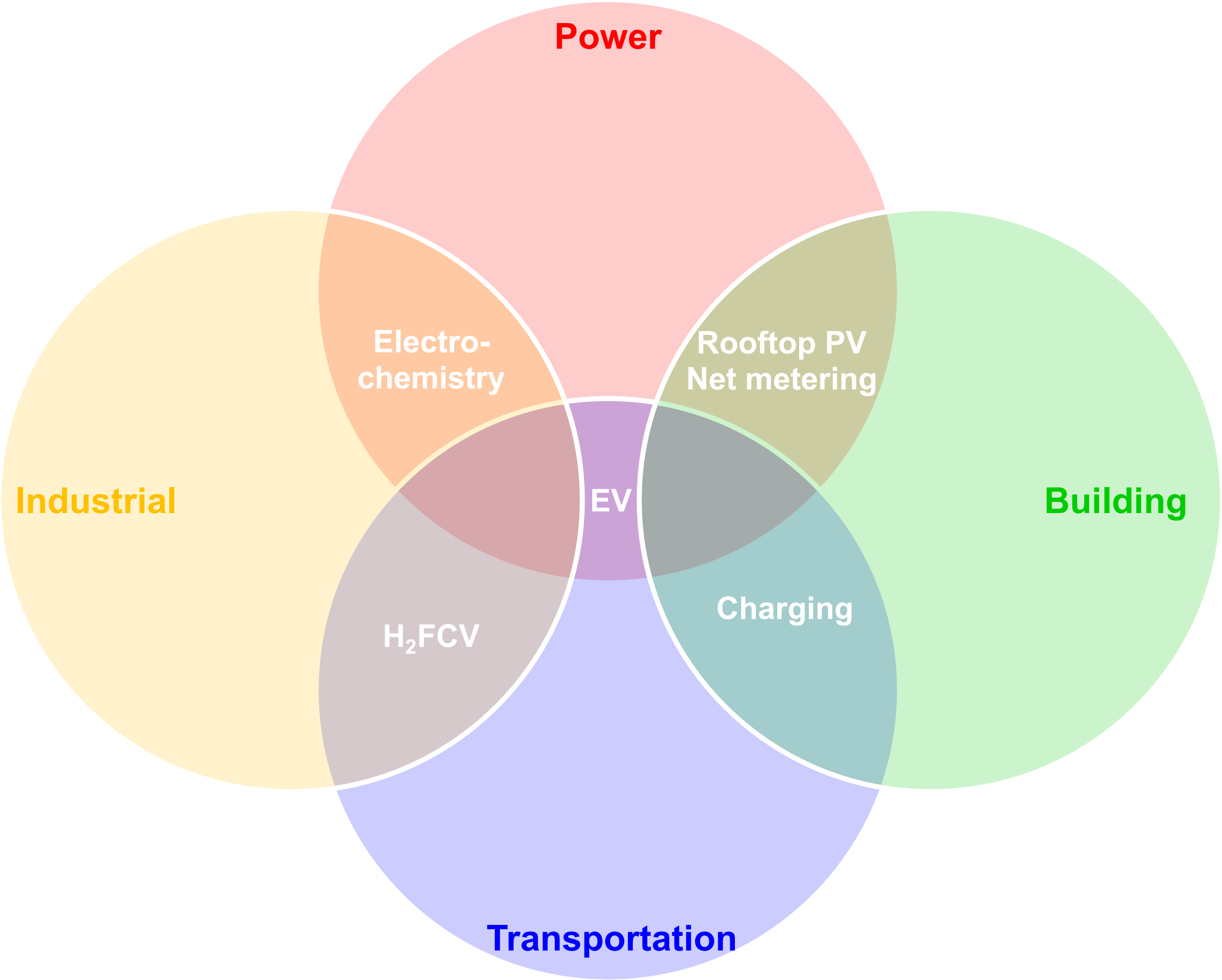
Industrial Decarbonization Key Questions

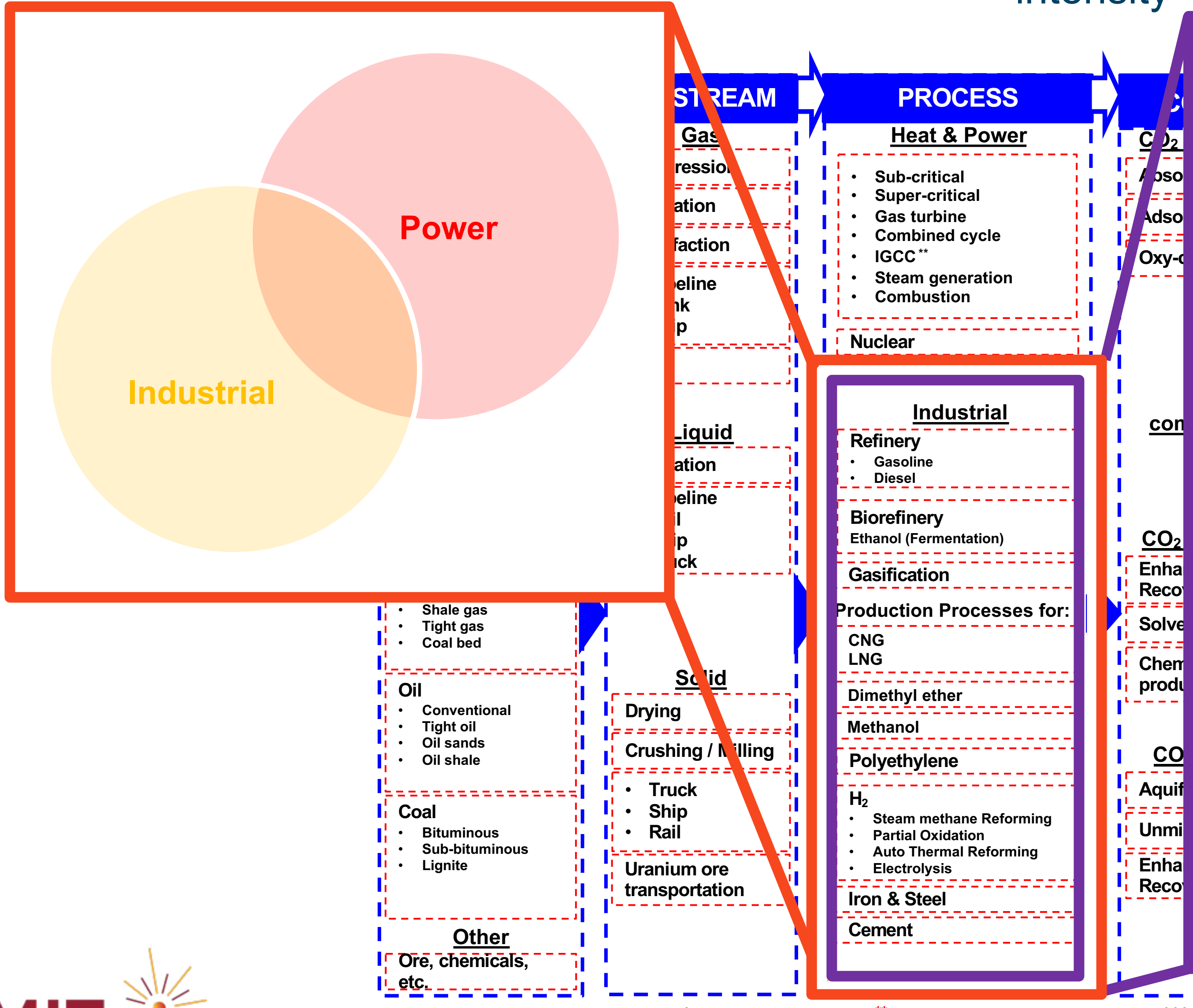
- What are the economically feasible options to be prioritized to achieve deep decarbonization focus on Industrial decarbonization?
- What sectors/technology pathways should be prioritized to achieve environmental targets?
- What multi-sector dimensions impact transition to clean energy?
- What are long-term best policy and regulatory considerations?

Today's energy systems are undergoing major transformations, which are leading towards greater convergence and inter-sectoral integration

- Electrification
- **Hydrogen**
- Manufacturing
- CCUS
- System integration



Develop an in-depth understanding of industrial sector, decarbonization pathways – Life cycle and techno-economic assessment of commercially available and emerging technologies for reducing emission intensity

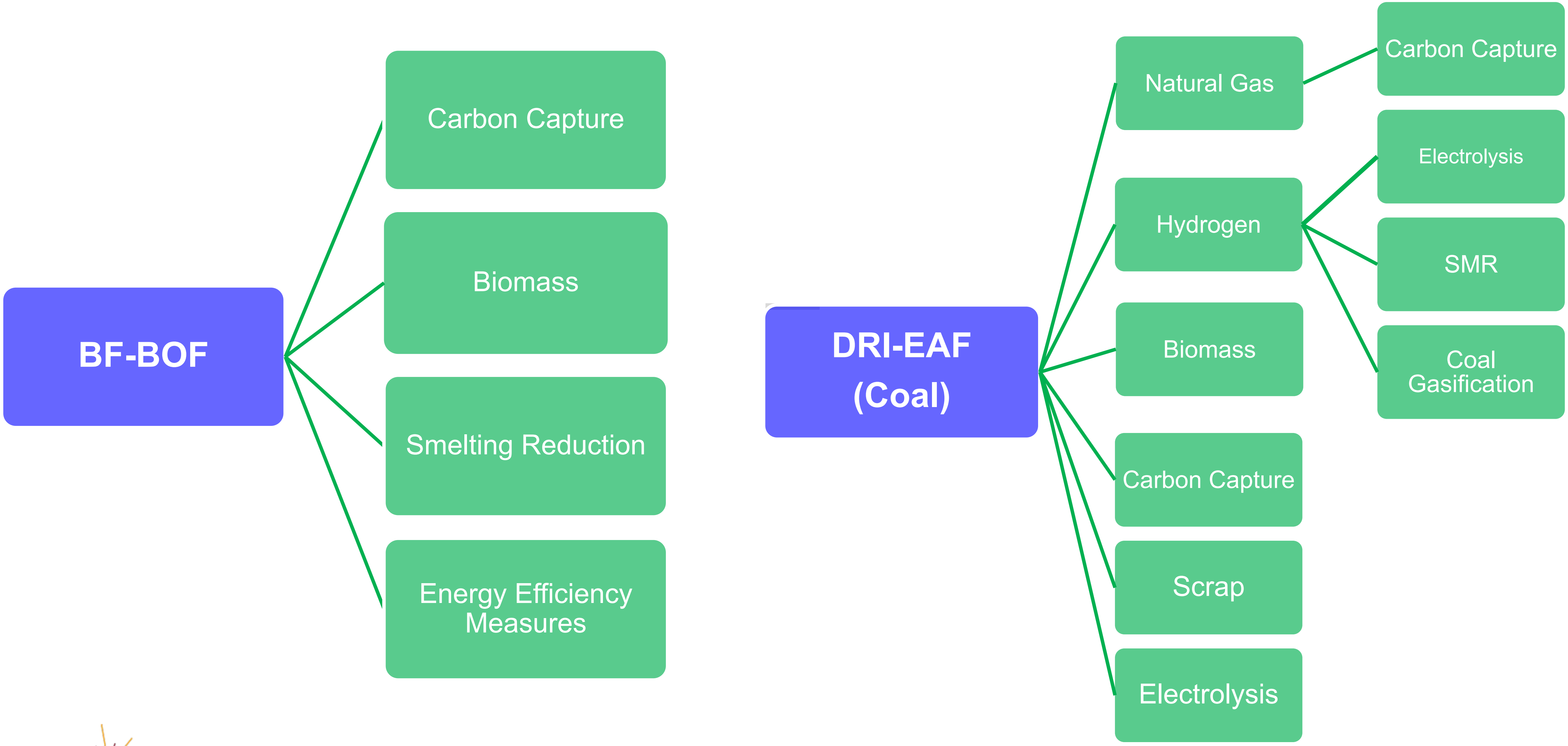


- Cement
- Iron and Steel
- Non-ferrous metals
- Chemicals (fertilizers)
- Refineries

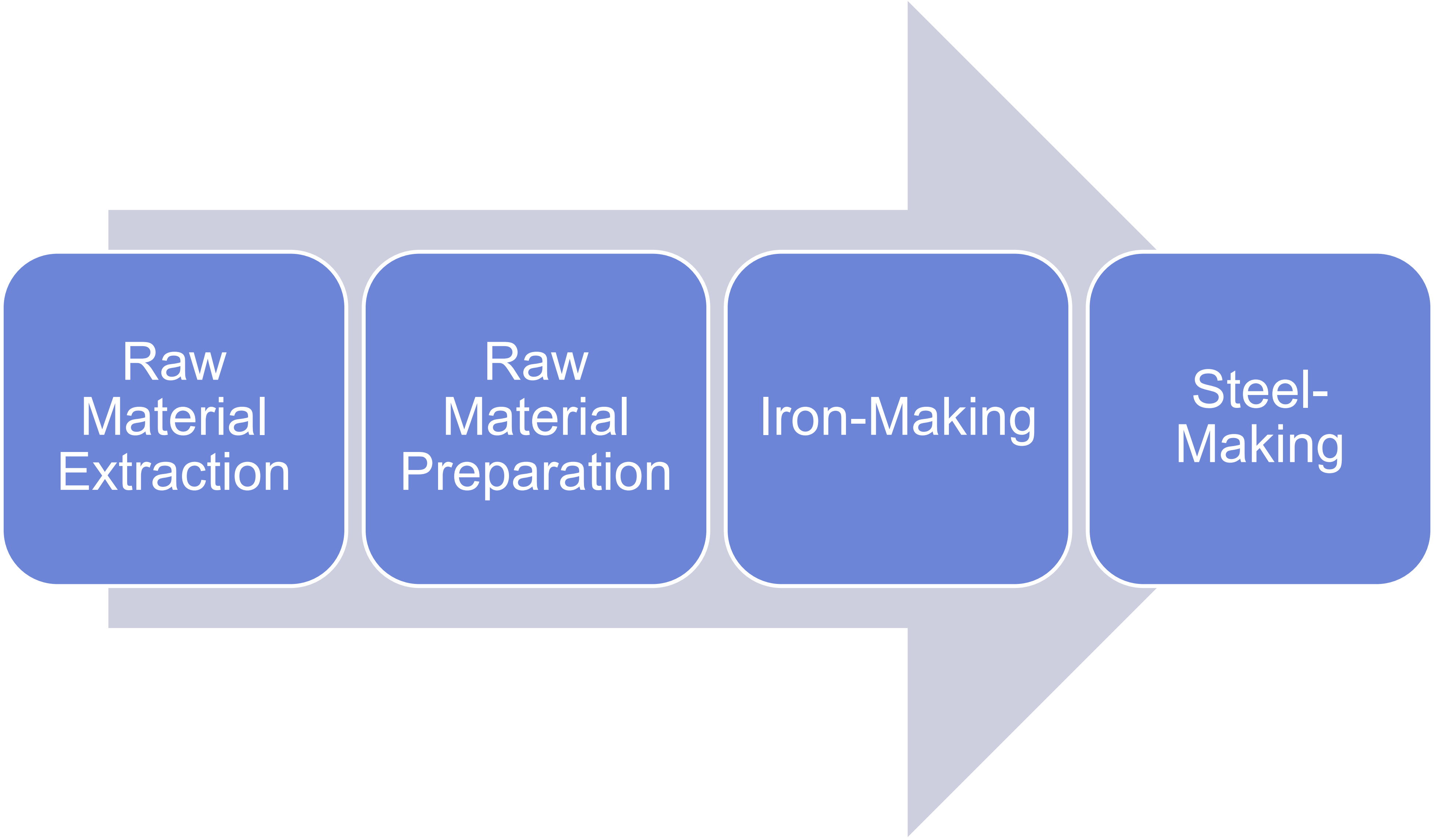
- Current production processes, production levels and emission levels
- Future projections for each industry and corresponding emissions, under different scenarios
- Decarbonization options/technologies (switching to low carbon fuel, use of hydrogen, electrification, carbon capture and sequestration, etc.)

*Concentrated Solar Power, **Integrated Gasification Combined Cycle, ***Carbon Capture, Utilization & Storage

Low-Carbon Steel Production Pathways



System Boundaries



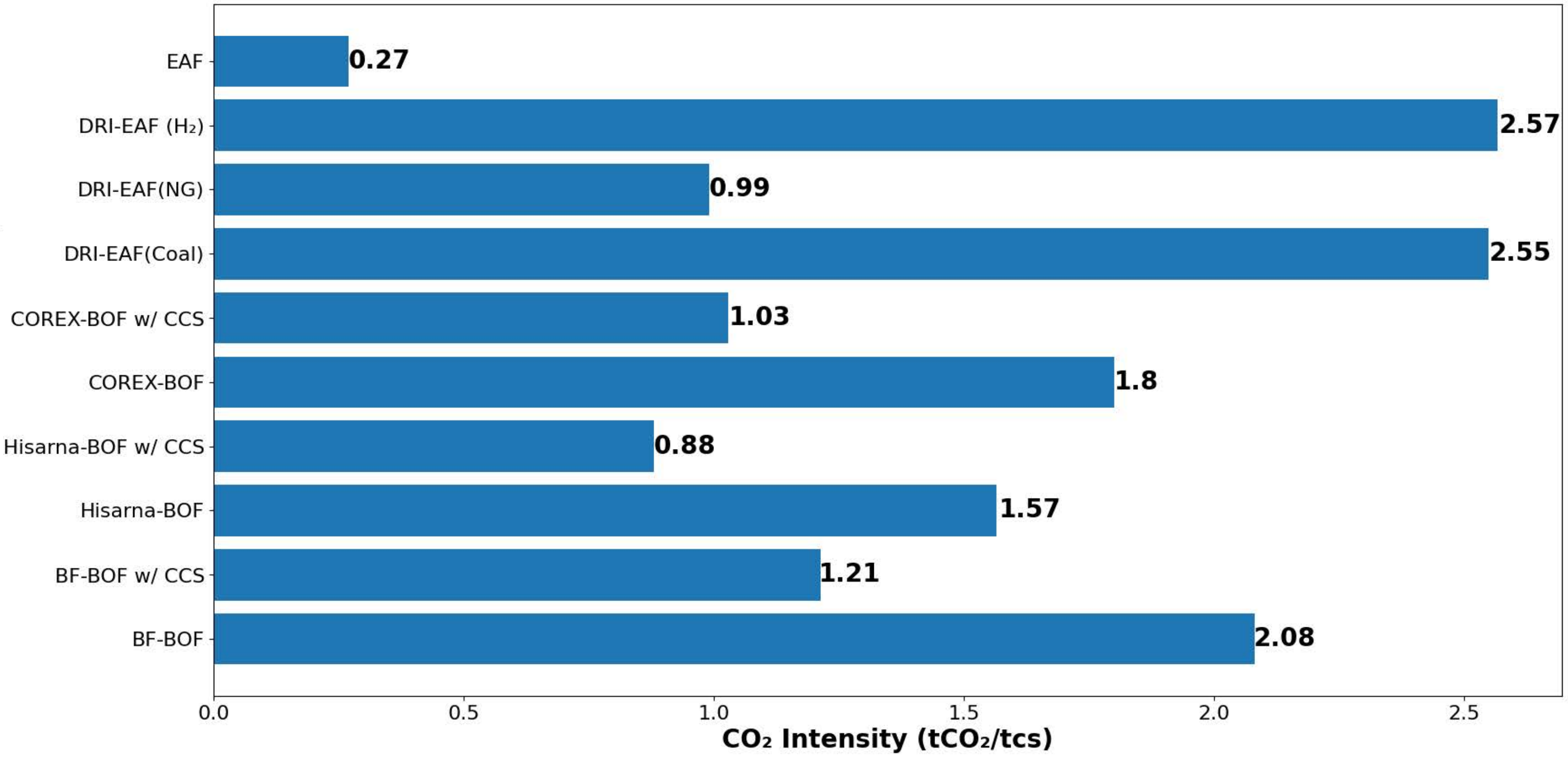
Carbon capture & fuel switching offers greatest emission reduction

BF-BOF

- Key Assumptions
  - 14% Scrap Input to BOF
  - Raniganj Coal
  - Including coking, sintering, limemaking (for COREX) process
  - MEA & natural gas for regeneration of all CCS tech
- Of the blast & smelting technologies**, HIsarna-BOF reduces emissions most (24%)**
  - No need for coking
- Of **CCS** technologies, **HIsarna-BOF has lowest emissions (57% reduction)**

DRI-EAF

- Key Assumptions
  - 19% Scrap Input to EAF [1]
  - Pelletization for NG, H_2
- **Scrap-based** offers lowest emissions, but is **not sustainable** (nearly 200 Mt deficit anticipated in 2050) [3]
- Electrolytic H_2 – DRI emissions are slightly higher than coal-DRI
  - IEA Grid Intensity:
    - 707 g CO_2 /kWh [4]



[1]Shakti Foundation, "Resource-efficiency-in-the-steel-and-paper-sectors.pdf," Confederation of Indian Industry, 2019. Accessed: Jul. 23, 2021. [Online]. Available: https://shaktifoundation.in/wp-content/uploads/2020/03/Resource-efficiency-in-the-steel-and-paper-sectors.pdf
[2] IEA. Iron and Steel Technology Roadmap - Towards More Sustainable Steelmaking. **2020**, 190
[3] IEA (2020), *Tracking Power 2020*, IEA, Paris https://www.iea.org/reports/tracking-power-2020

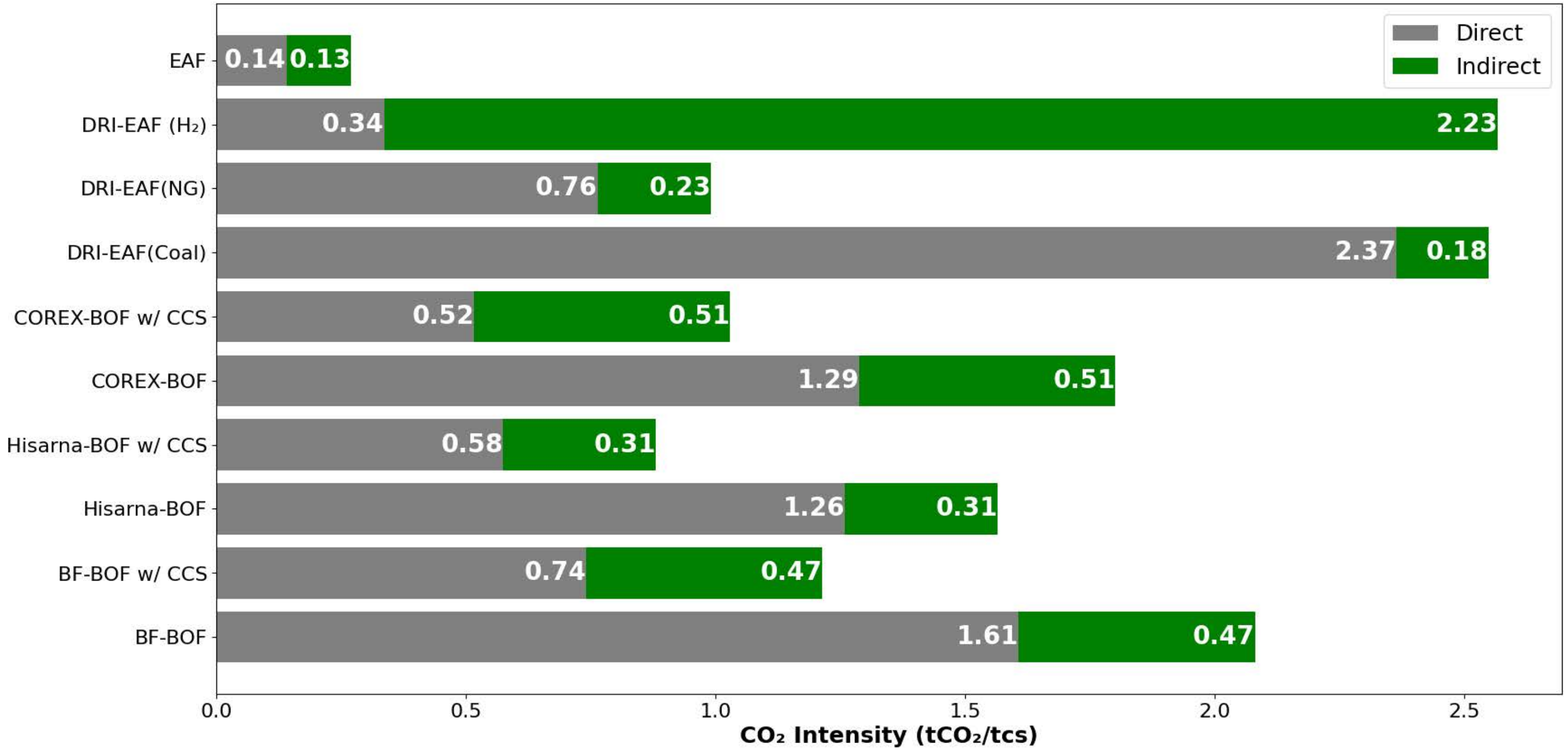
Deep decarbonization requires combination of strategies and infrastructure

BF-BOF

- Similar to DRI-EAF (Coal), direct emissions must be significantly reduced to approach near-zero emissions
  - CCS with electricity (vs. NG for regeneration)
  - Biofuel
  - Recovery/Energy Efficiency (Top Recovery Turbine)
- Increasing CCS options will require adequate storage/use cases

DRI-EAF

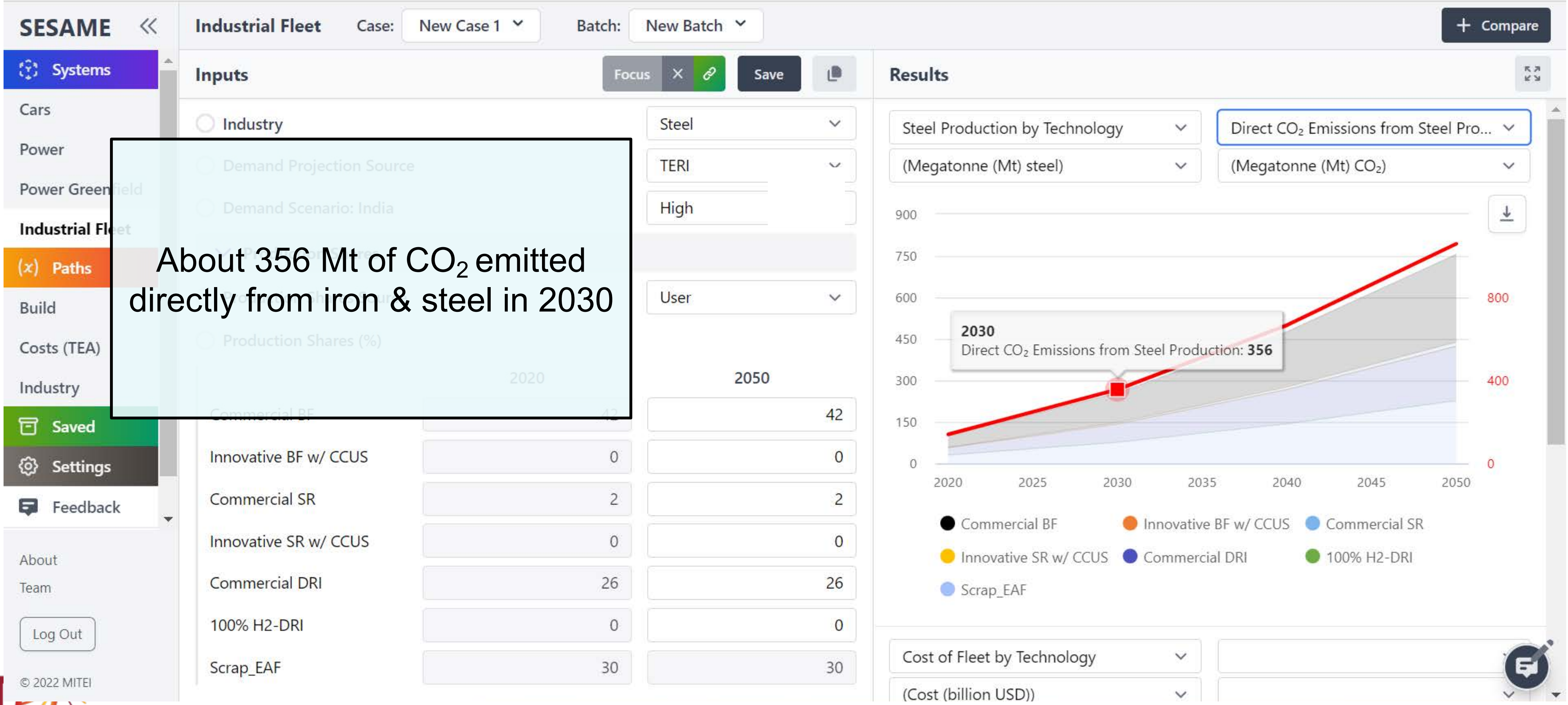
- Coal-based pathway is majority direct emissions
  - Could be reduced with natural gas, biofuels, CCS, and/or waste heat recovery
- H_2 has lowest direct emissions (0.34 tCO_2) next to scrap-based EAF
  - Need reliable renewable energy sources for electricity demand



India Steel Fleet Analysis: National Steel Policy Case Study

India's National Steel Policy (2017)

- Anticipated 255 Mt production by 2030-2031
- How much CO_2 per year would be emitted with the current steel plants?

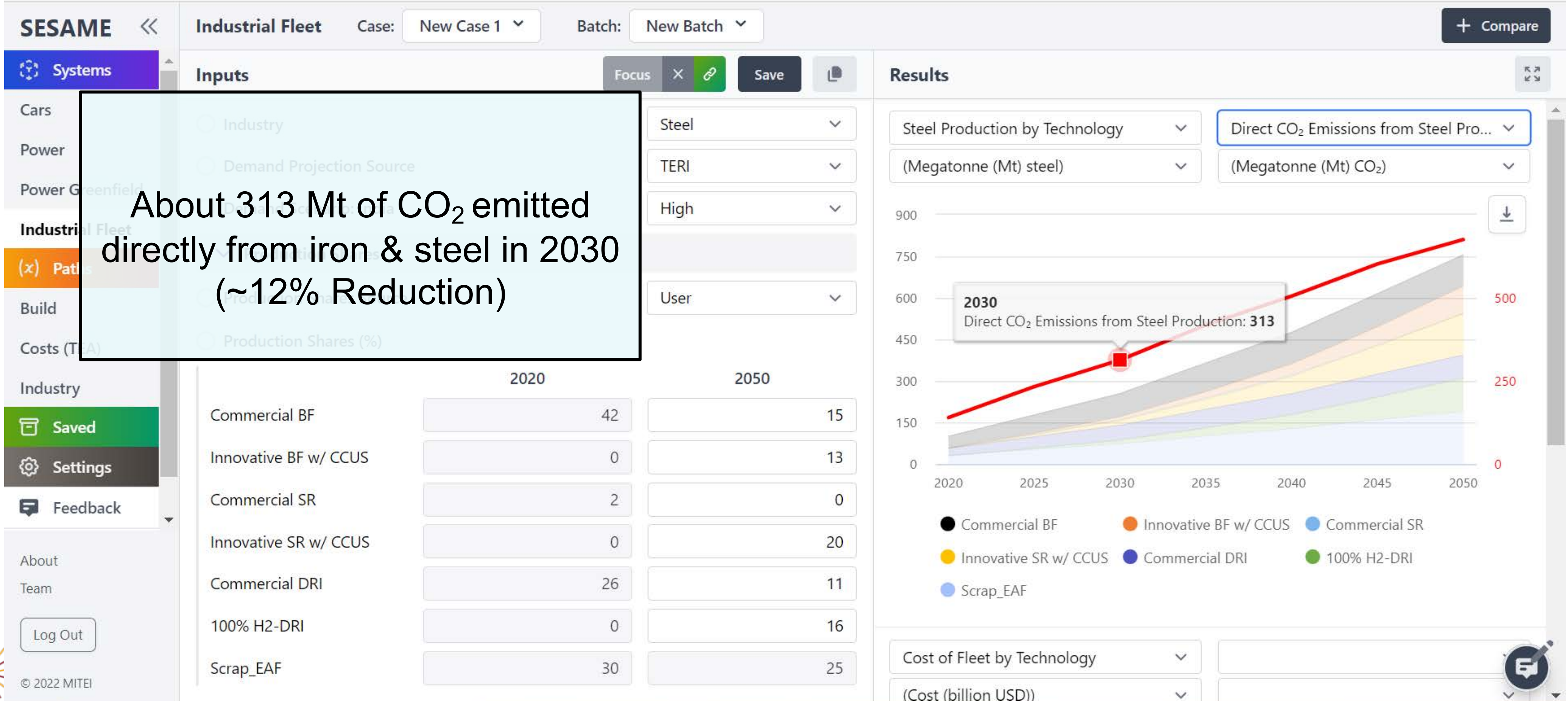


About 356 Mt of CO_2 emitted directly from iron & steel in 2030

India Steel Fleet Analysis:
National Steel Policy Case Study

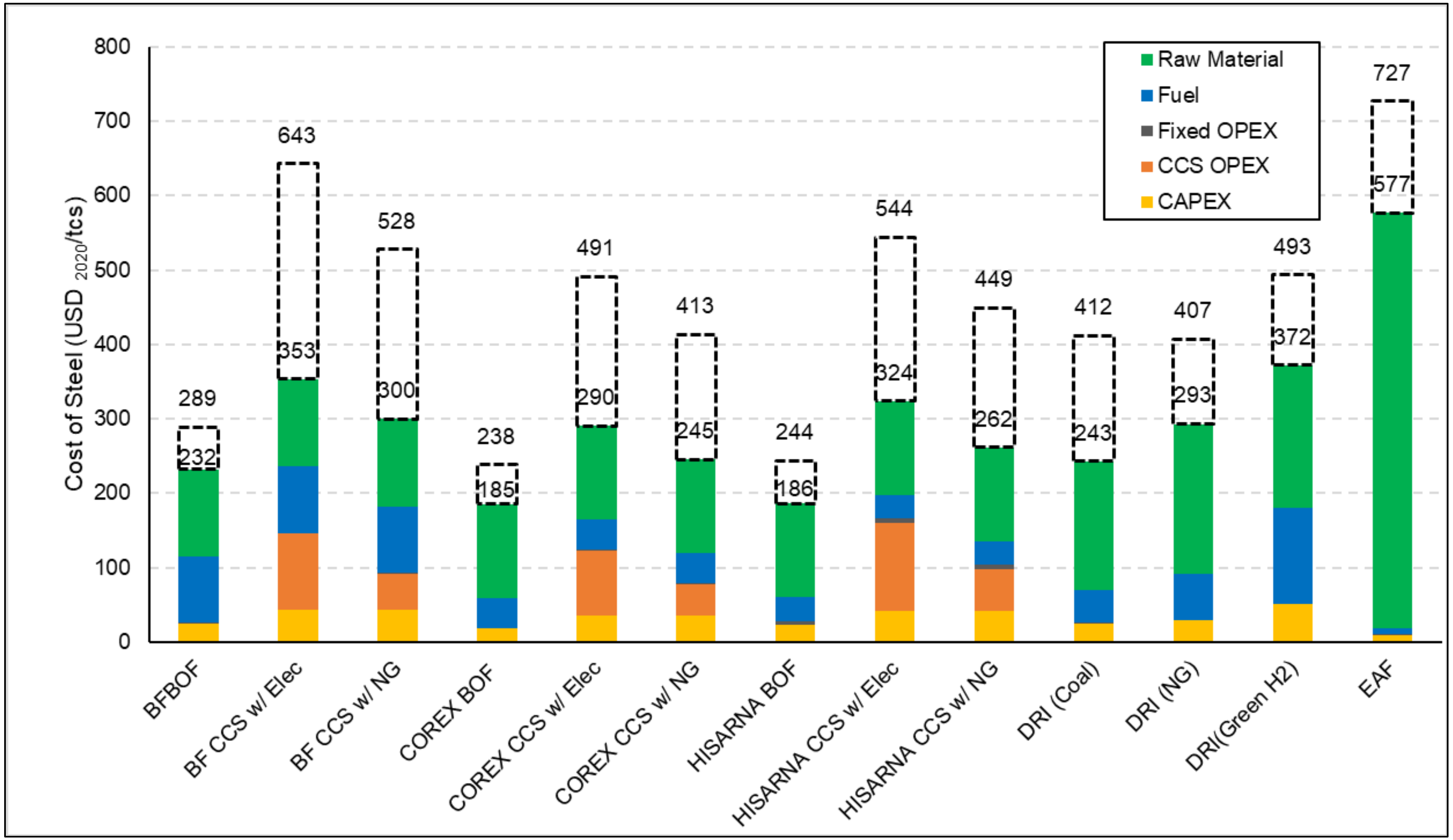
India's National Steel Policy (2017)

- Anticipated 255 Mt production by 2030-2031
    - **With more decarbonization strategies? → Inspired by IEA SDS Projections**



About 313 Mt of CO_2 emitted directly from iron & steel in 2030 (~12% Reduction)

Preliminary cost comparison

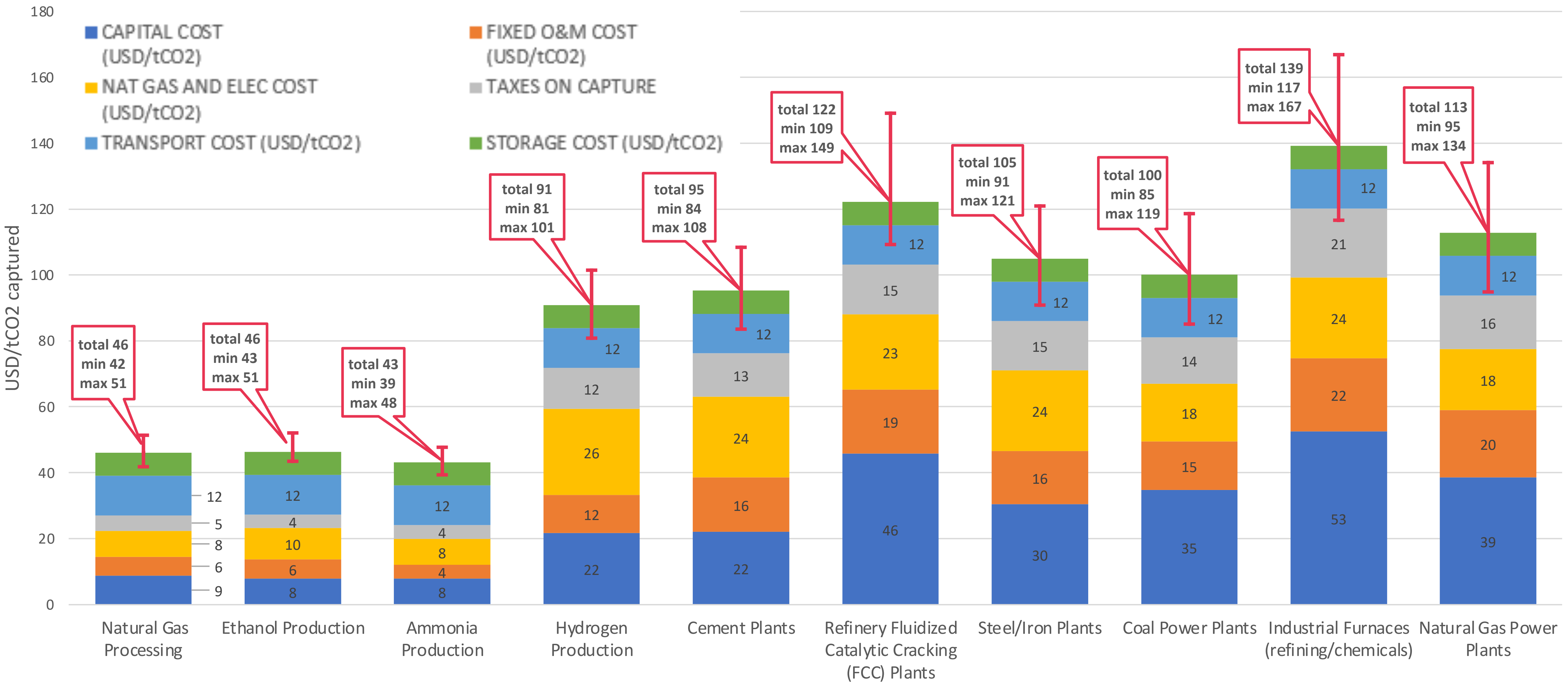


*Dotted values represent "high price scenarios" of electricity, natural gas, coal (coking & non-coking), as well as higher capex from literature, primarily from India's industrial reports. Other listed values are of "mid-range" cost.

Key Takeaways

- To significantly reduce emissions, a combination of solutions are needed:
  - **Short Term**
    - Fuel Switching for DRI & BF Ironmaking Process
      - Natural Gas, Biofuels
    - Technology Shift
      - HIsarna, COREX
    - Energy & Material Efficiency Measures
  - **Long Term**
    - Infrastructure Development
      - Electrolytic Hydrogen, Renewable Energy Sources
      - Carbon Capture Use/Storage
    - Energy & Material Efficiency Measures
    - New Decarbonization Strategies

CCUS cost for various applications



Low Carbon Hydrogen Supply for Germany

Key Questions

Where will future low carbon hydrogen be supplied from?

- Contingent on neighboring countries' strategies [1]
- Will likely require H_2 produced from natural gas with CCS

- Can existing SMR facilities in Germany be retrofitted with CCS?
- If no, should new facilities be built?

How will it be stored?

- Current consensus: large scale underground storage [2-4]

- Readily available: 27 TWh [4]. Large potential, not technically proven

How will it be distributed?

- Current consensus: pipeline transmission [5-6]

- Retrofitting hurdles [5]. Cost overshadowed by cost of production.

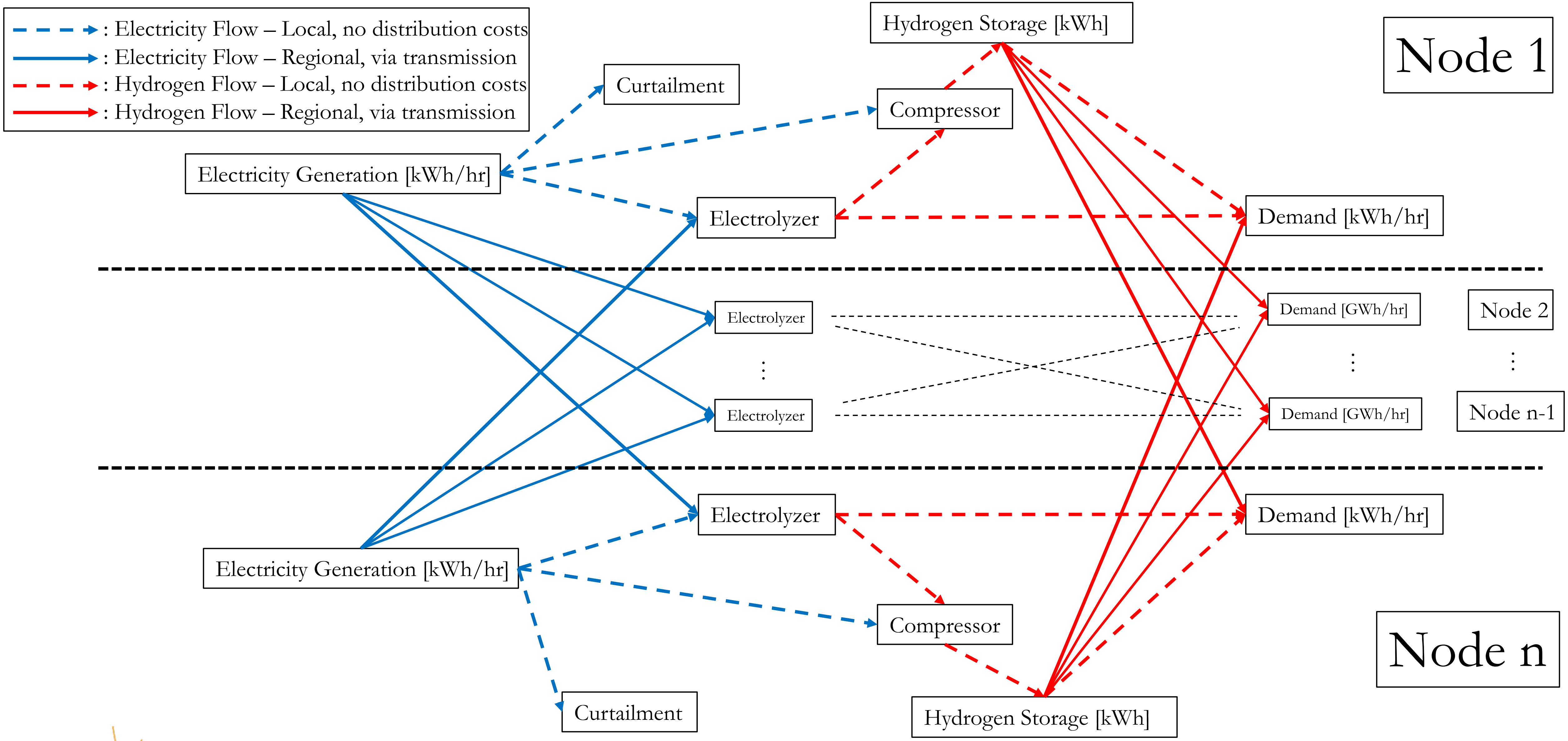
How much will it cost?

- Electrolytic hydrogen only profitable for mobility [4,7,8]

- Creation of the value chain can be costly depending on the amount of new infrastructure required.

[1]: Westphal K et al (2020) [2]: Reuß M et al (2019) [3]: Elberry A et al (2021) [4]: Michalski J et al. (2017) [5]: Cerniauskas S et al (2020) [6]: H2morrow project (2021) [7]: Coleman et al (2020) [8]: Welder et al (2020)

Multi-nodal Model Design for SESAME

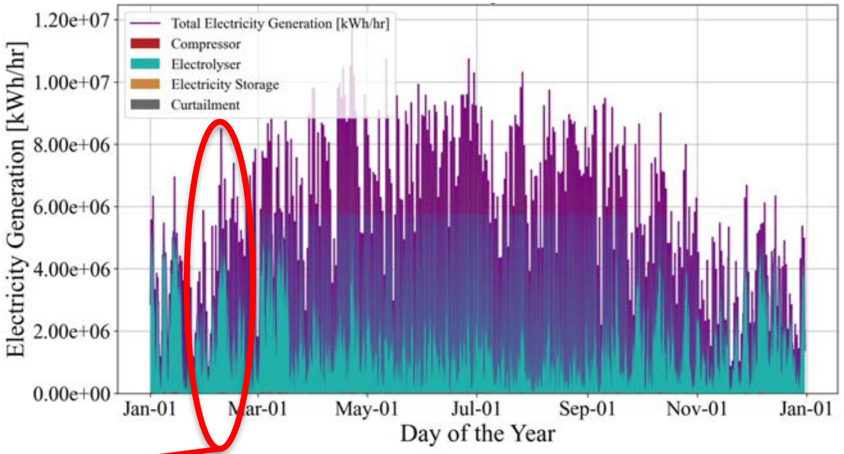


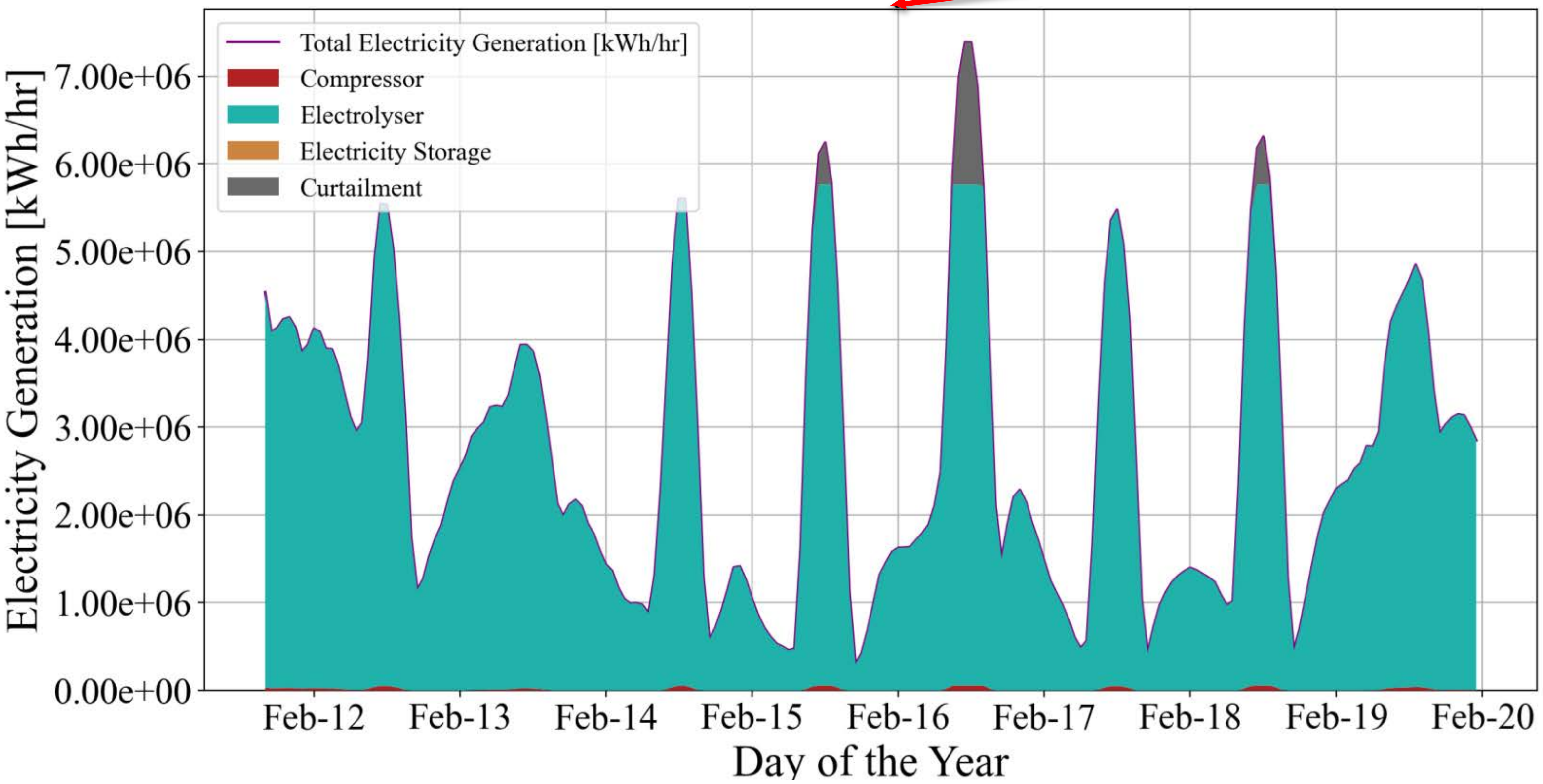
Green hydrogen production for Germany with Salt Cavern Storage

Hydrogen cost: $4.45/kg

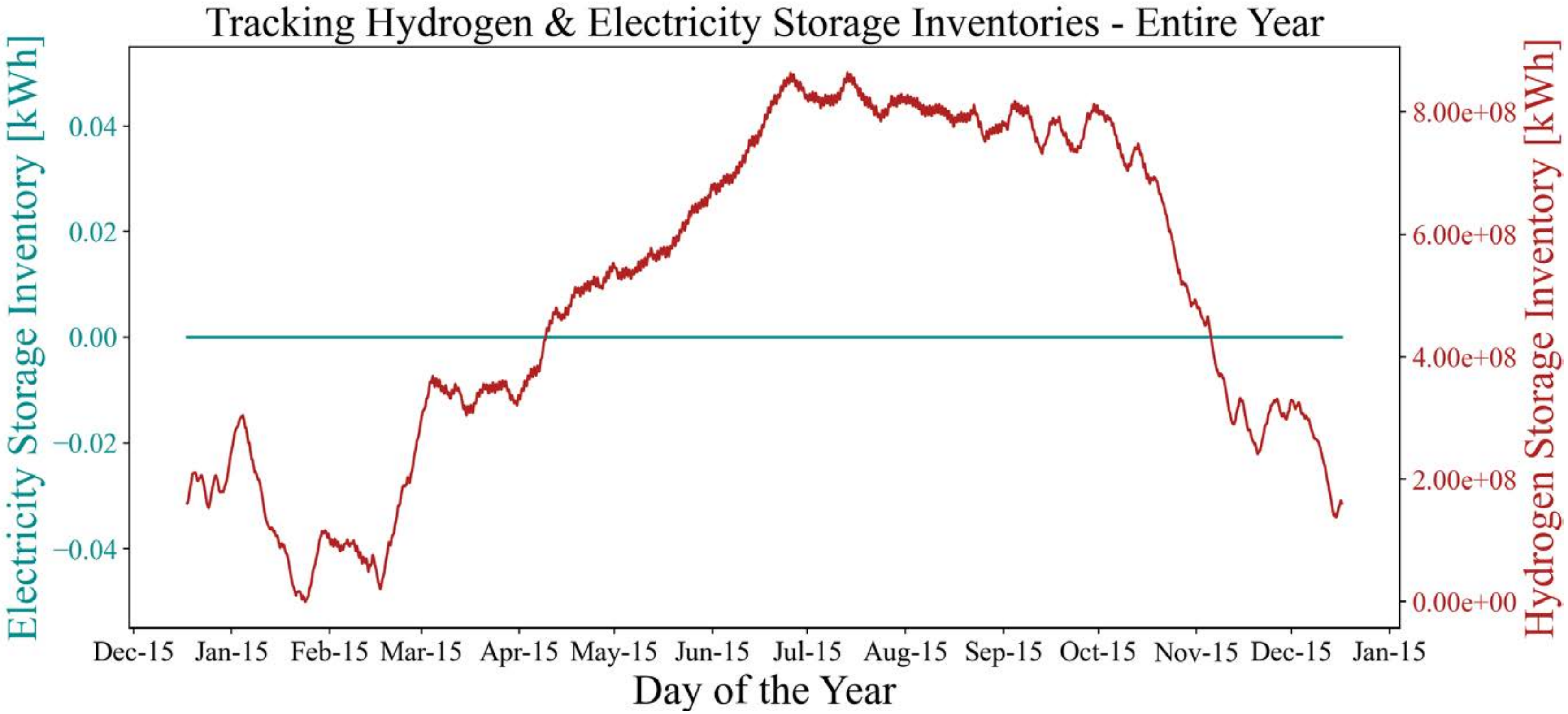
Total hydrogen production: 14 TWh
Electrolyzer capacity: 3.4 GW
Renewable/Electrolyzer Oversize: 5.51 GW_{re}/GW_{el}
Hydrogen storage capacity: 863.6 GWh

Total electricity generated: 25.4 TWh
Renewable generation capacity: 18.9 GW
Electrolyzer capacity factor: 46.7%
Electricity storage capacity: 0 GWh





Variation in Hydrogen Storage Inventory



Hydrogen cost: $4.45/kg

Required H_2 storage capacity: 863.6 GWh

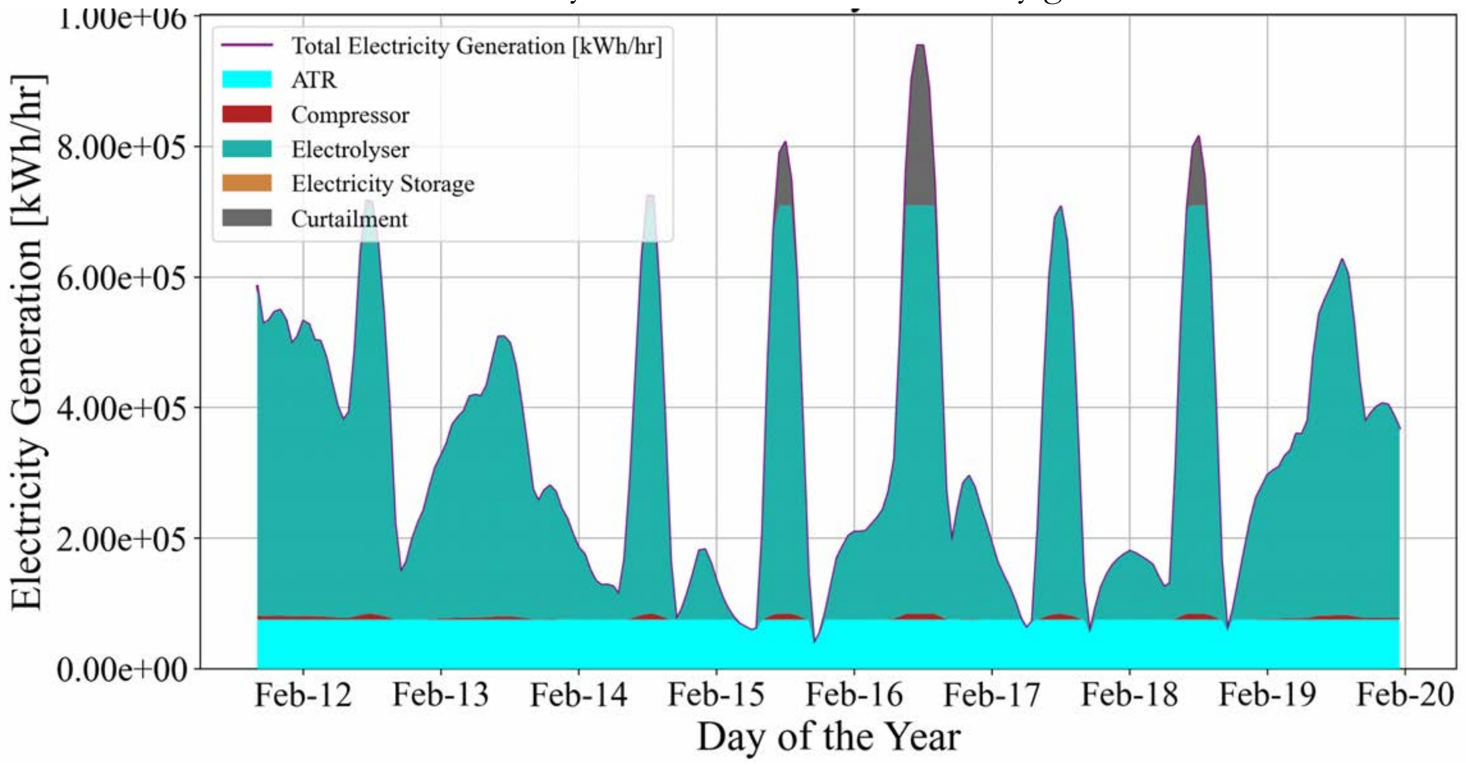
System stores more hydrogen during summer due to greater renewable electricity generation. Electricity storage is not economical for hydrogen production application.

Exploring the Addition of Natural Gas-based Hydrogen Production

Hydrogen cost: $2.7/kg

Total hydrogen production: 14 TWh
Total electricity generation: 3.3 TWh
Electrolyzer capacity: 0.4 GW
Renewable generation capacity: 2.4 GW
Hydrogen storage capacity: 237.1 GWh
Total ATR capacity: 1.51 GW

Pathways of the renewable electricity generated



Auto thermal reforming (ATR) with carbon capture and sequestration (CCS) is used for natural gas-based hydrogen production.

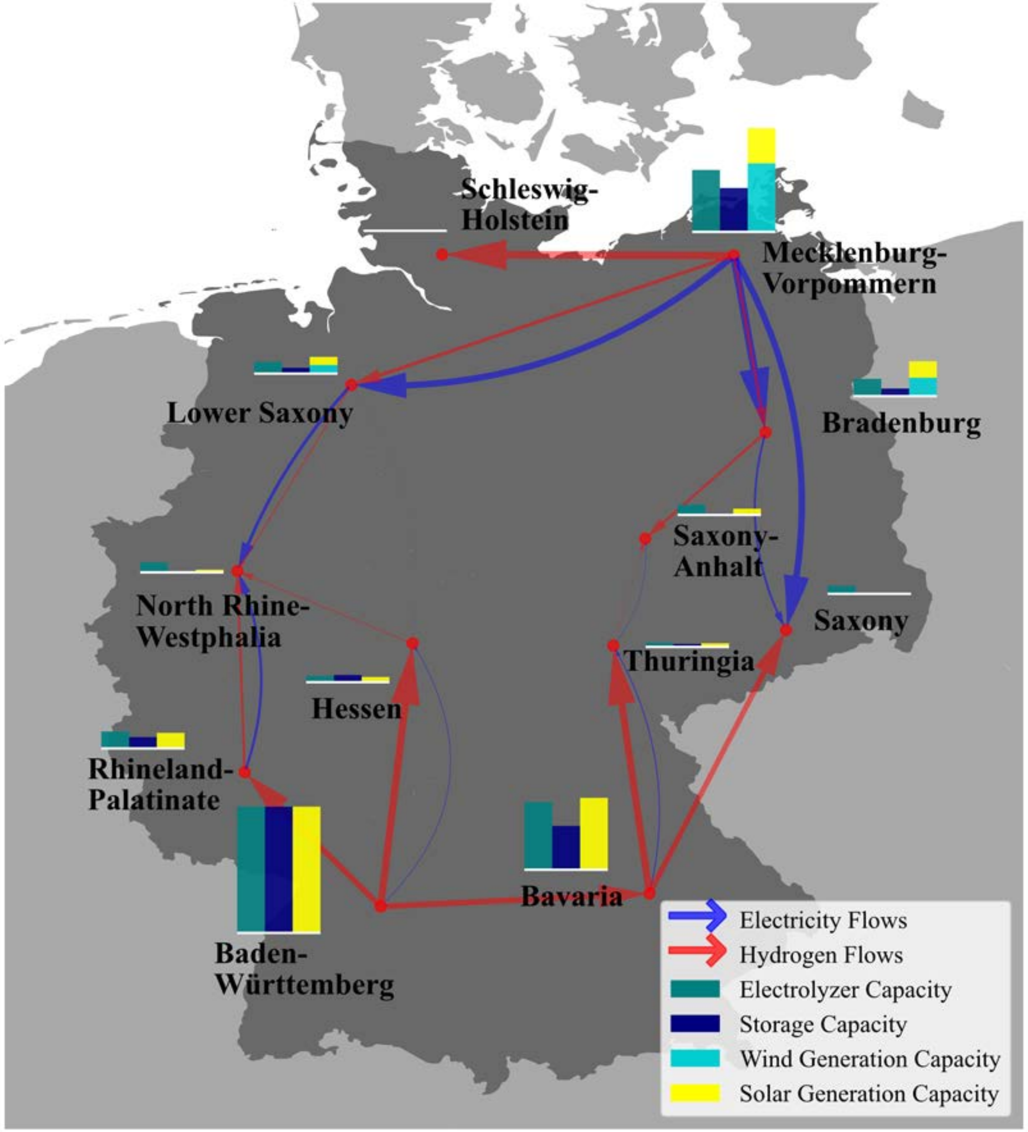
These results assume CO_2 sequestration will be availabile.

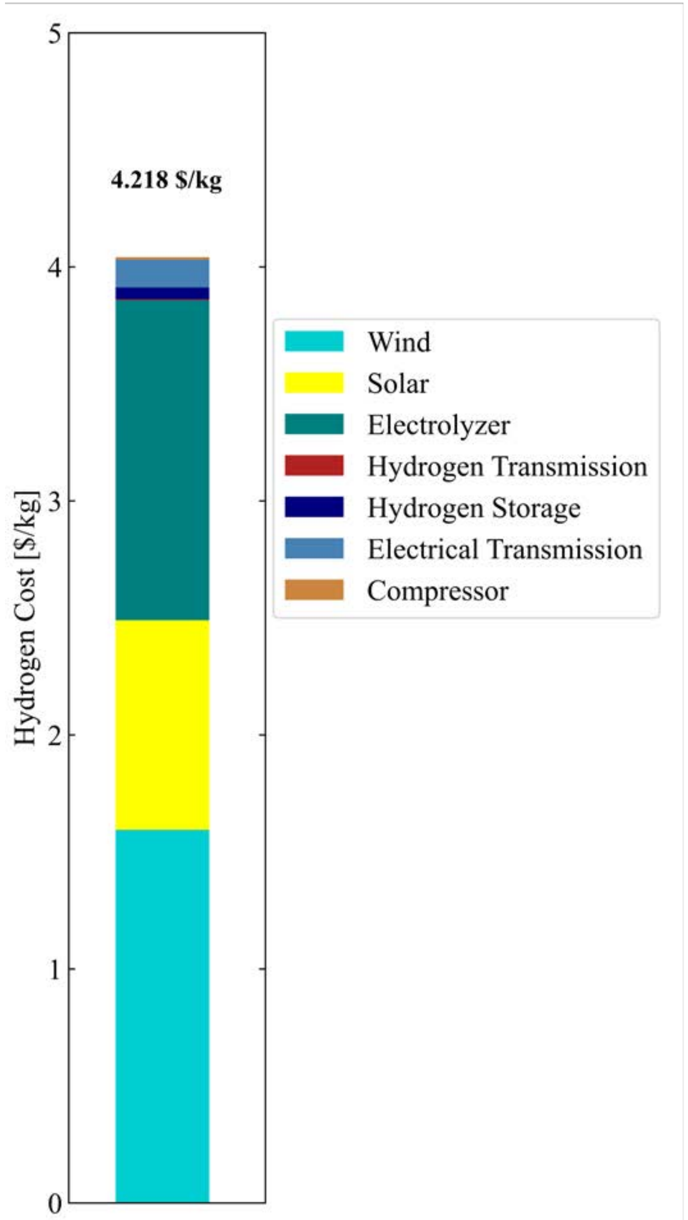
The cost of CO_2 transport and storage is not included.

Preliminary Results: 12 Nodal System – German Only Production

Transmission lines are assumed to be installable between only neighboring regions.

→ Results 2 electricity production hubs – the north and the south. Interesting to note that the model prefers sending electricity to other nodes in the north, while it prefers sending hydrogen to other nodes in the south.





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Conclusions

- The cost competitiveness of green hydrogen is dependent on the capacity factor at which electrolyzers are operated.

- Higher utilization of hydrogen production assets can be achieved by system optimization,. *i.e.* electricity transmission from renewable power rich regions, which can lower cost of hydrogen.

- Expansion of hydrogen production system to include regions with rich natural resources can further improve the economics for low carbon hydrogen.

Thank you

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