The (Industrial) Ecology of Steel

René Kleijn, Institute of Environmental Sciences (CML) Delft, March 31st 2023

Universiteit Leiden
The Netherlands

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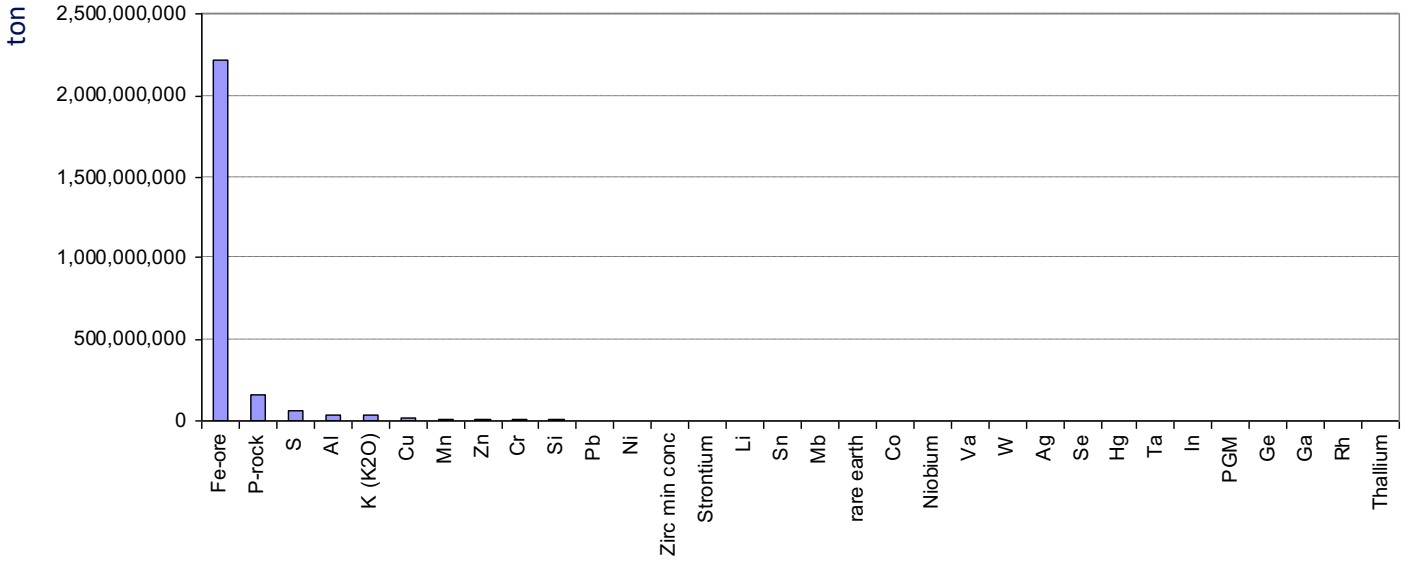
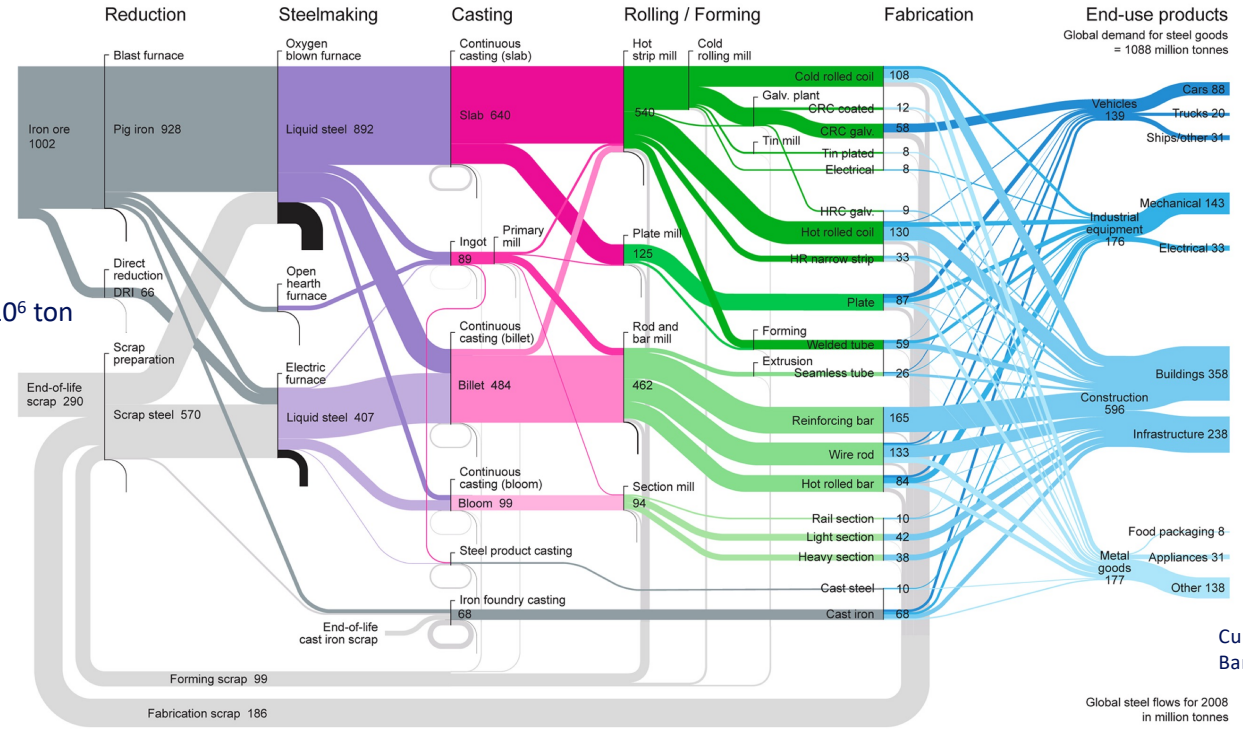
We still live in the iron age !



Global steel flows (2008)

1292 10^6 ton



1088 10^6 ton

Cullen, Allwood & Bambach, ES&T, 2012

Global steel flows for 2008
in million tonnes

Shanghai

1990

2010

Shenzen

1980

2011

Kuala Lumpur

1990

2015

Dubai

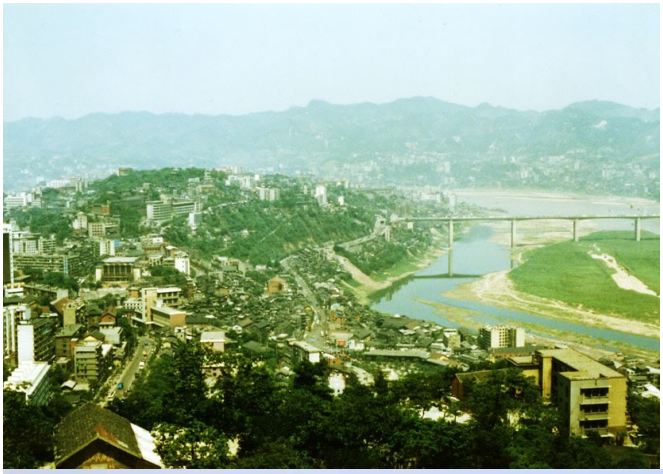
1990

2015

Fortaleza
Brazil

1970s

2011



Chongqing

1990

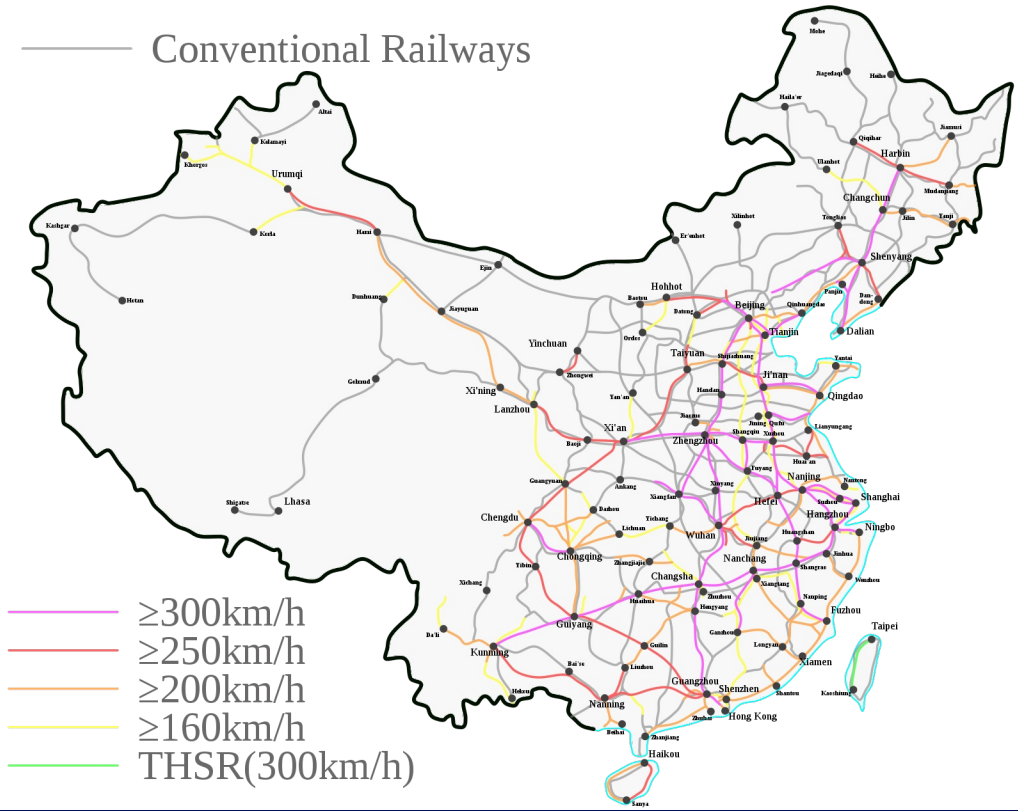
2007


China Changji-to-Guquan
3300 km, 1100 kV, 12 GW
Direct current
$ 6 billion

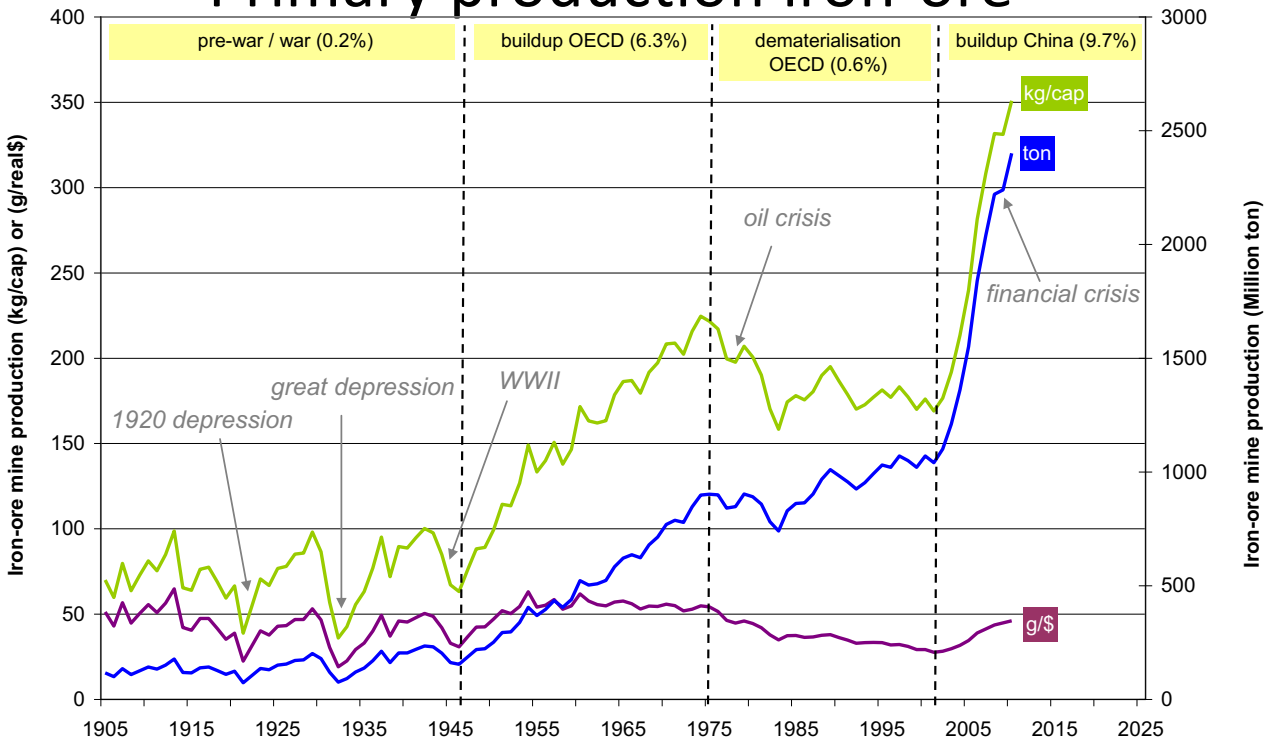
12 GW crossing the Yangtze River


CRH

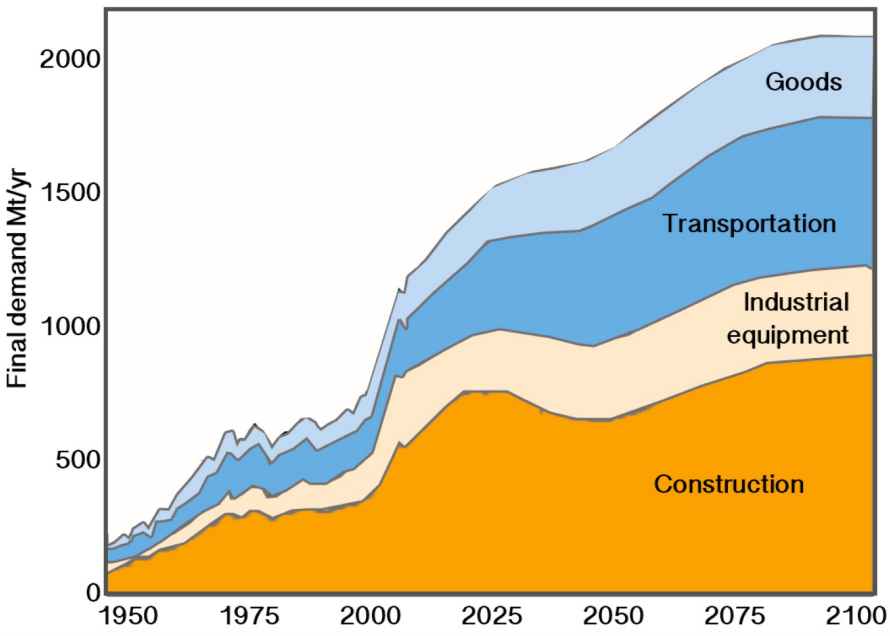
Disc



Primary production iron-ore

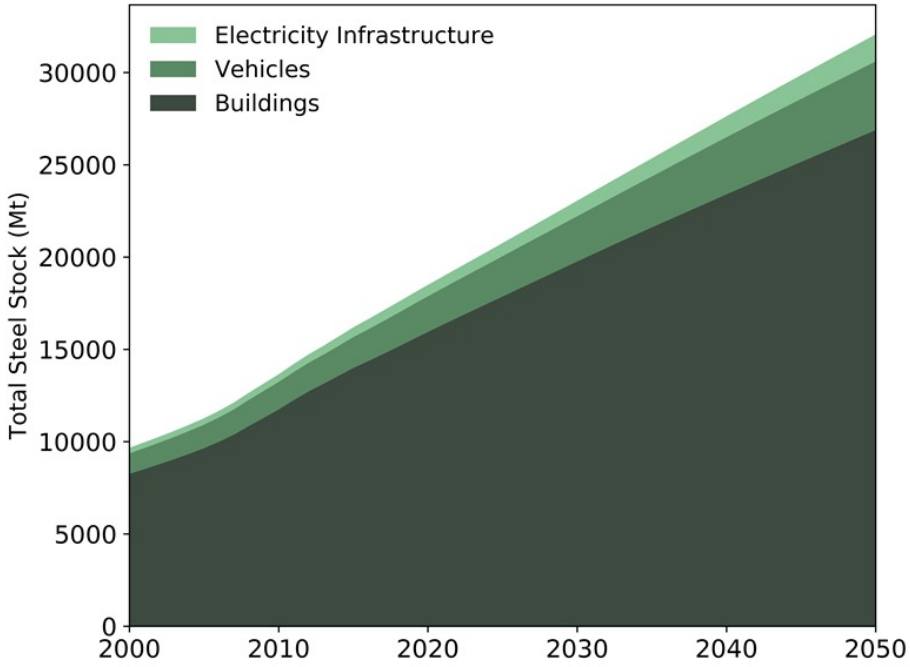


Final steel demand by end-use sector



Pauliuk et al, 2013
ES&T 2013

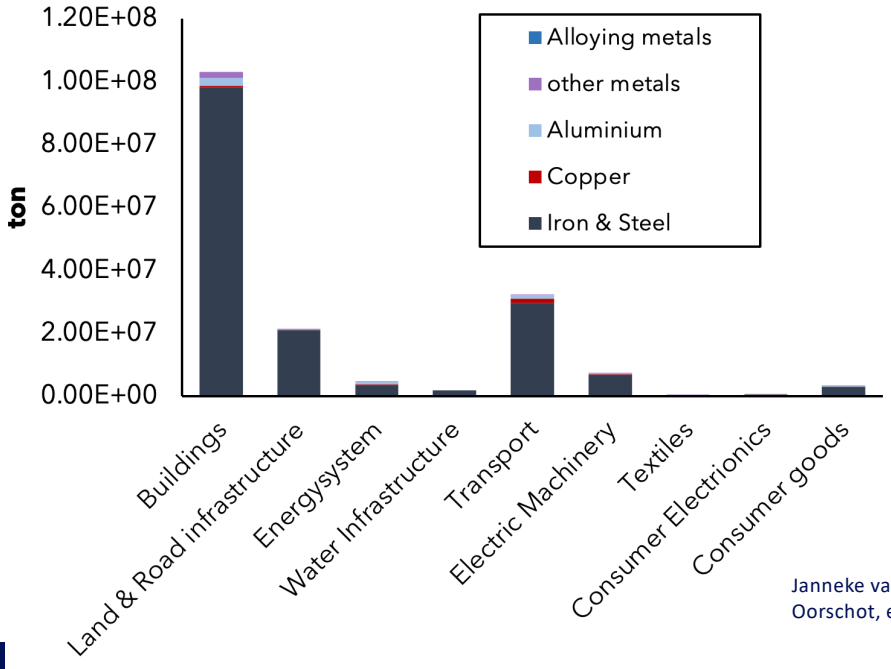
Future global steel stocks



Sebastiaan Deetman,
PhD thesis 2021

Metals in the Dutch Urban mine

- Iron and alloying elements dominate this picture
- Buildings are dominant in terms of stocks
- However, transport is significant too ! (mainly ships)



Janneke van Oorschot, et al. 2023

Steel intensity of the energy sector will increase significantly in a 2 degree world

- steel intensity electricity generation capacity (2015) was around **65** metric ton/MW
- In a two-degree scenario (SSP2) this will be over **100** metric ton steel/MW
- From securing continuous inflow of fossil fuels to fostering stocks of metals in society

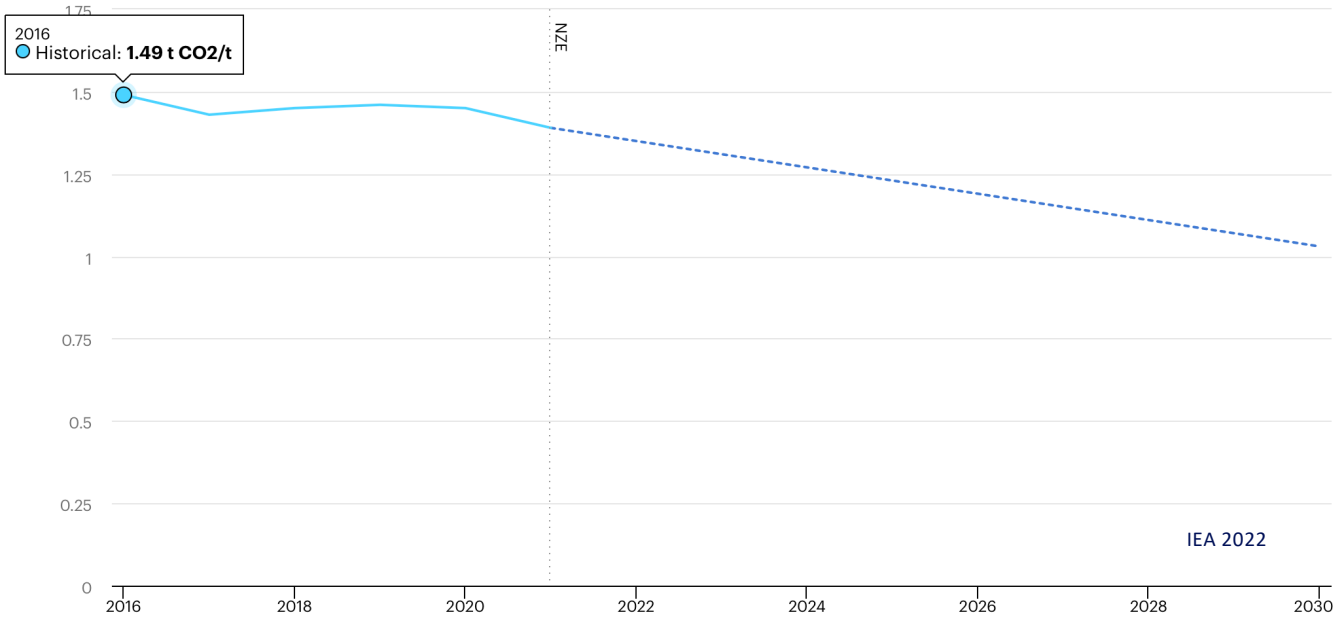
Steel: a sustainable material !

- Durable
- Many options for re-use (building materials etc)
- Fully recyclable (can be carbon neutral with renewable electricity)
- Plenty of geological resources

Steel: a sustainable material ?

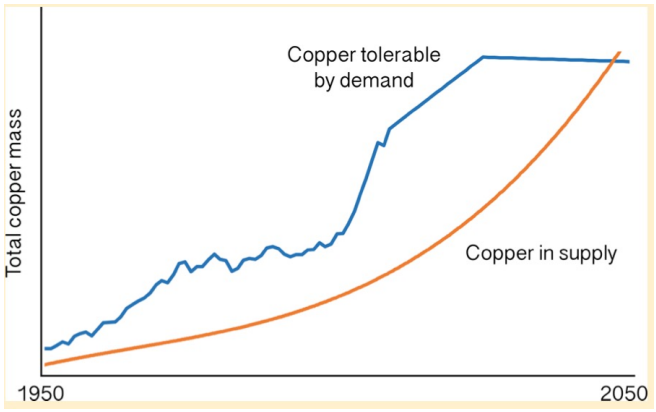
- 1.3 ton CO_2 per ton steel, 9% of global anthropogenic CO_2 emissions
- Other emissions: PM, heavy metals, PAH, N
- Virgin iron input remains necessary for recycling (copper contamination)
- Security of supply of alloying elements (60-70% nickel, 80-90% chromium, 80—90% vanadium, 90%, niobium, 85-90% manganese, 80% molybdenum, 40-50% Tungsten, 55% zinc)
- Mining of iron ore and alloying metals has significant impacts

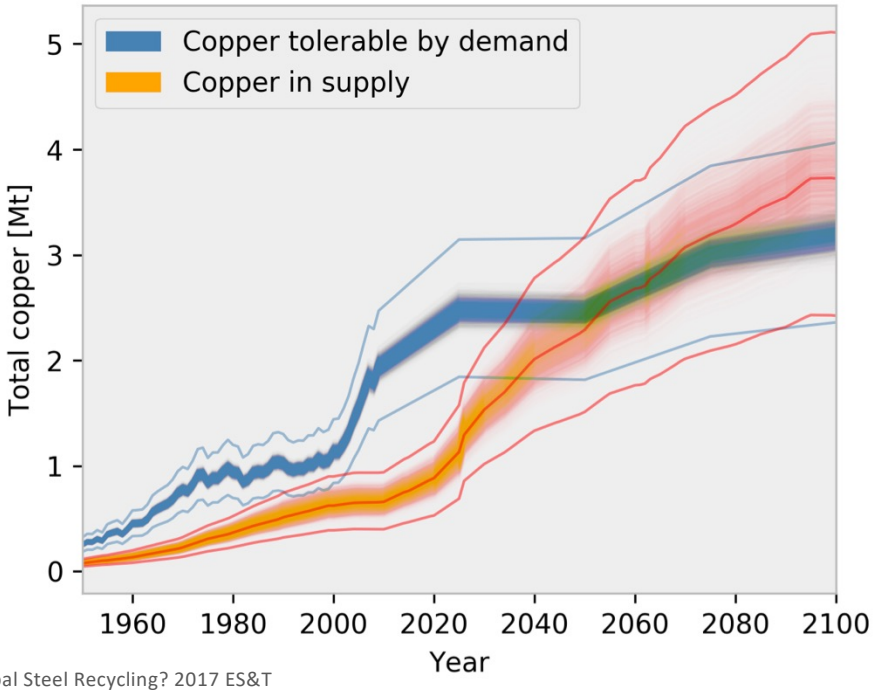
CO_2 emission intensity is decreasing



Copper contamination

- Around 2050 copper contamination could become problematic





Daehn et al., How Will Copper Contamination Constrain Future Global Steel Recycling? 2017 ES&T

EU's Net-Zero Industry Act aims to bring home clean tech production

By Kira Taylor | EURACTIV.com Mar 17, 2023 (updated: Mar 18, 2023)

EU unveils Critical Raw Materials Act, aiming to lessen dependence on China

By Théo Bourgery-Gonse | EURACTIV.com Mar 16, 2023

Vale Tailing dam collapse, Brasil January 2019

Disco


TV Globo
25/01/2019 12:28

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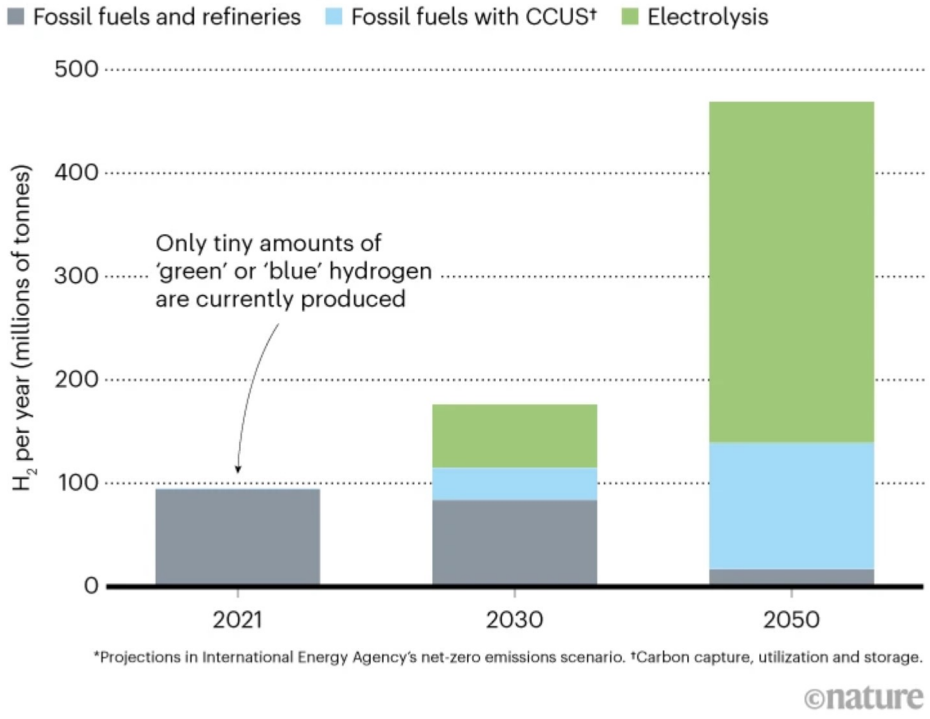
Greening the steel cycle

- Fossil fuel based electricity & cokes -> renewable electricity & hydrogen
- Reduce: more efficient use -> less mining
- Close the loop -> less virgin production
- Reduce the need for alloying elements -> less mining, easier recycling *(material science!)*
- Prevent (copper) contamination (collection, separation, ..) *(material science!)*

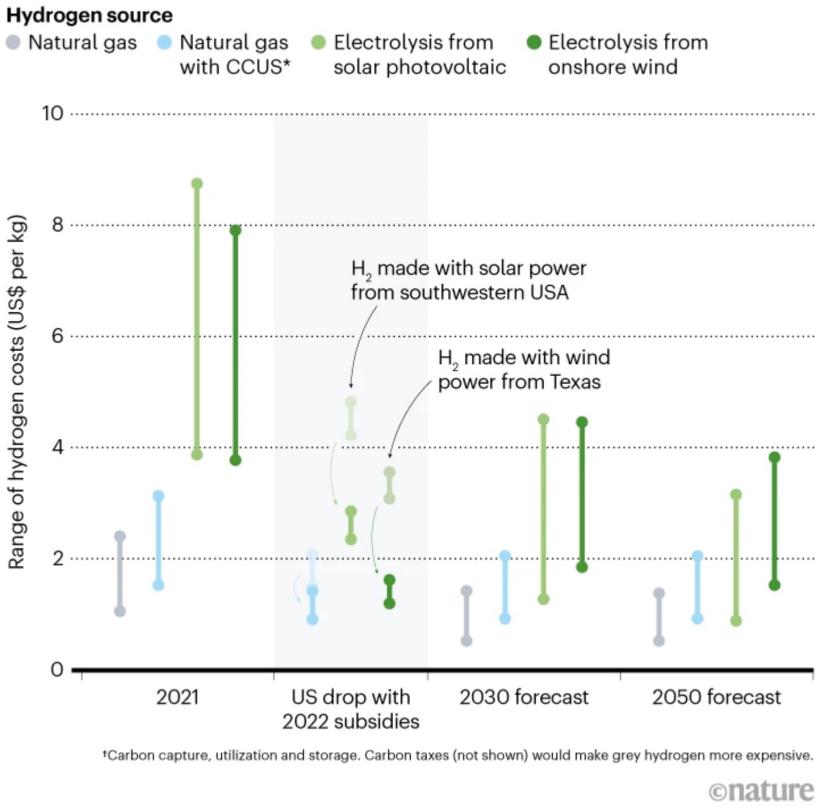
Consequences of greening the steel cycle

- Replacing coal with hydrogen would drive up the price of a ton of steel by about one third
- Less in future due lower cost renewables and higher carbon price
- Requires an increase in electricity production of the order of 20 %
- Requires a huge increase in green hydrogen production
- Geospatial distribution of steelmaking would shift to places with ample renewable electricity

Hydrogen production in IEA NZE scenario

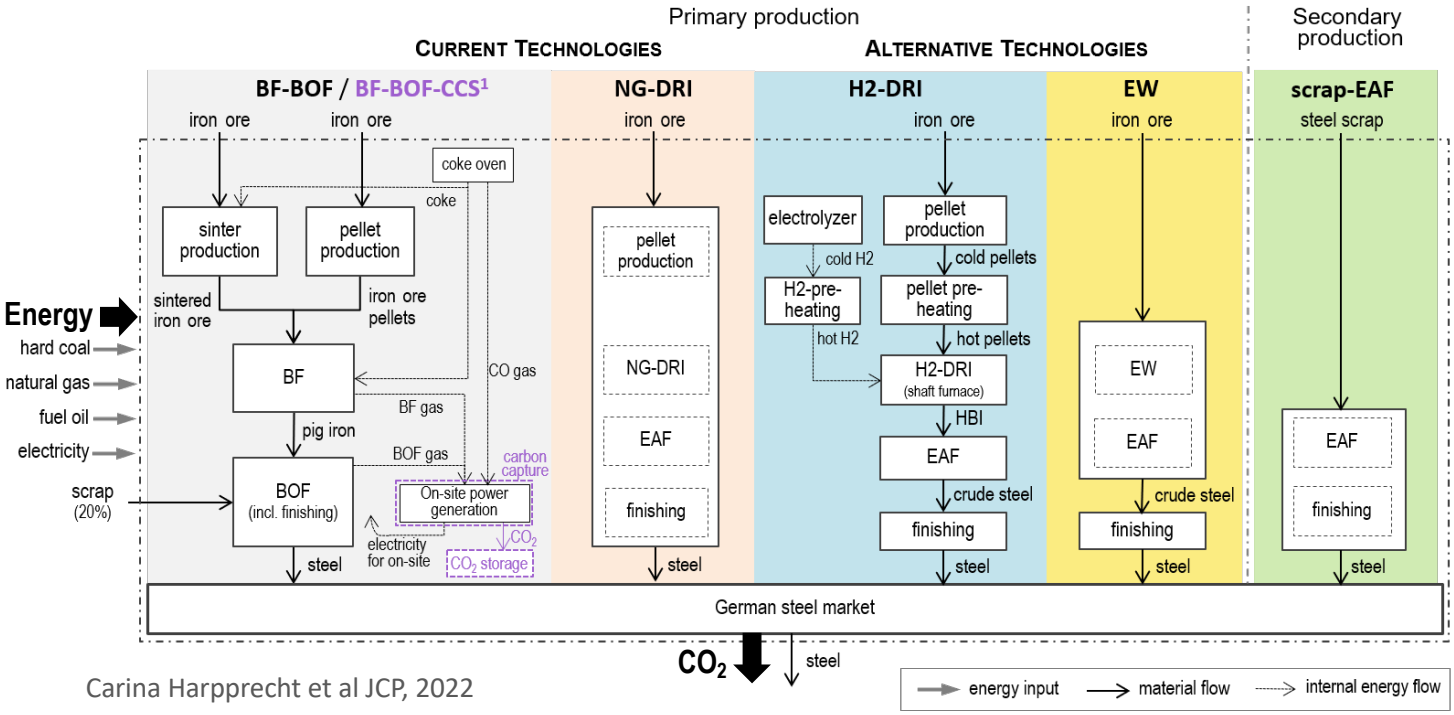


Hydrogen costs



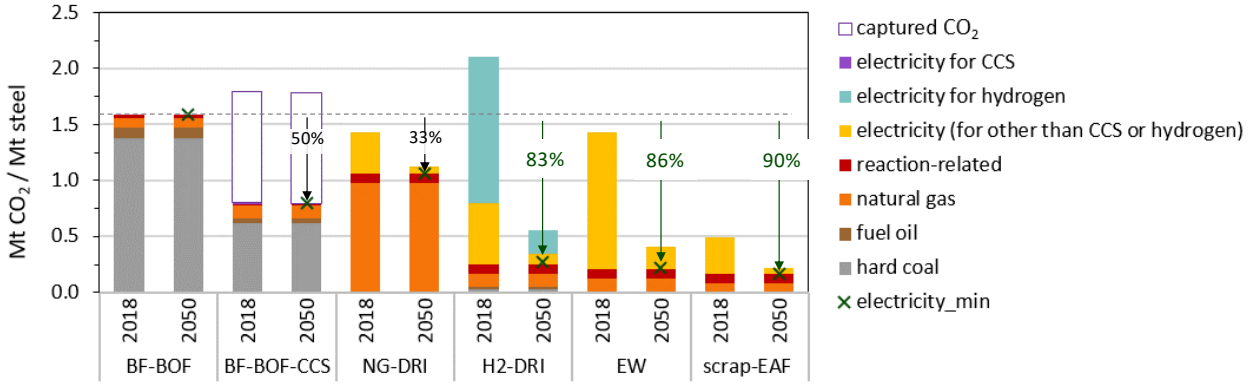
Sources: IEA Global Hydrogen Review 2022; BloombergNEF analysis

Decarbonisation of German Steel Industry



Carina Harpprecht et al JCP, 2022

CO_2 emission intensities per production route



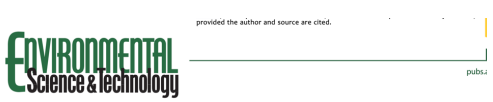
Renewable power is crucial

Carina Harpprecht et al JCP, 2022

Conclusion & reflections

- Steel can be one of the ingredients of a sustainable material basis of society
- Industry should decarbonize as quickly as possible
- Durability and re-use potential should be optimized
- Solutions for contaminations needed to achieve full circularity
- Governments need to set clear goals, with clear timelines, and help provide the required infrastructure (also in terms of renewables and hydrogen)

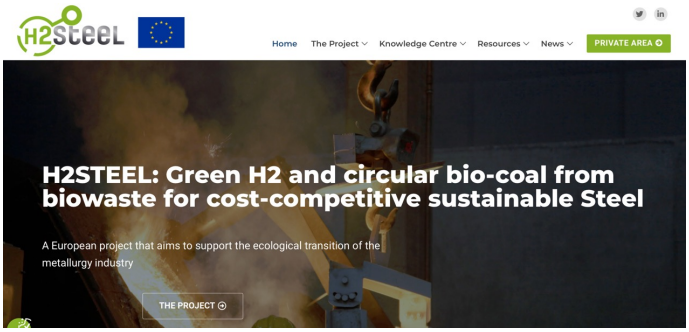
Thanks to my colleagues & further reading:



Overview of the CML reports

Year: 2023

Oorschot J. van, Verhagen T.J., Oers L. van, Voet E. van der
Materiaalvoorraden in de maatschappij: Overzicht van meterialen in de Nederlandse stedelijke mijn
Bijlage:
Bijlage - Totaaloverzicht stedelijke mijn



Deetman, S.P. (2021)

Stock-driven scenarios on global material demand: the story of a lifetime

Doctoral Thesis