Facility level net-zero steel pathways for China

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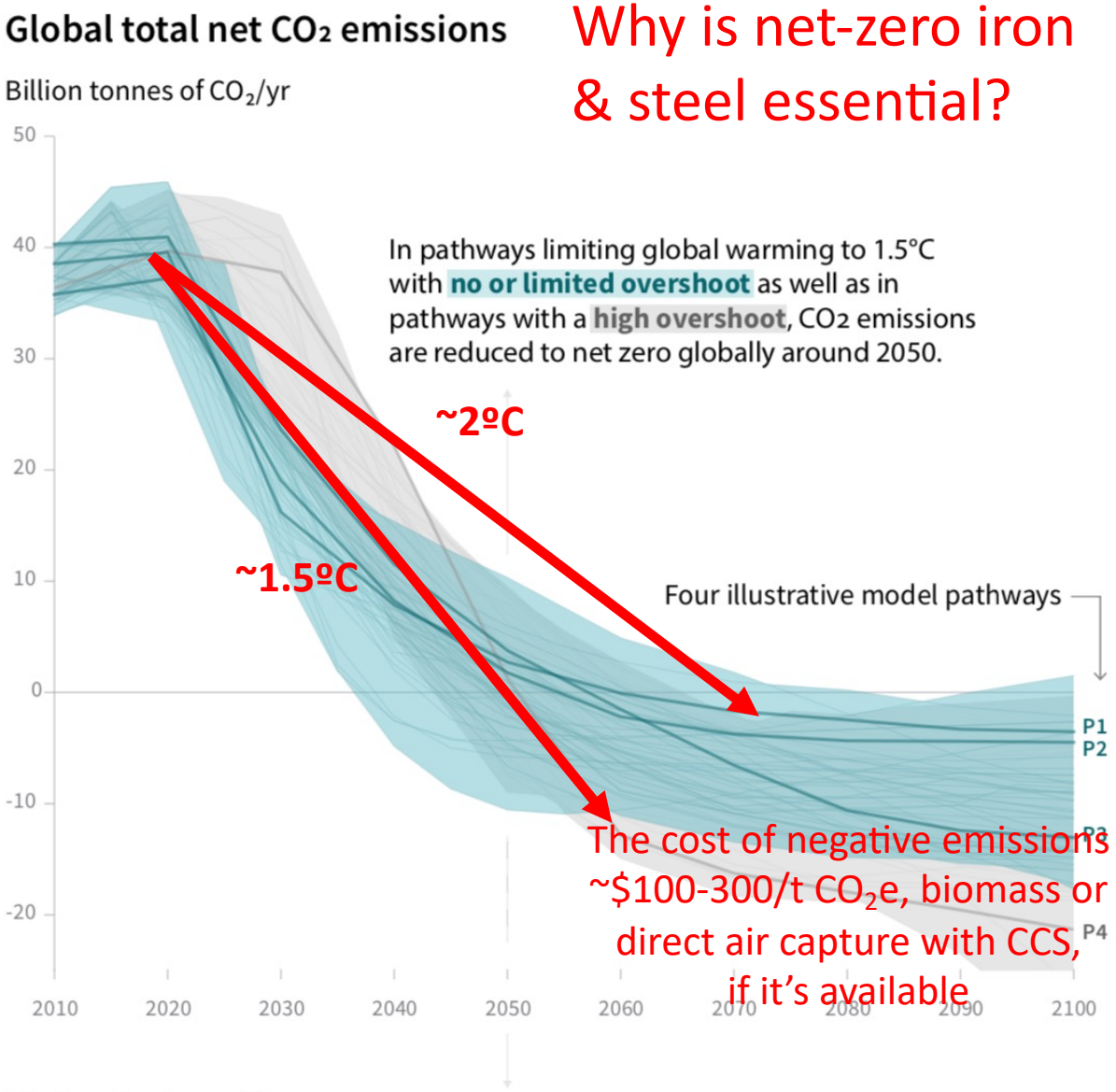
DEEP DECARBONIZATION PATHWAYS

IDDRI

Outline of the next 25 minutes

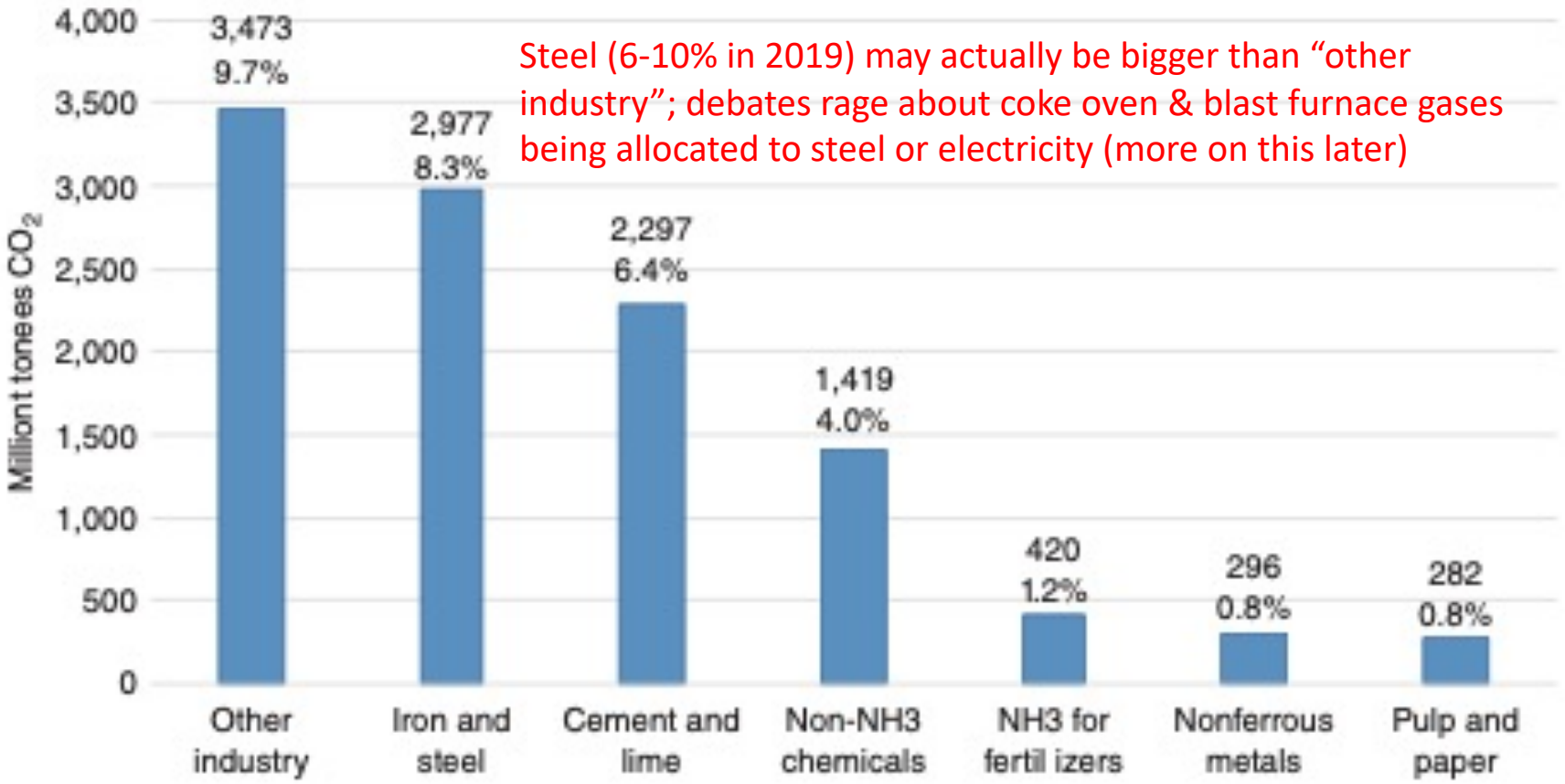
- Why we need net-zero greenhouse gas (GHG) emissions steel; the global carbon budget
- Why net-zero steel is within reach; the 7 pathways
- High level Methodology: A series of geospatially detailed plant level global transitions to net zero for steel, including projections of demand, evolving secondary recycled and new primary production
- Scenario design and data sources
- Preliminary results for China in a global context
- Some important details on how steel emissions are measured – there are three main ways.
- Global policy implications

Why is net-zero iron & steel essential?

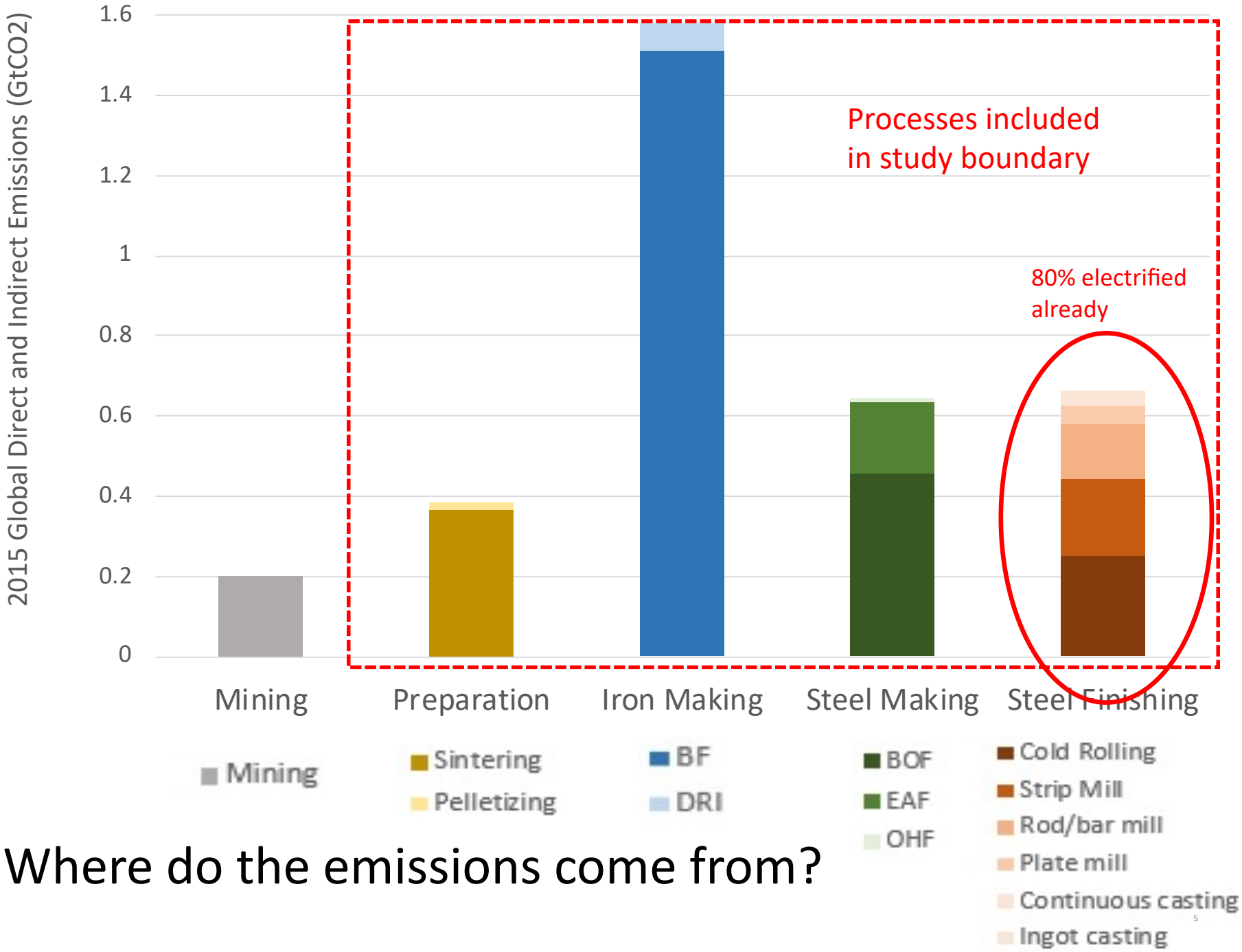


- Steel is the second most used material globally after concrete, and currently very GHG intensive.
- Steel is essential for modern civilization, for developed and developing countries alike for energy, water, sanitary, and transport infrastructure as well as vehicles and machinery.

Global sector combustion and process CO_2 emissions in 2016



Source: Physical and policy pathways to net-zero emissions industry. Bataille, WIRES Interdisciplinary Reviews, 2019.

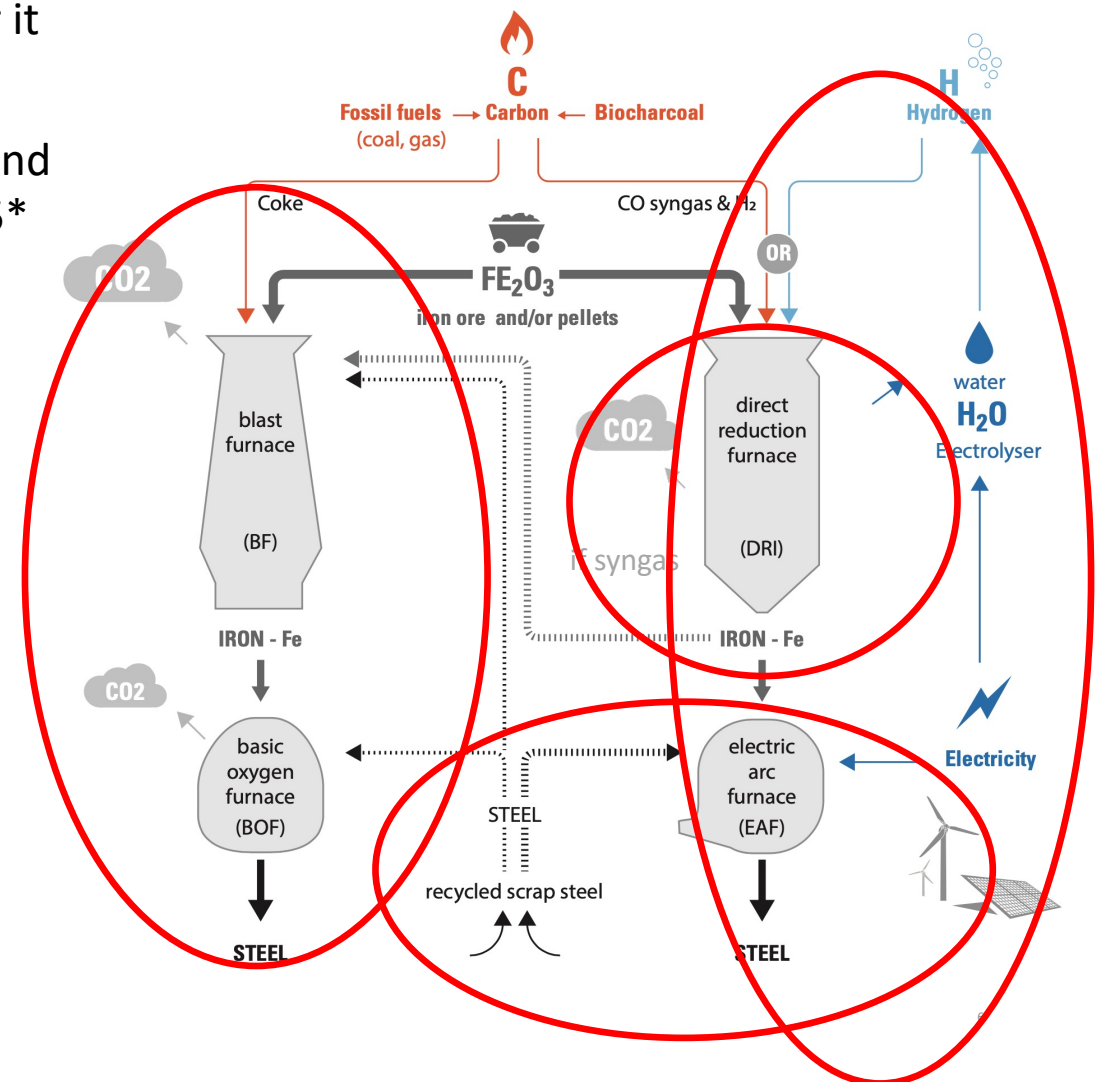


Where do the emissions come from?

The technical means to net-zero steel

- Less demand, more material efficiency
- More recycling. Depends on supply of reasonable quality scrap + DRI sweetening and a network to gather it (TRL 9)
- BF-BOF with 90%+ Carbon capture and storage, possibly with biomass TRL 5* (2030?)
- Advanced smelting with CCS (not shown, TRL 7)
- Syngas based DRI EAF with concentrated flow CCS TRL 9*. Replaceable with 100% hydrogen
- Green hydrogen DRI EAF TRL 5-7+ (2028-'30)
- Molten oxide or aqueous oxide electrolysis TRL 4 (2035-'40?) Not in diagram.

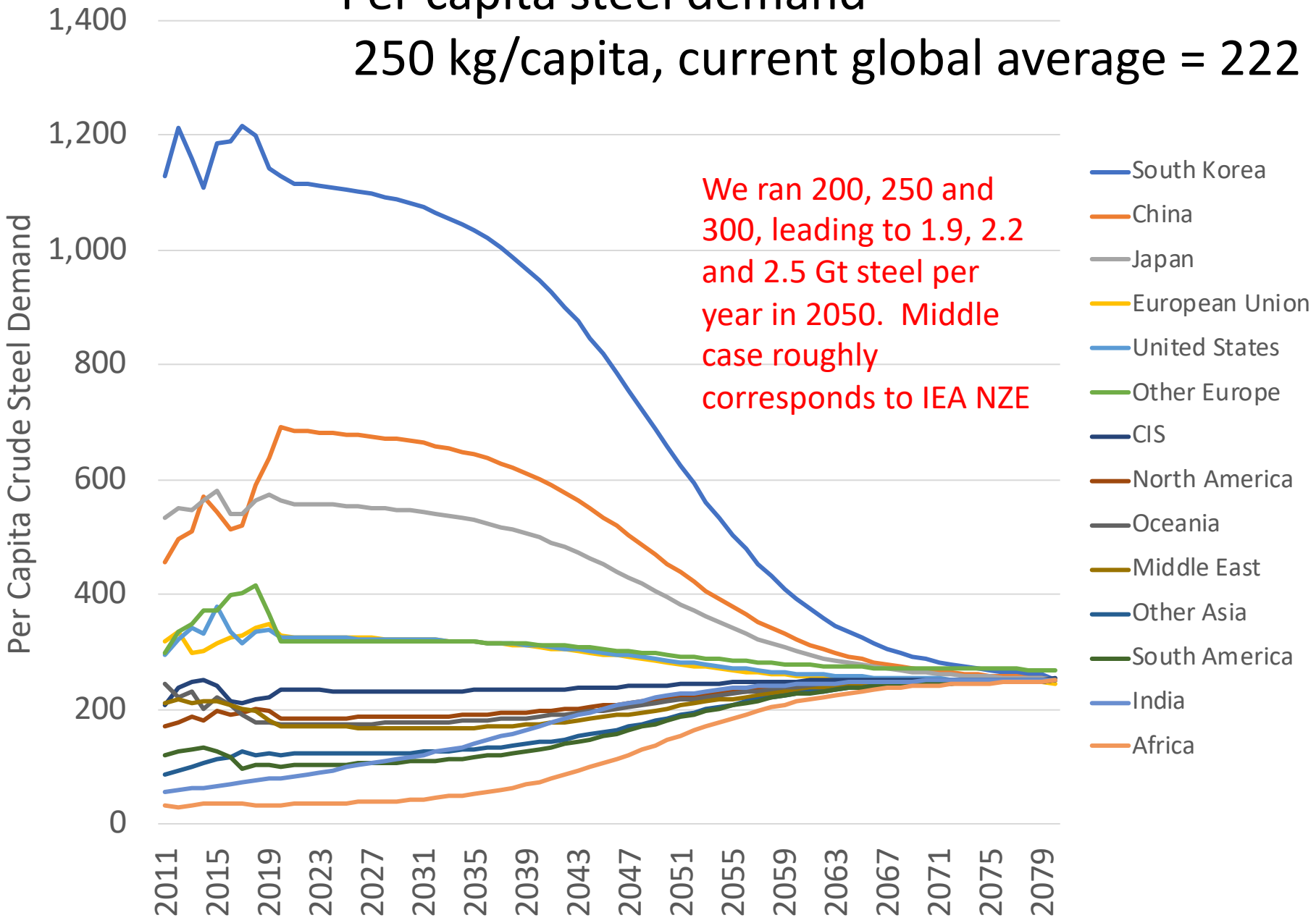
* Hydrogen blending would allow partial reductions



High level methodology

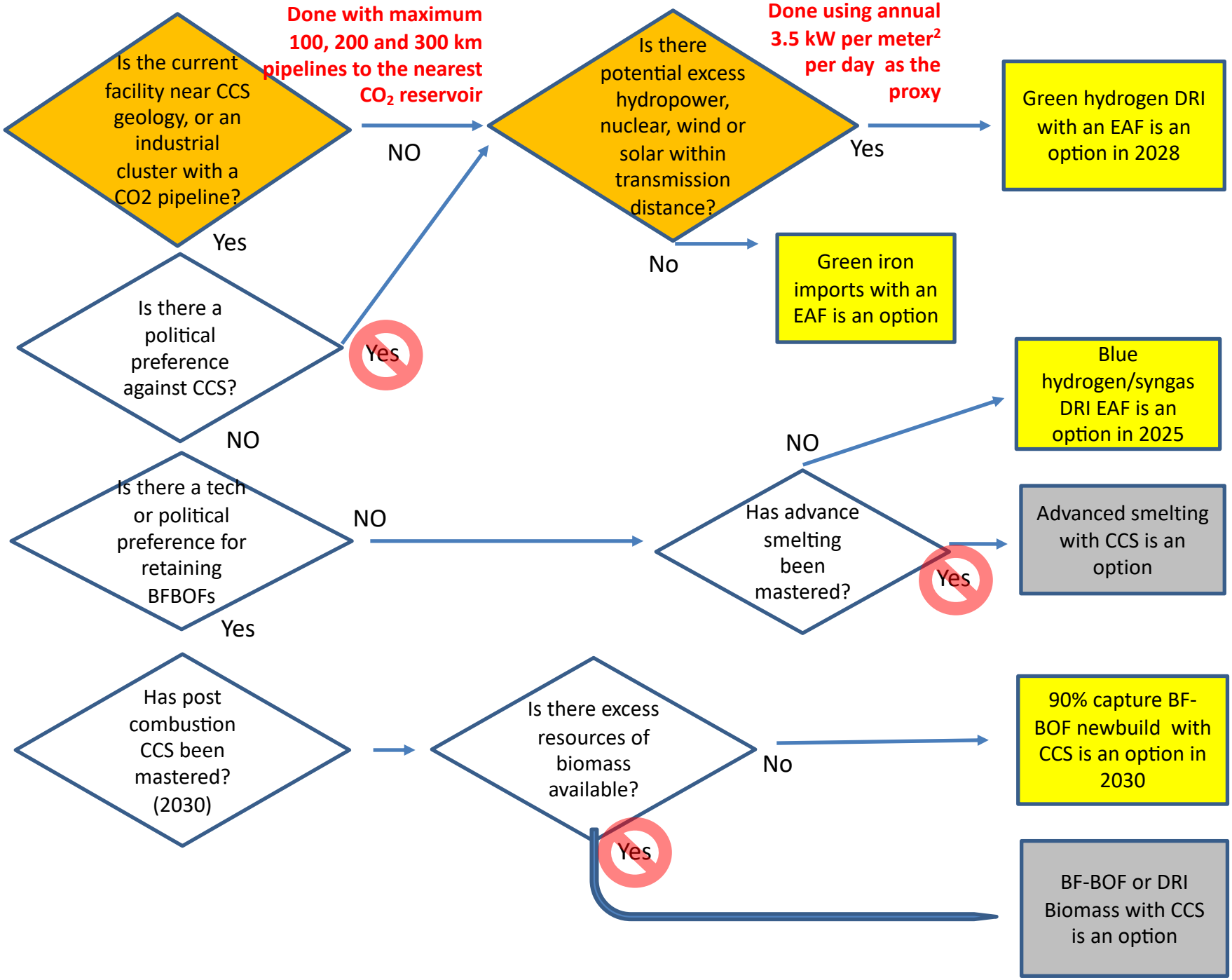
- We begin with a global dataset of existing geospatially distinct steel plants over 1Mt per year in 2019 provided by the Global Energy Monitor, and added from other data sources to build up a full data set
- Demand is assessed on a global evolution towards 200, 250 and 300 kg per capita in 2080, using ”s” curves

Per capita steel demand – 250 kg/capita, current global average = 222

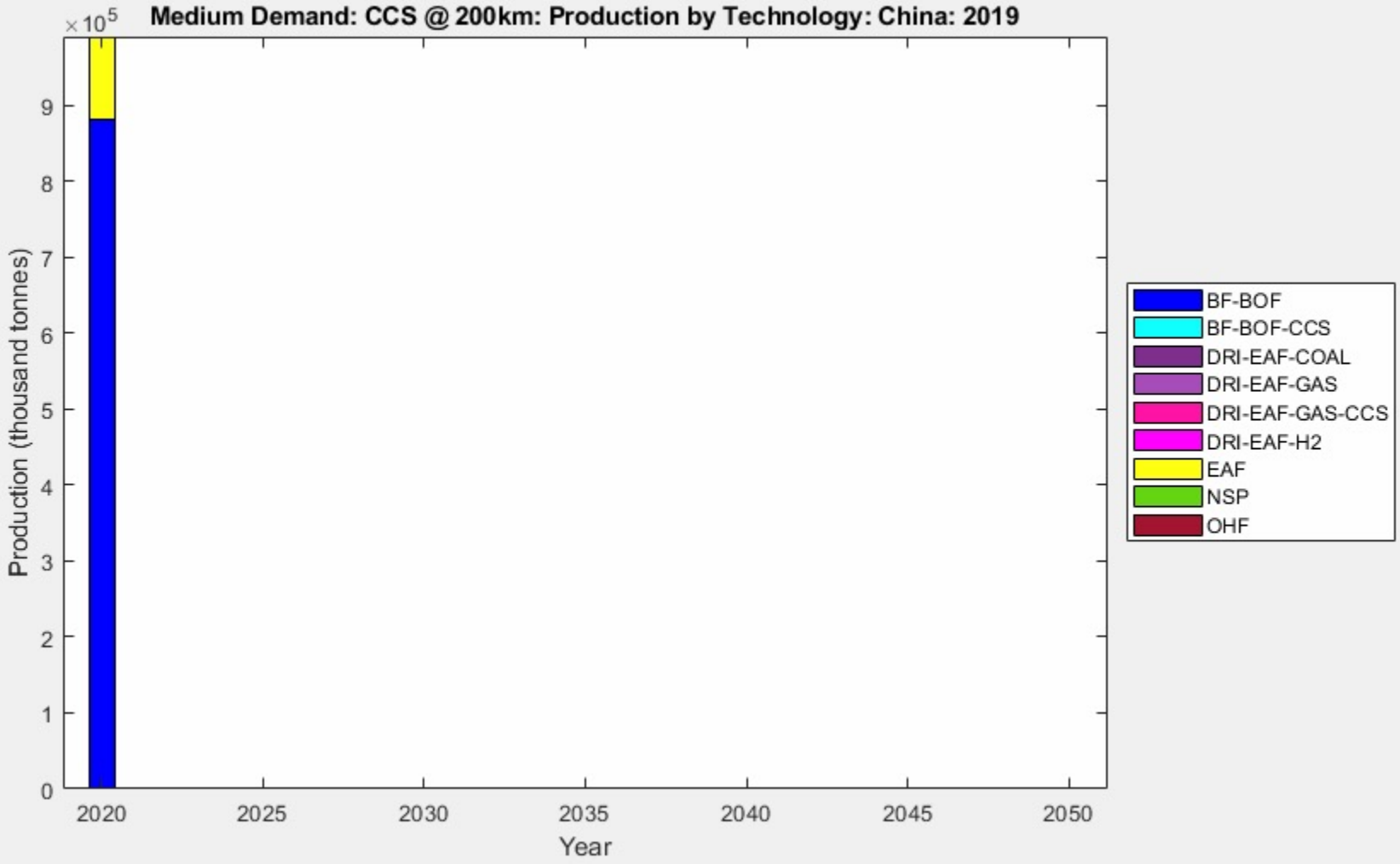


High level methodology

- We begin with a global dataset of existing geospatially distinct steel plants over 1Mt in 2019 provided by the Global Energy Monitor, and added from other data sources to build up a full data set.
- Demand is assessed on a global evolution towards 200, 250 and 300 kg per capita in 2080, using ”s” curves
- Because it’s cheaper, scrap availability determines recycled production. Global scrap availability forecasts are ~1.4 Gt in 2050 for similar demand scenarios, with ~83% use. Model assumes for 133 countries that forecast scrap supply will be equal to scrap EAF production by 2050 (61 countries with currently no known EAF production become producers)
- For new primary facilities, working with the premise that steel makers would prefer to keep using existing sites if possible, and working with a retrofit cycle of 25 years, we use GEM data where available and otherwise estimate the time to the next retrofit. At retrofit, for new primary, we use the following algorithm


Is the current facility near CCS geology, or an industrial cluster with a CO2 pipeline?
Done with maximum 100, 200 and 300 km pipelines to the nearest CO_2 reservoir
NO
Yes
Is there potential excess hydropower, nuclear, wind or solar within transmission distance?
Done using annual 3.5 kW per meter^2 per day as the proxy
Yes
Green hydrogen DRI with an EAF is an option in 2028
No
Green iron imports with an EAF is an option
Is there a political preference against CCS?
Yes
NO
Is there a tech or political preference for retaining BFBOFs
NO
Yes
Has advance smelting been mastered?
NO
Yes
Blue hydrogen/syngas DRI EAF is an option in 2025
Advanced smelting with CCS is an option
Has post combustion CCS been mastered? (2030)
Is there excess resources of biomass available?
No
Yes
90% capture BF-BOF newbuild with CCS is an option in 2030
BF-BOF or DRI Biomass with CCS is an option

Results for China – medium demand, 200km of CO_2 pipelines available



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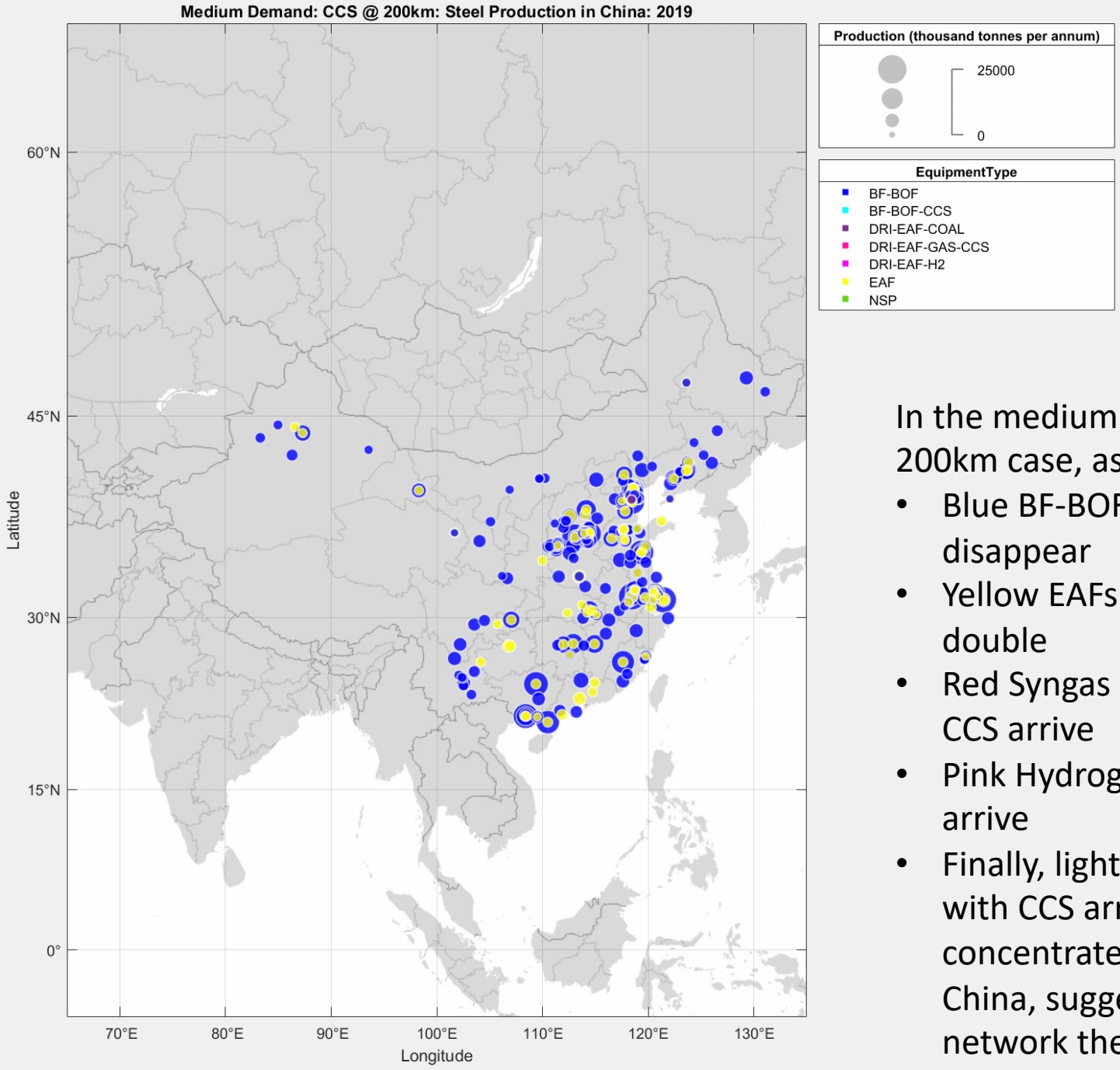
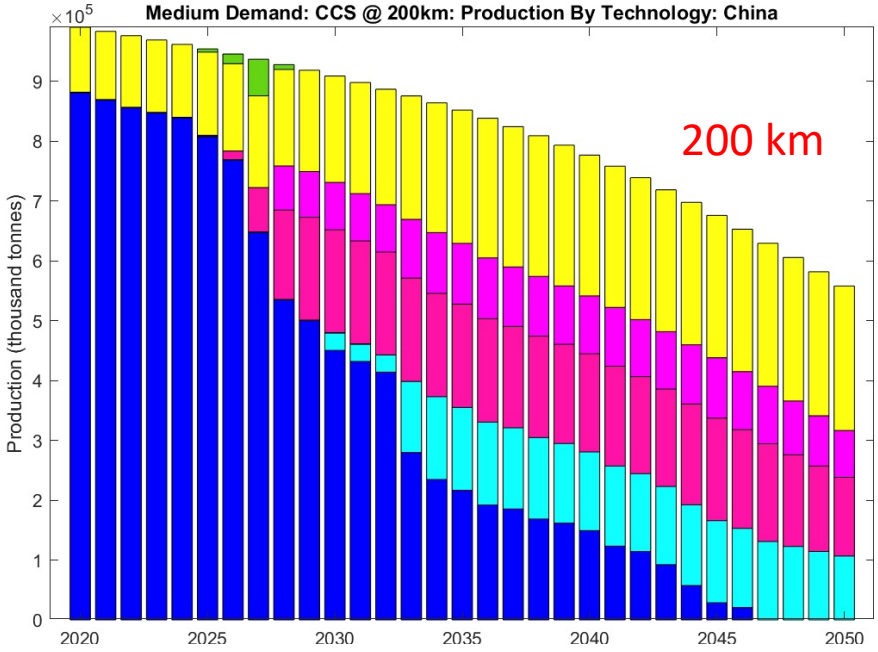
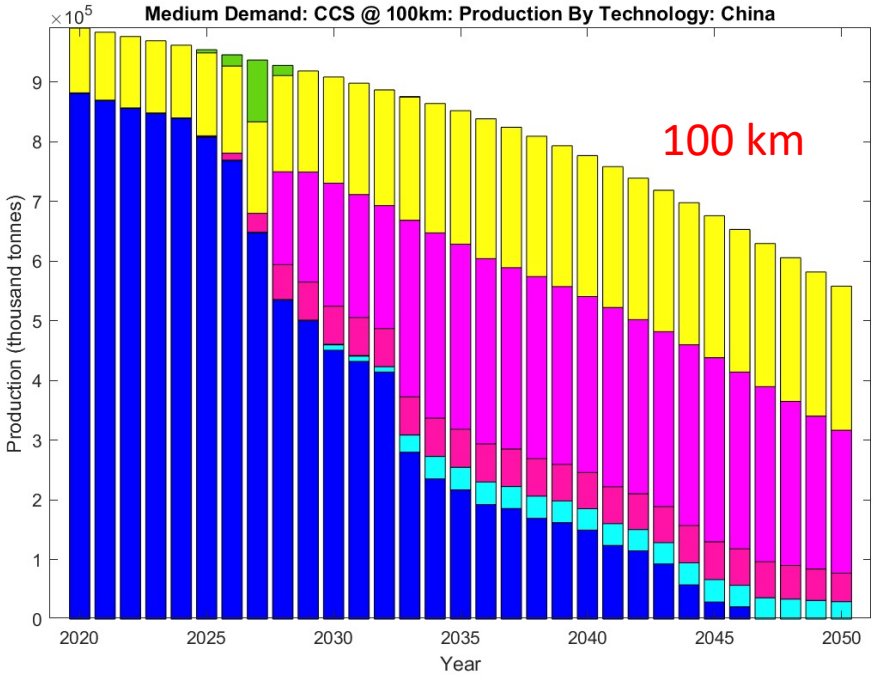


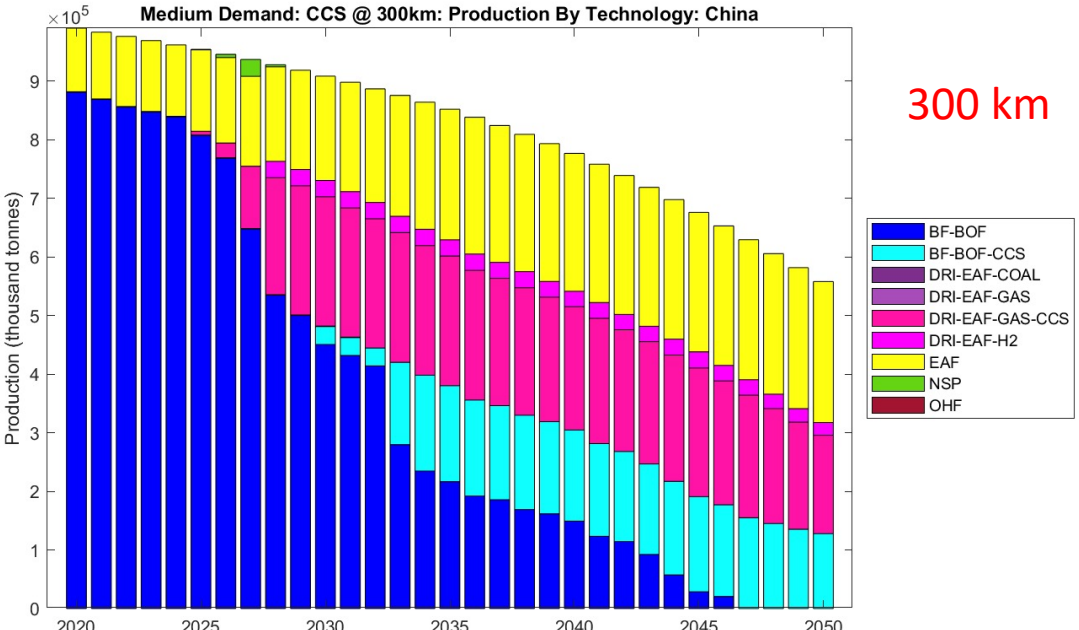
In the medium demand, 200km case, as time passes …

- Blue BF-BOFs gradually disappear
- Yellow EAFs gradually double
- Red Syngas DRI EAFs with CCS arrive
- Pink Hydrogen DRI EAFs arrive
- Finally, light blue BF-BOF with CCS arrive concentrated in northeast China, suggesting a CO_2 network there.

China – low, medium and high pipeline availability

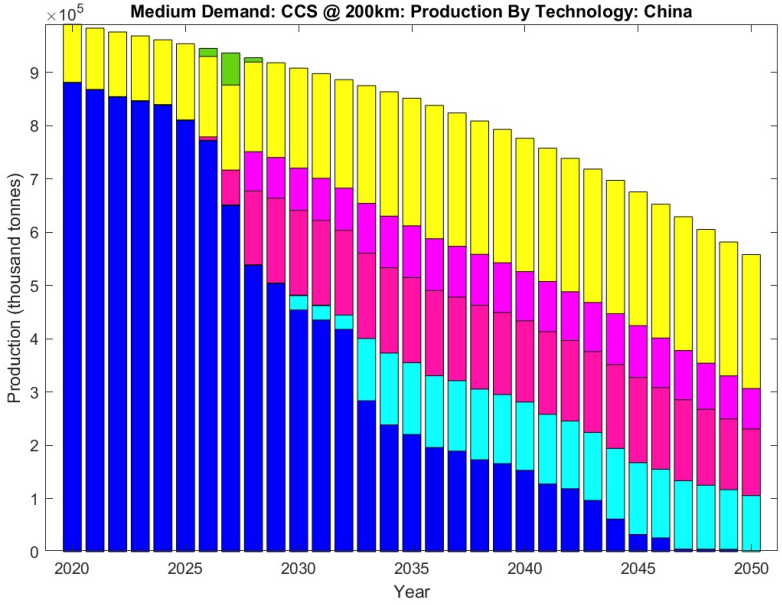




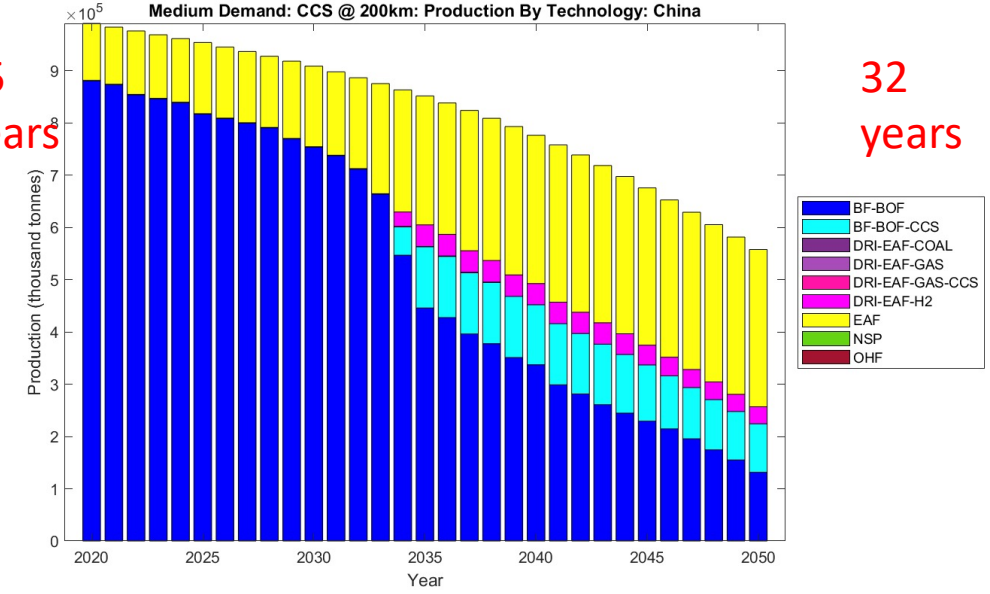


- Pipeline availability, e.g., through an industrial cluster in northeast China, is critical to use of CCS, but not critical to decarbonization of steel.
- The km distances are from existing steel production sites to the centroid of known potential CO_2 disposal sites from the Oil & Gas Climate Initiative database.

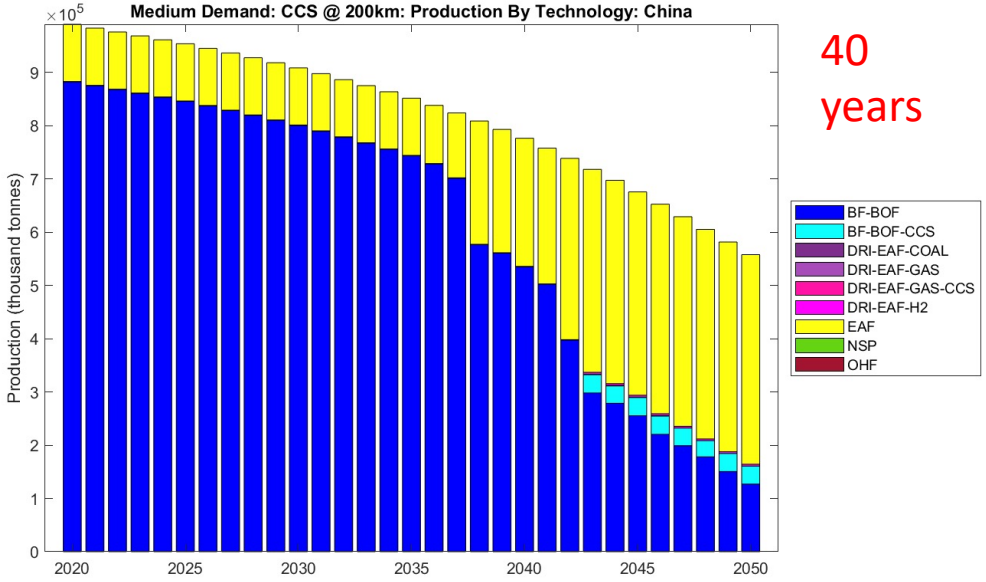
The other big sensitivity – asset renewal timetable



25 years



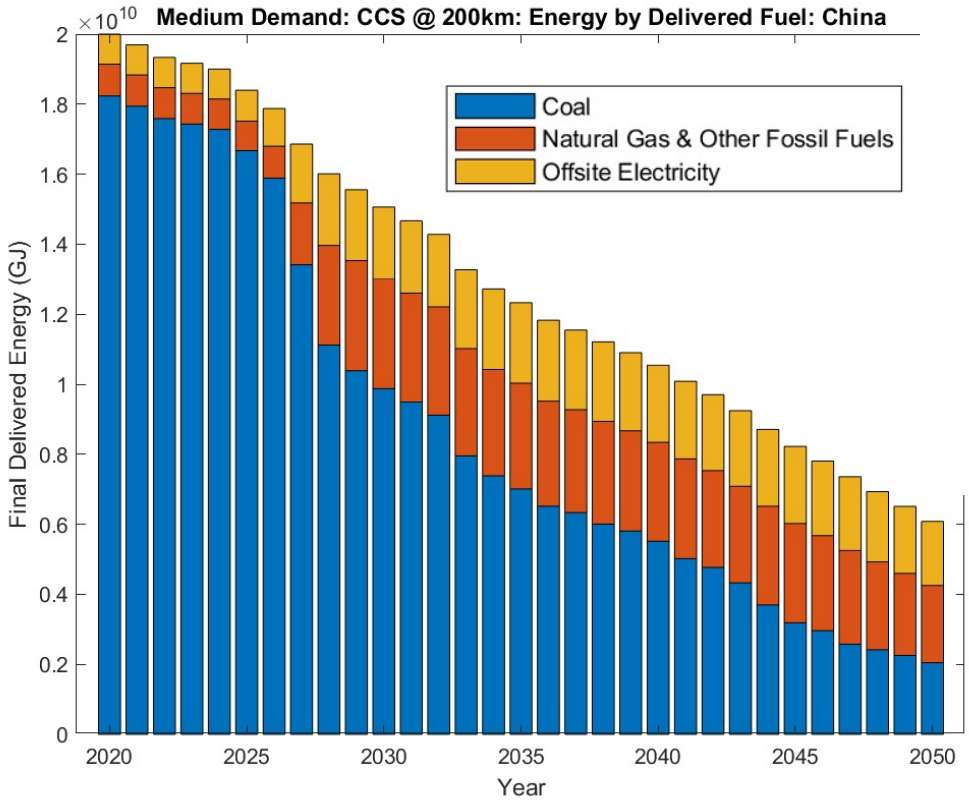
32 years

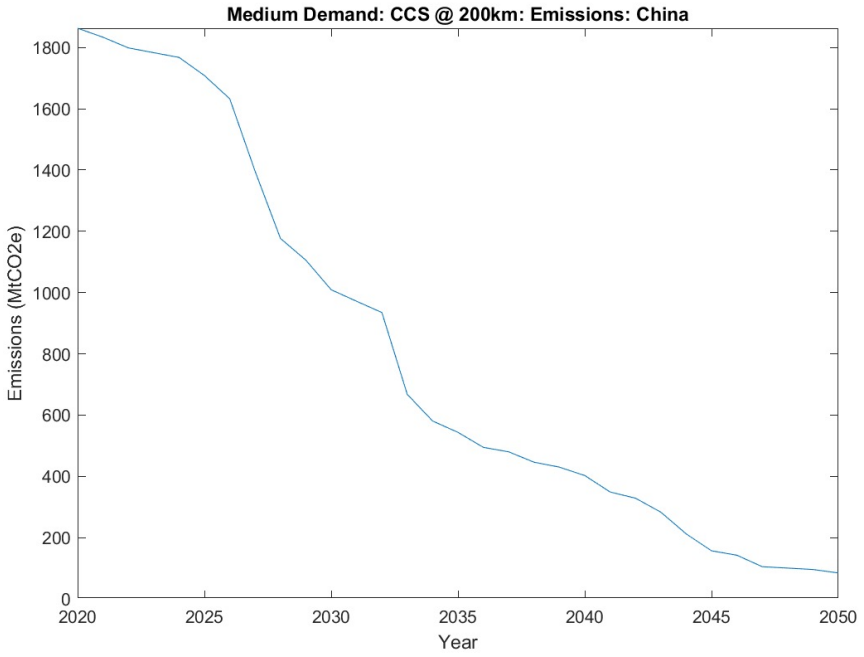


40 years

- The most emitting parts are sintering, reduction (BF, DRI) and smelting (BOF, EAF). The renovation schedule for these components matter.
- IEA provides 25 & 40 years as brackets. It could be as low as 20 years in some cases.

China – Fuel use and direct scope 1 process and combustion emissions. Medium demand, 200km





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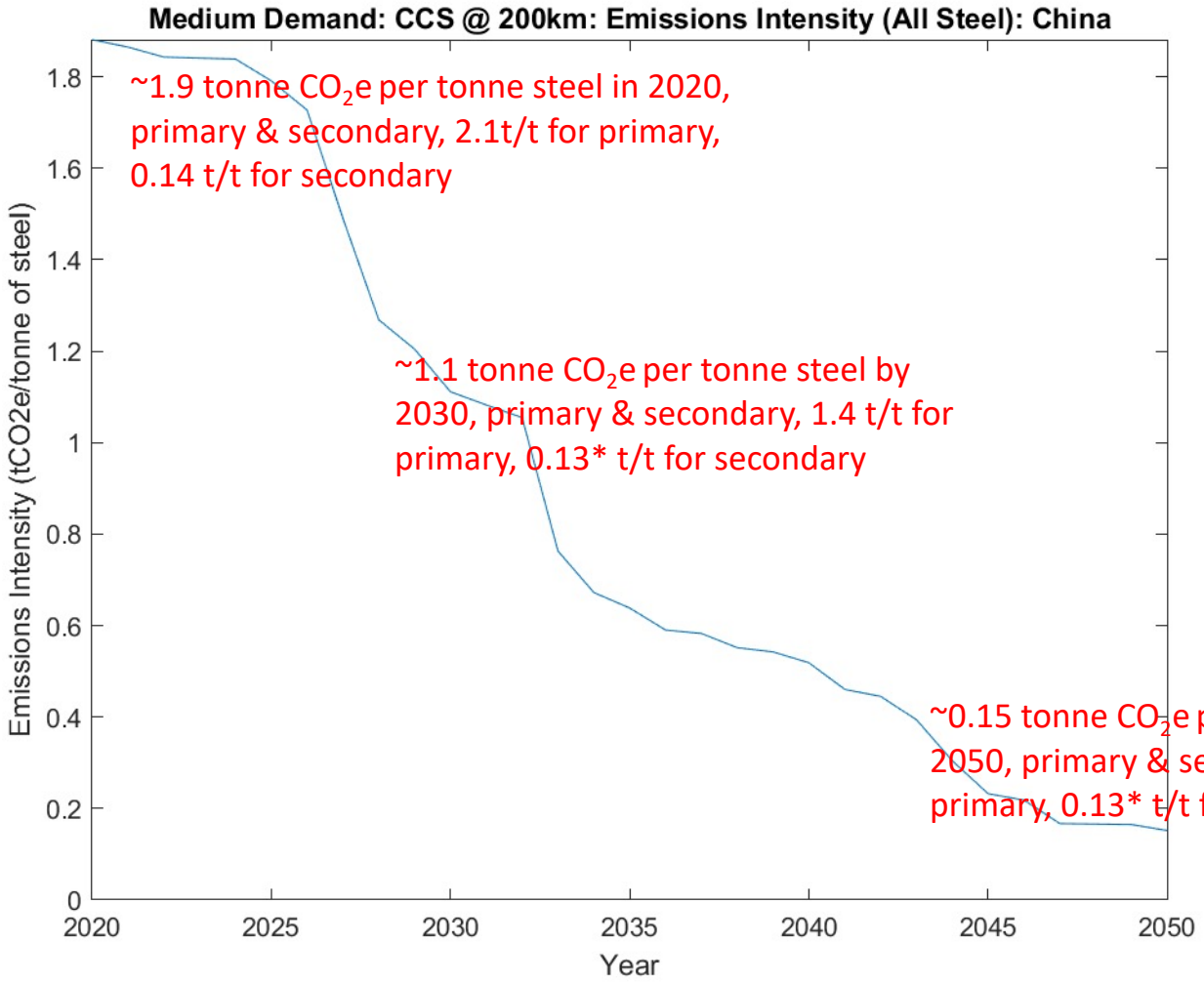
GHG & energy intensity benchmarks
All (primary and secondary) facilities



Our stock turnover was determined by a 25 year retrofit cycle, the GEM database age data, and probabilistic estimate for facilities of unknown age – it's relatively fast compared to the IEA, which has more remnant emissions.

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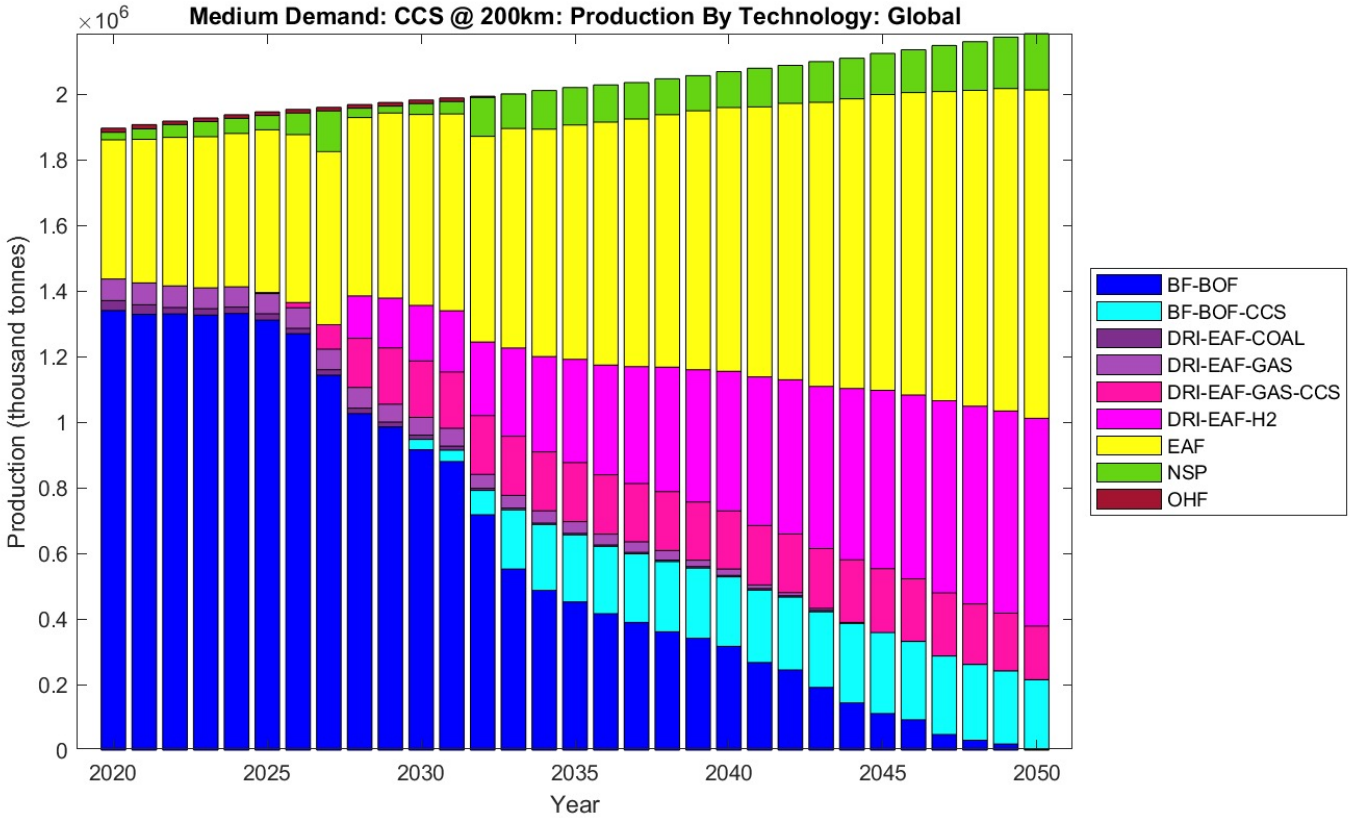
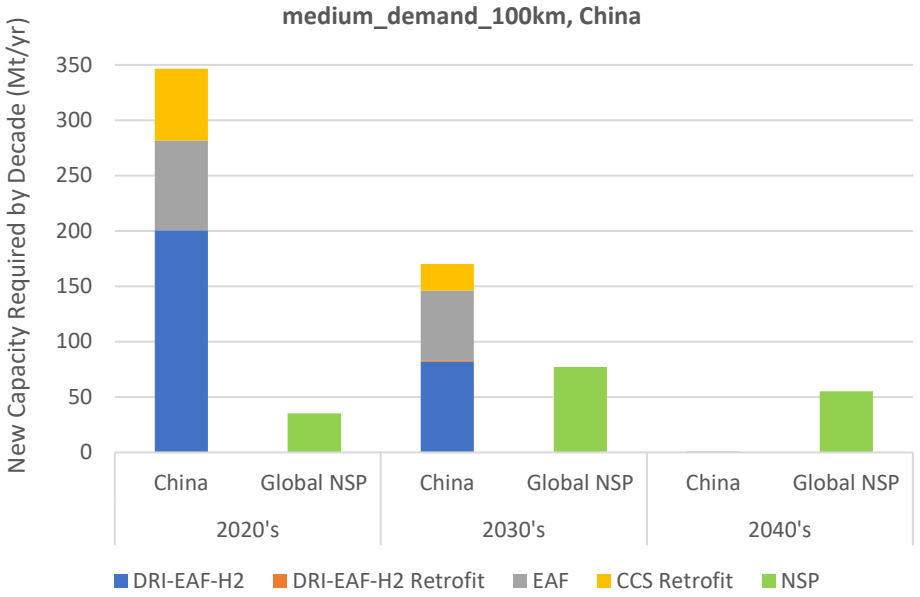
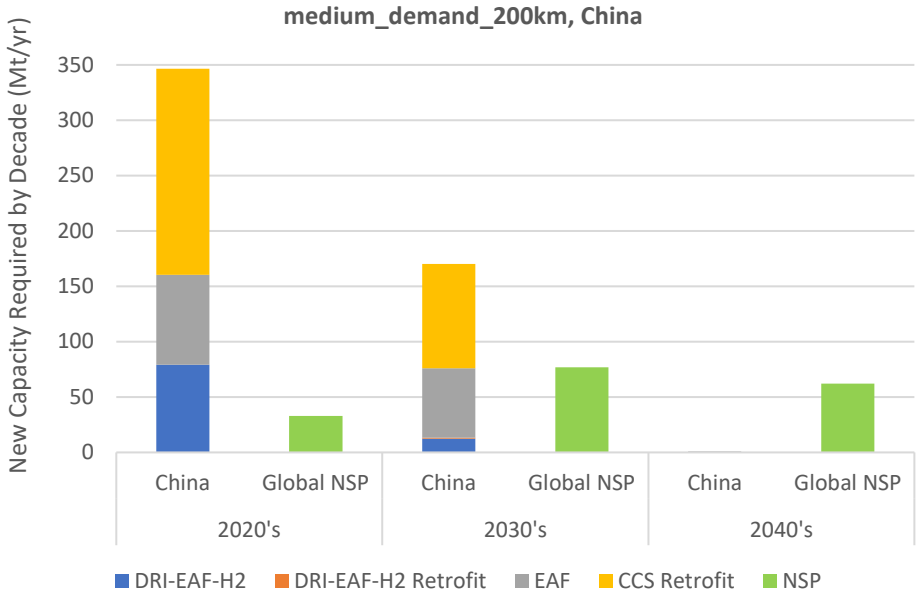
The global picture, and the export opportunity

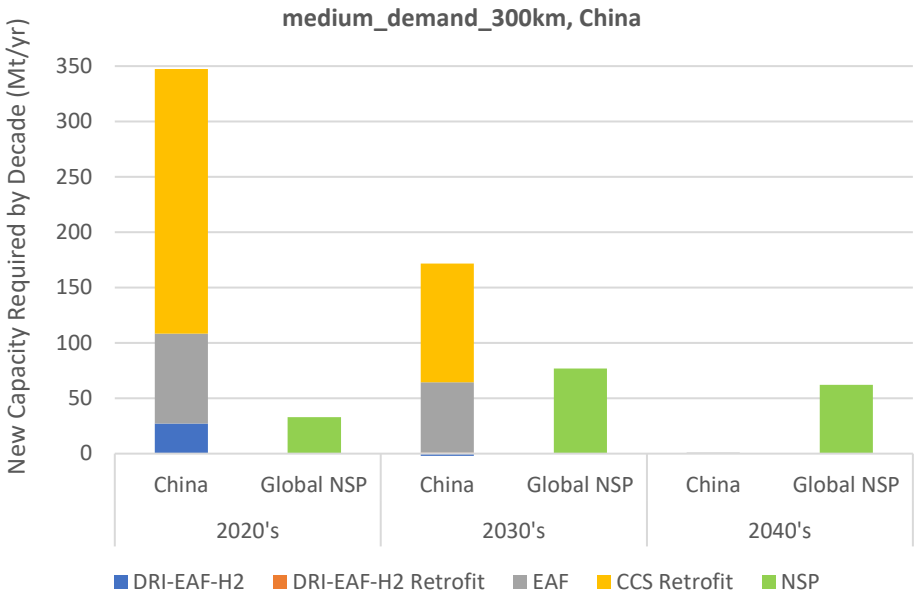


The green line on top that grows to ~200 Mt/yr, that mostly doesn't show up in China because it is self sufficient, is the opportunity for net-export of green iron and steel products to the world, on top of local demand. China has some room to meet this opportunity.

China – low, medium and high pipeline availability
New capacity additions to plan for







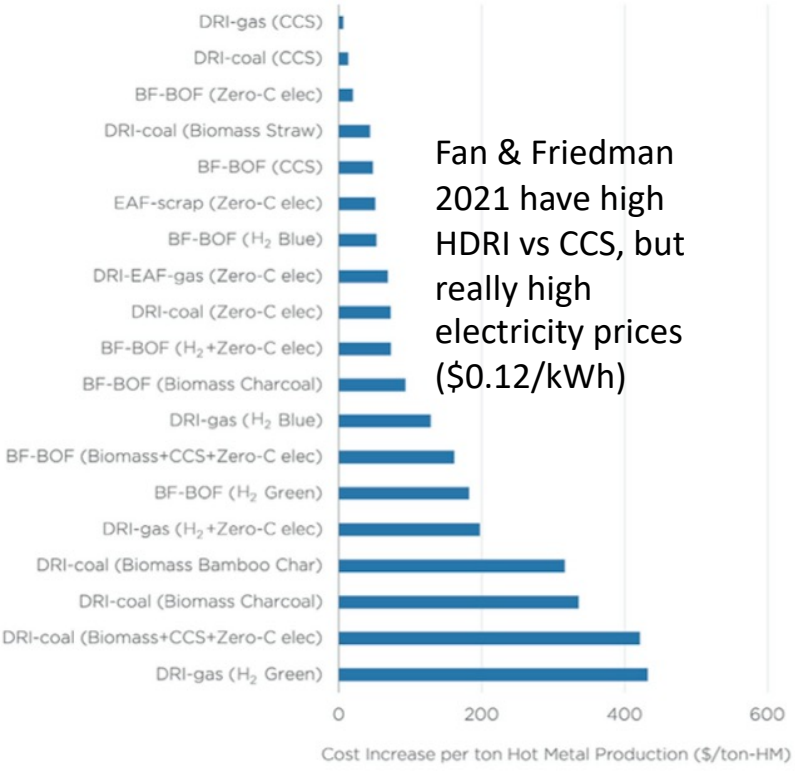
Where the iron ore is …

Other possibilities – restructuring the supply chains, with steel as an example

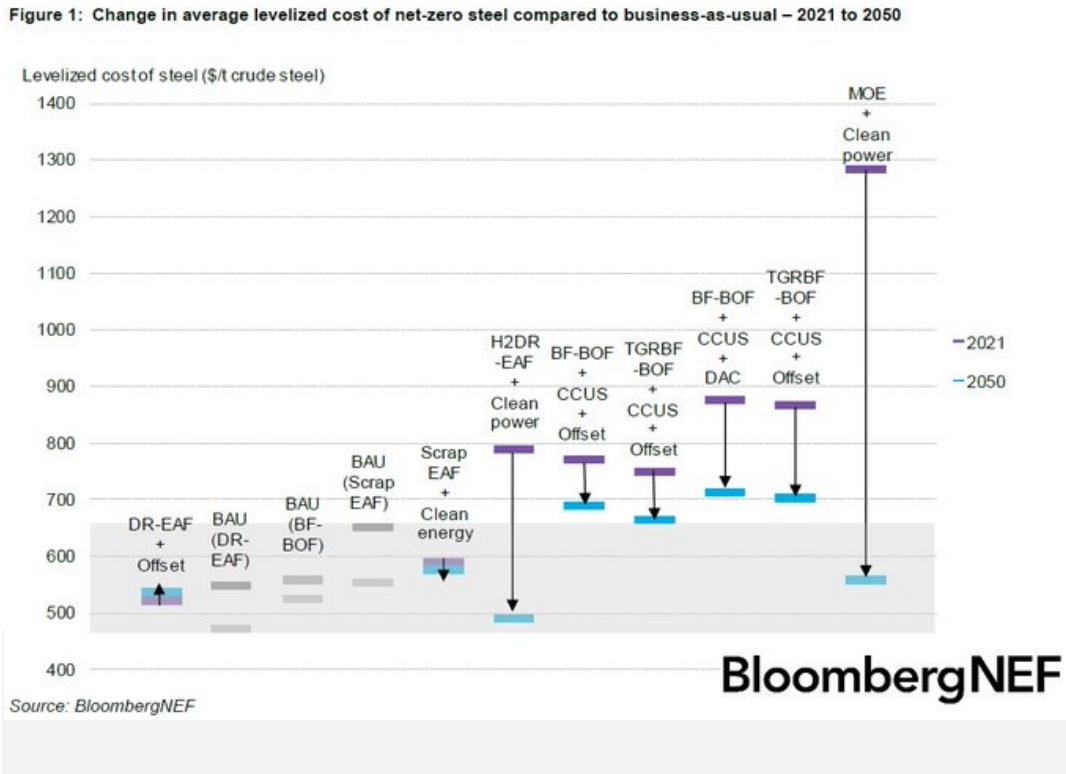
- We currently make primary iron and steel near coal and iron ore and move it where it's needed; with hydrogen DRI we can make it near iron ore, cheap clean electricity (green), or cheap methane and CCS (blue), and move green iron where it is needed.
- Electric arc furnaces can stay where they are, near markets and supply chains.
- BF-BOFs can be preloaded with up to 30% green iron and cofired with hydrogen until the end of their kiln lives
- Eventually primary steel could all be run through DRI and EAFs, with iron being reduced and traded globally
- Eventually, when there is lots of clean electricity and power capacity, molten oxide furnaces can take over to supplement recycling, which should eventually dominate.
- China could import reduced iron from Australia, South Africa, etc. and eventually run almost only electric arc furnaces for primary steel.

But what about cost per tonne (1)

- This is not an optimization exercise. Technology uptake is based on technical possibility and aggressive innovation and uptake policies in China and globally.
- Estimates of additional costs per tonne wildly differ, mostly based on varying electricity prices and CCS costs, but range from +20 to +70% for >=-90% reductions.
- This would only increase vehicle, bridge or building costs by +1-2%. Nationally appropriate means for risk & cost pass through must be found.

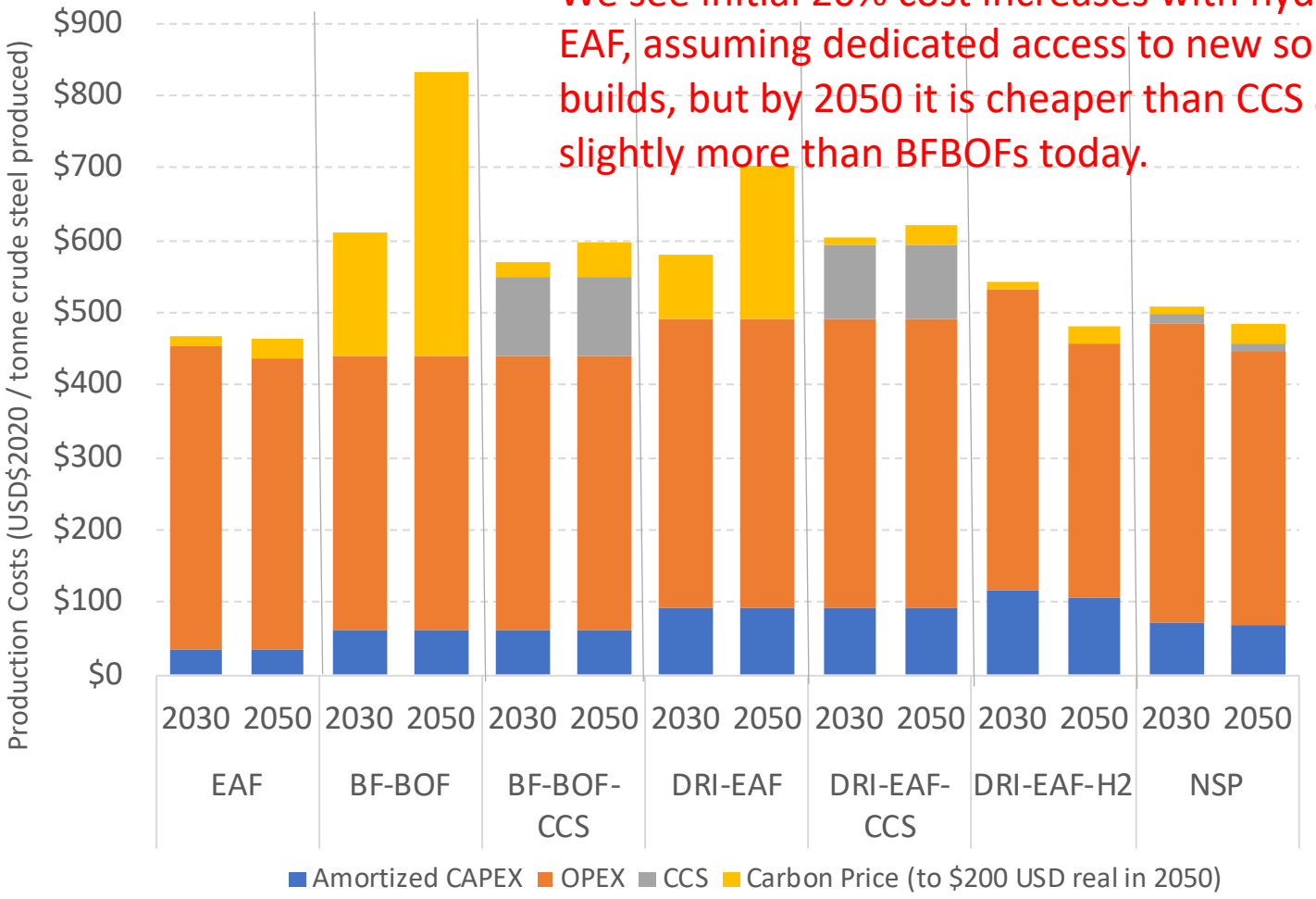


Fan & Friedman 2021 have high HDRI vs CCS, but really high electricity prices ($0.12/kWh)



But what about cost per tonne (2) ?
Our estimates

We see initial 20% cost increases with hydrogen DRI EAF, assuming dedicated access to new solar & wind builds, but by 2050 it is cheaper than CCS and only slightly more than BFBOFs today.



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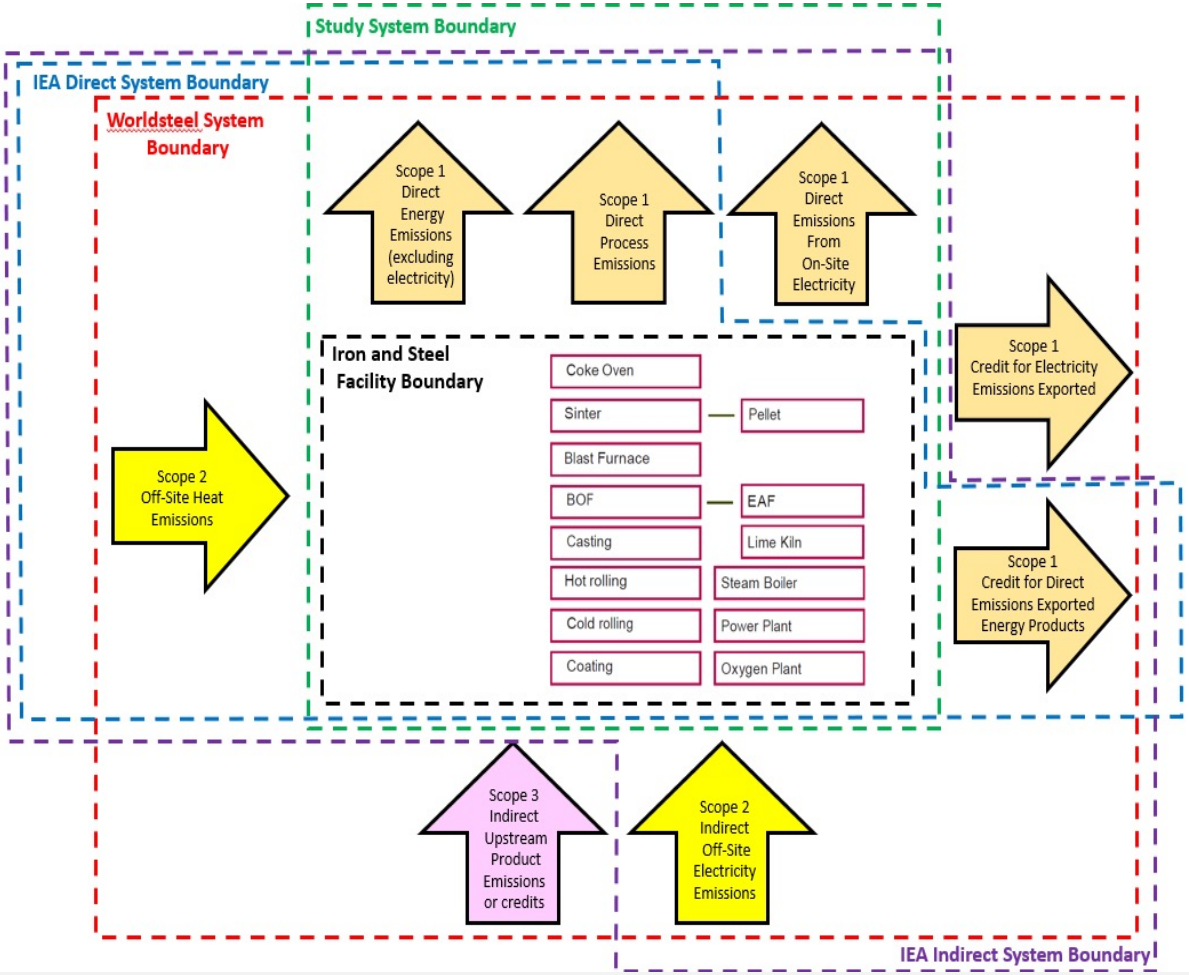
Study Emission Boundary



We, the IEA, and Worldsteel all measure steel GHG intensity slightly differently. What are the key differences that matter?

- We include all GHGs from all fuels that enter the facility, without credit for sales
- We don't credit for offsite electricity sales (WS does)
- We don't credit for offgas or heat sales (WS & IEA do)
- We don't include GHGs from purchased electricity (WS does), assuming system electricity GHGs are supposed to go to zero.
- Our system is designed for primary process replacement and elec->zero GHGs.

Summary headline take away messages
"We can do it, but time is of the essence"

- Decarbonisation of global steel manufacturing by 2050 is technologically feasible using high TRL technologies. This requires all new facilities & retrofits are near zero emission by the later 2020s, latest early 2030s. If this is delayed early retirements will become necessary.
- China has a key role to play because of the BF-BOF capacity built ~1995-2015, 54% of global. This capacity is coming due for retrofit.
- Global innovation and commercialization programs, including private and public green procurement & lead market contracting, will be needed to make sure technologies are ready to replace all steel facilities up for retrofit from the late 2020s onward.
- The scale of investment is VERY large, but has been accomplished in the past
- The geographical distribution of demand will shift over time with implications for governments, manufacturers, trade and end users.
- The varying global spatial distribution of resources (i.e., scrap, carbon storage locations, renewable generation) means countries and regions have varying opportunities, with different infrastructure needs, e.g., recycling needs gathering networks, CCS needs at least ~200km of pipeline access to be relevant for existing steel facilities, hydrogen needs clean generation and overnight hydrogen storage if solar PV based.

« Not the end, nor the beginning of the end,
but the end of the beginning »

Please send questions to:

Email: chris.bataille@iddri.org Twitter DM:@chris.bataille

Existing Iron & Steel Facilities Included in Model (Additional slide for questions)

- Start with GEM Database facilities (only facilities > 1 MT of capacity)
  - 2.0 Gt of crude steel capacity in 2019, 67 countries, 622 facilities
  - Estimate of 1.6 Gt of 2019 production / 86% of global
- Cross referenced with GIDS Database, country level production identified by the Worldsteel Association and OECD national capacity database to identify remaining 14% of global production:
  - 27 additional countries (94 total) with reported production and/or capacity
  - Estimate of 213 additional facilities (mostly smaller EAF) - based on average regional operating characteristics of facilities and spatially allocated near existing production or in major country industry centres.
- Additional 39 countries are also seeded in the model for future production based on scrap availability and national demand for steel.