How renewables costs, demand dynamics, new near zero GHG processes and trade are changing heavy industry analysis & policy

Is there such a thing as “positive leakage”?

Loosely based on a recent presentation to EU officials

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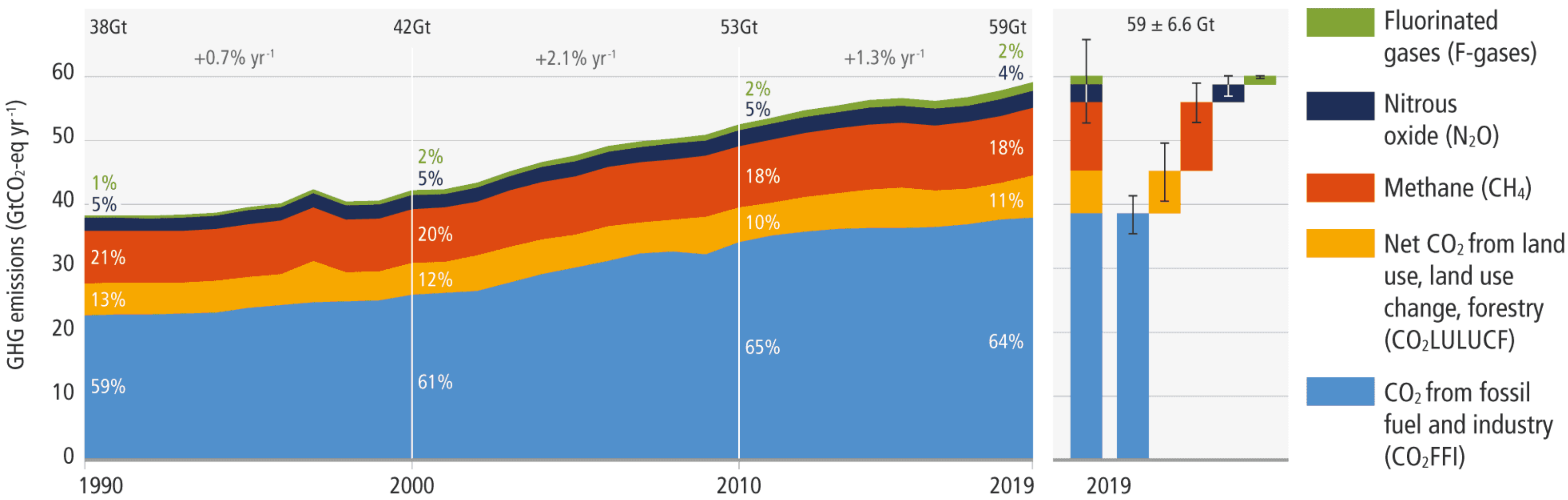
DEEP DECARBONIZATION PATHWAYS

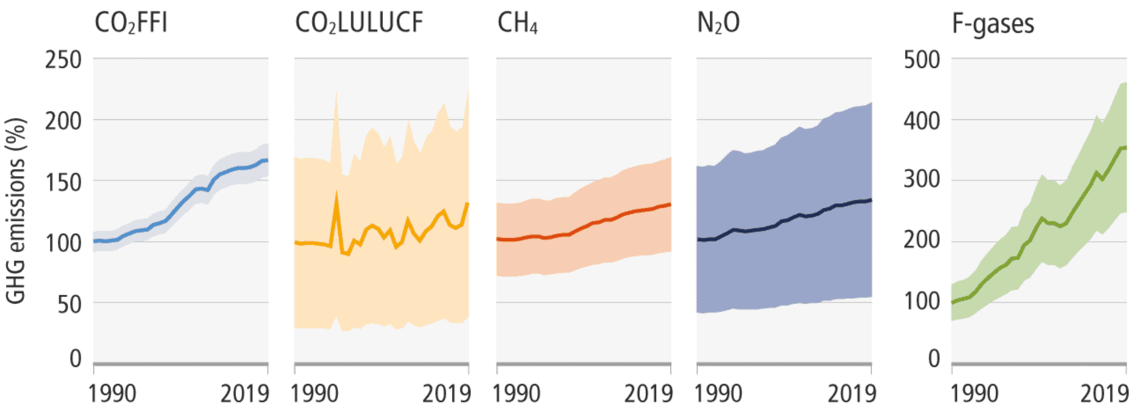
IDDRI

Global net anthropogenic emissions have continued to rise across all major groups of greenhouse gases.

a. Global net anthropogenic GHG emissions 1990–2019 (5)



b. Global anthropogenic GHG emissions and uncertainties by gas – relative to 1990

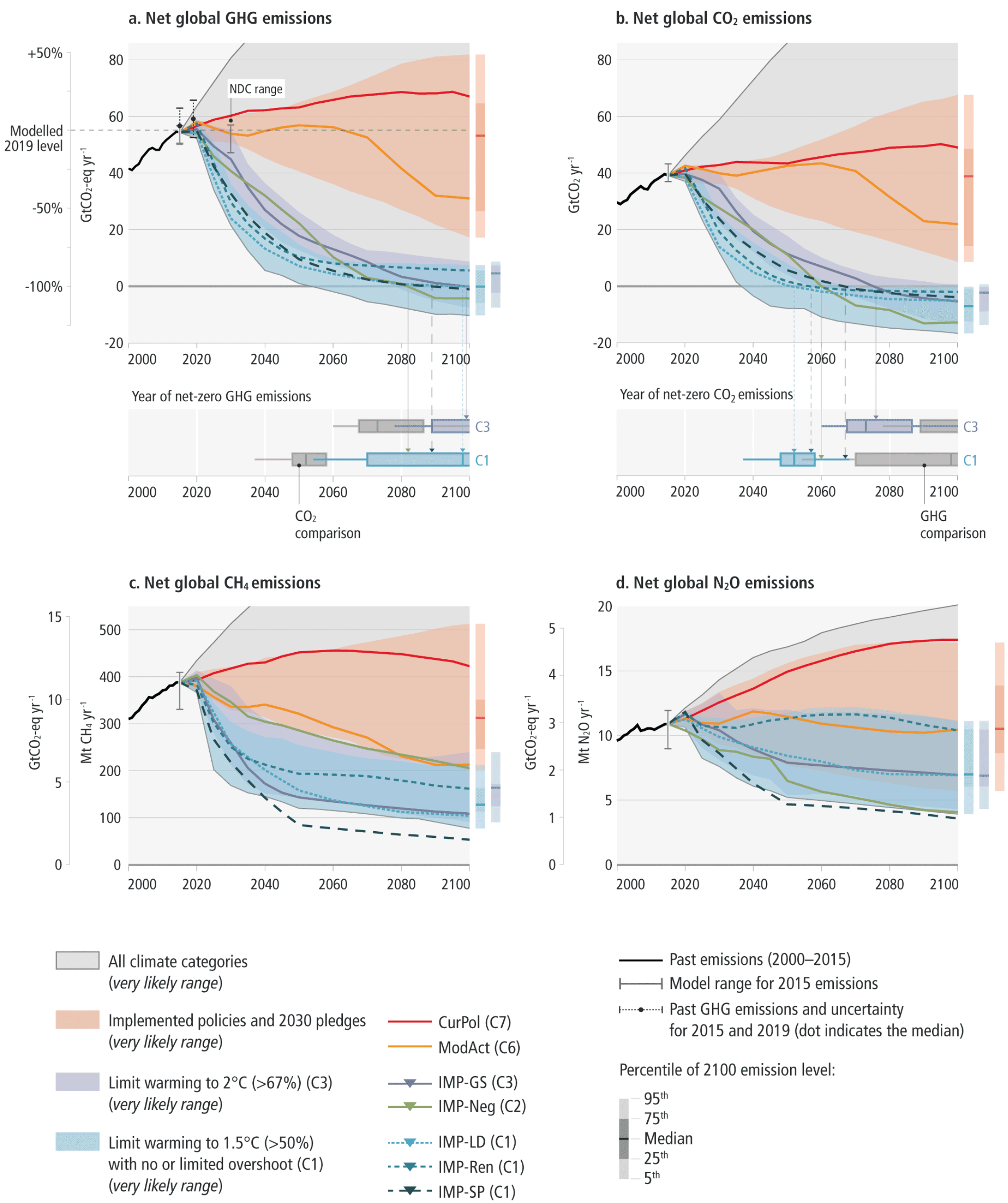


	2019 emissions ($GtCO_2$-eq)	1990–2019 increase ($GtCO_2$-eq)	Emissions in 2019, relative to 1990 (%)
CO_2 FFI	38±3	15	167
CO_2 LULUCF	6.6±4.6	1.6	133
CH_4	11±3.2	2.4	129
N_2O	2.7±1.6	0.65	133
F-gases	1.4±0.41	0.97	354
Total	59±6.6	21	154

The solid line indicates central estimate of emissions trends. The shaded area indicates the uncertainty range.

The big message: All GHG emissions are still going the wrong way.

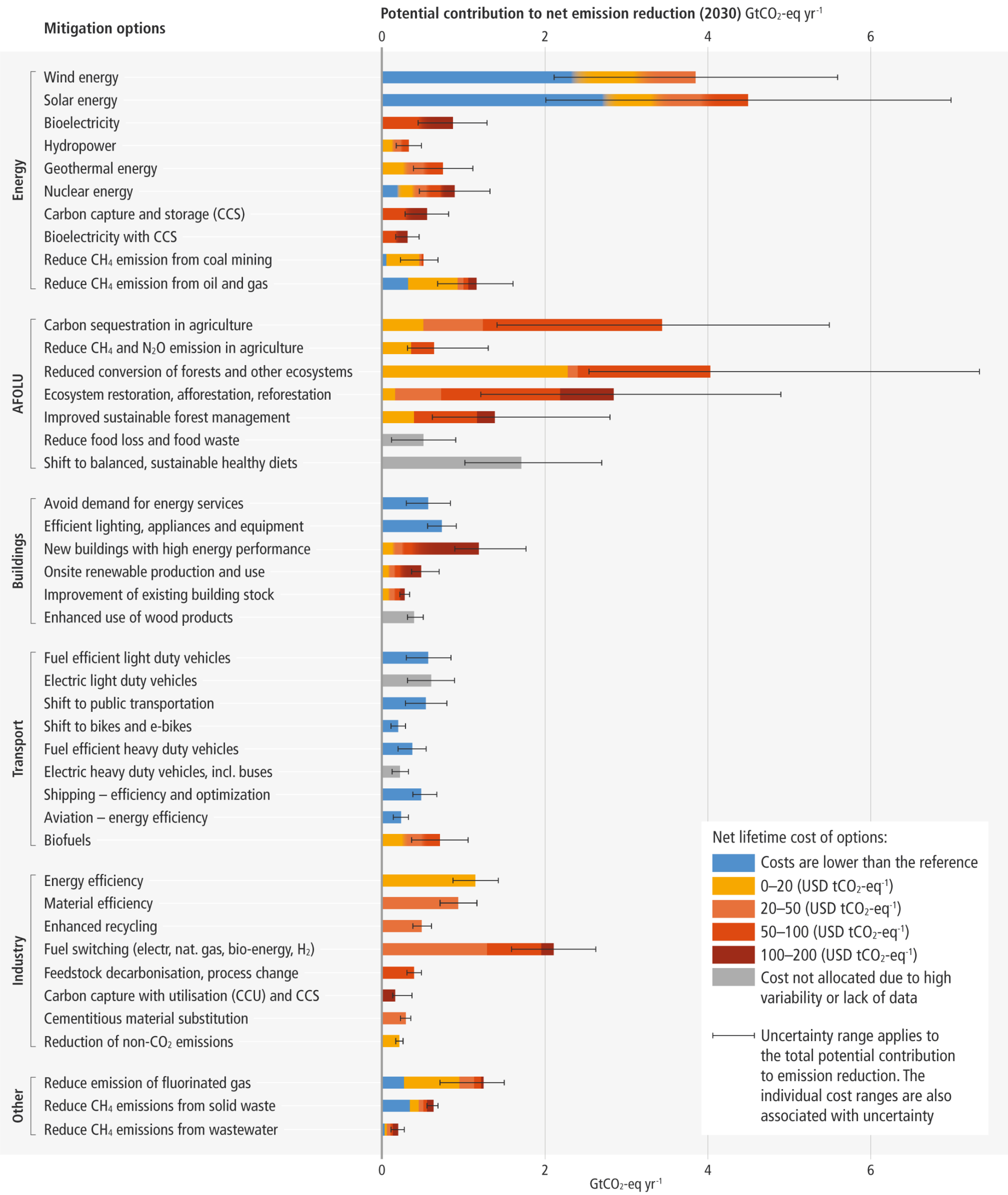
Modelled mitigation pathways that limit warming to 1.5°C, and 2°C, involve deep, rapid and sustained emissions reductions.



The big message:
CO2 emissions have to drop by half by 2030 and get to net-zero by ~2055 to keep 1.5-2ºC in sight. All GHGs need to go to netzero by ~2070. We are at +1.2ºC and have baked in ~1.7ºC without CO2 removal.

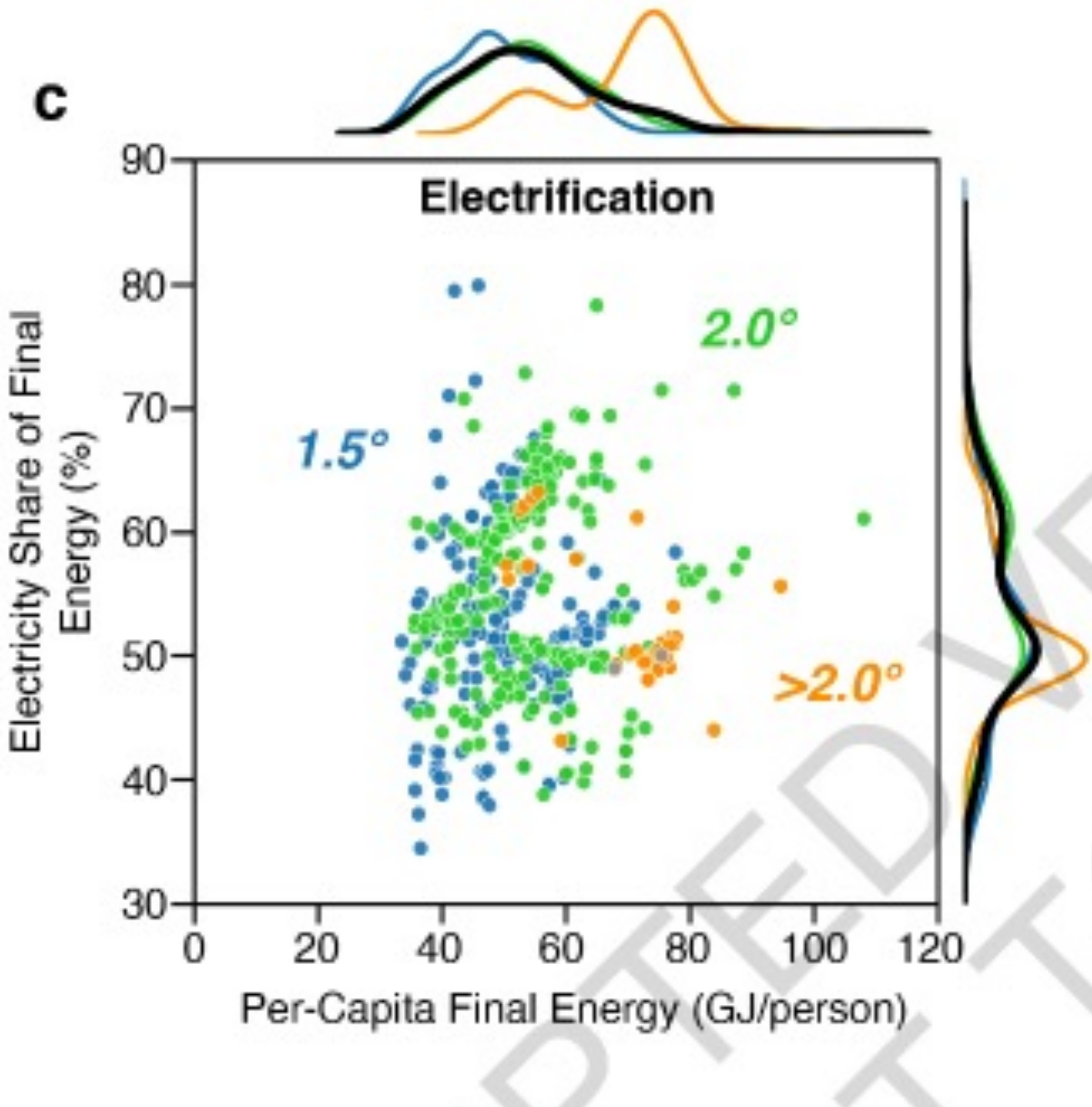
Hold on to this - all reductions are good and help reduce damages and climate tipping points. But 1.5ºC is much better than 2ºC, which is much better than 2.5ºC, and so on.

Many options available now in all sectors are estimated to offer substantial potential to reduce net emissions by 2030. Relative potentials and costs will vary across countries and in the longer term compared to 2030.



The big message: "Based on a detailed sectoral assessment of mitigation options, it is estimated that mitigation options costing USD100 tCO2-eq-1 or less could reduce global GHG emissions by at least half of the 2019 level by 2030 (options costing less than USD20 tCO2-eq-1 are estimated to make up more than half of this potential) "

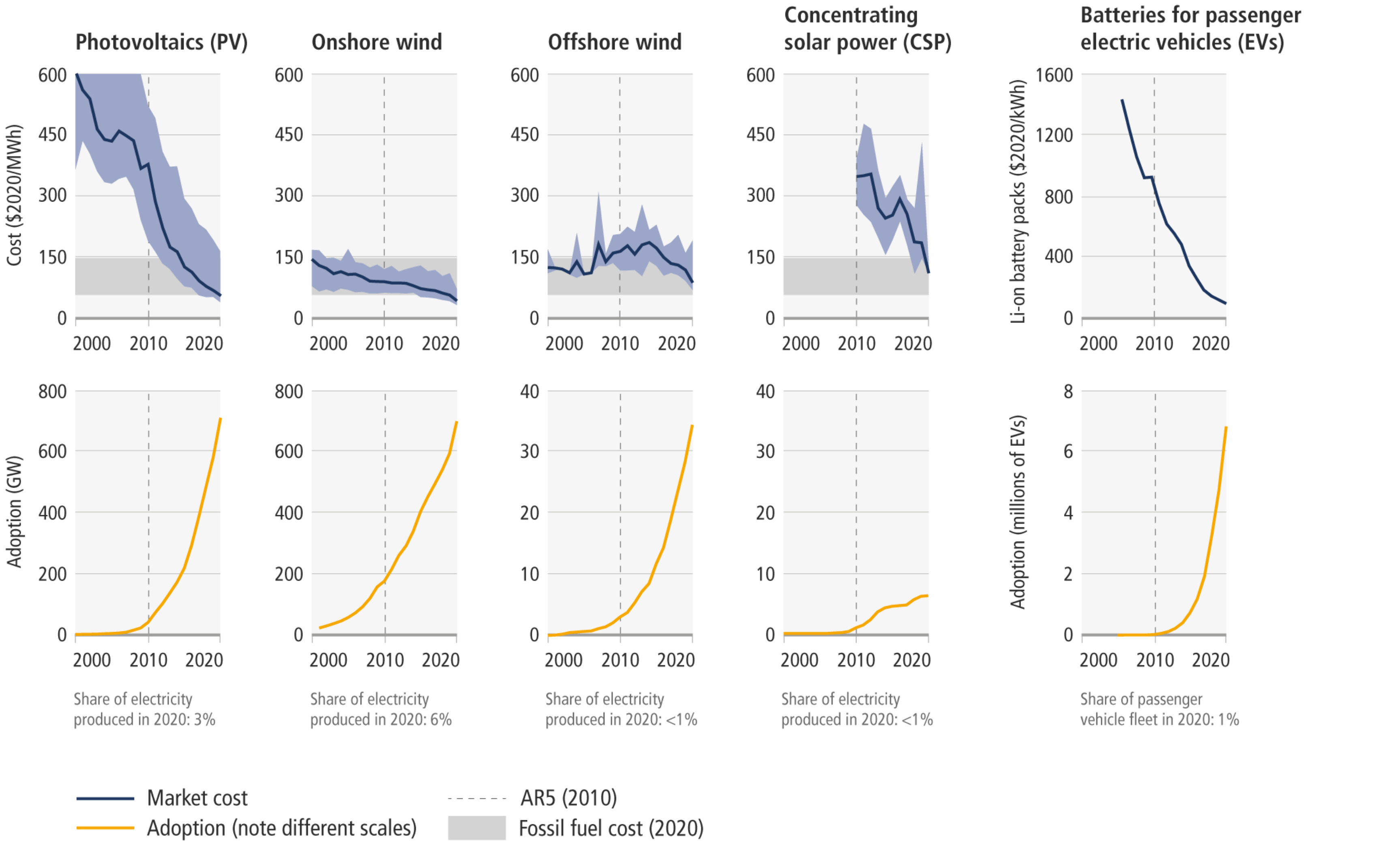
Mitigation is cheap, but we have to do it.



The big message:
Clean electrification of vehicles, buildings, light industry and some heavy industry will provide at least double and possibly triple the final energy used today. This is one of the biggest business opportunities of the century.

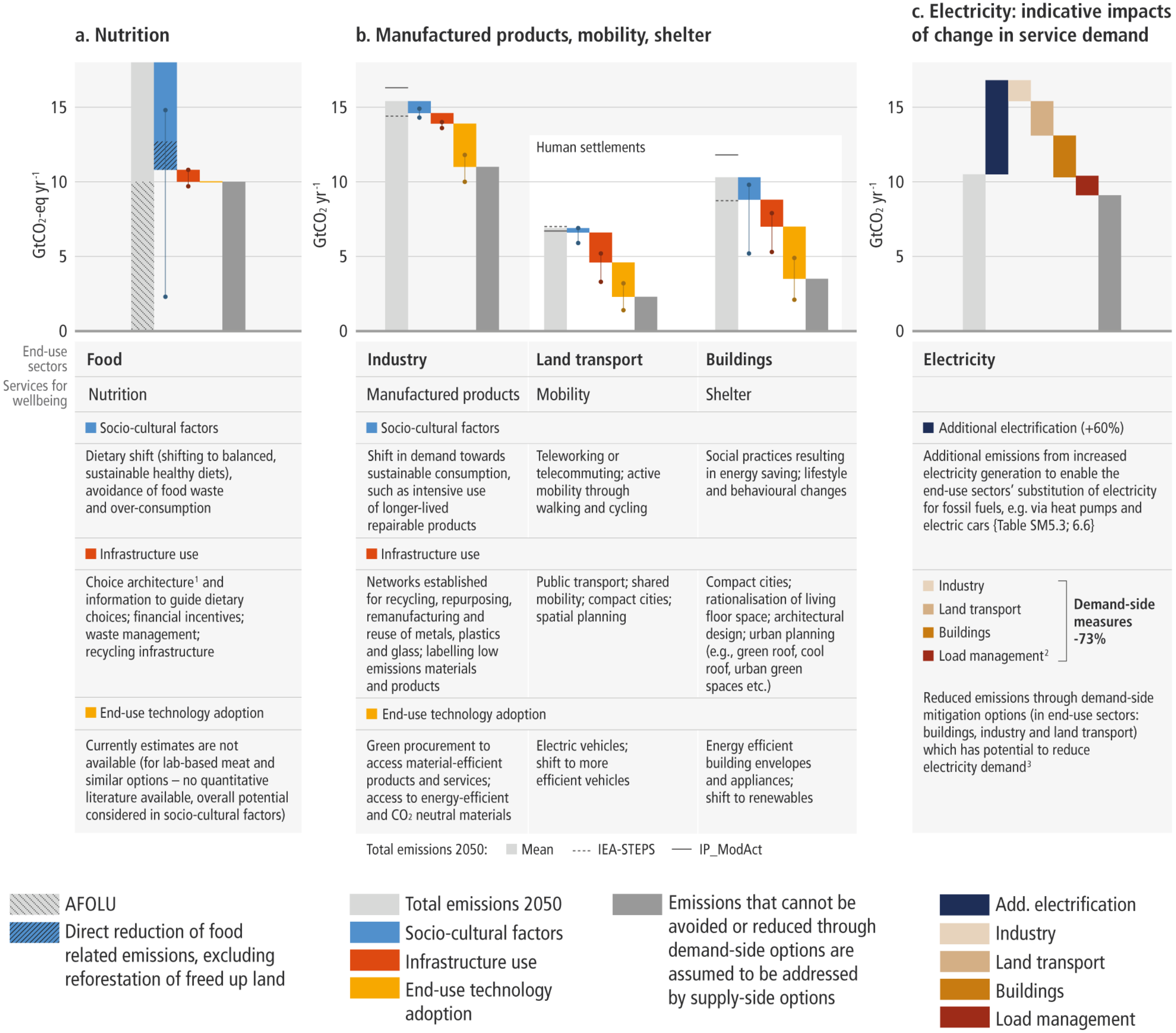
One of the things that doesn't come out as strongly as I would have liked is electrification of transport and buildings has local air quality benefits equal to or higher than climate in the short run.

The unit costs of some forms of renewable energy and of batteries for passenger EVs have fallen, and their use continues to rise.



The really good news: There has been a revolution in solar, wind and battery costs. This literally took us from north of +3ºC to the mid 2ºC range all by itself. Providing firm clean power to supplement this will be big business, worth ~3x per kWh.

Demand-side mitigation can be achieved through changes in socio-cultural factors, infrastructure design and use, and end-use technology adoption by 2050.



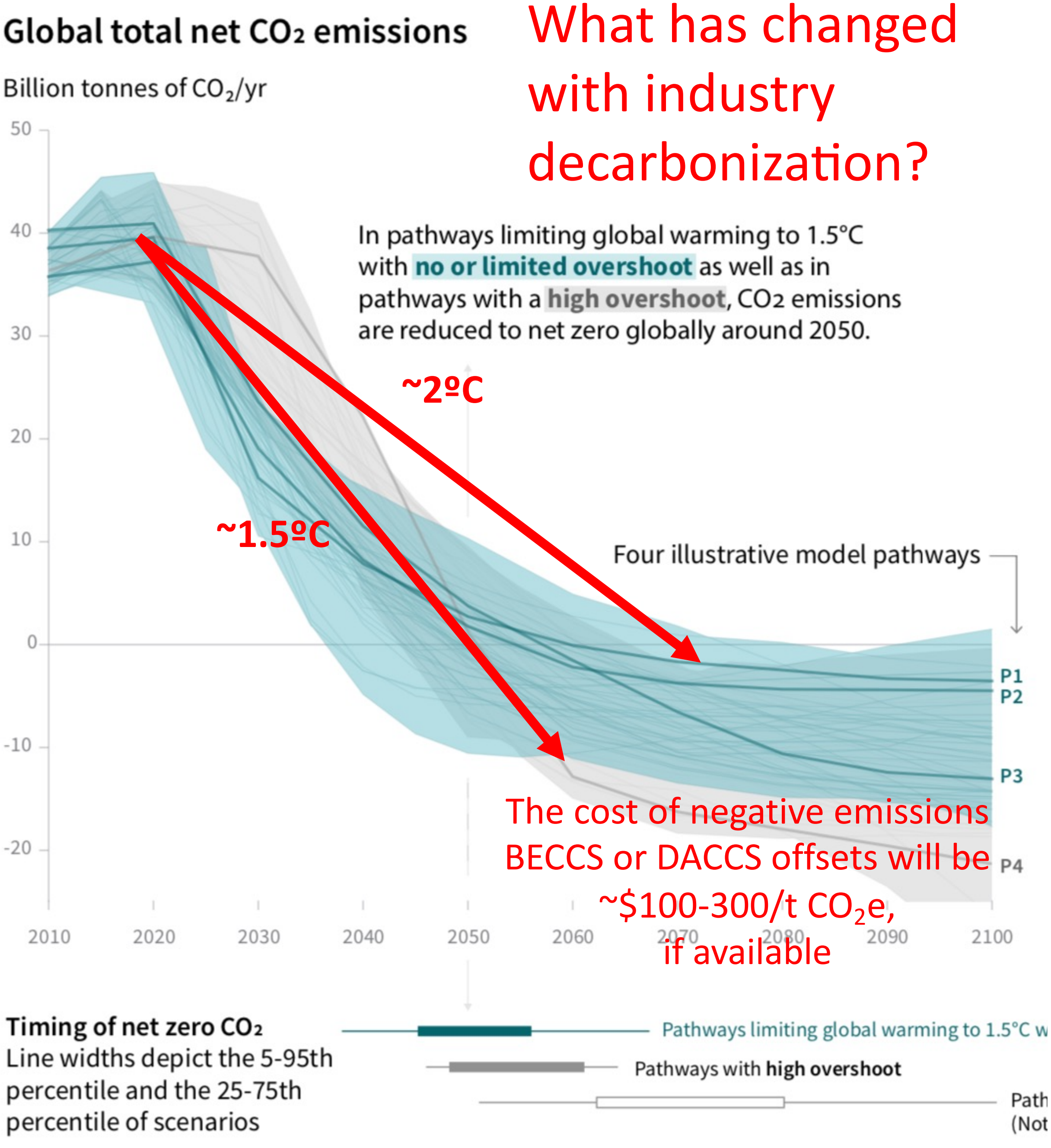
[1] The presentation of choices to consumers, and the impact of that presentation on consumer decision-making.

[2] Load management refers to demand-side flexibility that cuts across all sectors and can be achieved through incentive design like time of use pricing/monitoring by artificial intelligence, diversification of storage facilities, etc.

[3] The impact of demand-side mitigation on electricity sector emissions depends on the baseline carbon intensity of electricity supply, which is scenario dependent.

It's not all about supply. 40-70% of mitigation could come from smart, welfare enhancing demand management. This is largest in diets and personal transport in the short run, and buildings and urban form in the long run.

What has changed with industry decarbonization?

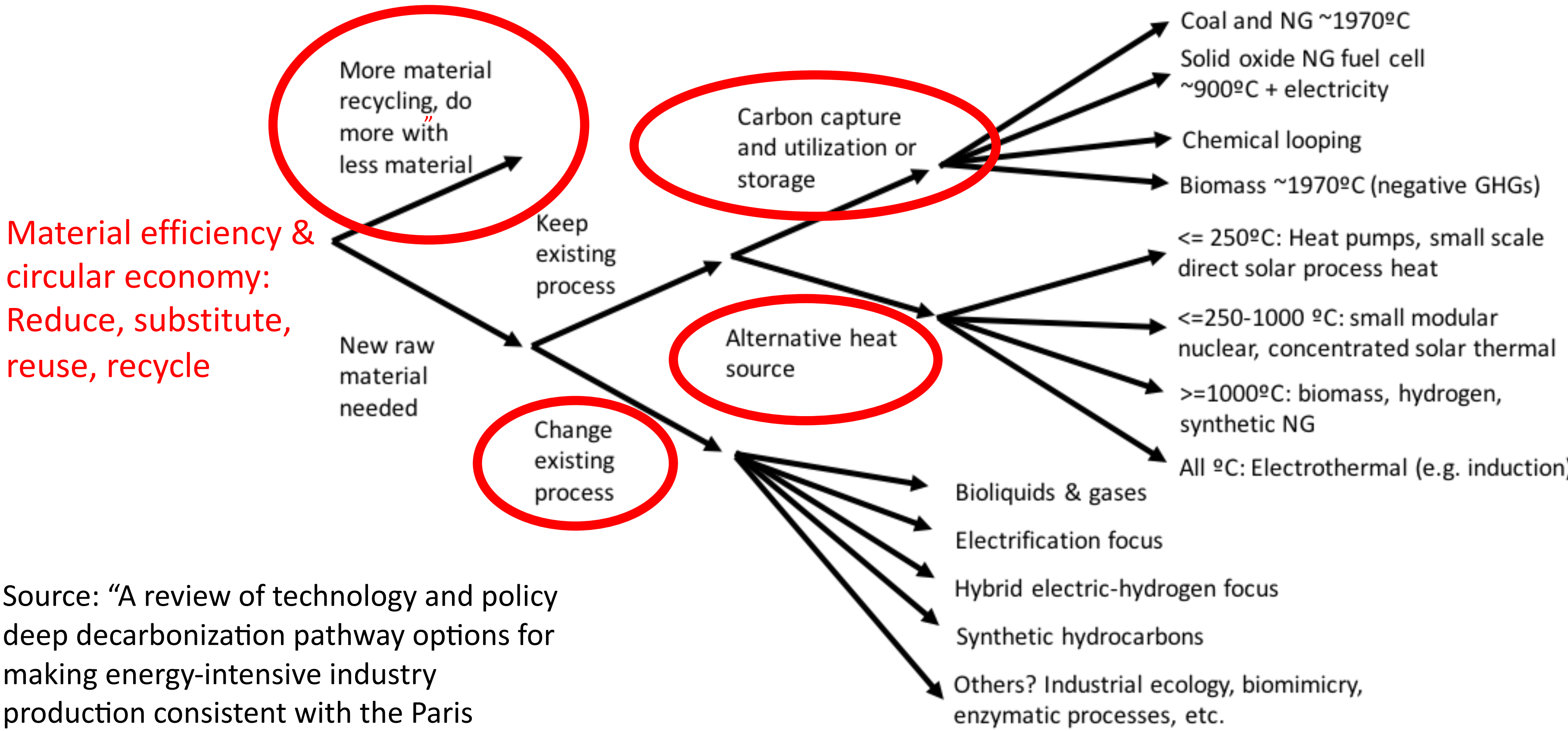


- Before Paris the focus was on energy efficiency, some fuel switching & electrification, some CCS, and absorbing some negative BECCS emissions from electricity.
- The policy priority was avoiding leakage, not deep decarbonization
- After Paris the -50% vacation on the back of electricity BECCS was over
- Now, everything under the price of DACCS needs to be done, and more given the uncertainties
- But how?

While much of industry can be electrified, there are big sector specific challenges

- The “extract-use-throw away” model for most material use (steel & aluminum as exceptions)
- Maxed out thermodynamic efficiency of core technologies (but not systems)
- Low (<=250ºC), medium (250-1000ºC) & high (>1000ºC) process heat
- Steel iron ore “deoxidization” CO_2 process emissions (& melting heat)
- Cement lime calcination CO_2 process GHGs (and 850/1450ºC process heat)
- Hydrogen production for ammonia for fertilizers and other chemicals; coal & steam methane reforming CO_2 process emissions
- Non-ferrous metals & alloys (big progress in bauxite electrolysis, i.e. Elysis)
- Carbon feedstock needed for chemicals
- **Making sure new materials aren’t GHG combustion or process intense!**

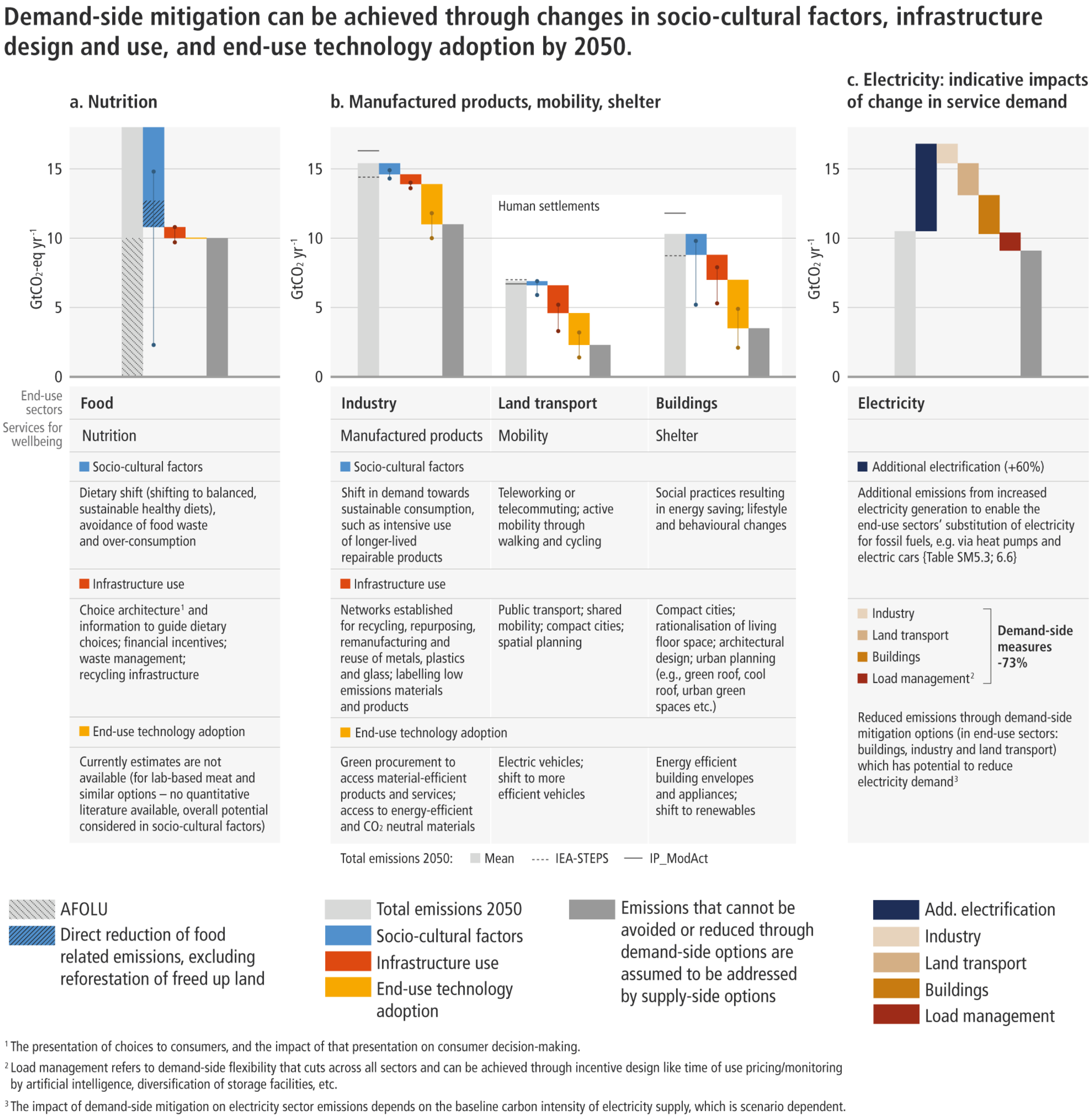
Recent literature has shown there are emerging and near commercial options to decarbonize all industrial sectors



Source: "A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris agreement", Bataille et al (2018) Journal of Cleaner Production

Dynamic questions that have to be addressed

1. *Material efficiency & circular economy*: High potential, but what happens if it isn't easy, cheap, or fast?



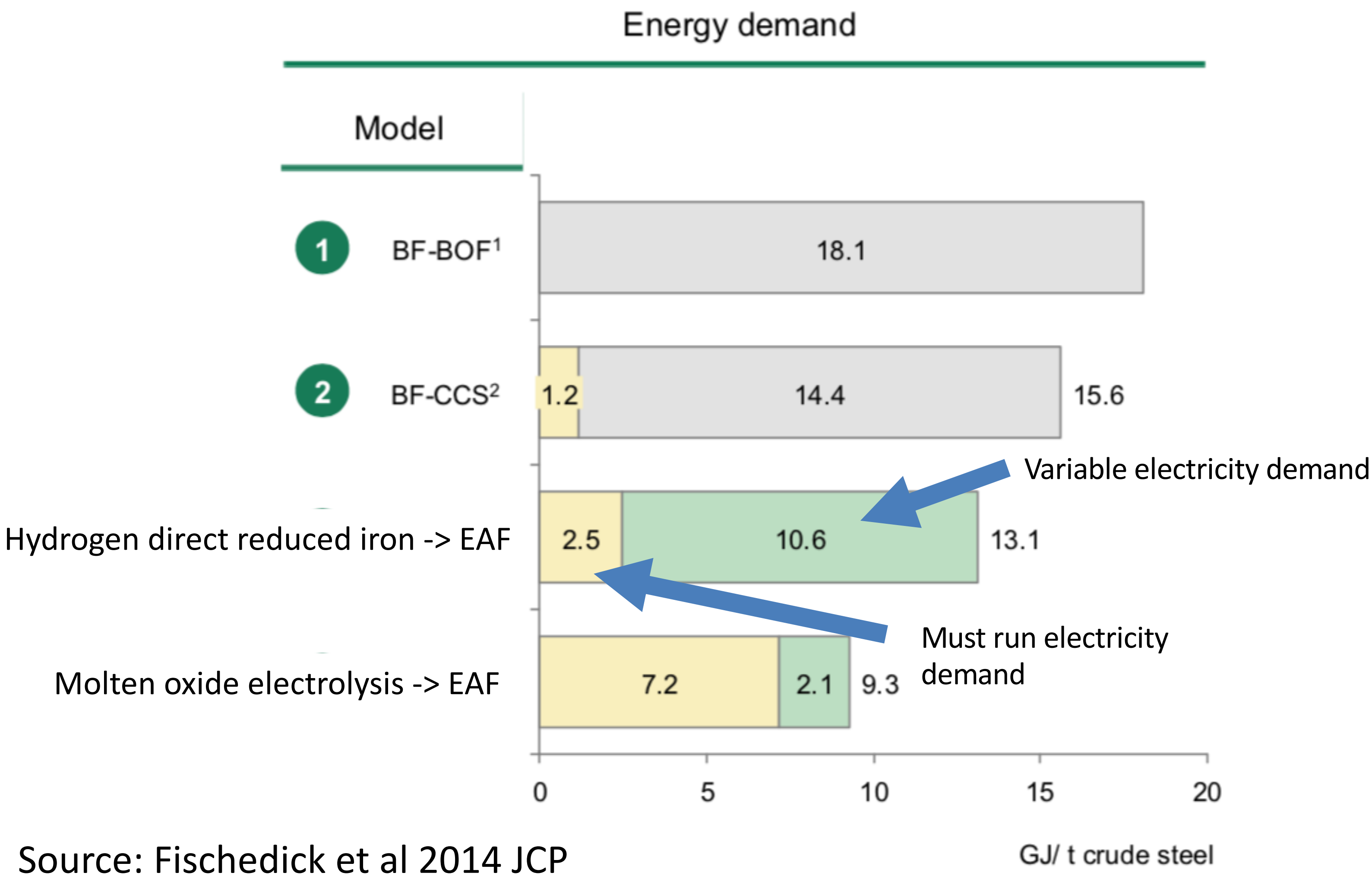
IPCC 2022 indicates that over the long haul material efficiency, more recycling building and urban design could reduce cement demand by at least 26% and steel by 40%

It requires design to make better use of steel, cement, and other materials for infrastructure, buildings and vehicles; requires supply chain overhaul of architectural, civil engineering, and construction firms.

Dynamic questions that have to be addressed

1. *Material efficiency & circular economy*: High potential, but what happens if it isn't easy, cheap, or fast?
2. *Electrification*: Capacity constraints matter and could be very expensive (electric steel example).

Must run electric capacity needs of a couple of different steel decarbonization options

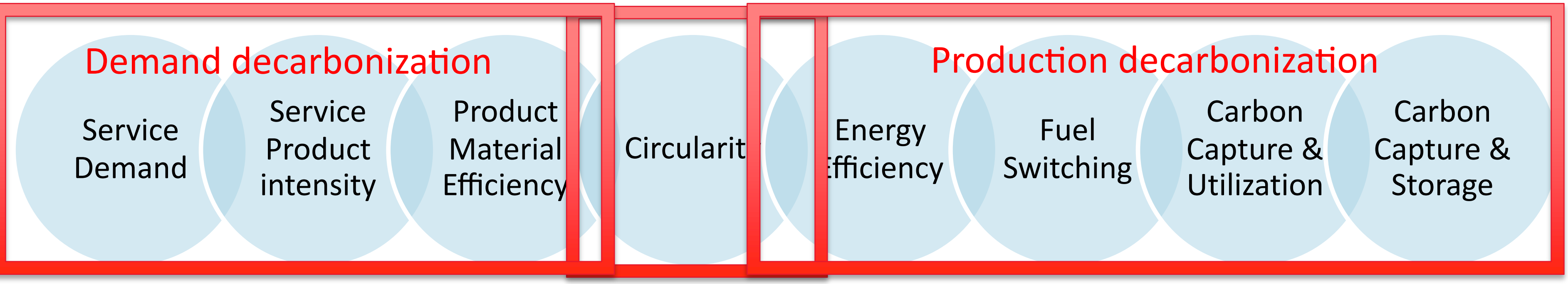


Source: Fischedick et al 2014 JCP

Dynamic questions that have to be addressed

1. *Material efficiency & circular economy*: High potential, but what happens if it isn't easy, cheap, or fast?
2. *Electrification*: Capacity constraints matter and could be very expensive (electric steel example).
3. *Carbon capture, utilization, storage:* What happens if CCS reservoirs, CCUS opportunities in a given region are limited? Or post-combustion CCS doesn't pan out (concentrated flow is already commercial)?
4. *Alternative heat sources:* Regional limits on biomass, solar, etc.
5. *What about long-lived legacy facilities?* e.g. Chinese BF-BOFs
6. *How can we build situation specific technology and policy hybrids to solve for all of the above?*

The options for decarbonizing steel, cement and chemicals

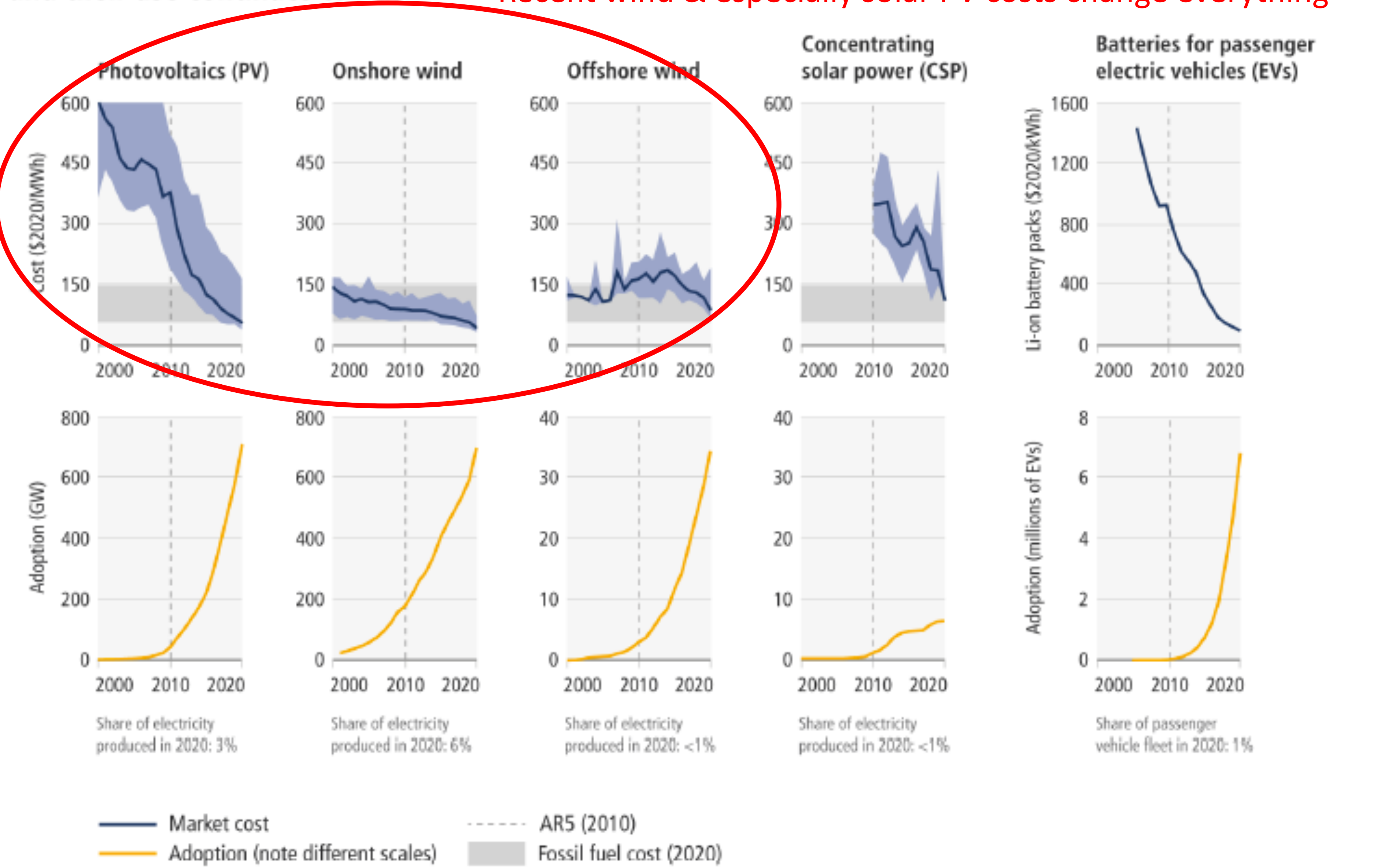


Houses-> m^2 per person-> cement kg/t concrete & kg OPC/ kg cement

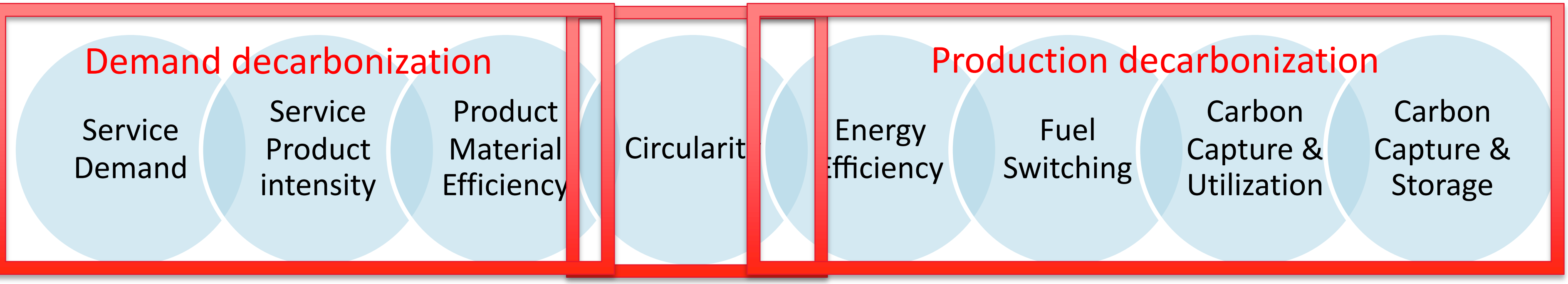
- DD Design to make better use of steel, cement, and other materials for infrastructure, buildings and vehicles; requires multi-generational supply chain overhaul of architectural, civil engineering, and construction firms. 26-40% reductions
- CIRC Recycling of concrete by grinding up and recovering unreacted cement & aggregates
- CIRC More steel recycling; needs less contamination, especially of copper (design issue).

The unit costs of some forms of renewable energy and of batteries for passenger EVs have fallen, and their use continues to rise.

Recent wind & especially solar PV costs change everything



The options for decarbonizing steel, cement and chemicals



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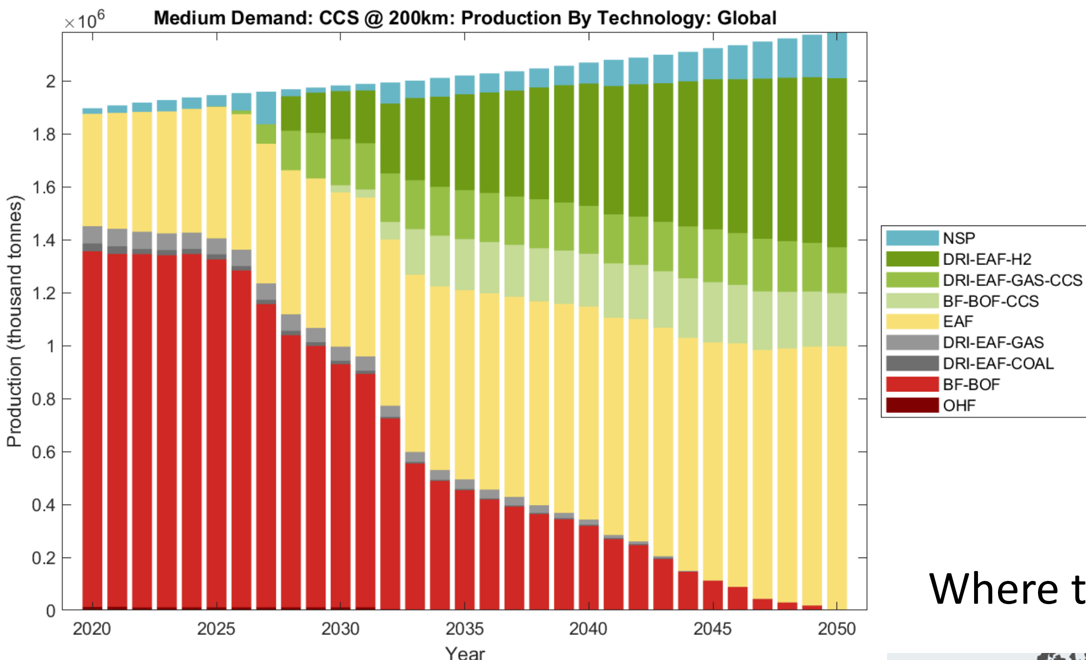
- CIRC Recycling of concrete by grinding up and recovering unreacted cement & aggregates
- CIRC More steel recycling; needs less contamination, especially of copper (design issue)
- PD Steel: biocharcoal; BF-BOF with post combustion CCS; advanced smelting + concentrated CCS; blue or green hydrogen DRI EAF; aqueous or molten oxide electrolysis;
- PD Cement: cementious material substitution; better concrete mixing; alternative fuels; CCS for process and or heat
- PD Chemicals: hydrogen; CCU, biogenic or DAC carbon; electrocatalysis

How we might restructure 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; economies of scale effects for cost and energy efficiency typically favoured integrated BFBOFs and to a certain extent cement concrete plants that kept getting bigger and bigger
- 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.
- 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.
- Same dynamics could be applied to hydrogen, ammonia, methanol, ethanol, and ethylene based on hydrogen, oxygen and low GHG carbon costs, and to clinker based on access to CCS geology and limestone.

The global picture, and the export opportunity from *Netzerosteel.org*



- At least 200 Mt per year of new production could occur anywhere there is access to iron ore, inexpensive clean electricity, or access to CCS geology.
- The big potential exporters are Australia, Brazil, Russia, South Africa, Canada …

Where the iron ore is …

- Global, facility level transitions scenarios to net zero steel based on furnace relining schedules and local resources. See *Netzerosteel.org*

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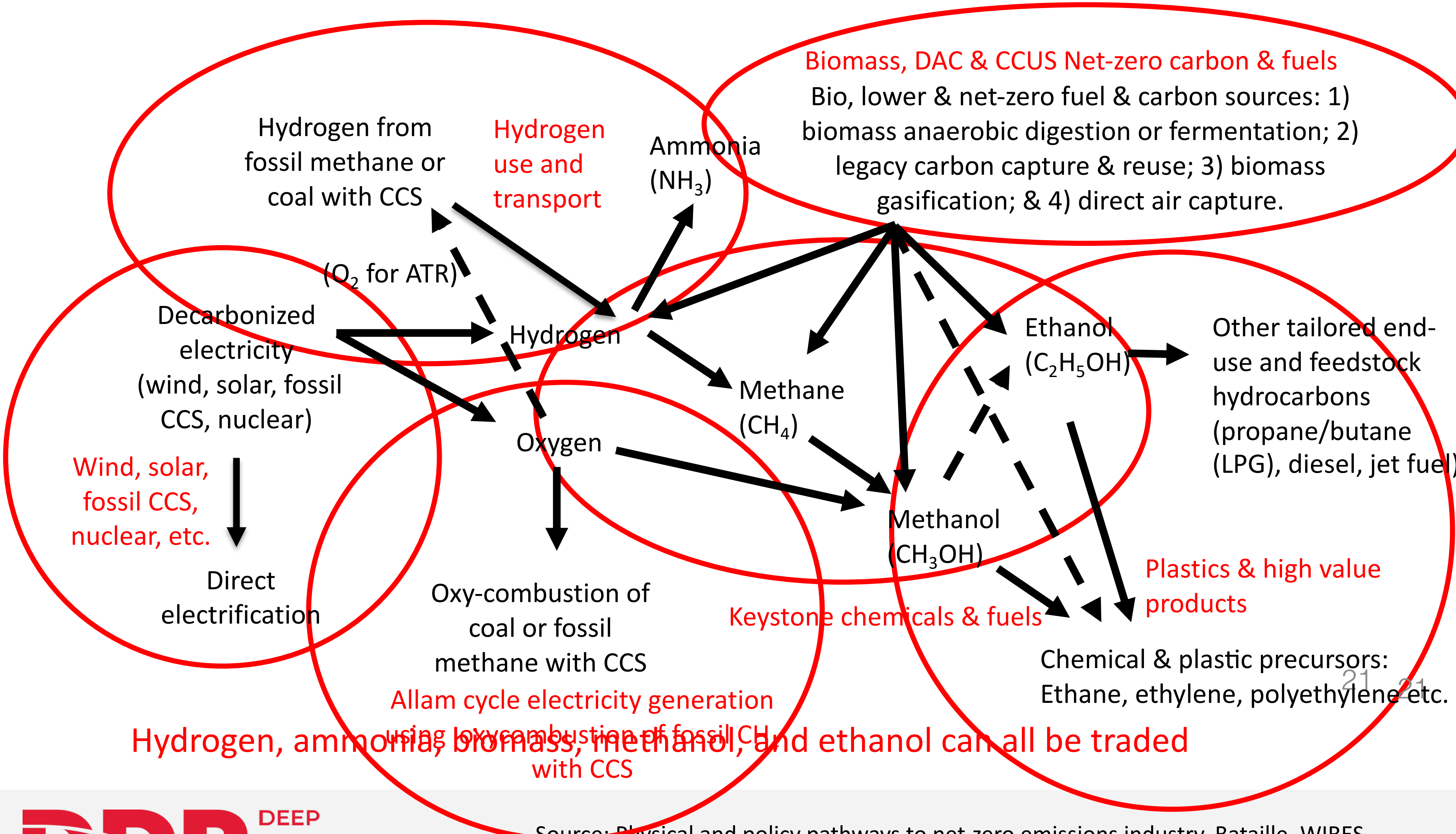
One possibility for heat and feedstocks: Regionally tailored hybrids of electricity, hydrogen, biomass & synthetic hydrocarbons?



Hydrogen, ammonia, biomass, methanol, and ethanol can all be traded

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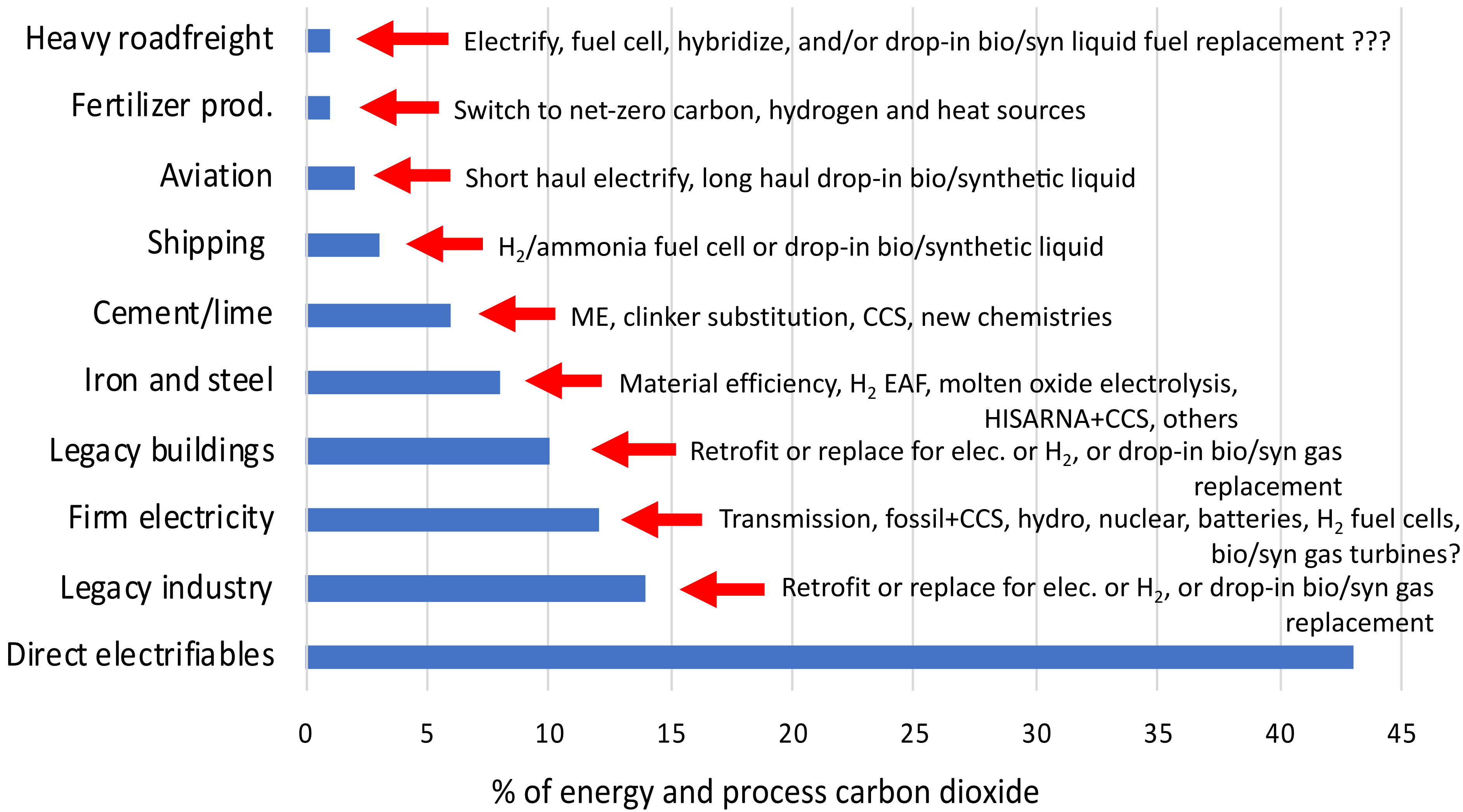
Source: Physical and policy pathways to net-zero emissions industry. Bataille, WIRES Interdisciplinary Reviews, 2019.

Potential hybrid actions to eliminate 2016 emissions



Source: Bataille, "Physical and policy pathways to low and zero emissions industry", WILEY Interdisciplinary Reviews, 2019, expanded out from Davis et al 2018

To make this possible, we need a diversified portfolio (i.e. “toolbox”) of tools to be used based on regional resources and needs

- “Only where necessary” design for cement and steel
- Aggressive clinker substitution -> alternative cement chemistries
- High temperature heat pumps
- Electrothermal technologies
- Electrolytic smelting & electric virgin steel production (DRI hydrogen EAF or molten oxide electrolysis EAF)
- Lower cost, more efficient electrolysis for hydrogen (alkaline to PEM or solid oxide fuel cells, cost/2, efficiency X2?); methane pyrolysis?
- Electro-catalytic and bio-catalytic instead of thermal processes
- Post-combustion and direct-from-air CO_2 capture
- Woody biomass gasification to commercialize bulk net-zero carbon sources, e.g. for methane & chemical feedstocks

Simple carbon pricing and regulations are not enough: The challenges are more than technological

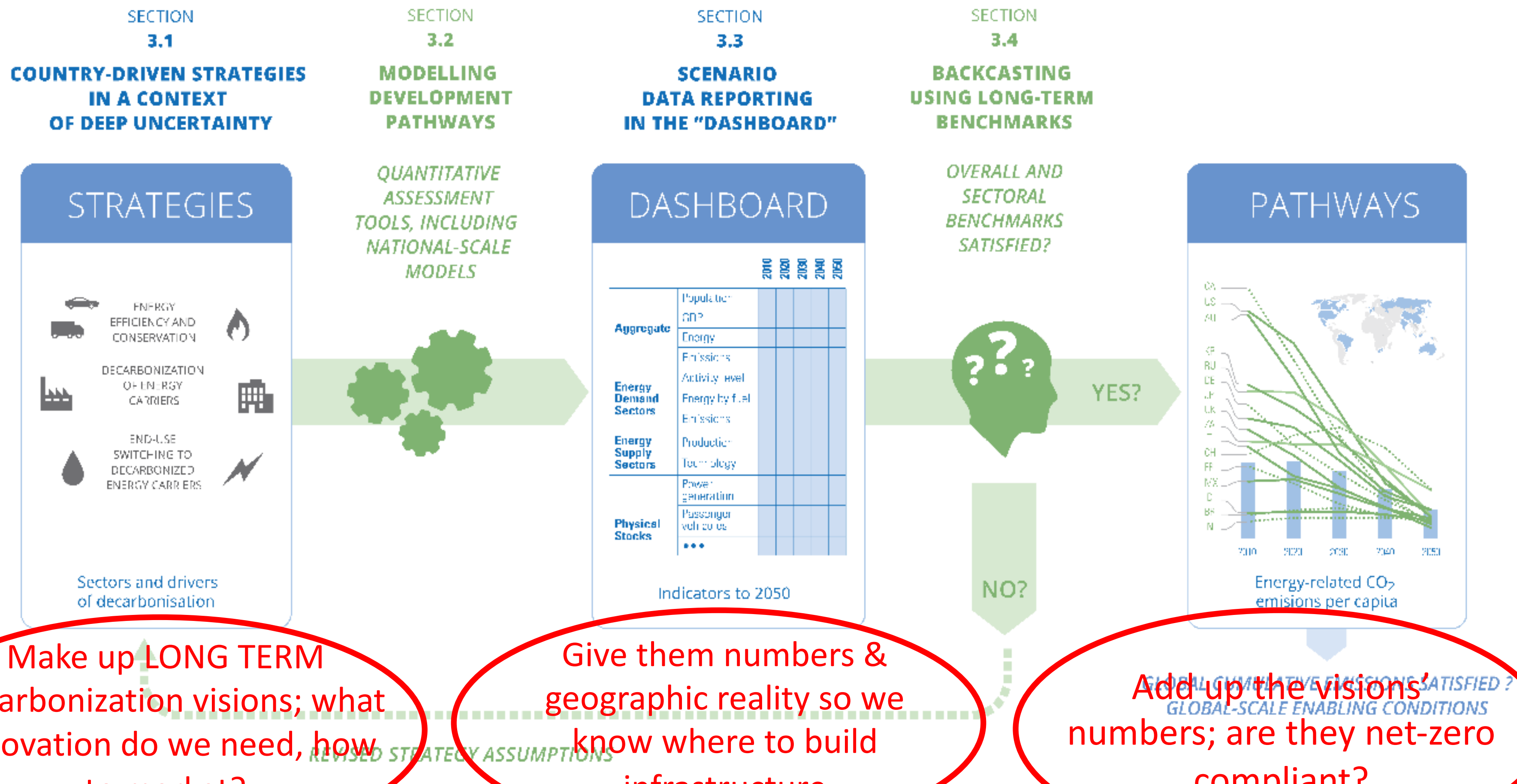
- While emerging tech exists, innovation will be slow because:
  - of low profit margins
  - competitive; they can’t pass on costs without losing market share
  - capital costs are focussed and upfront
  - they often can't capture the benefits of innovation
  - facility lives are long and turnover is slow
  - ***there is no market for more expensive low GHG materials***
- Policy for heavy industry needs to target these challenges directly
- Fundamentally, this is about reducing and controlling risk

Combined strategies for a "local solution finding" policy package

- A multi-level **policy commitment** to transition to net-zero GHG industry
- Building code, design & recyclability policies for material efficiency/circularity
- A transition pathway planning process including all key stakeholders to assess strategic & tech options, competitive advantages, and uncertainties

Transition planning with all key stakeholders

Source: Waisman et al 2019, Nature Climate Change



Make up LONG TERM decarbonization visions; what innovation do we need, how to market?

Give them numbers & geographic reality so we know where to build infrastructure

Add up the visions' numbers; are they net-zero compliant?

DEEP DECARBONIZATION PATHWAYS

Build adaptive policy around the working vision

Combined strategies for a "local solution finding" policy package

- A multi-level **policy commitment** to transition to net-zero GHG industry
- Building code, design & recyclability policies for material efficiency/circularity
- A transition pathway planning process including all key stakeholders to assess strategic & tech options, competitive advantages, and uncertainties
- Accelerated R&D and commercialization; create lead markets to build economies of scale w/ green procurement, content regs, supply chain branding, guaranteed pricing & output subsidies (e.g. CfDs)
- Eventual exposure of all sectors to **full GHG pricing** with competitiveness protection, CBAM that don't penalize highly traded green commodities
- Early retirement if necessary for long lived, highly GHG intense facilities
- **Supporting institutions**: Just transition; monitoring; electricity, H_2 & CCS infrastructure; lifecycle accounting; education; regulatory backdrop

DDP DEEP DECARBONIZATION PATHWAYS

In summary: net-zero industry is possible, but will require planning as well as subtle, staged, & stringent policy

Source papers:

IPCC AR6 WGIII Ch.11 Industry Bashmakov et al 2022

Bataille, C., L. J. Nilsson, and F. Jotzo, 2021: Industry in a net-zero emissions world: New mitigation pathways, new supply chains, modelling needs and policy implications. Energy Strategy Reviews, (September), 100059, doi:10.1016/j.egycc.2021.100059.

Trollip, H., B. McCall, and C. Bataille, 2022: How green primary iron production in South Africa could help global decarbonization. Climate Policy, 22(2), 236–247, doi:10.1080/14693062.2021.2024123.

Extended recorded presentations and country and scenario data are available at *Netzerosteel.org*

Please send questions to:

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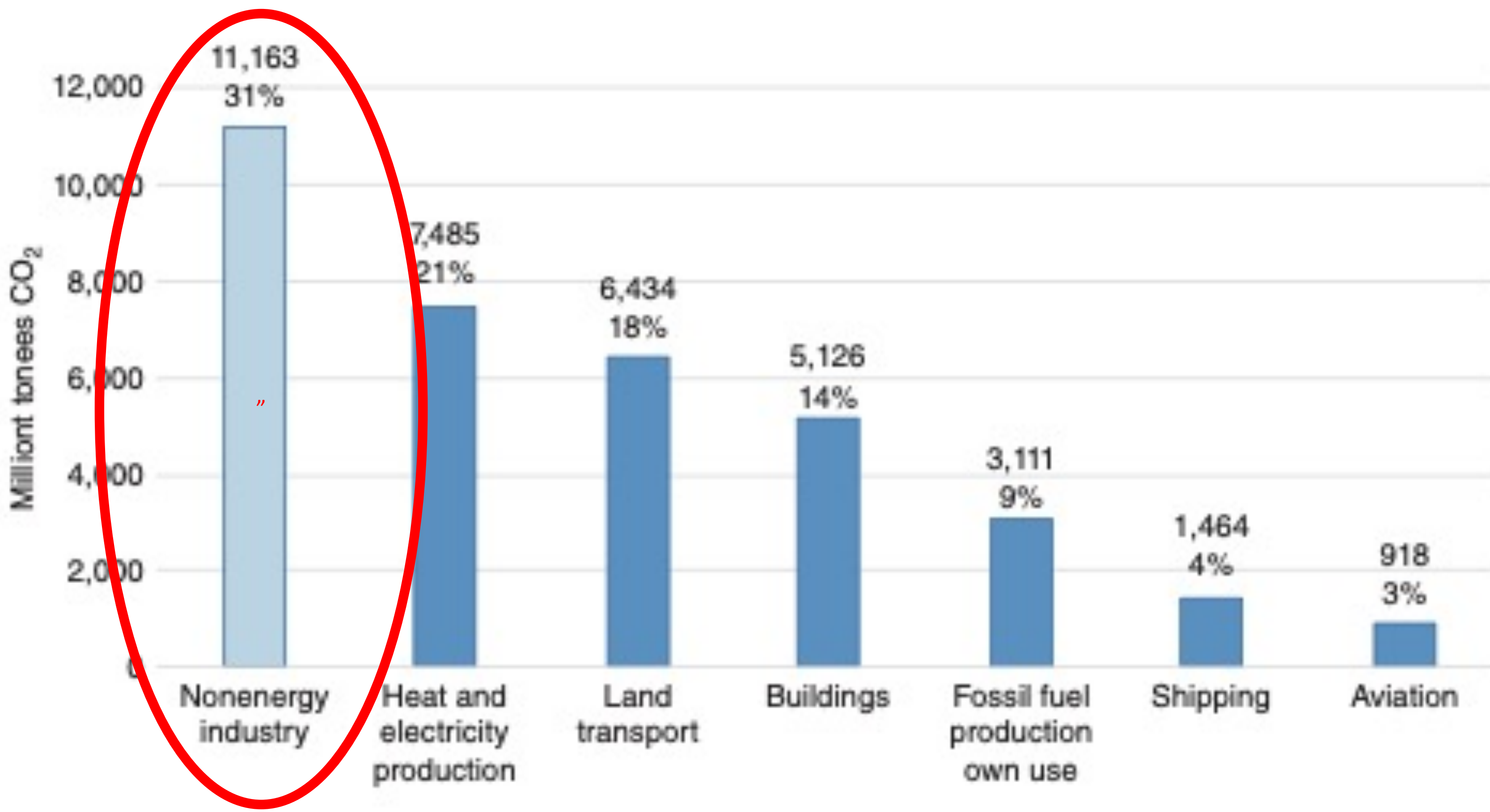
Global combustion and process CO_2 emissions in 2016



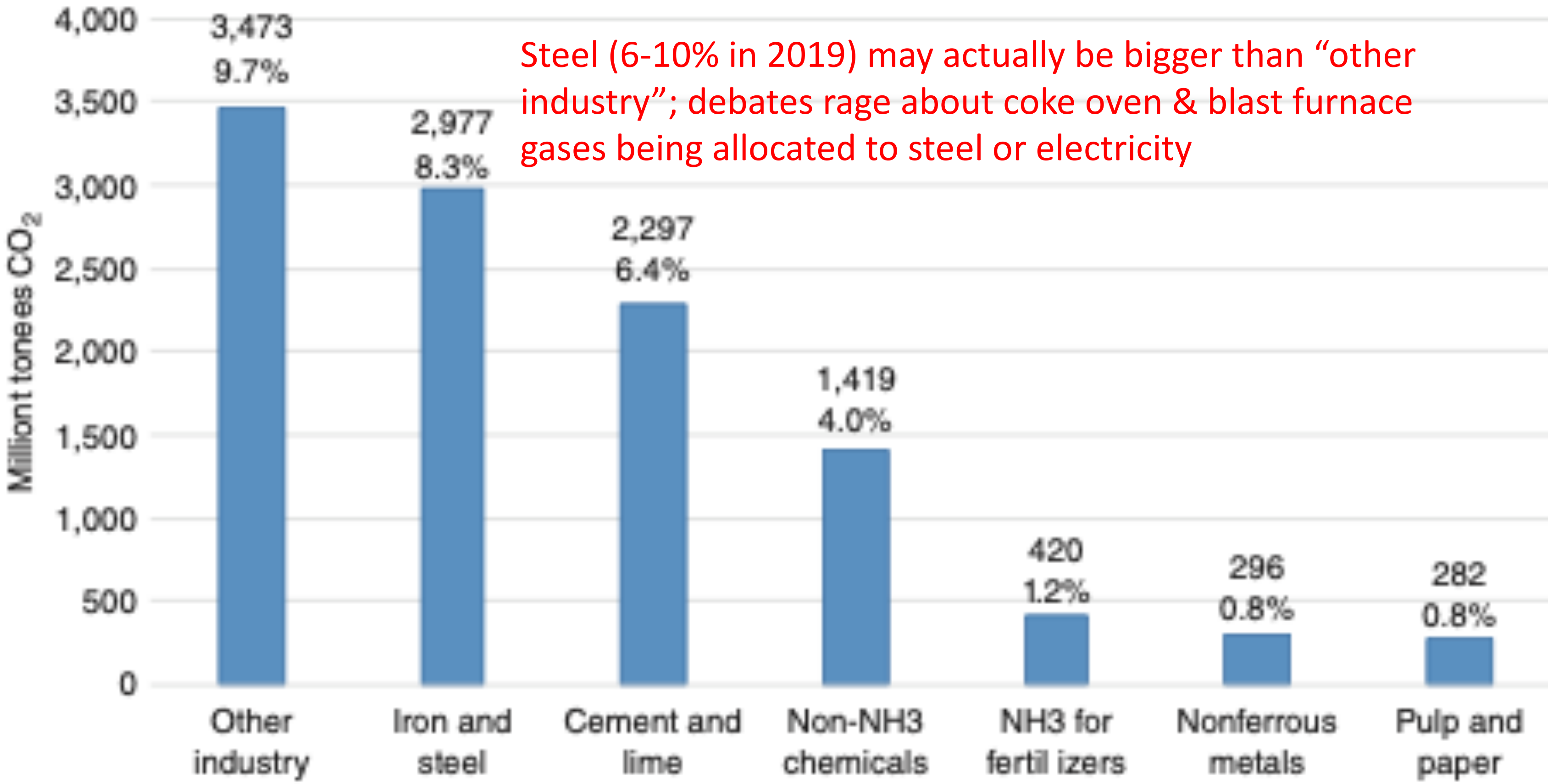
2016 Global combustion and process CO_2 emissions by sector (MMt CO_2e)

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

Global sector combustion and process CO_2 emissions in 2016

"Other industry" is mainly light industry, which is technically easily electrifiable, but economically hard because of NG:Elec spark spread

Steel (6-10% in 2019) may actually be bigger than "other industry"; debates rage about coke oven & blast furnace gases being allocated to steel or electricity



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