

The (Industrial) Ecology of Steel

René Kleijn, Institute of Environmental Sciences (CML)

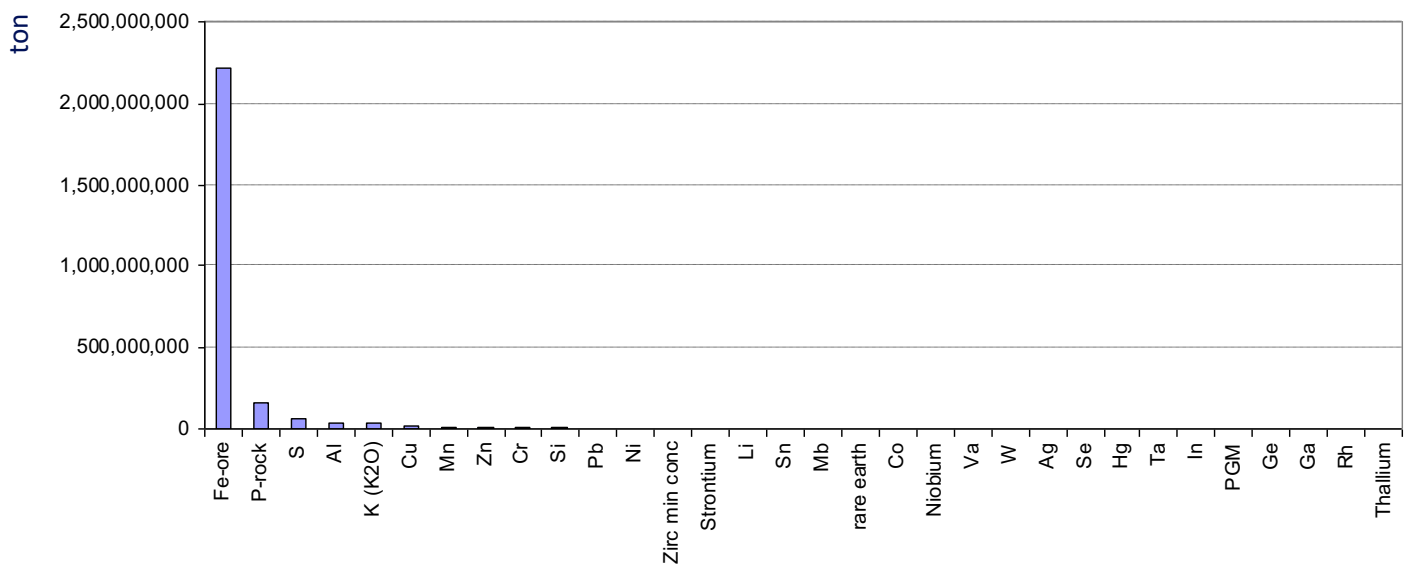
Delft, March 31st 2023



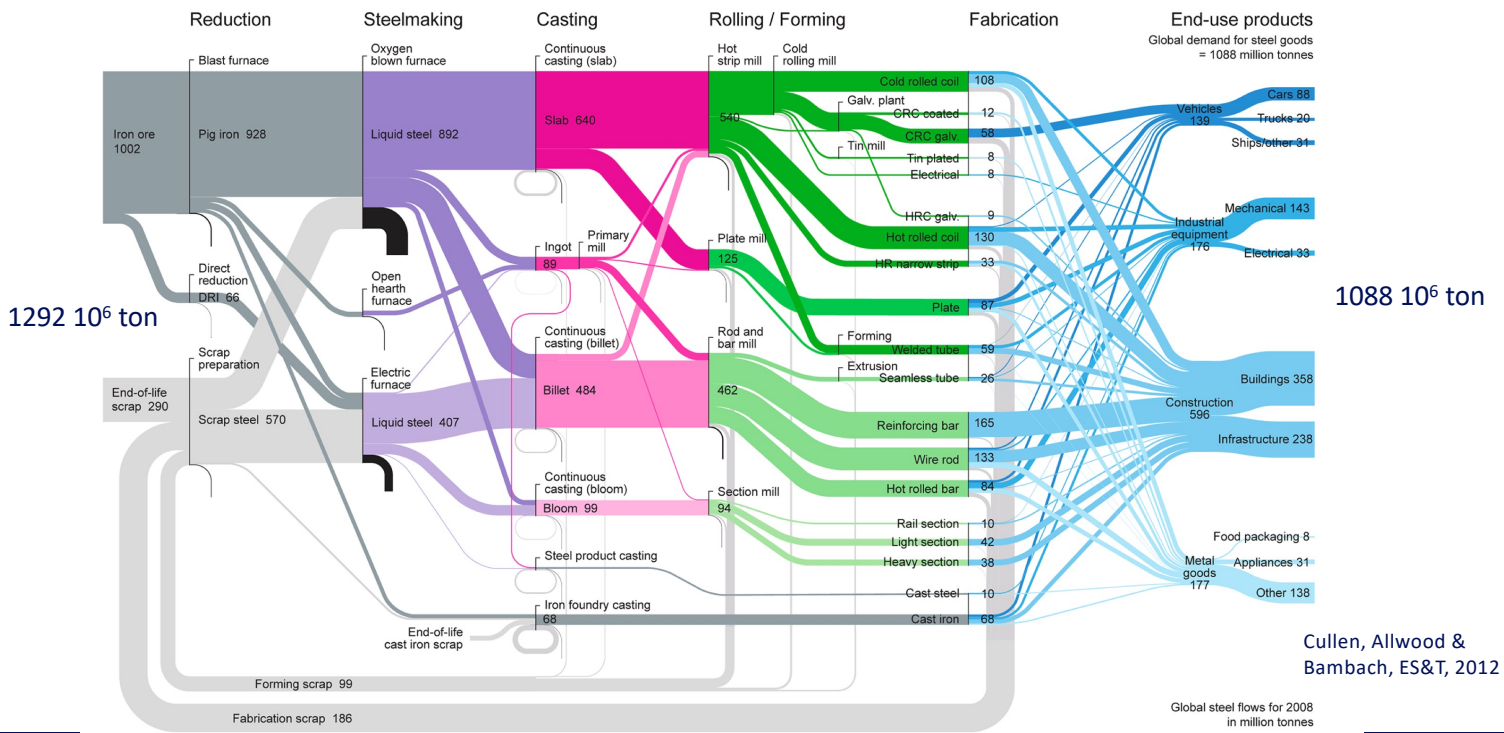
**Universiteit
Leiden**
The Netherlands

Discover the world at Leiden University

We still live in the iron age !

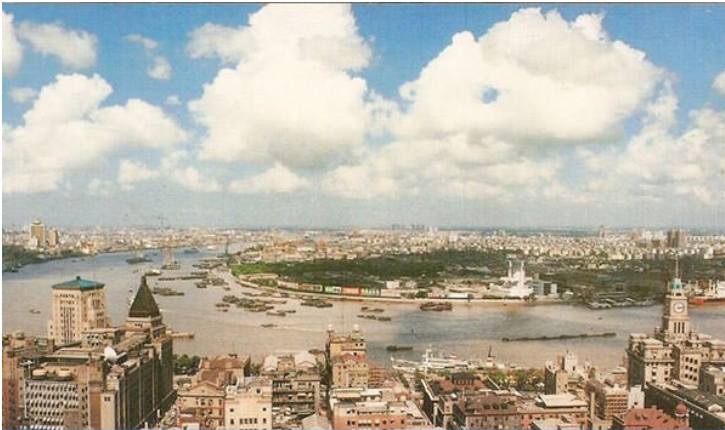


Global steel flows (2008)



Shanghai

1990



2010





Shenzhen

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

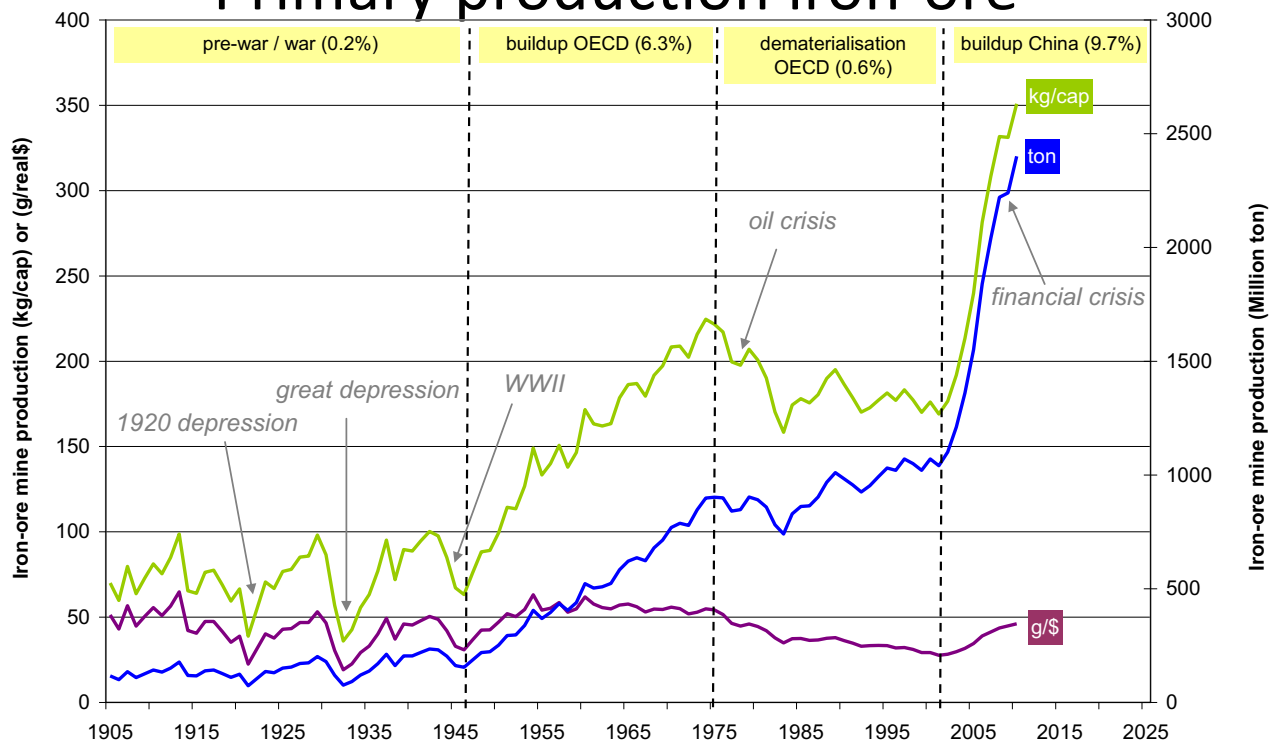




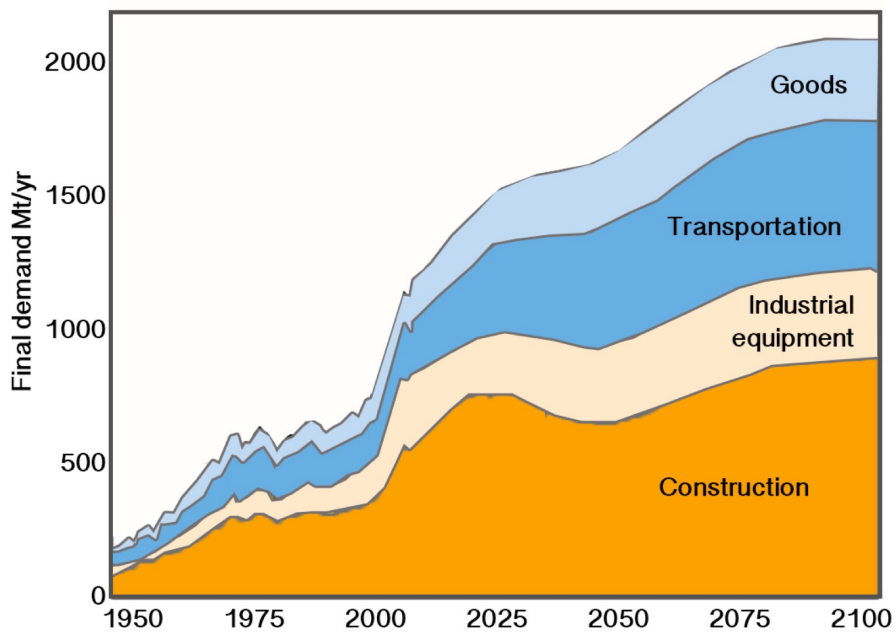


Disc

Primary production iron-ore

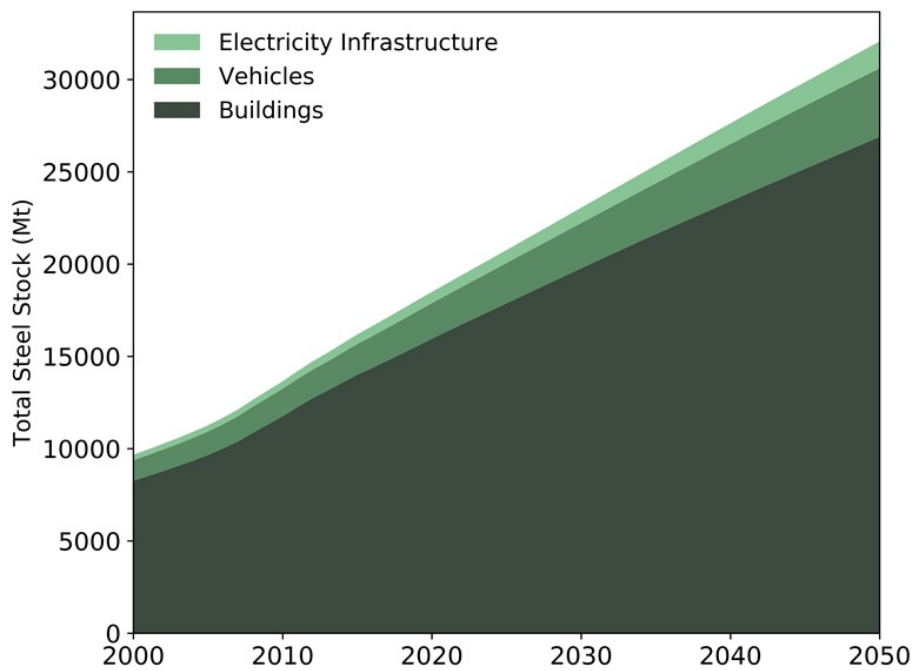


Final steel demand by end-use sector



Pauliuk et al, 2013
ES&T 2013

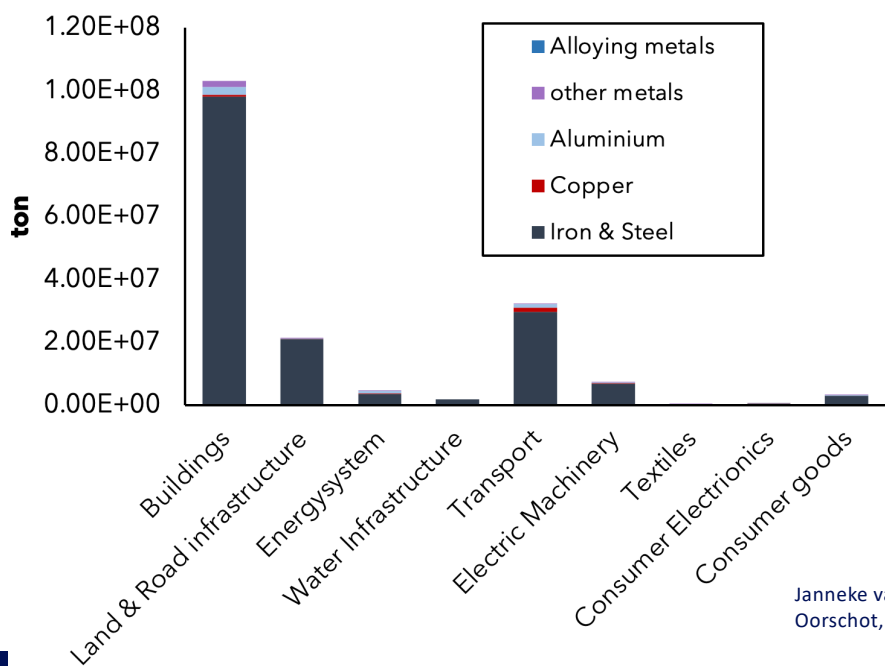
Future global steel stocks



Sebastian 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

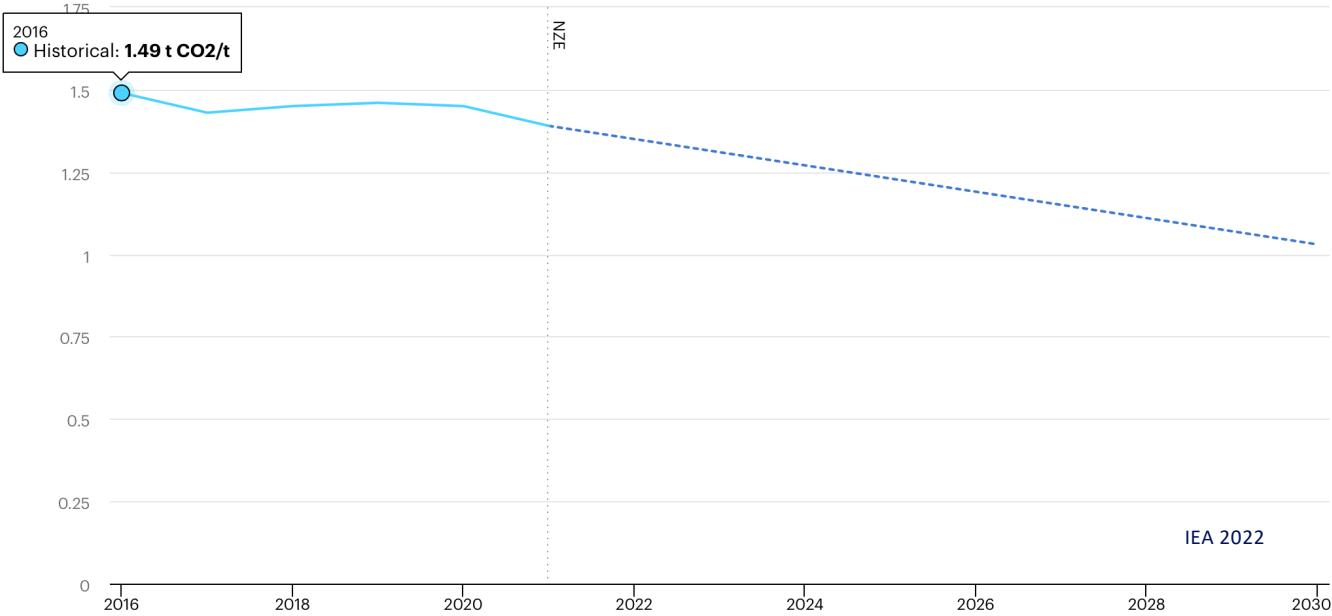
Steel: a sustainable material !

- 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 ?

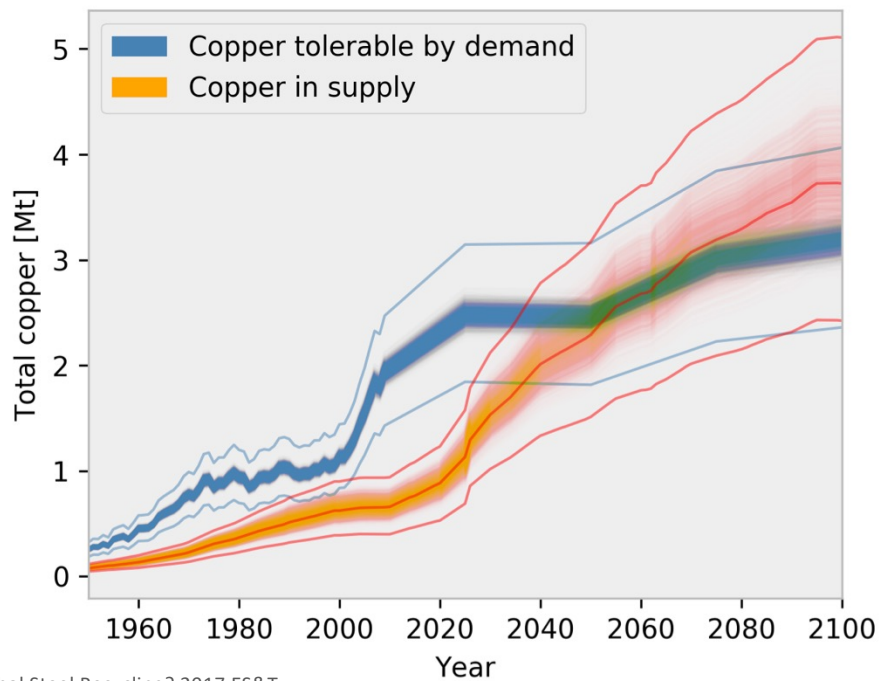
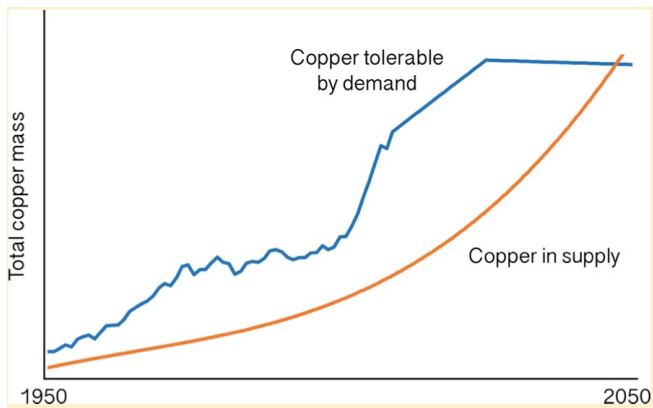
- 1.3 ton CO₂ per ton steel, 9% of global anthropogenic CO₂ emissions
- Other emissions: PM, heavy metals, PAH, N
- Virgin iron input remains necessary for recycling (copper contamination)
- Security of supply of alloying elements (60-70% nickel, 80-90% chromium, 80—90% vanadium, 90%, niobium, 85-90% manganese, 80% molybdenum, 40-50% Tungsten, 55% zinc)
- Mining of iron ore and alloying metals has significant impacts

CO₂ 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

Home / News / Energy & Environment / European Green Deal / EU's Net-Zero Industry Act aims to bring home clean tech production

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)

Advertisement



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

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

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

Ad



Vale Tailing dam collapse, Brasil January 2019

TV Globo

25/01/2019 12:28



SUBSC

TV GLOBE

25/01/2019 12:28



SUBSC

TV GLOBO

25/01/2019 12:28:49



SUBSC

TV GLOBE

25/01/2019 12



SUBSCRIBE

Discover the world at Leiden University

TV Globo

25/01/2018 12:30

Guardian





Discover

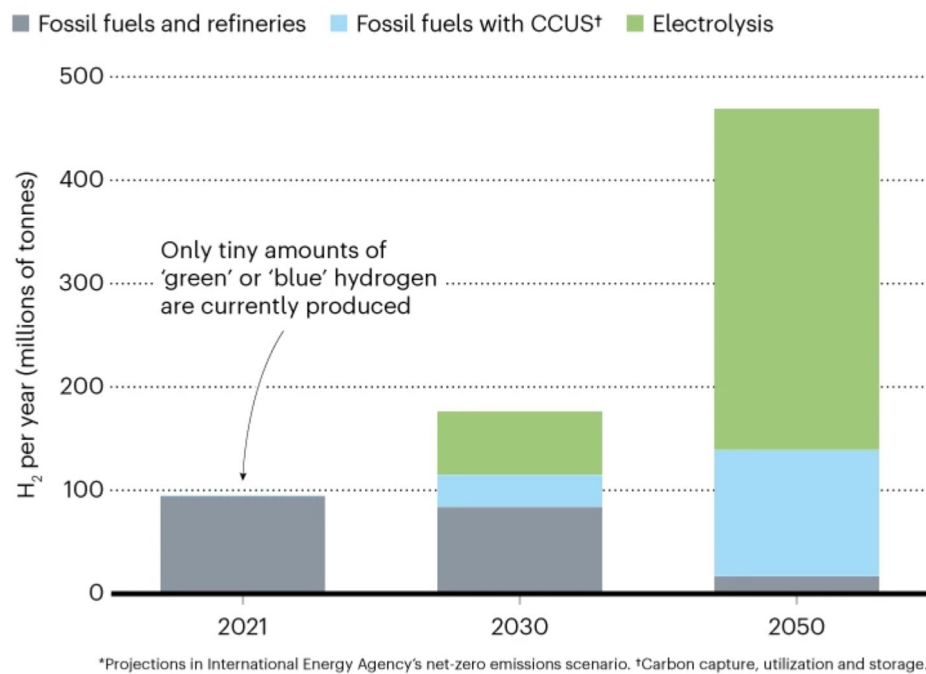
Greening the steel cycle

- 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

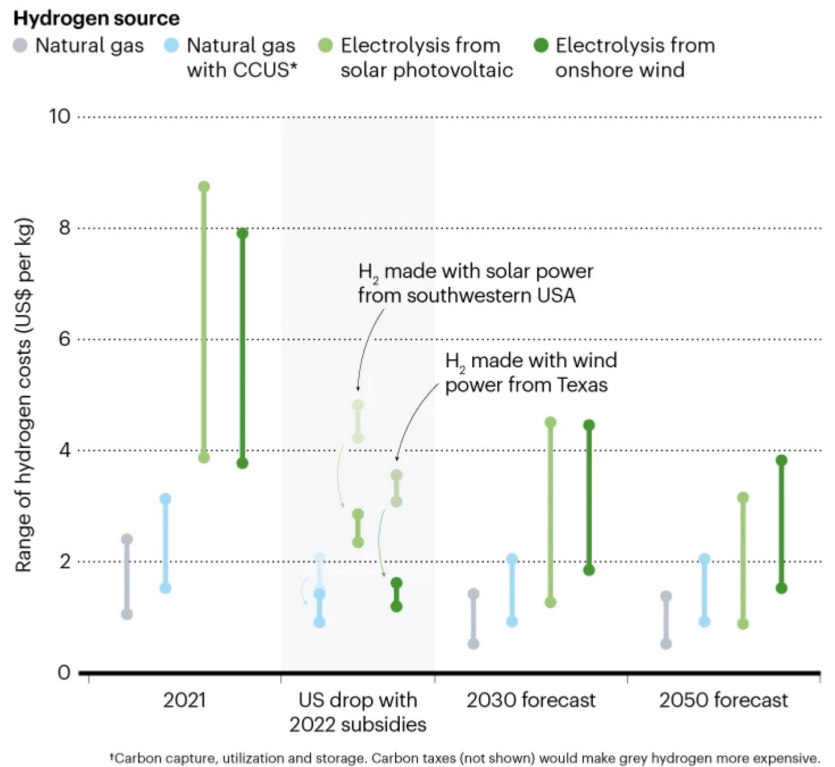
- Replacing coal with hydrogen would drive up the price of a ton of steel by about one third
- Less in future due lower cost renewables and higher carbon price
- Requires an increase in electricity production of the order of 20 %
- Requires a huge increase in green hydrogen production
- Geospatial distribution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

Hydrogen production in IEA NZE scenario



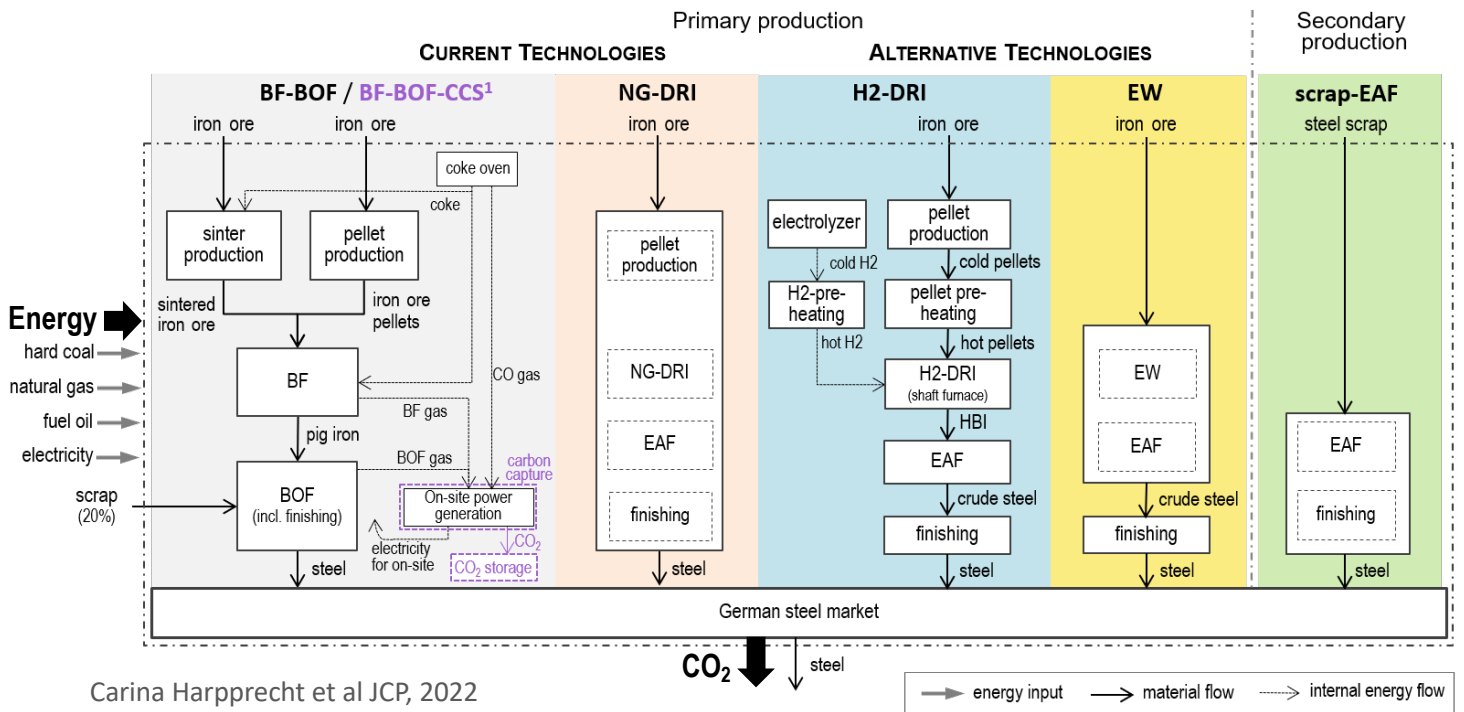
©nature

Hydrogen costs



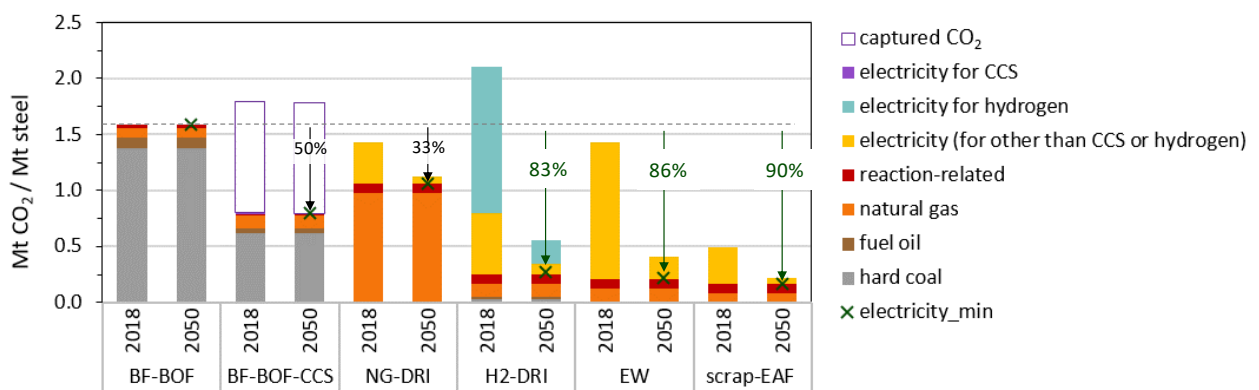
©nature

Decarbonisation of German Steel Industry



Carina Harpprecht et al JCP, 2022

CO₂ 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:



Journal of Cleaner Production
Volume 380, Part 2, 20 December 2022, 134846



Decarbonization scenarios for the iron and steel industry in context of a sectoral carbon budget: Germany as a case study

Carina Harpprecht ^{a, b}, Tobias Naegler ^a, Bernhard Steubing ^b, Arnold Tukker ^{b, c}, Sonja Simon ^a

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 materialen 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



provided the author and source are cited.

How Will Copper Contamination Constrain Future Global Steel Recycling?

Katrin E. Daehn, André Cabrera Serrenho, and Julian M. Allwood ^a

Department of Engineering, University of Cambridge, Cambridge CB2 1PZ, United Kingdom



Policy Analysis
pubs.acs.org/est

Mapping the Global Flow of Steel: From Steelmaking to End-Use Goods

Jonathan M. Cullen ^{a, †}, Julian M. Allwood [†], and Margarita D. Bambach [‡]

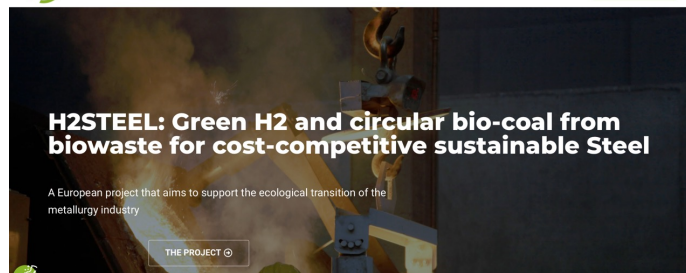
[†]Department of Engineering, University of Cambridge, Trumpington Street Cambridge, CB21 1PZ United Kingdom

[‡]Institute of Ferrous Metallurgy, RWTH Aachen University

[Supporting Information](#)



Home The Project Knowledge Centre Resources News PRIVATE AREA



nature

Explore content About the journal Publish with us Subscribe

nature > news > feature > article

NEWS FEATURE | 16 November 2022

How the hydrogen revolution can help save the planet – and how it can't

Many researchers see a huge role for the gas in decarbonizing economies.