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## The role of demand, recycling, CO2 capture and hydrogen in the global race for zero-emissions steel

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# Plan

- 1. The issue**
2. Methodology and setup
3. Projections: towards one net-zero future
4. Case study: alternative for advanced electrification
5. Conclusions

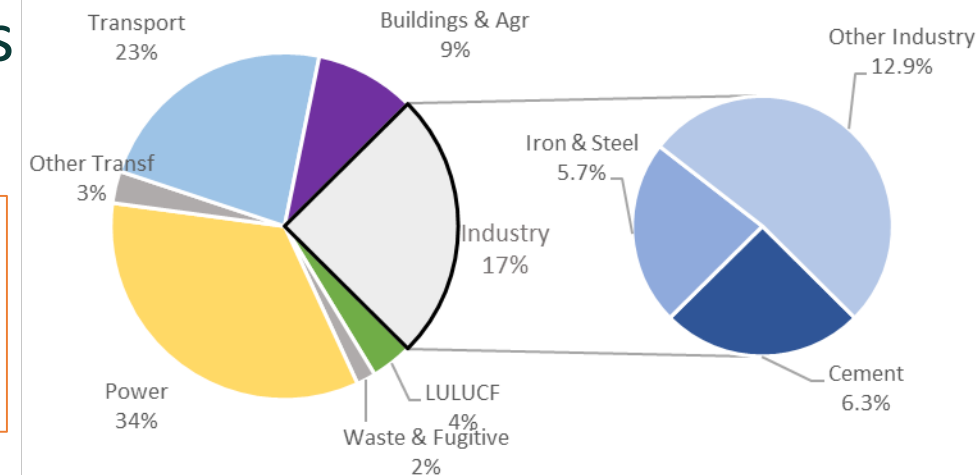
# How to supply materials while meeting the net-zero emissions targets?

- Growing demand for CO<sub>2</sub>-intensive base materials
- G20 climate change targets of net-zero emissions by 2050-2060

**Is it possible to reconcile increase in well-being for all (and associated materials demand increase) with aspirations of decarbonization of the world economy?**

- We propose to represent steel demand and production in an energy model
- We include hydrogen demand and production associated to emerging uses

World CO<sub>2</sub> emissions, 2018



Source: GECO 2020, JRC

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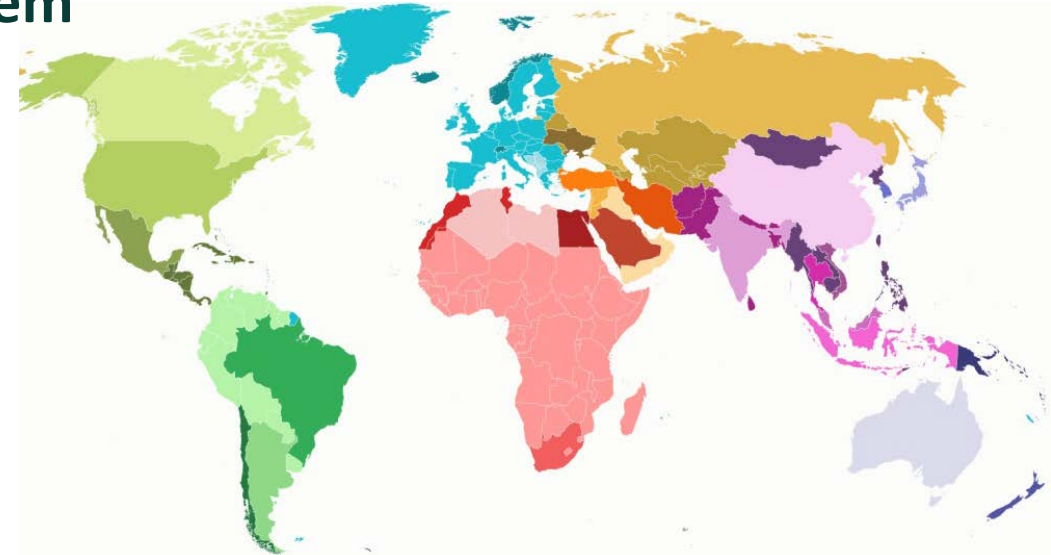
# POLES: Prospective Outlook on Long-term Energy Systems

## Projections of the evolution of the world energy system

- Long-term model (to 2050-2100)
- EU + 39 countries / regions (OECD, G20)
- Partial equilibrium, simulation

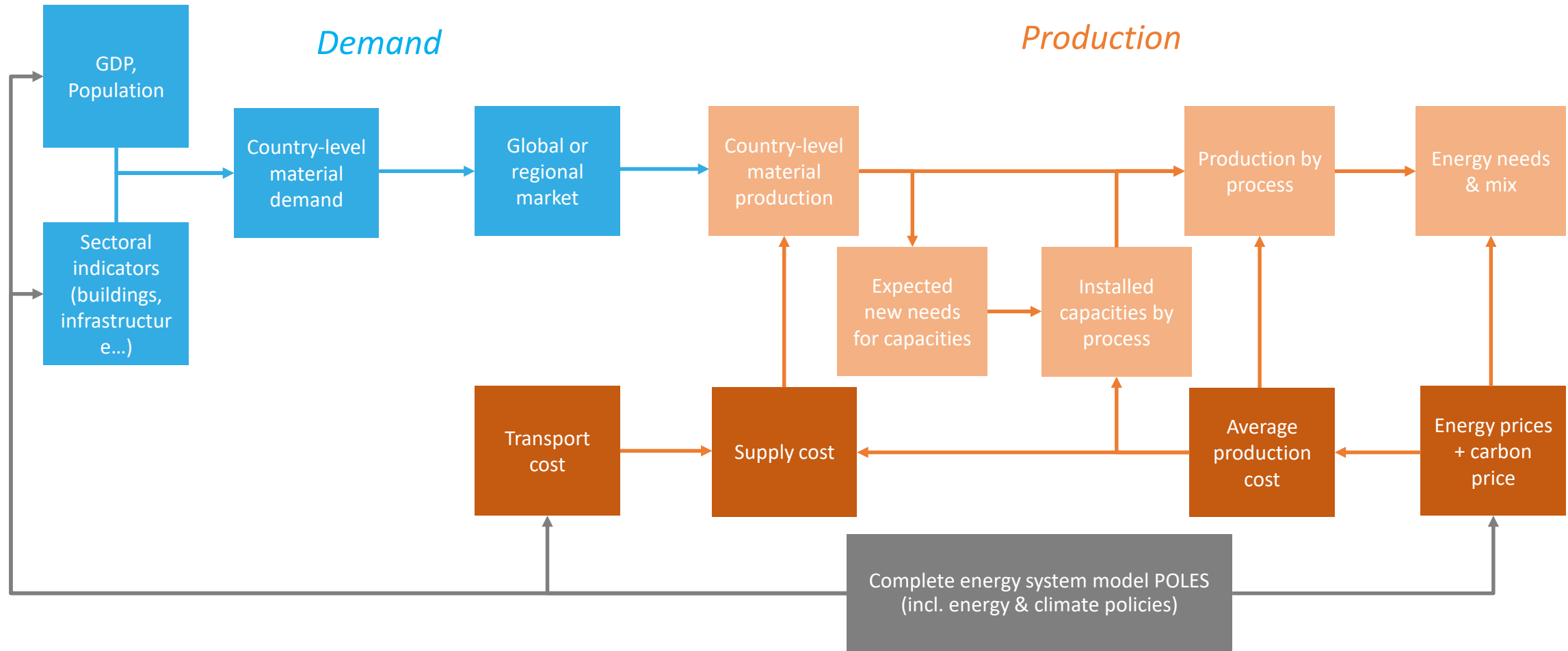
## Output

- International energy prices & trade
- All energy sources and vectors
- All GHG emissions (linkage with specialist tools for non-energy)



[https://joint-research-centre.ec.europa.eu/poles\\_en](https://joint-research-centre.ec.europa.eu/poles_en)

# Overall structure of the materials industry POLES module



# Estimating demand: from services to stock to flows

Apparent  
**Demand** =  
Production +  
Net trade

## Buildings construction

Surfaces =  $f(\text{income, lifestyle, renewal rate}) \rightarrow$  material for new surfaces (kg/m<sup>2</sup>)

## Automotive

Light & Heavy vehicles =  $f(\text{income, ownership, modal choice, renewal rate}) \rightarrow$  material for new sales (kg/veh)

## Power

$\rightarrow$  Generation capacities =  $f(\text{elec demand, cost, renewal rate}) \rightarrow$  material for new installations kg/MW

$\rightarrow$  T&D grid =  $f(\text{elec demad, renewal rate}) \rightarrow$  material for new grid kg/MWh delivered

**Rest** = % of total (infrastructure, other transport modes...)

# Modelling multiple steel production processes

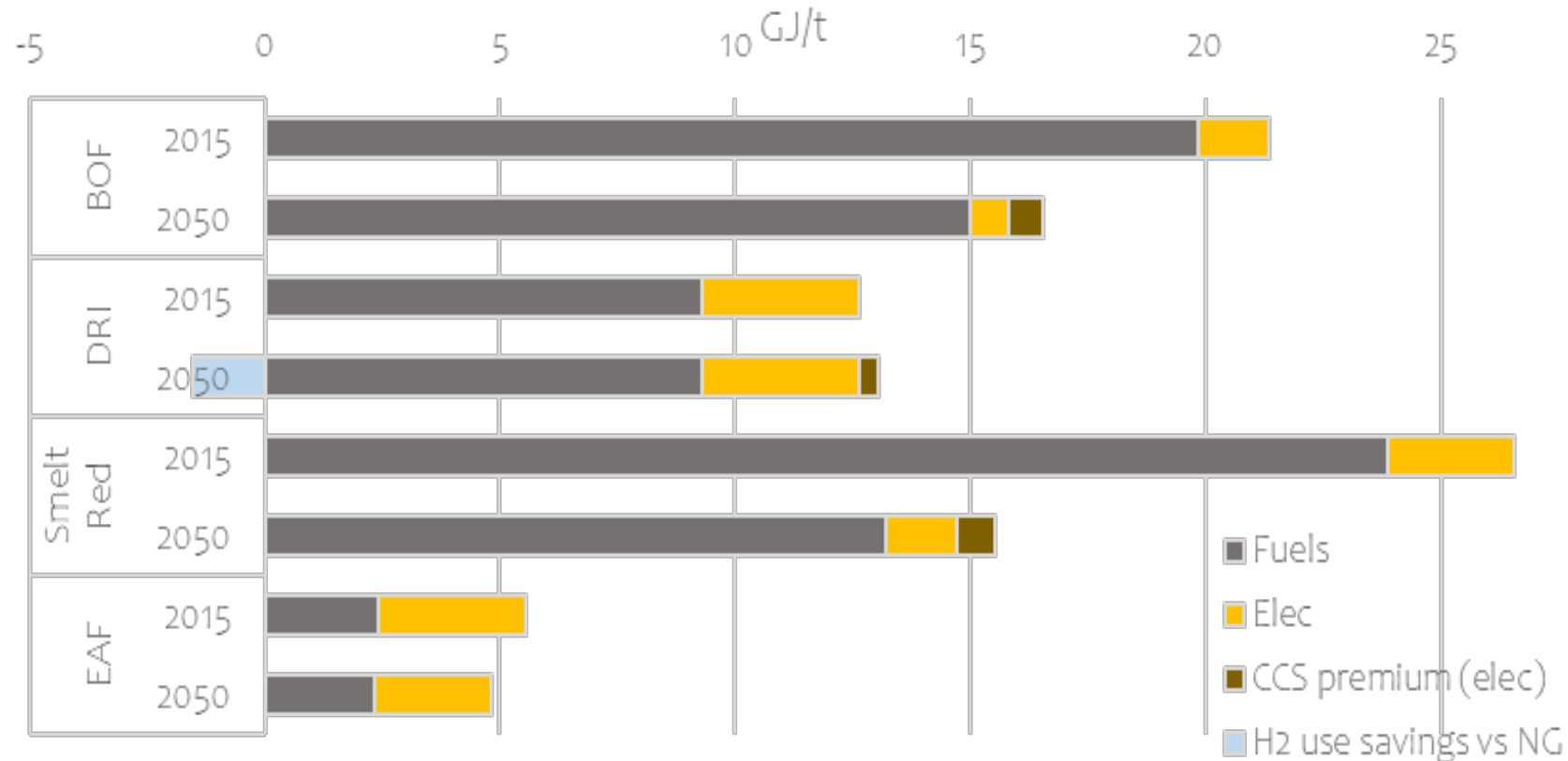
## Processes:

- Ore reduction: basic oxygen, direct reduction, smelting reduction
- Scrap smelting: electric arc

## Decarbonisation options:

- Biomass
- CCS
- Hydrogen ← 13 technologies
- Recycling + electricity ← 30 technologies

Specific energy consumption, by steel production process





# Scenarios modelled: from current policies to net-zero

- Based on JRC Global Energy and Climate Outlook 2021
- Common macro-economic assumptions (SSP2 + updates)

NoCP	15C_Curr	15C_Adv
no climate policies (~ current policies)	ambitious climate policies (global carbon price for 1.5°C)	
Market forces drive energy mix	Use of current technologies with continued use of combustion: biomass, CCS, blue H2	Emergence of new business models: breakthrough in power-to-heat and electrolysis technologies, increased steel recycling

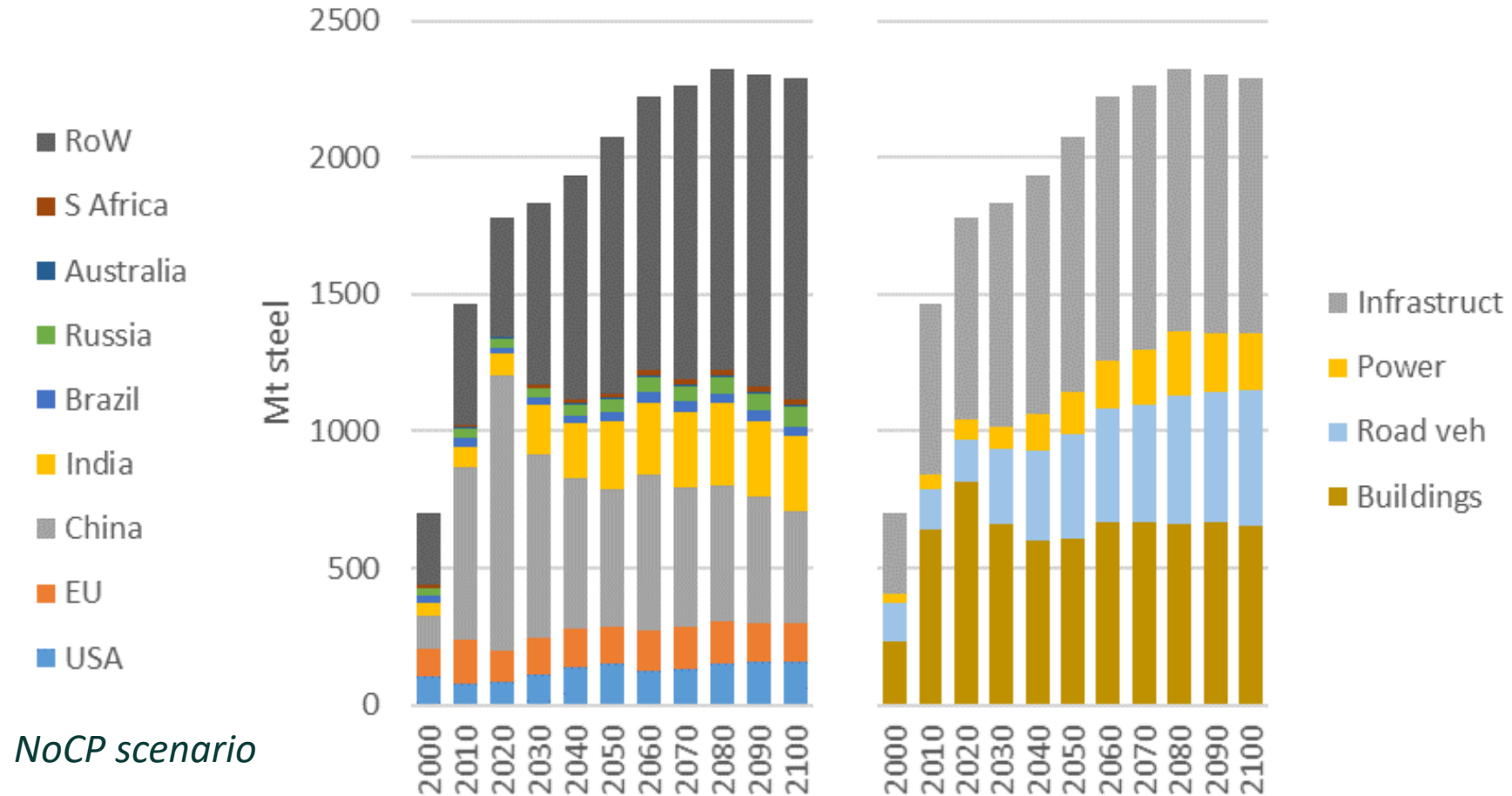


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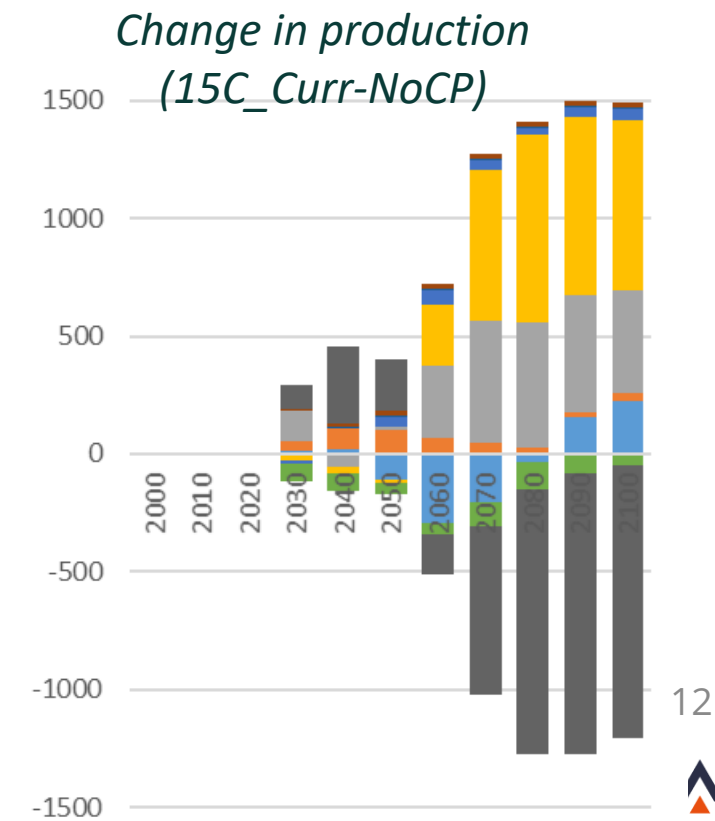
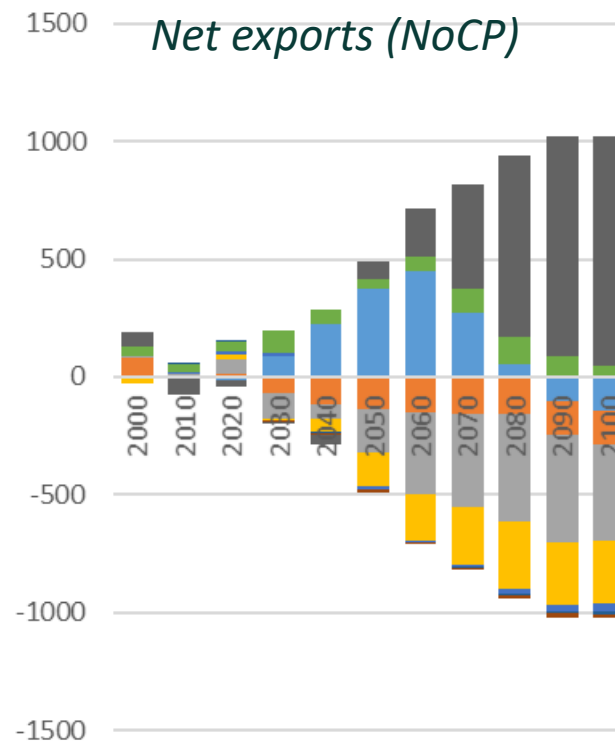
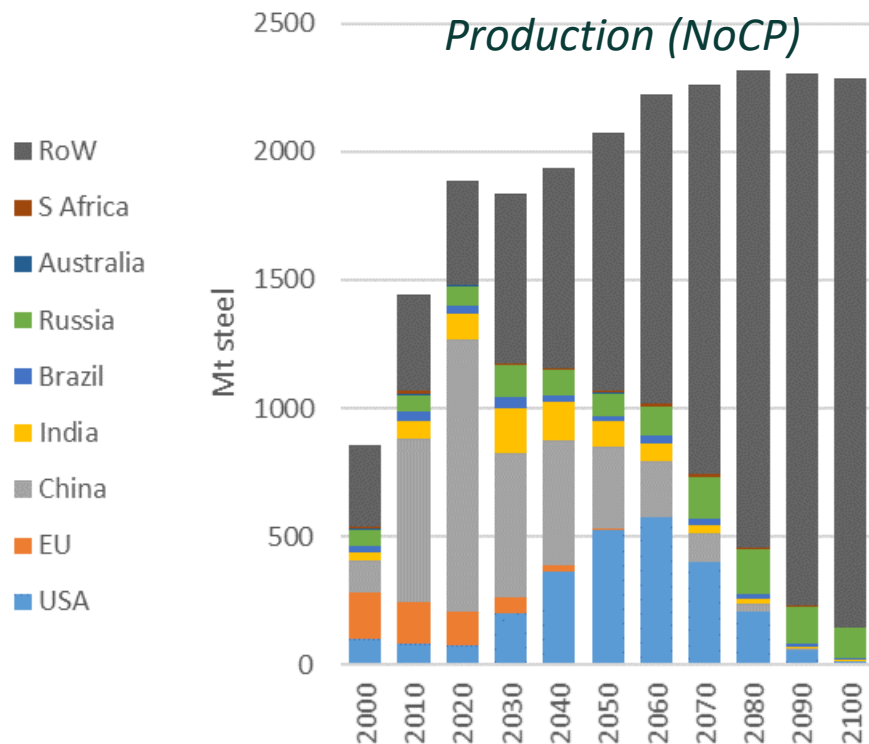
# Decelerated growth for steel demand

- Unprecedented growth 2000-2020 not to continue
- Total demand stabilization to 2.3 Gt
- China decrease, RoW increase

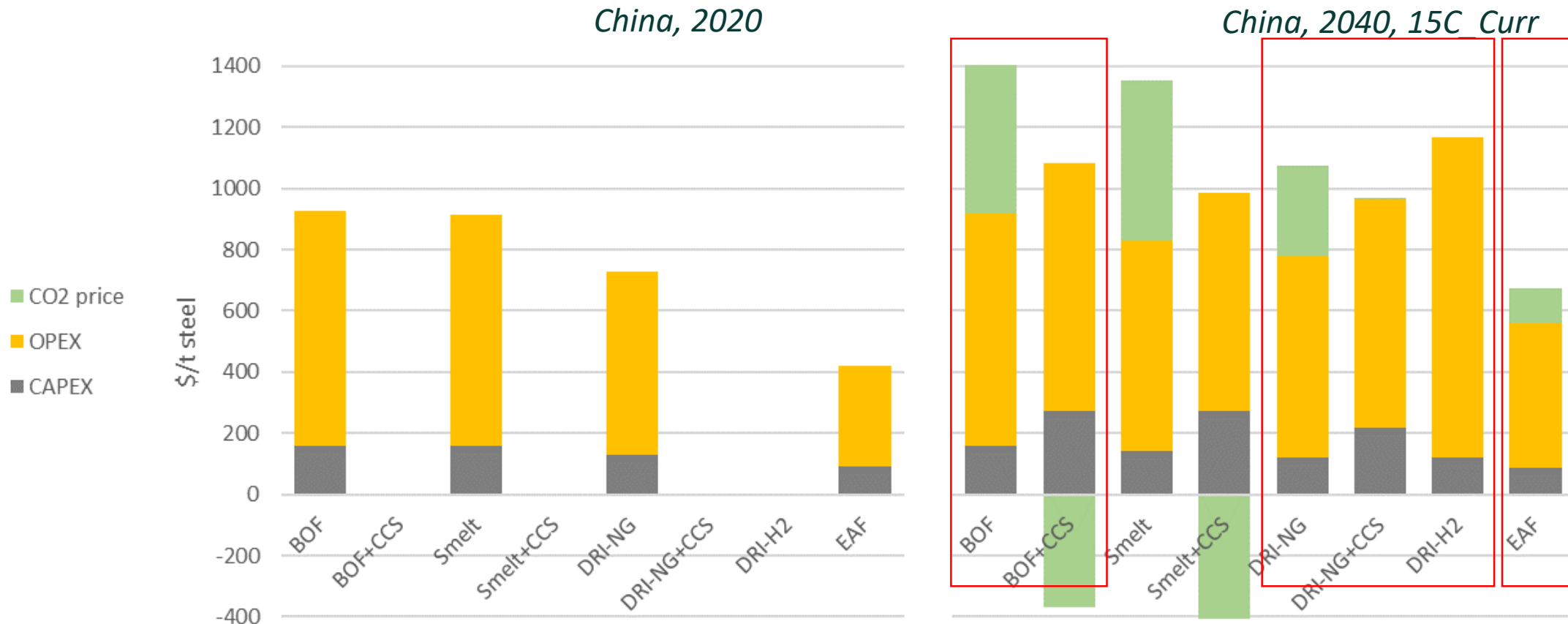


# Changing patterns for steel production and trade

- Production in RoW increases in volume and share
- USA emerge as major exporter
- China, India emerge as major importers
- Climate policy relocalize production (less trade)



# Climate policy is key in changing the steel production mix



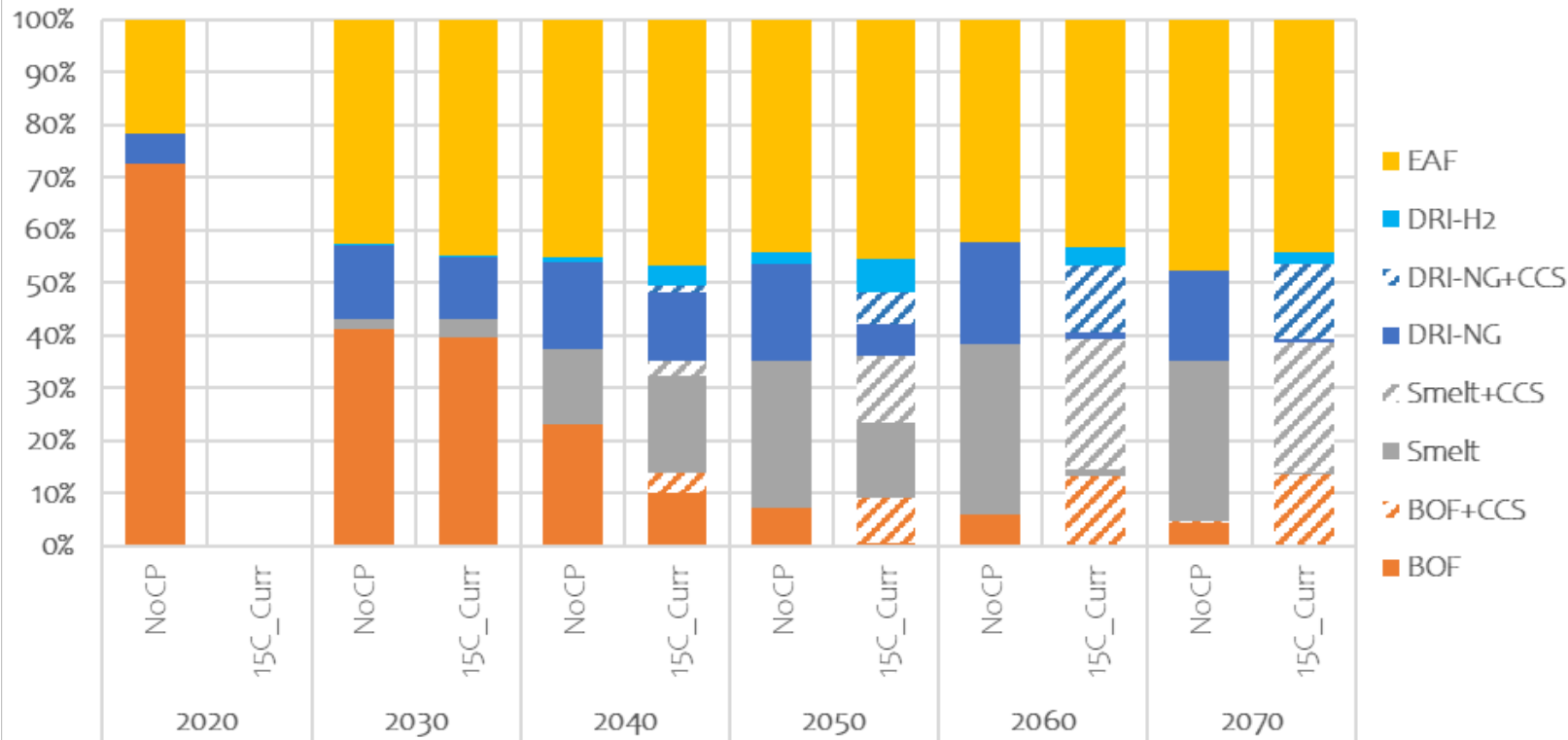
CCS retrofit competitive from around 50 \$/tCO2 + BECCS credits

DRI: H2 competitive vs NG and NG-CCS in the longer term (after 2040)

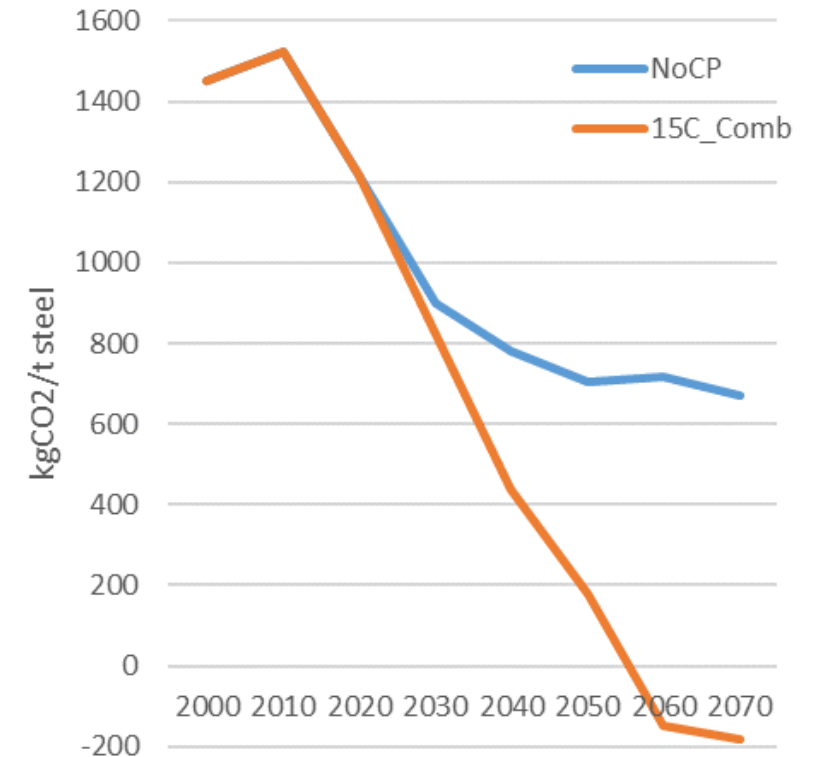
EAF: power sector decarb increases power price

# Diversification of steel production mix and decreasing emissions intensity

World steel production mix



World steel emissions intensity



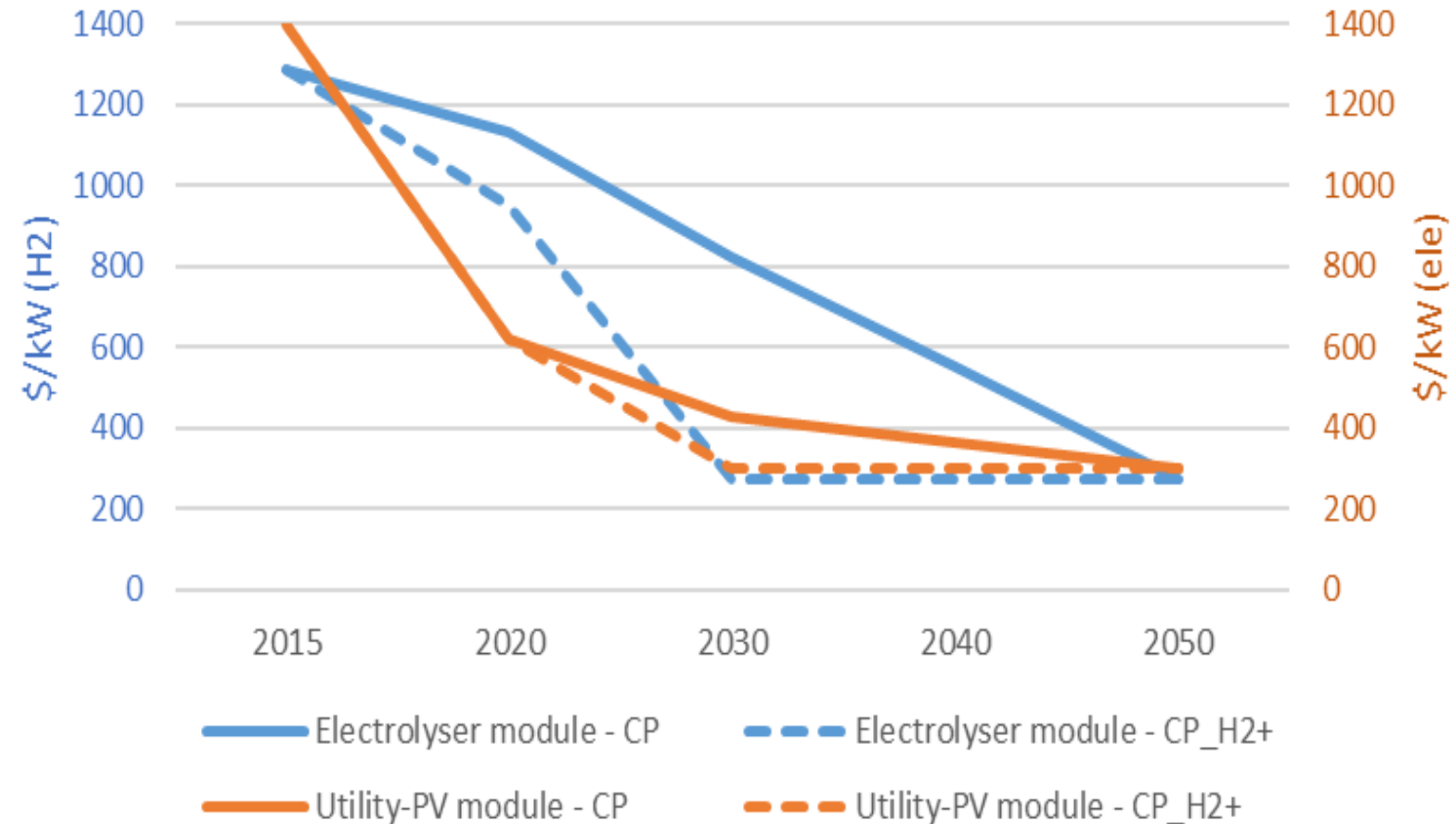
- DRI-H2 does not exceed 6%
- Half of CO2 reductions due to CCS, of which half is BECCS
- Net-zero steel reached in 2050s

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# 15C\_Adv: variant configuration to encourage direct and indirect (hydrogen) electrification in steelmaking

1. *Hydrogen production technology costs:*  
electrolyser, PV modules
2. *Competitors:* delay for CCS
3. *Recycling:* increased scrap recovery rate
4. *Sustainability:* limited biomass-for-energy use

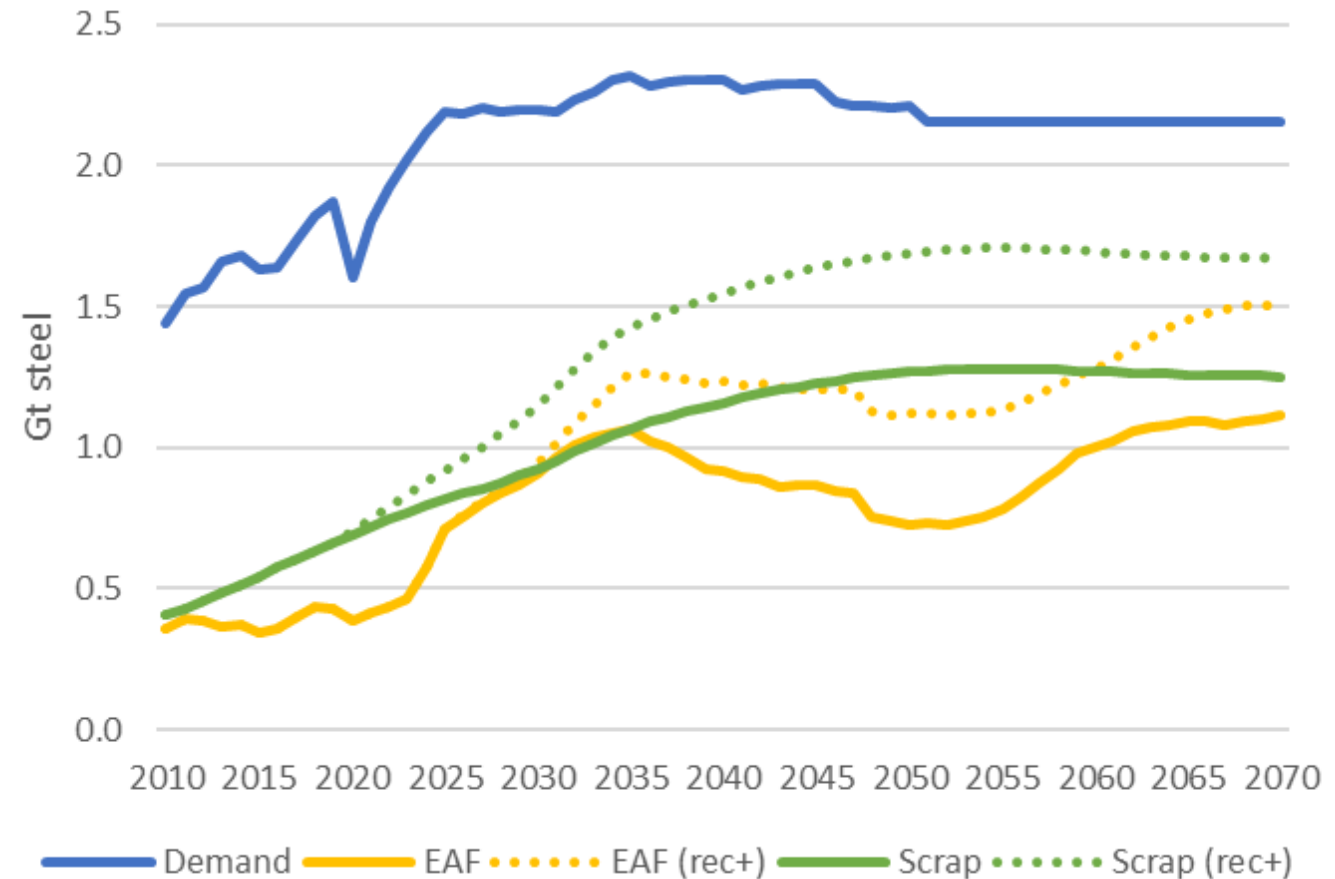




# Circular economy efforts can enhance electrification

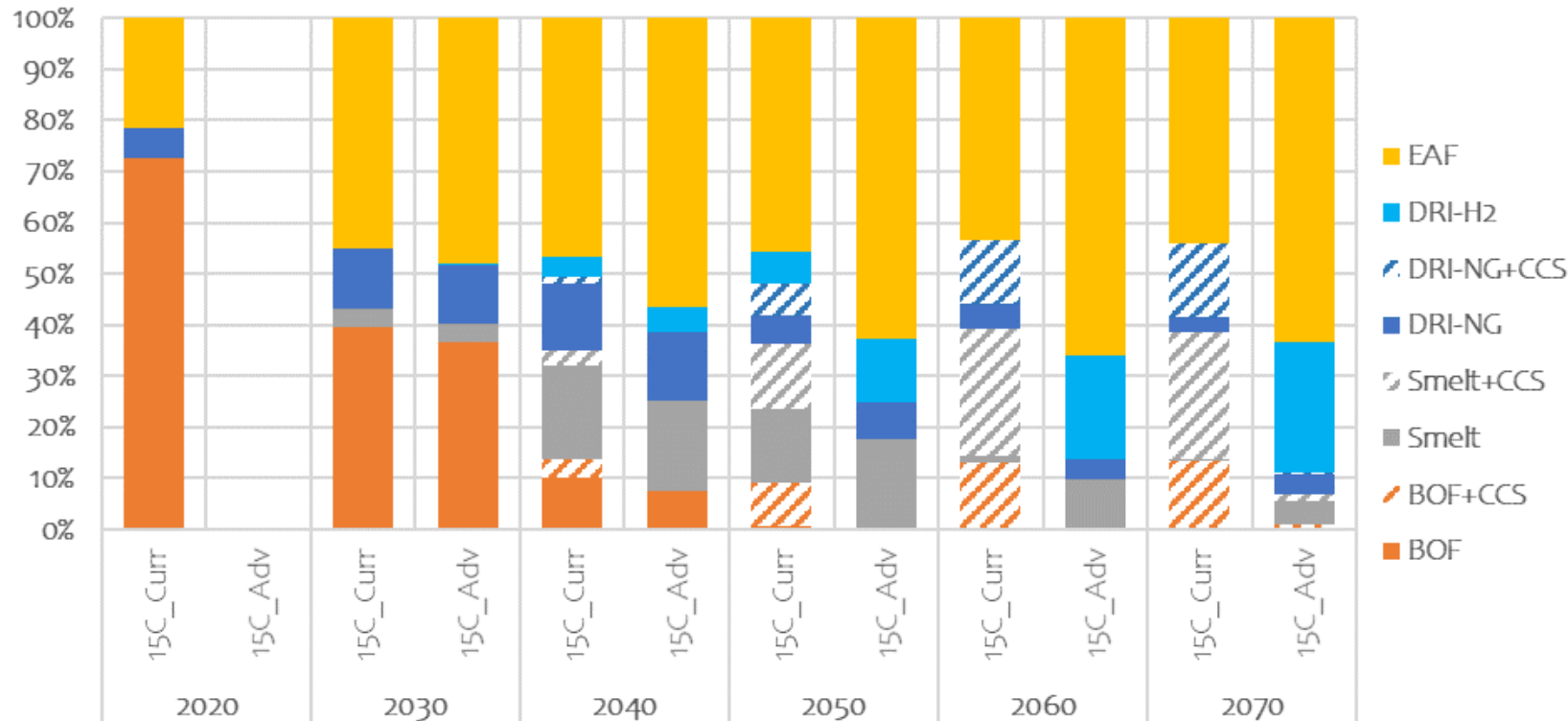
Rising steel demand: increased future availability of scrap

- *Recovery gap*: with recycling strategies, steel scrap price  $\searrow$ ,  $\nearrow$  scrap competitiveness
- *Economic gap*: with climate policies, electricity price  $\nearrow$ ,  $\searrow$  electric arc competitiveness
- 15C\_Adv: increased steel scrap recovery factor (55% $\rightarrow$ 75%)
  - $\rightarrow$  scrap available rises to 60-80% of annual demand
  - $\rightarrow$  EAF covers 50-70% of production

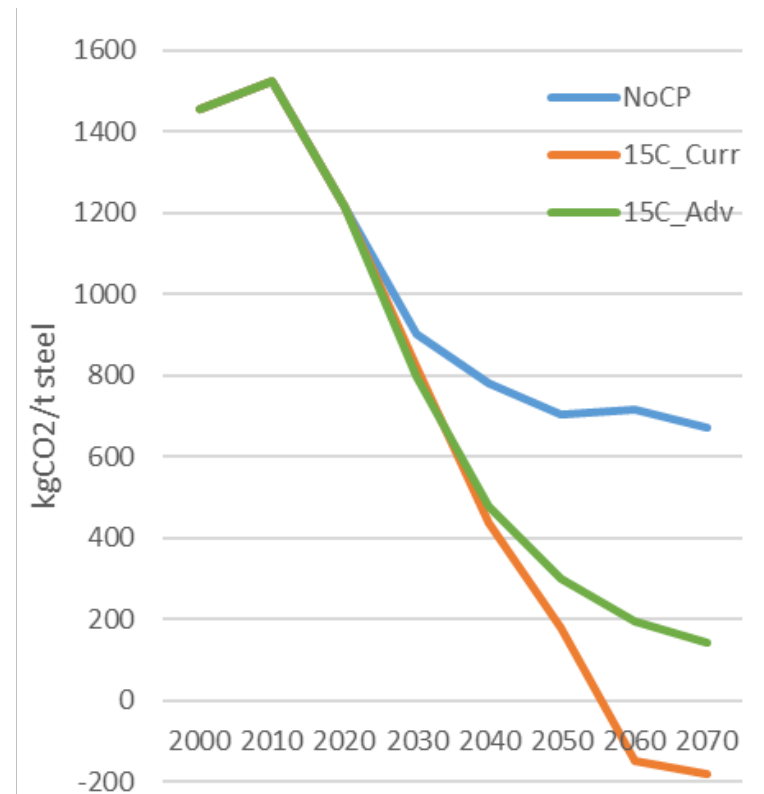


# Low-carbon steel thanks to gradual – not radical – direct and indirect electrification

World steel production mix

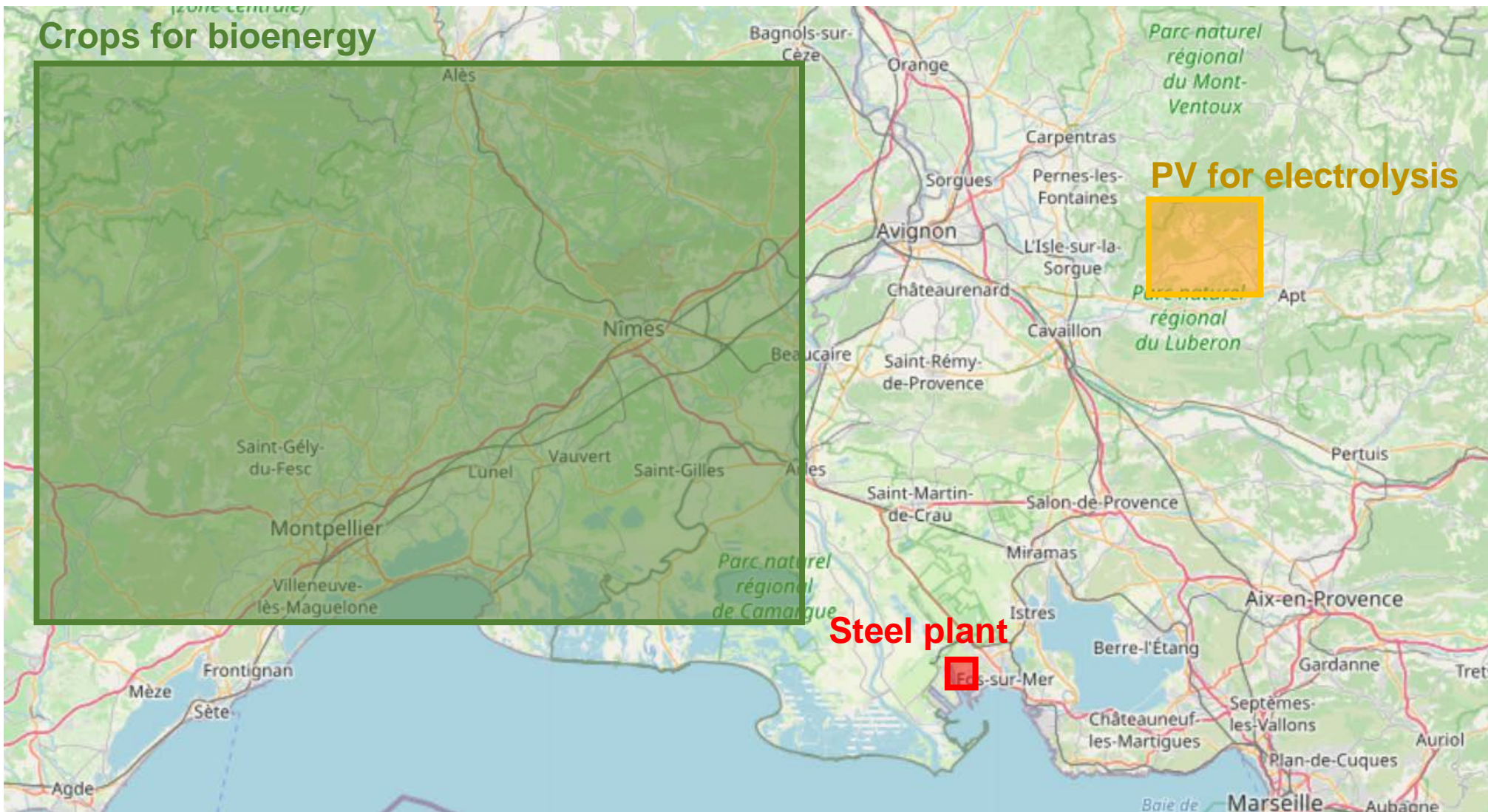


World steel emissions intensity



- CCS replaced by EAF and DRI-H2
- DRI-H2 reaches 26% in 2070
- Net-zero steel not reached: higher electrification but more emissions overall

# Wider trade-offs: land requirements



- 4.5 Mt/yr steel plant at Fos-sur-Mer, south France
- 100% DRI-H<sub>2</sub> w/ PV: 14x land area
- 100% BOF w/ bioenergy: 550x land area

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# Ranking of steel decarbonising options :

## 1. Improvement of material intensity:

1. revise construction codes in buildings,
2. partial substitution by timber,
3. increase reusability + recycling rate

## 2. Electrify as much as possible (mature technology)

## 3. CCS (untested at large scale):

1. retrofit on existing plants,
2. start building associated transport storage and infrastructure

## 4. Hydrogen (still costlier):

1. invest in R&D of green and other low-carbon hydrogen value chain,
2. use of non-green hydrogen as transitory phase

## 5. Biomass:

1. consider trade-offs with other sustainability indicators,
2. use when necessary

## 6. Reindustrialisation vs delocalisation:

1. consider wider social implications,
2. consider carbon content of imported products <sup>21</sup>

# Annex slides

# Modelling multiple production processes for hydrogen

Reforming

+ CCS

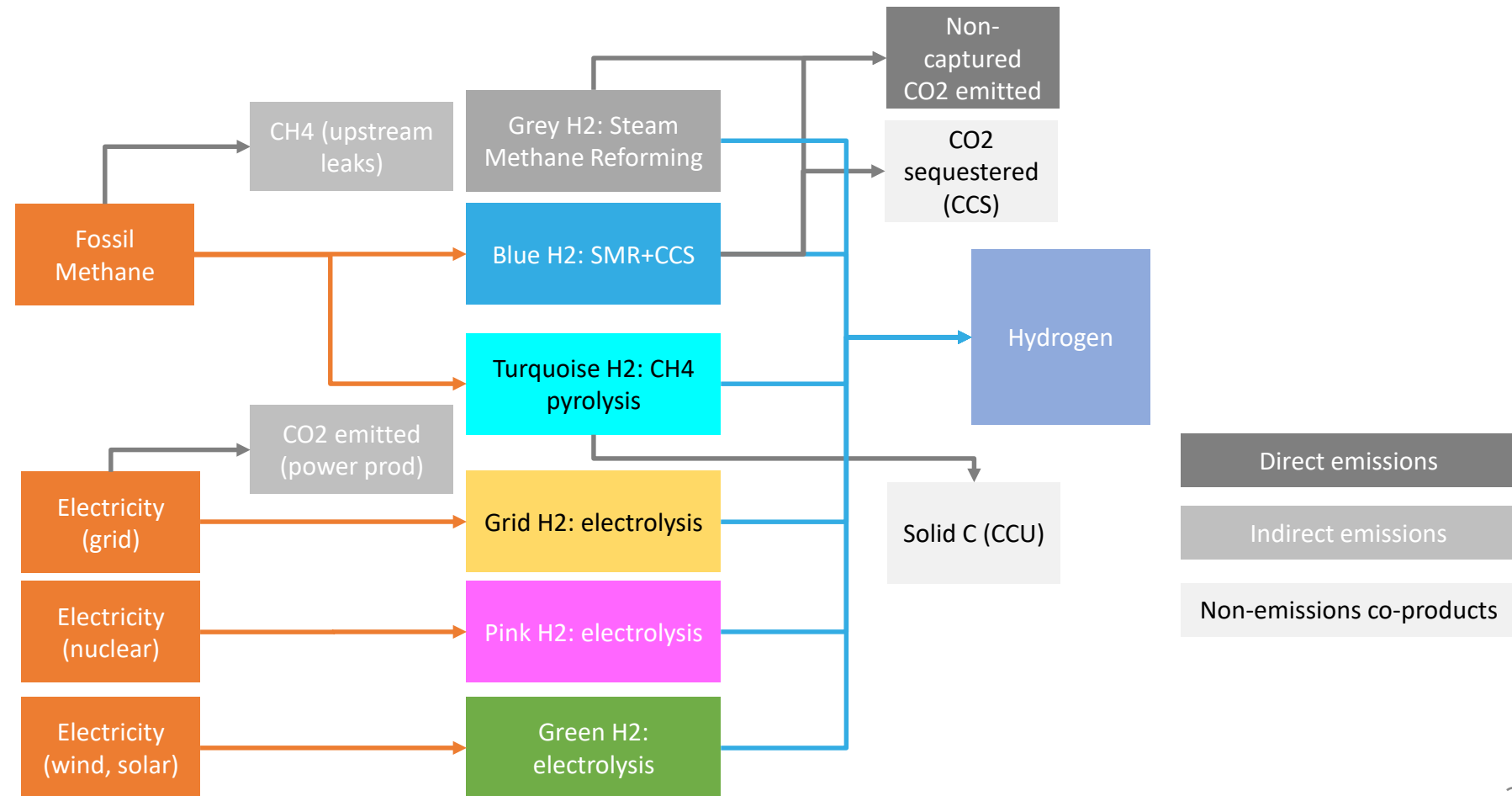
Gasification

+CCS

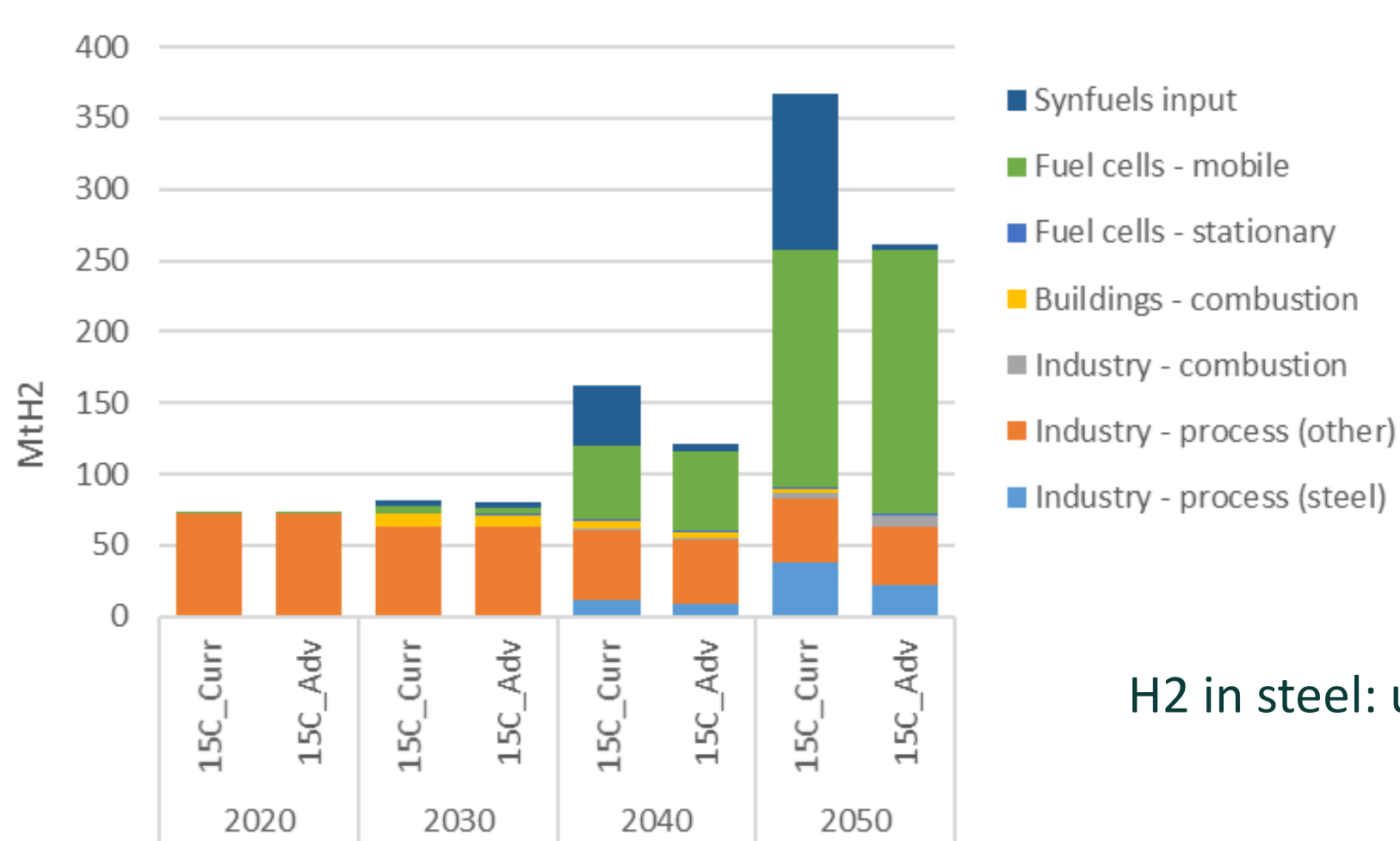
Pyrolysis

Electrolysis

4 low-temp,  
1 high-temp



# Projections: world hydrogen demand

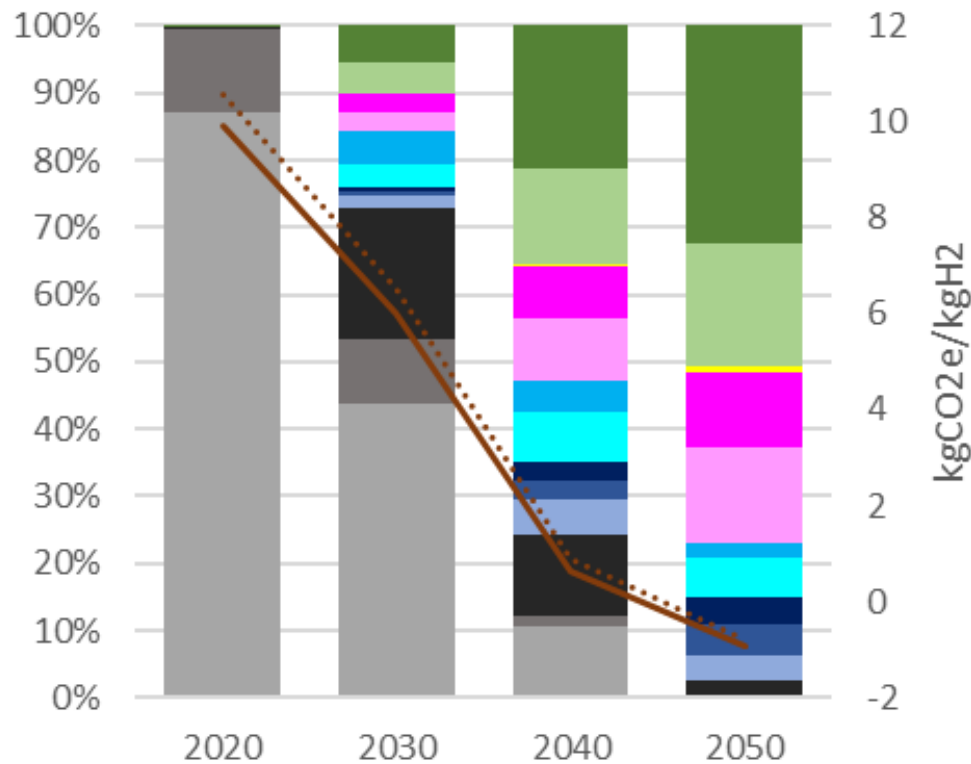


H2 in steel: up to 10% of demand

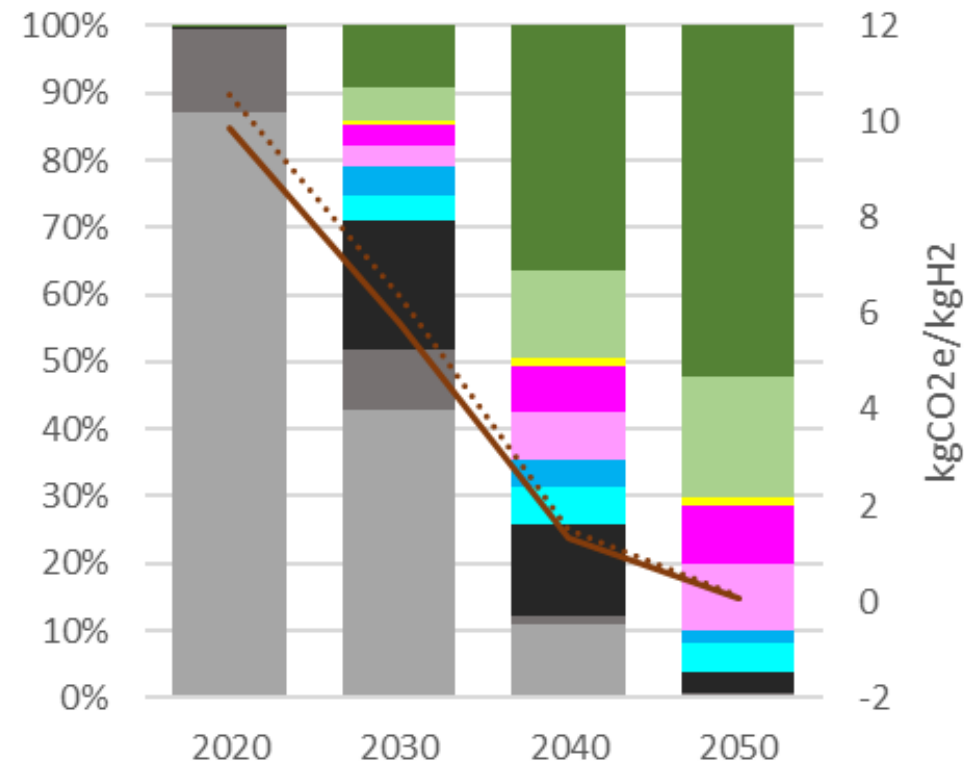


# Projections: world hydrogen production and emissions

15C\_Comb scenario

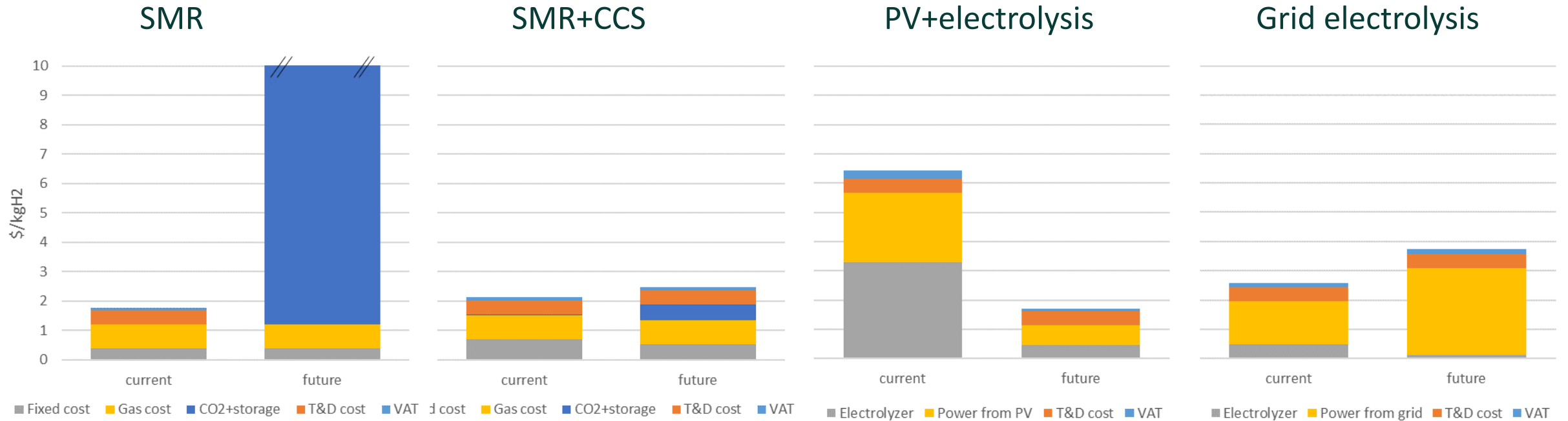


15C\_Adv scenario

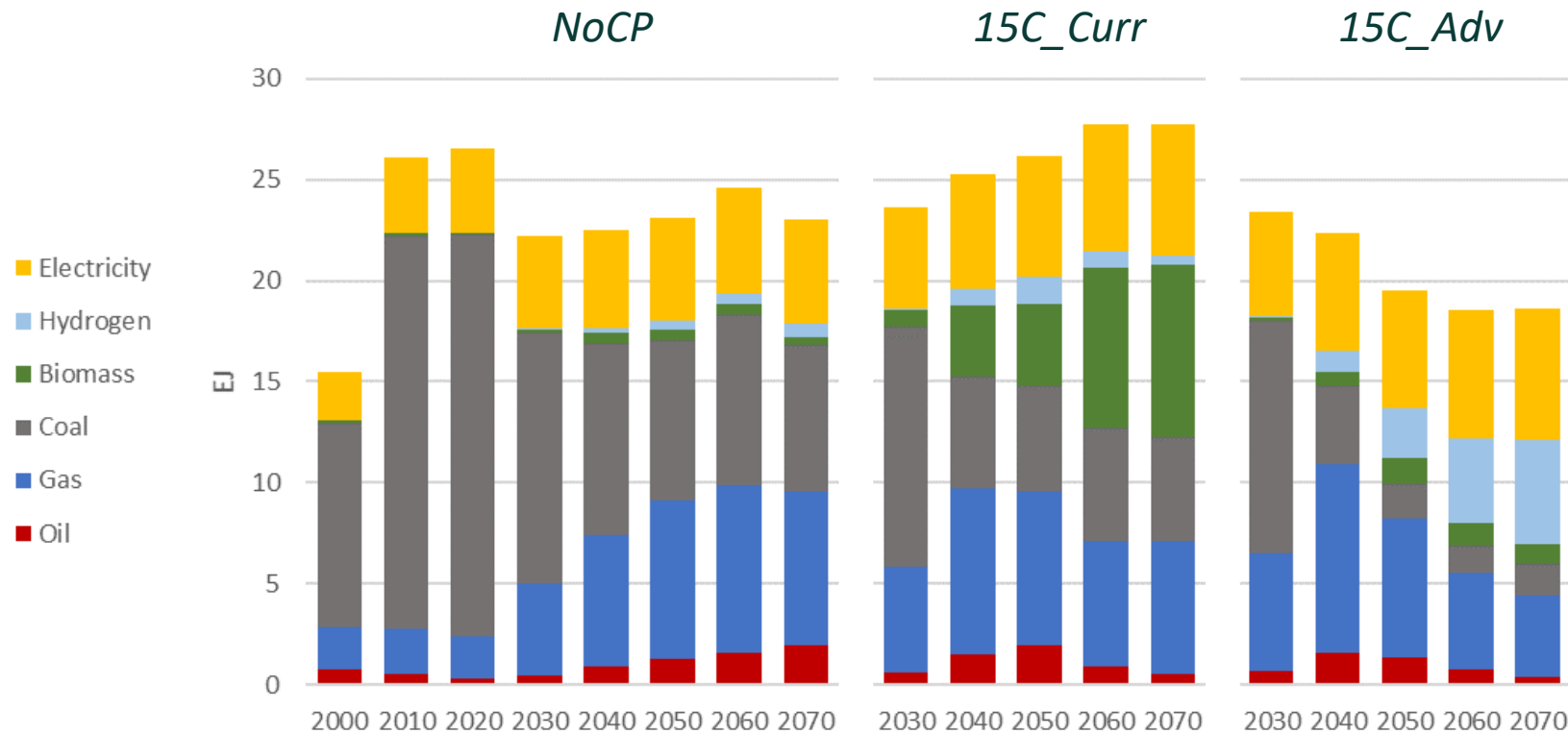


- E/lysis-PV
- E/lysis-wind
- E/lysis-grid
- E/lysis-nucl
- Nucl-HiTemp
- Pyro-bio
- Pyro-gas
- Gasif-bio+CCS
- Gasif-coal+CCS
- SMR+CCS
- Gasif-bio
- Gasif-coal
- SMR
- Direct
- Direct+Indirect

# Hydrogen: production costs



# World steel production energy mix



- CCS prolongs use of fossil fuels
- Electrification results in higher efficiency