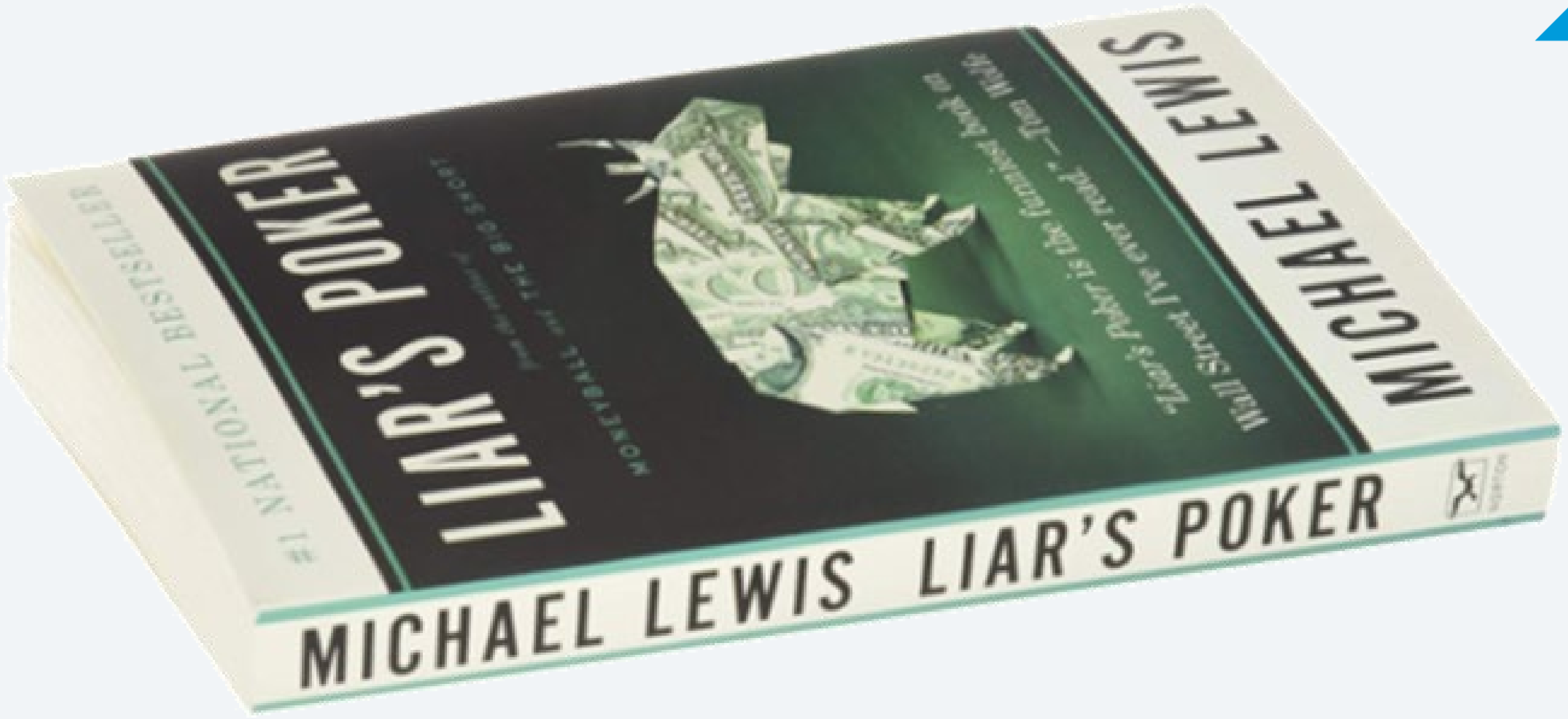
Climate Risks and Opportunities

17 January 2025

Gernot Wagner
gwagner@columbia.edu
gwagner.com



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gwagner.com

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1. Climate risk is financial risk
2. We know what to do, and how to make it profitable

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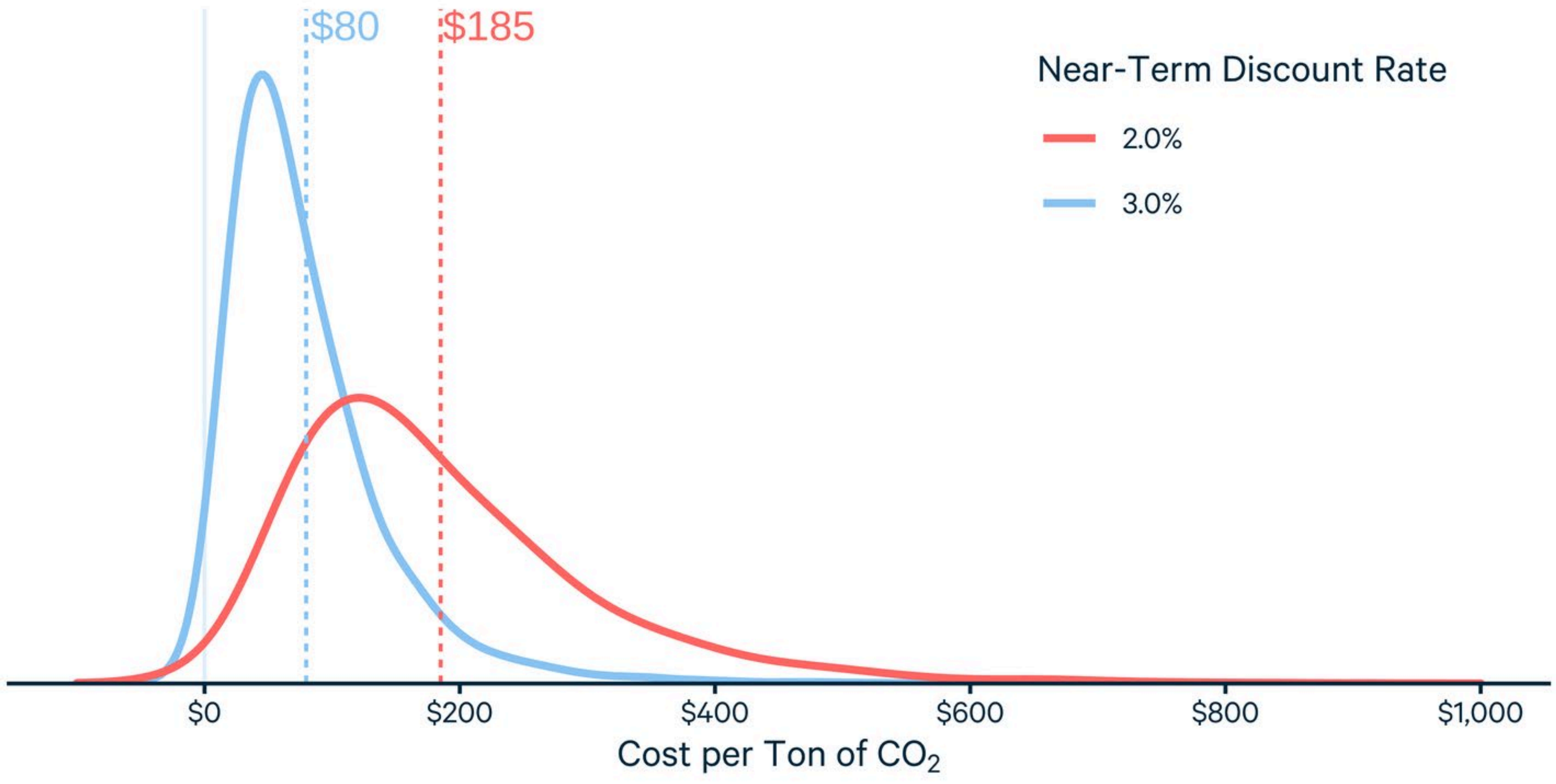
~$200 / t$CO_2$

~$185 Social Cost of CO_2

Based on 2% constant discount rate, with most of the increase due to discounting



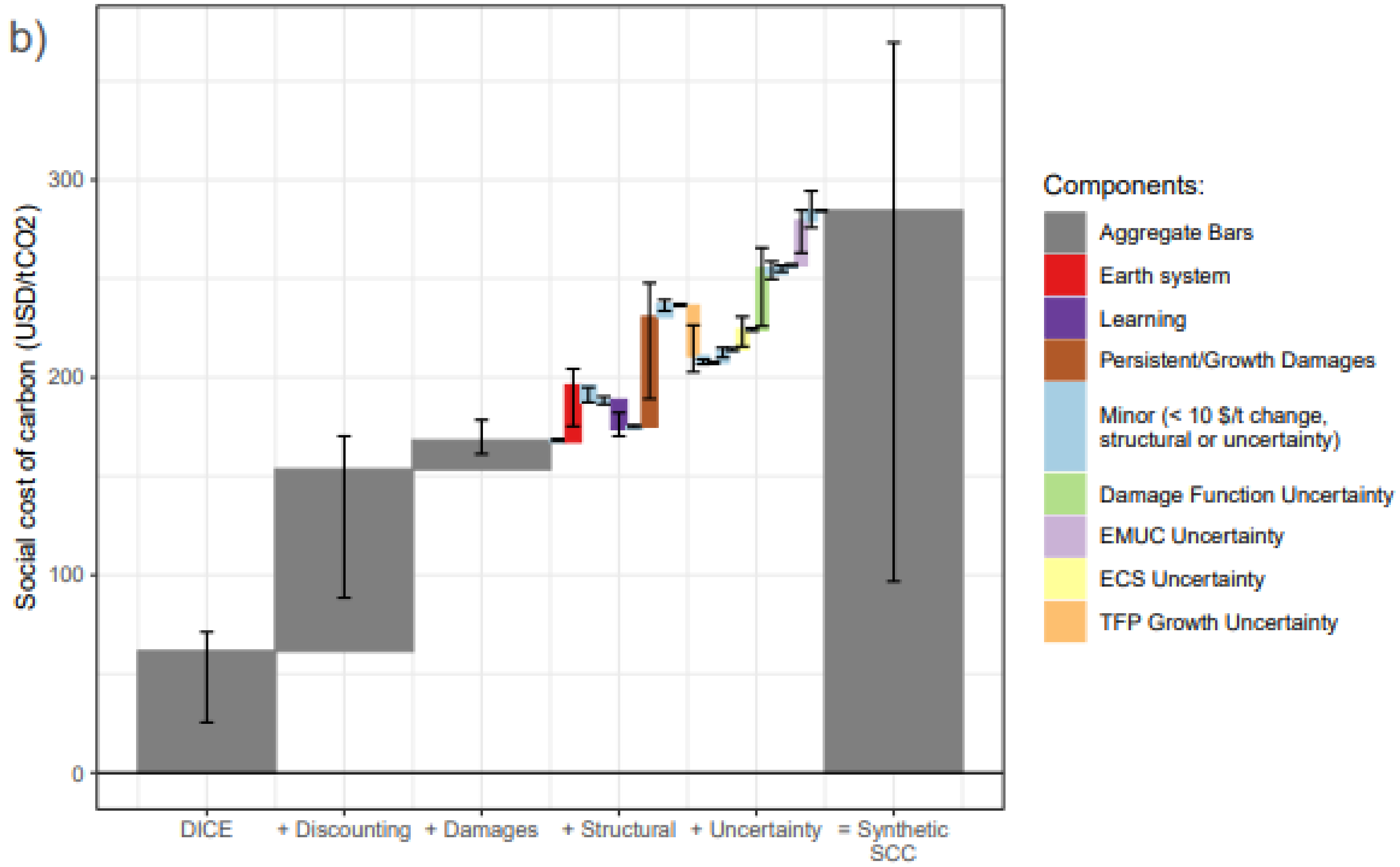
~$50 to ~$80 from updated damages,
~$80 to ~$185 from discounting

Source: Rennert *et al* "Comprehensive Evidence Implies a Higher Social Cost of CO_2" (*Nature*, September 2022).

$> \$200 / tCO_2$

“Synthetic” Social Cost of Carbon with median = $185 and mean = $284

For 1 tonne of CO_2 emitted in 2020, in $2020, with 5%–95% range of $32–$874(!)



Source: Moore, Drupp, Rising, Dietz, Rudik & Wagner (*2024*), gwagner.com/synthesis-scc

~ \$200 / tCO_2

=

~8-10% of

global GDP

~ $1,000 / tCO$_2$

=

~50%(!!) of *global* GDP

Source: Bilal & Känzig (NBER, 13 May 2024), nber.org/papers/w32450

> $150 /
car entering NYC*

* Manhattan below 60th Street

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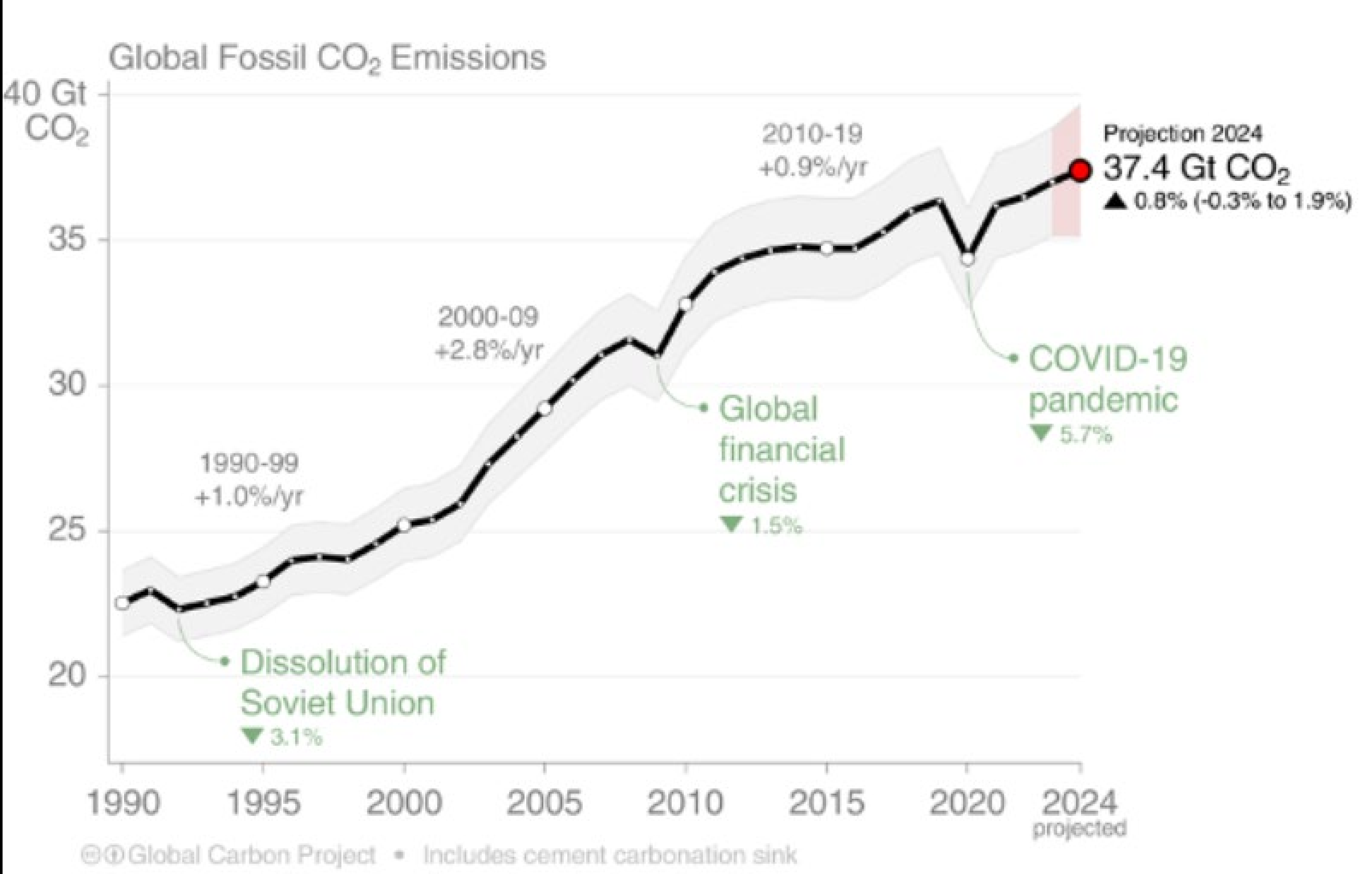
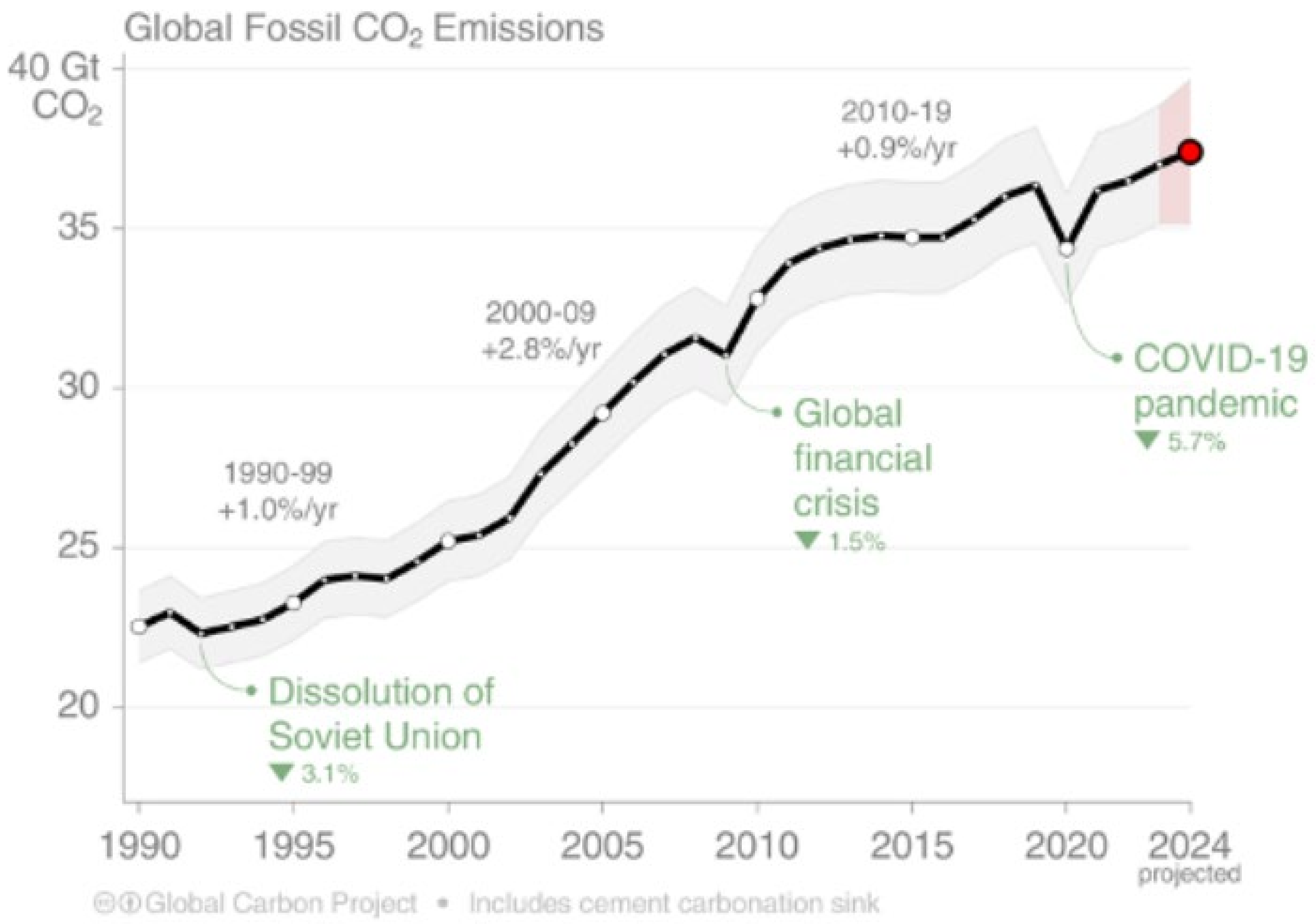
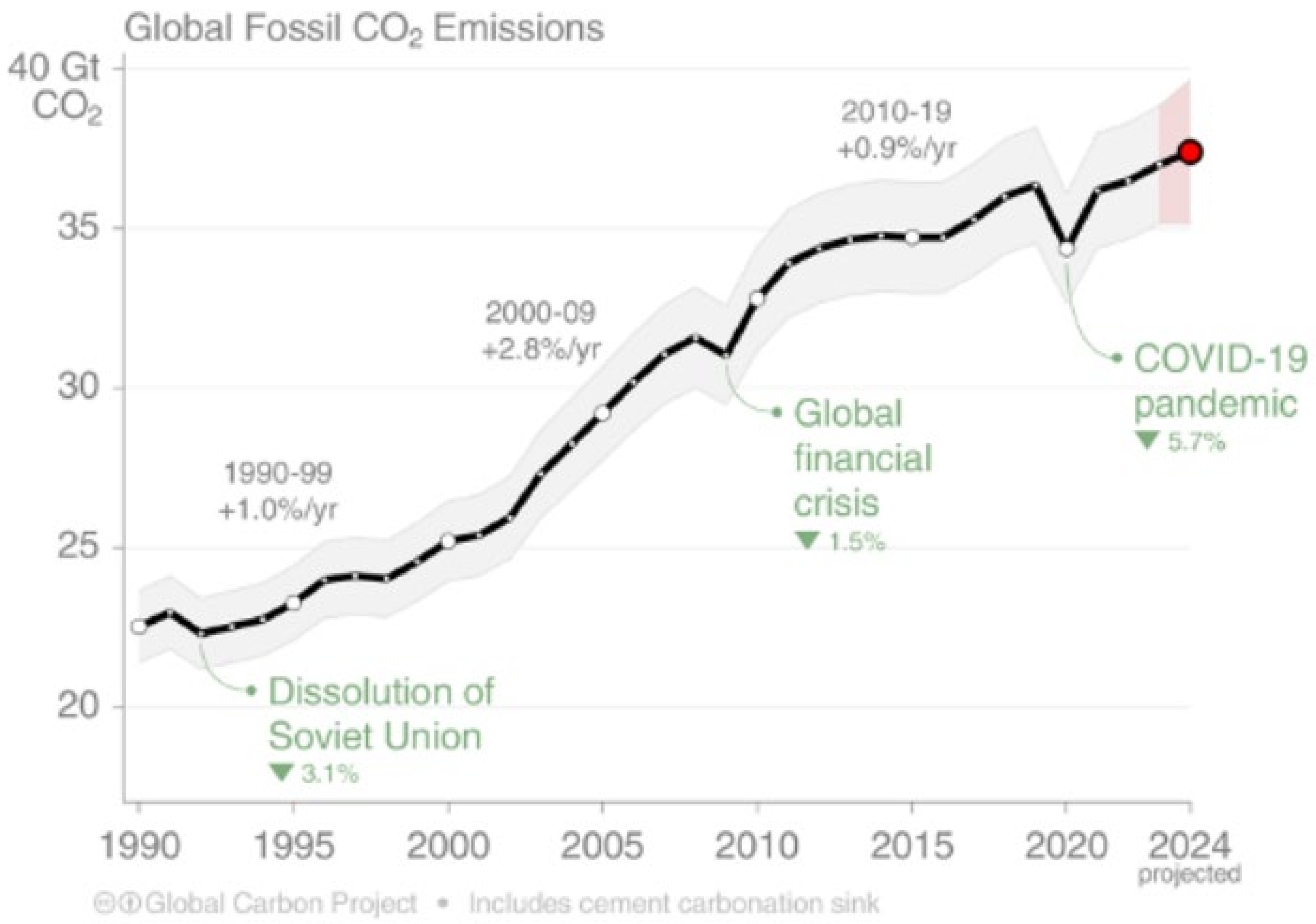


Source: Global Carbon Project (2024)

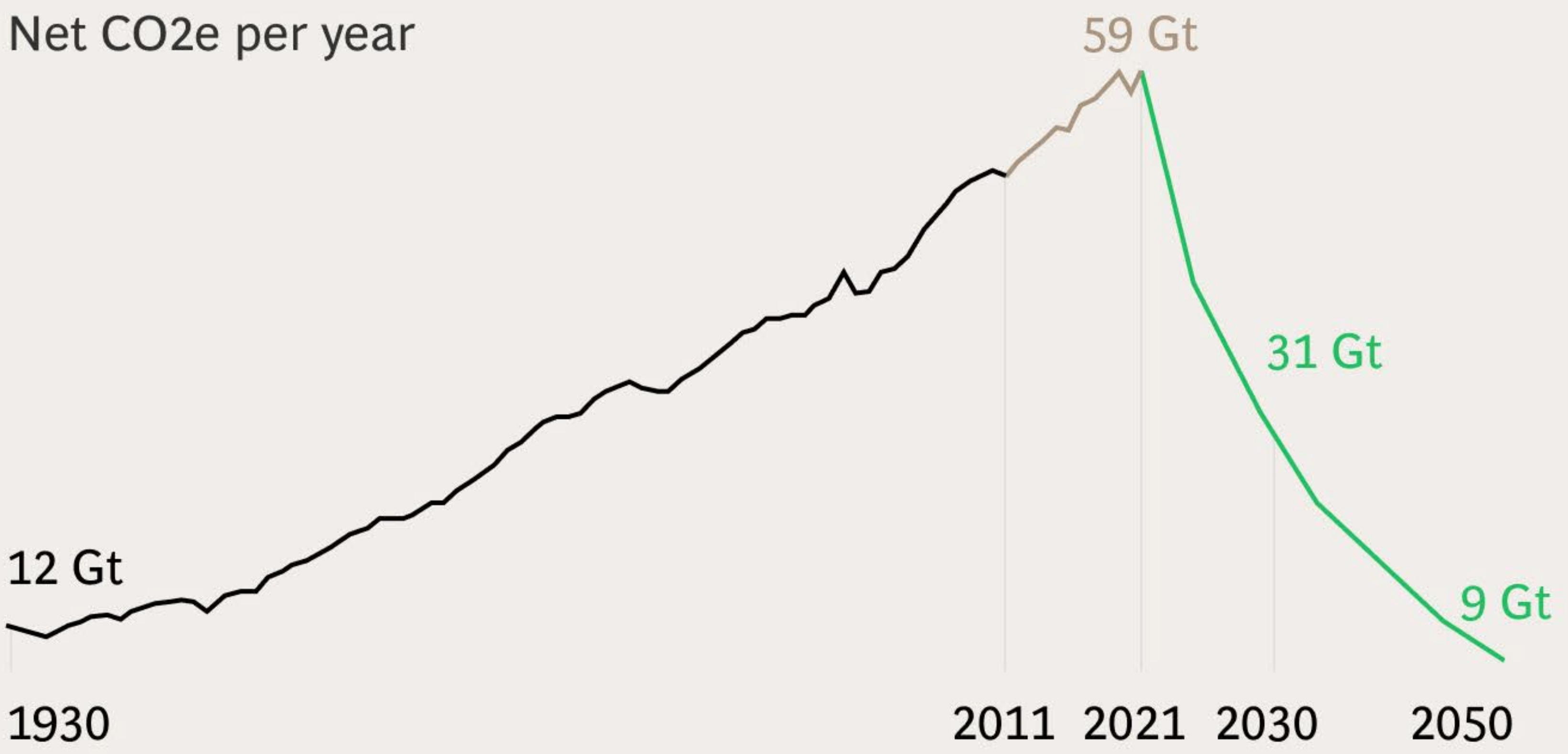


Source: Global Carbon Project (2024)



Source: Global Carbon Project (2024) + umpteen climate-economic model runs

Major course correction needed to achieve the 1.5°C ambition

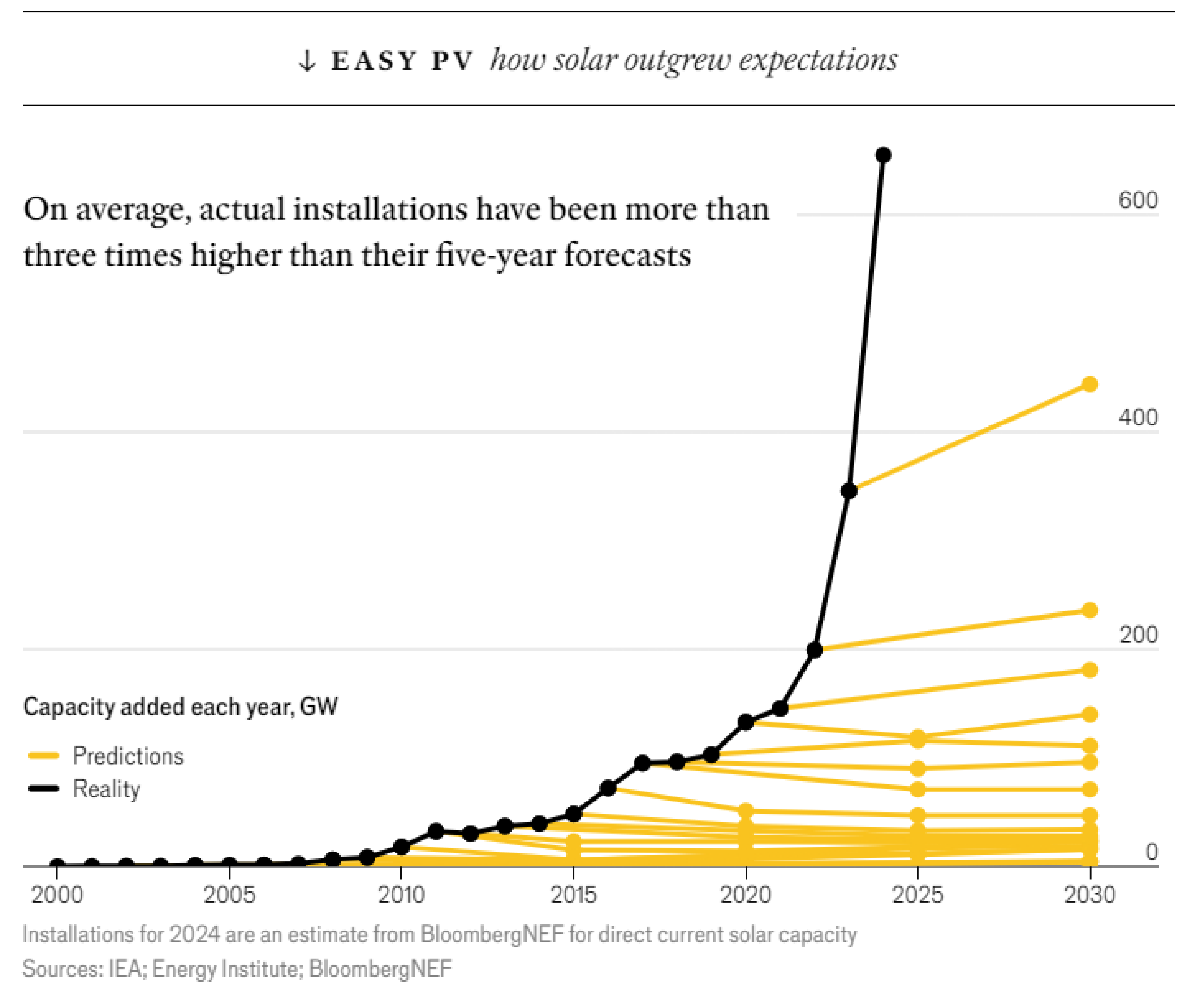


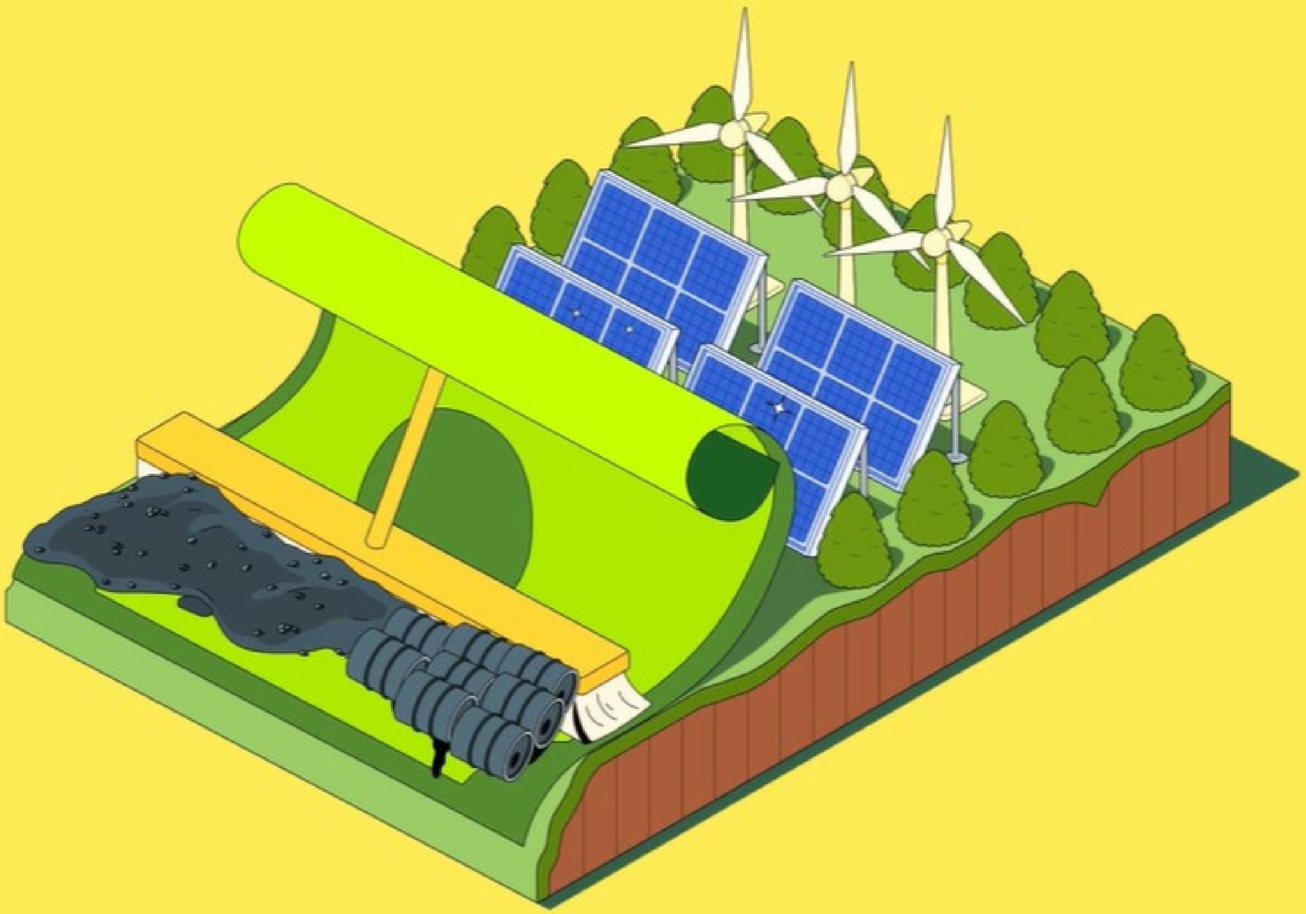
-7%
annual reduction in emissions needed by 2030 to meet the 1.5°C pathway

+1.5%
recent annual increase in emissions from 2011-2021

Sources: IPCC, PIK, BCG analysis


The Economist
AI and war
A report card on Milei's reforms
China in the Arctic
The champagne boom
JUNE 22ND–28TH 2024
DAWN OF THE SOLAR AGE
A SPECIAL ISSUE


↓ EASY PV how solar outgrew expectations
On average, actual installations have been more than three times higher than their five-year forecasts
Capacity added each year, GW
Predictions
Reality
600
400
200
0
2000
2005
2010
2015
2020
2025
2030
Installations for 2024 are an estimate from BloombergNEF for direct current solar capacity
Sources: IEA; Energy Institute; BloombergNEF



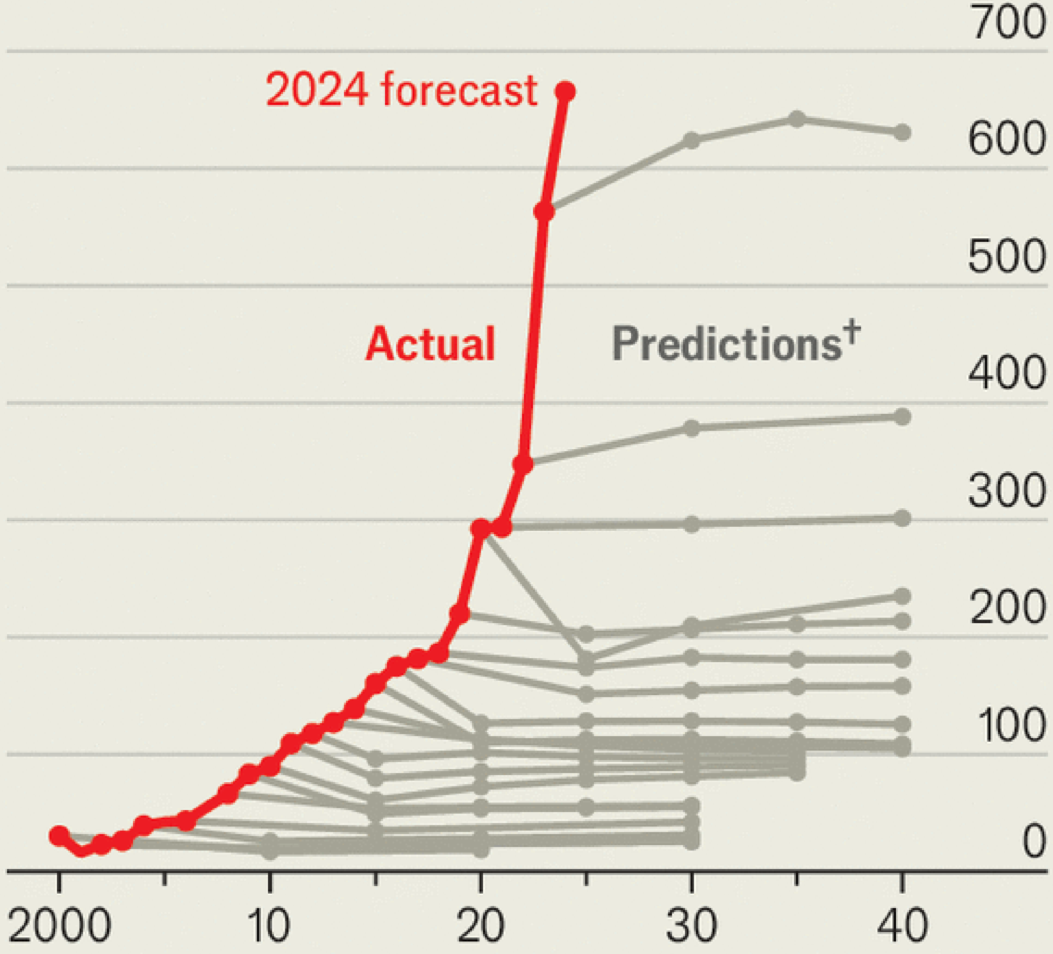
The energy transition will be much cheaper than you think

Most analysts overestimate energy demand and underestimate technological advances

Unshakable pessimism

2

Global renewable energy*, capacity added each year, GW



*Includes solar, wind, hydropower, bioenergy, geothermal and marine †Existing-policies scenario, lower-end estimates

Source: IEA

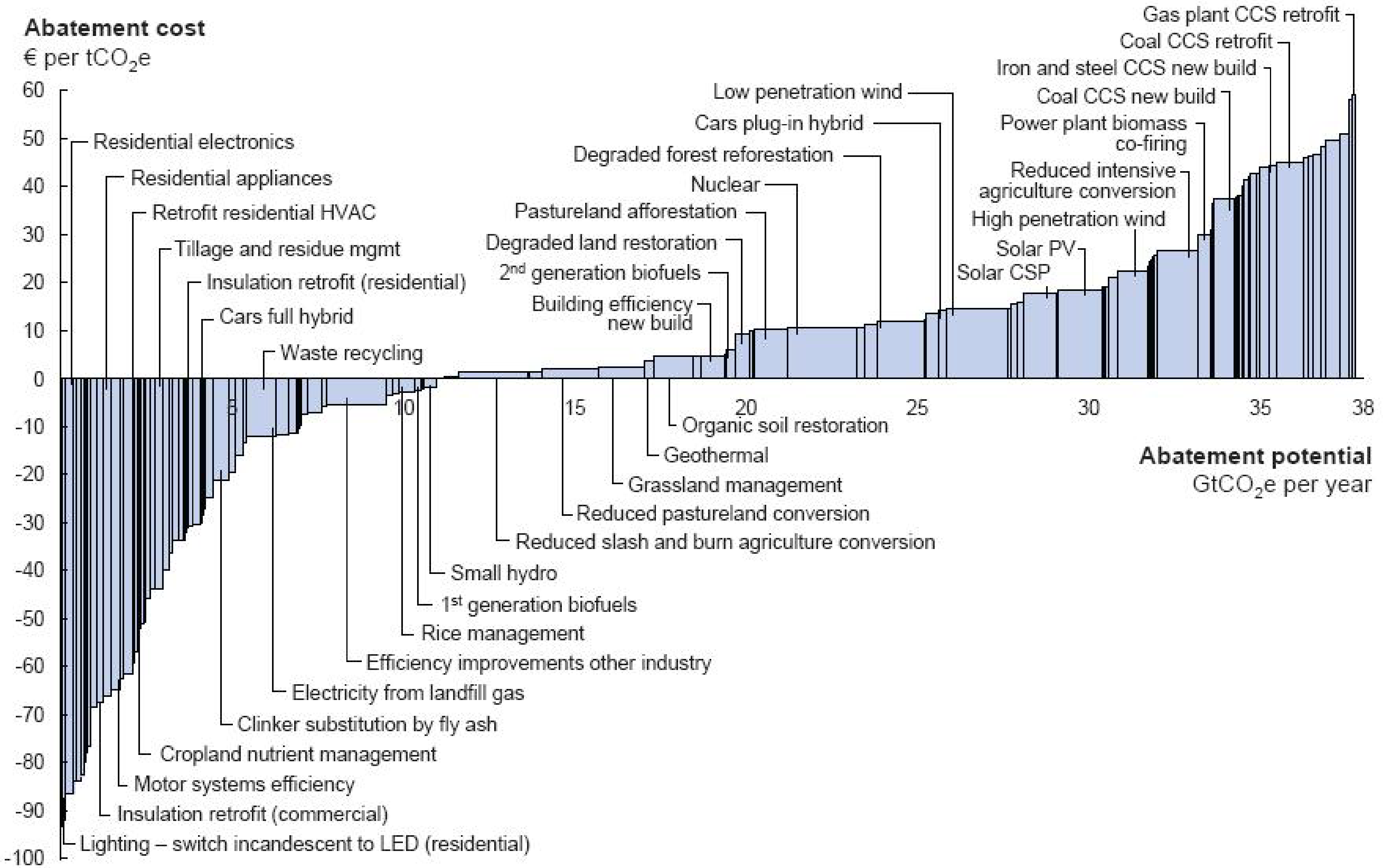
Renewables revolution unstoppable*

and so are climate impacts

* "Trump can and will handicap domestic industries in jockeying for positions in [the global climate race], but he cannot halt it." ([What Will Trump's Victory Mean for the Climate?](), 9 November 2024)

Large abatement opportunities available at low or no cost

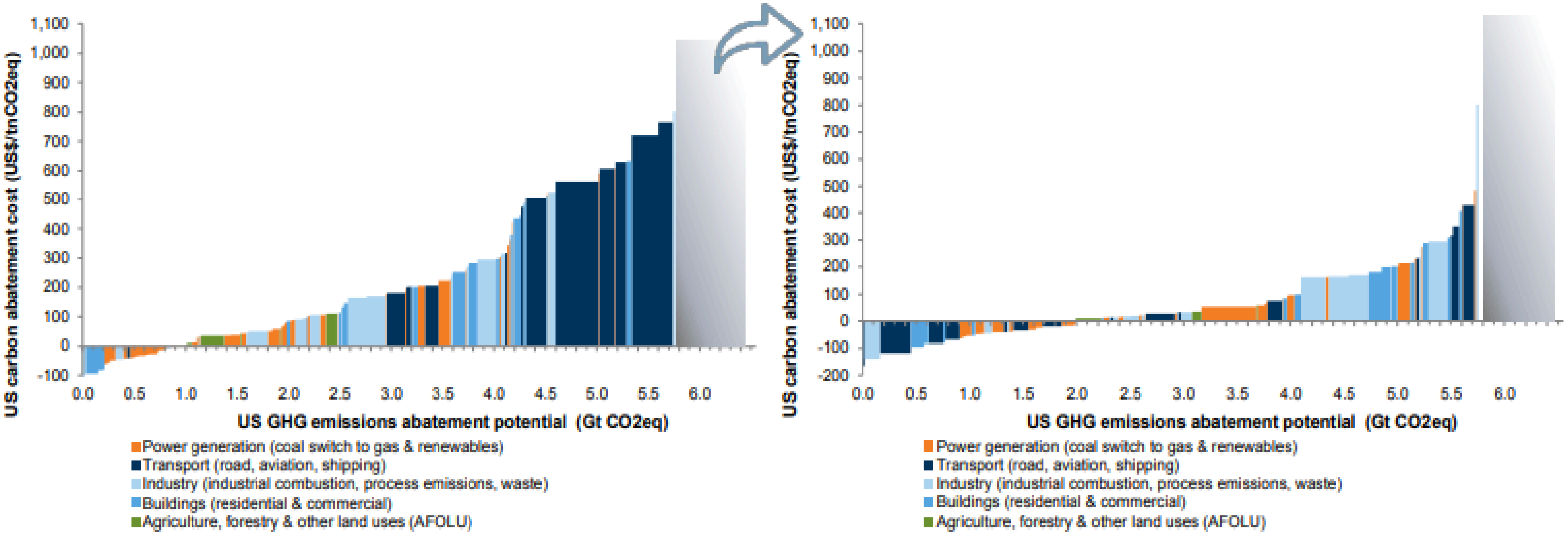
McKinsey Global v2.0 effort in 2009 identified 38 $GtCO_2e$ abatement potential in 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

Exhibit 46: The IRA has transformed the cost curve of the US bringing most technologies in the money, especially in the transportation and buildings sectors

US carbon abatement cost curve for anthropogenic GHG emissions, based on current technologies and current costs, assuming economies of scale for technologies in the pilot phase prior and after IRA

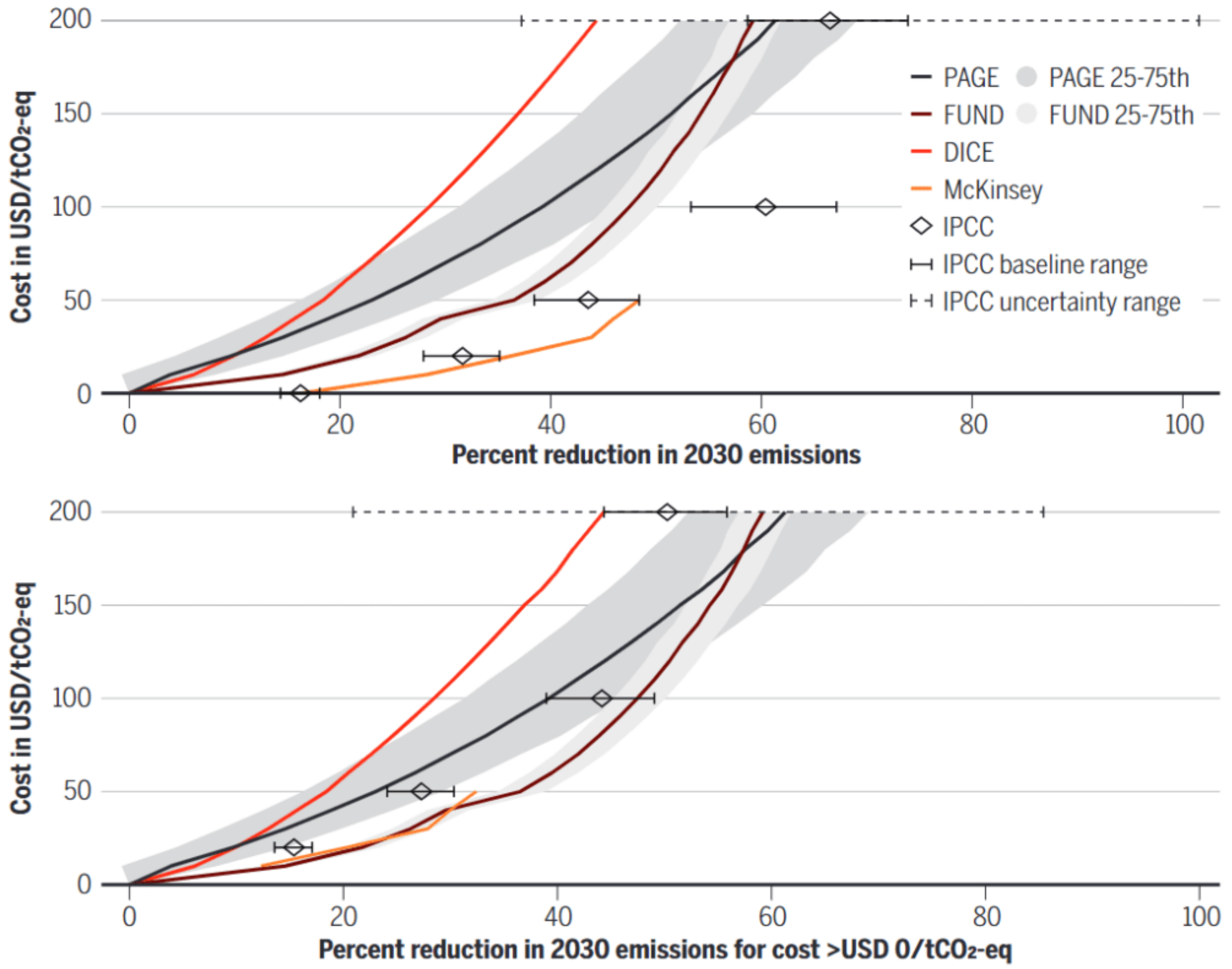


Source: Goldman Sachs Global Investment Research

How costly, or costless, is climate emissions mitigation? p. 1001

Comparison of global mitigation potentials at different costs

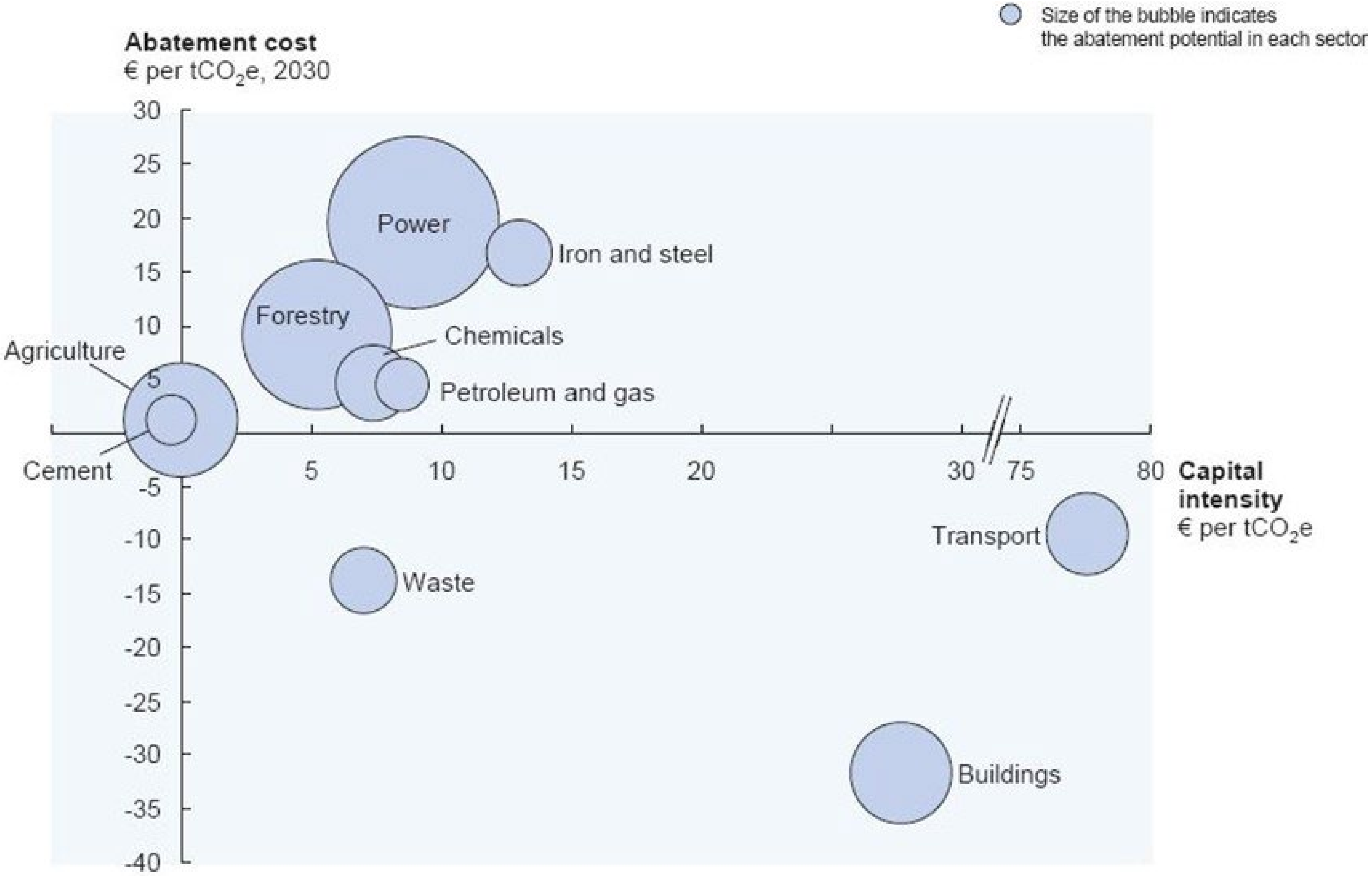
The IPCC results use different baseline emissions to calculate the range of mitigation potentials. The top panel reports the full set of results, and the bottom panel reports only the mitigation potentials with costs >$0 per tonne of CO_2 equivalent (tCO_2-eq). USD reported in 2020 dollars. See supplementary materials.



Source: Kotchen, Rising & Wagner. "The costs of "costless" climate mitigation." *Science* (30 November 2023).

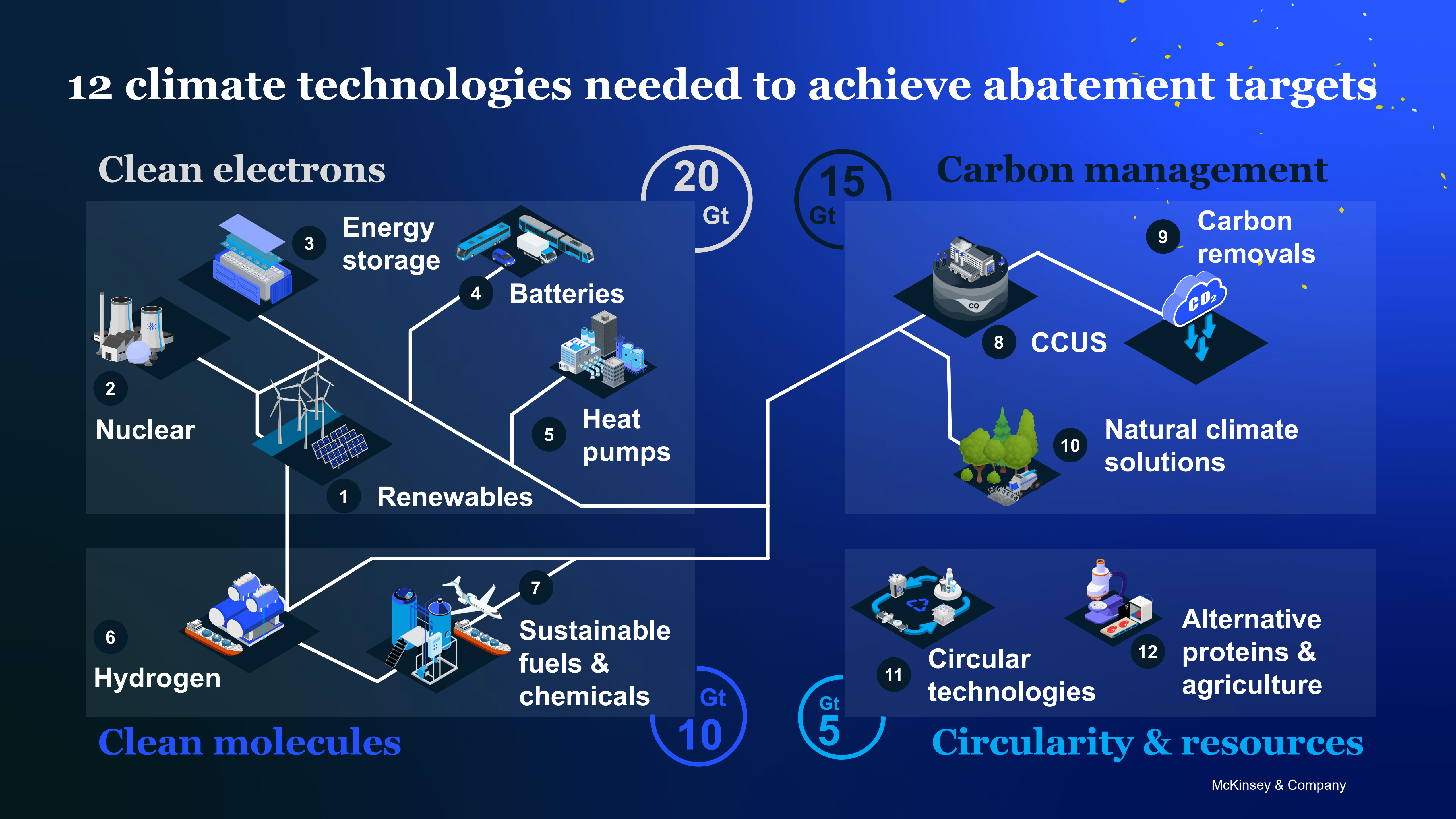
Capital intensity varies widely across sectors

Transport and buildings with largest up-front capital expenditure requirements



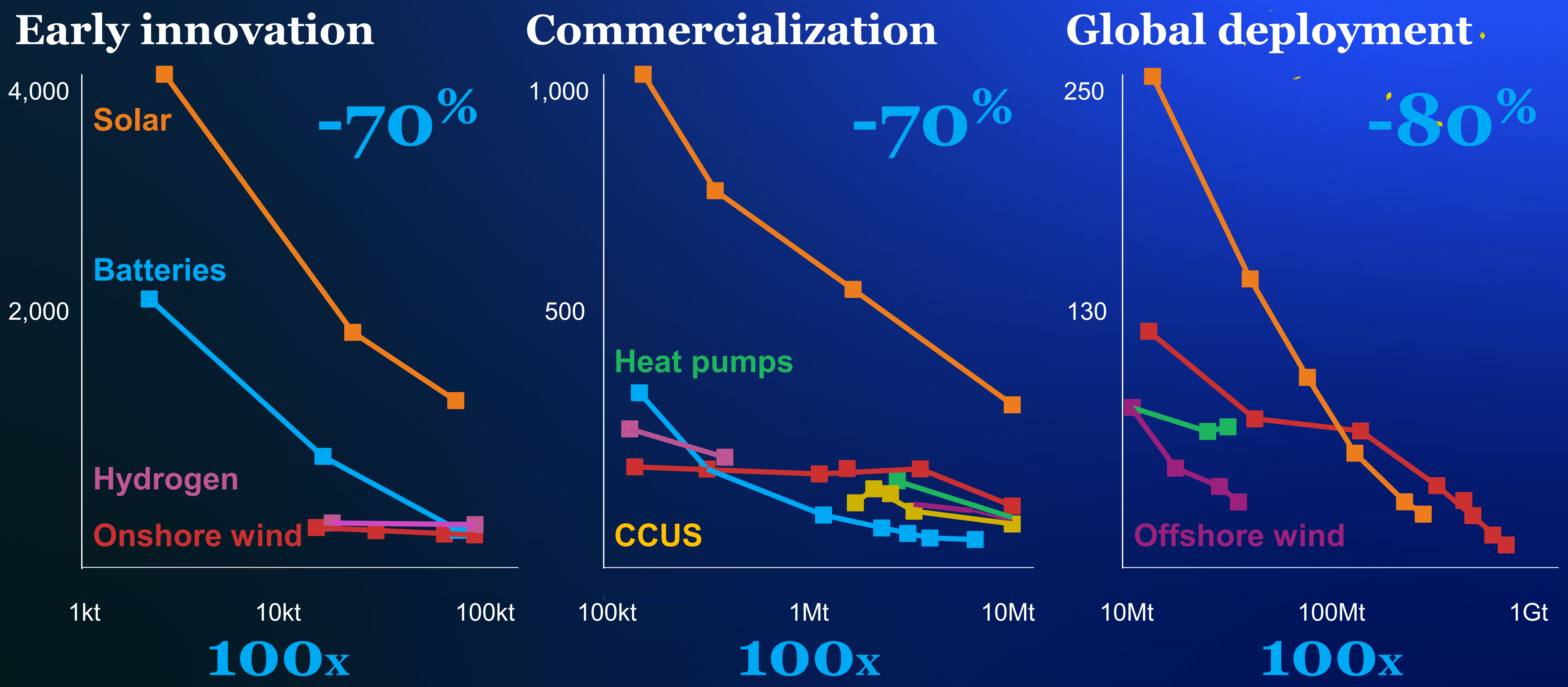
Source: Global GHG Abatement Cost Curve v2.0

Bernd Heid, Senior Partner, McKinsey, at Columbia Business School, 18 November 2024


12 climate technologies needed to achieve abatement targets
Clean electrons
20 Gt
15 Gt
Carbon management
3 Energy storage
4 Batteries
2 Nuclear
5 Heat pumps
1 Renewables
9 Carbon removals
8 CCUS
10 Natural climate solutions
6 Hydrogen
7 Sustainable fuels & chemicals
Gt 10
Clean molecules
Gt 5
11 Circular technologies
12 Alternative proteins & agriculture
Circularity & resources
McKinsey & Company

"Moore's Law" of climate technology: 100x scale-up drives 70%+ cost-down

Abatement cost, $/tCO_2$

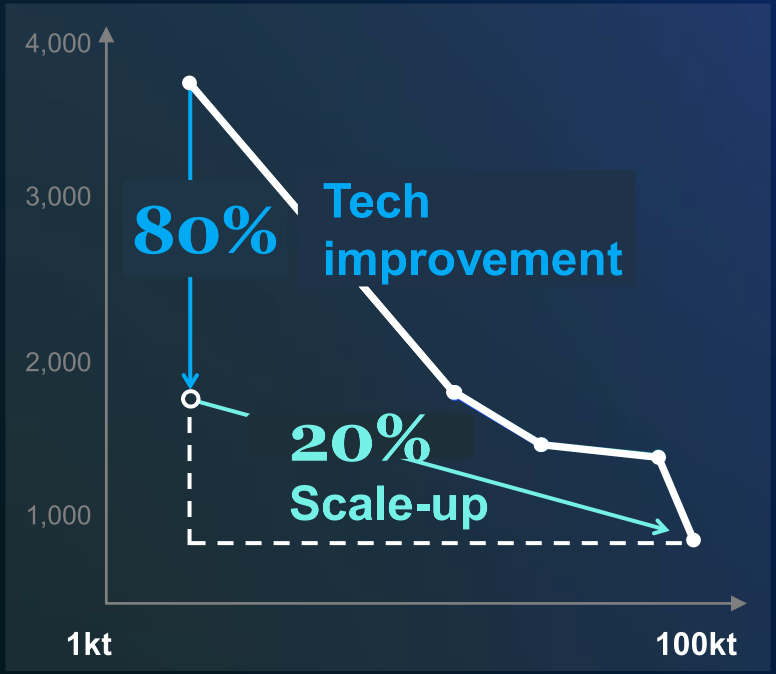


McKinsey & Company

"2nd Moore's Law of Climate Tech": 80-20, 50-50, 20-80.

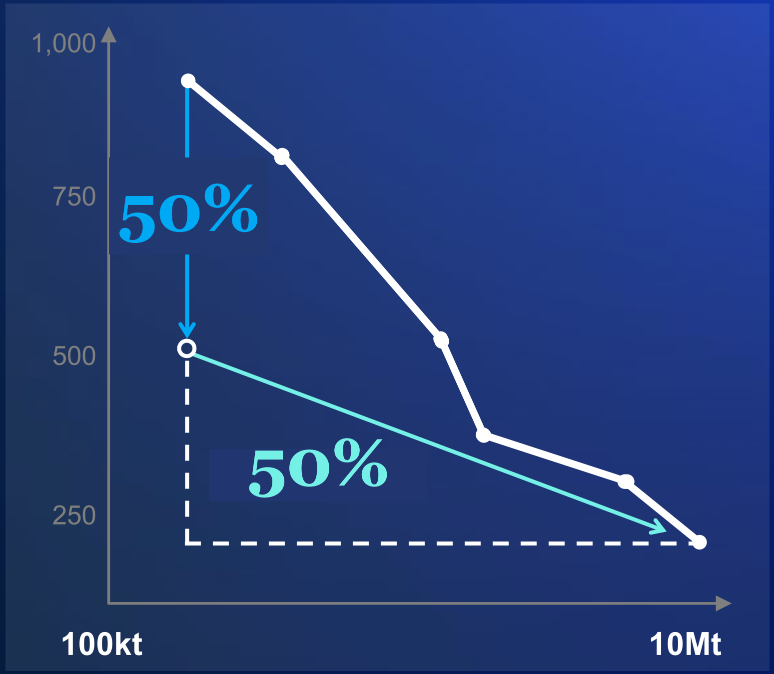
Cost degression, equivalent $/t$CO_2$

Early innovation



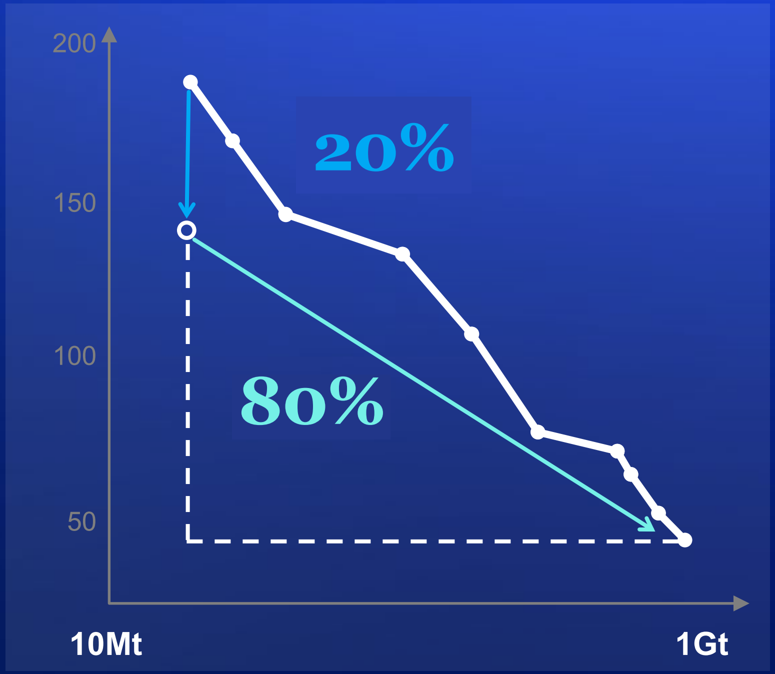
100x

Commercialization



100x

Global deployment

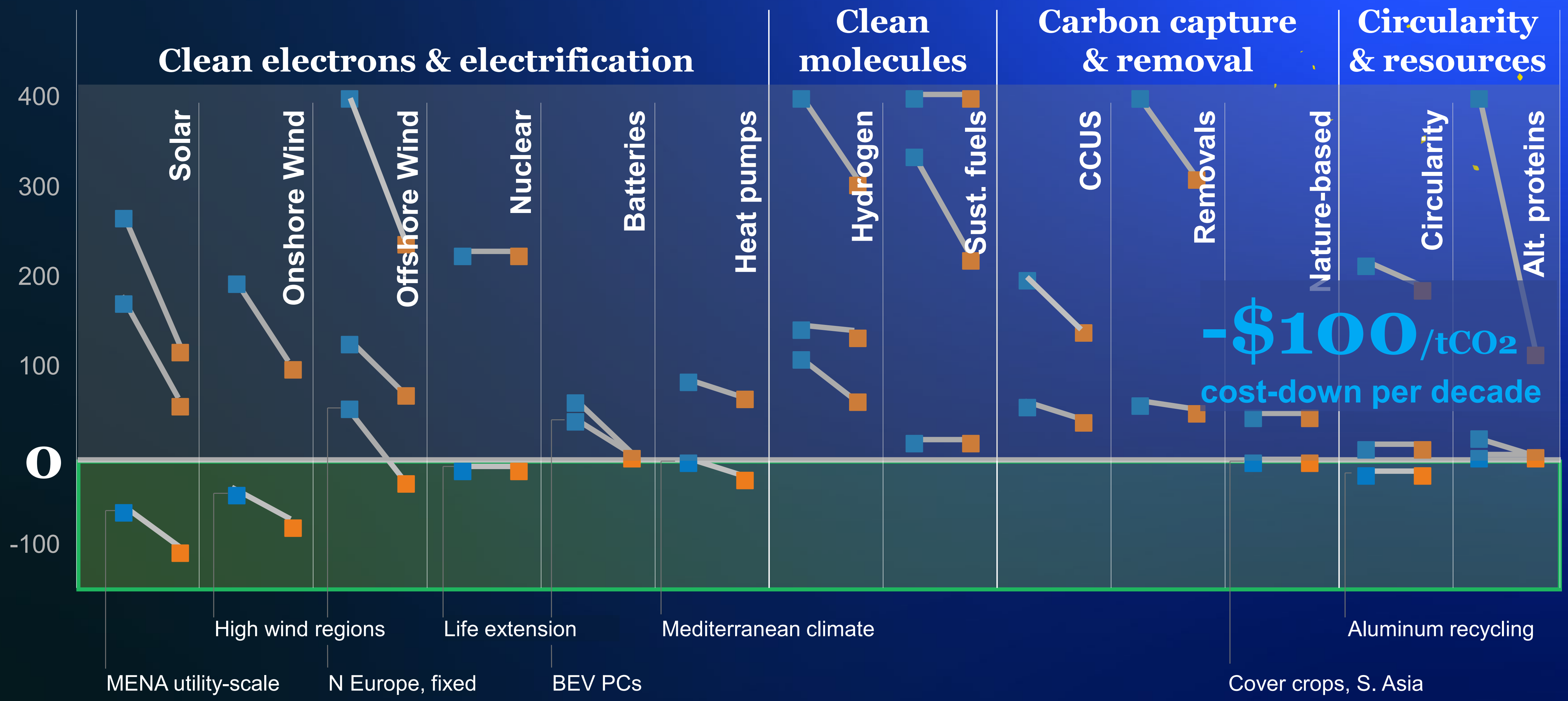


100x

Source: Kavlak et al. – Energy Policy, Ziegler et al. – Energy& Environmental Science, Battery Insights

10 % of techs in the money today – steep cost-down to 2030

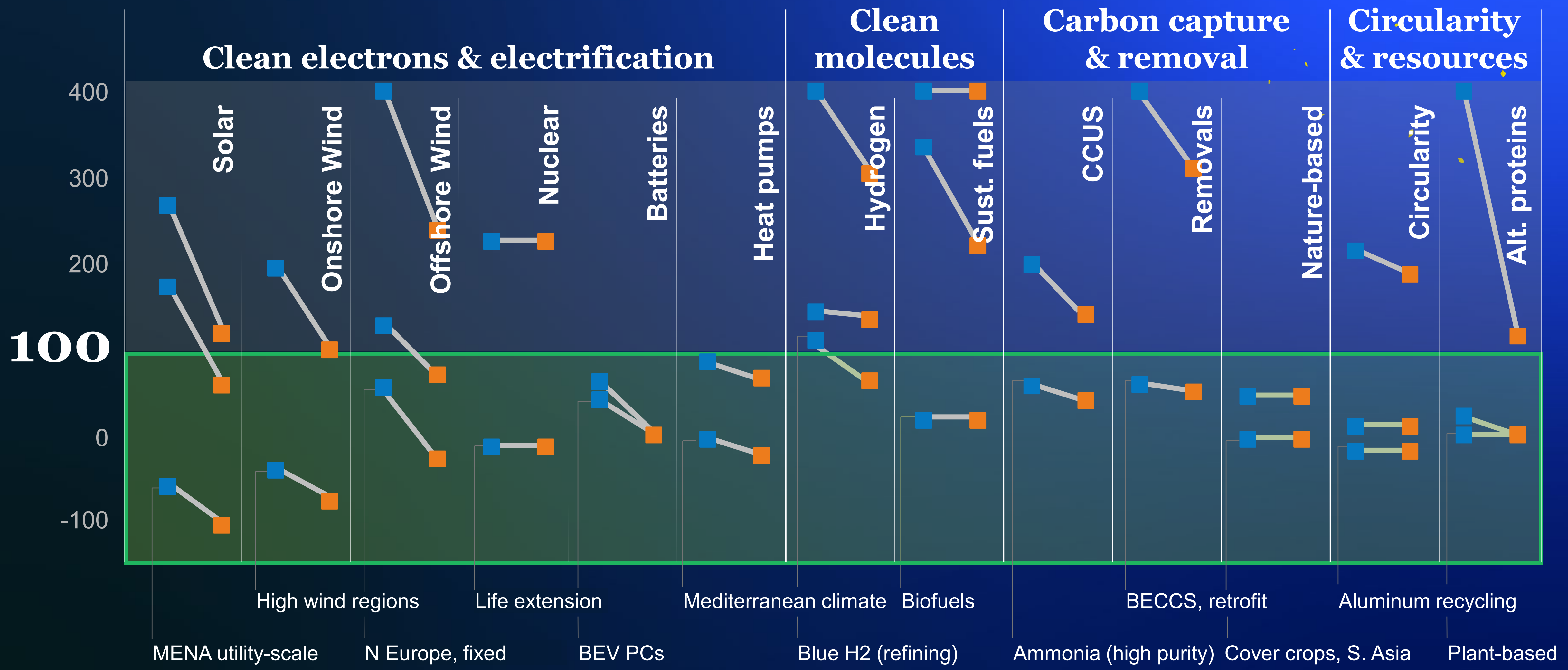
Estimated abatement costs, USD/tCO_2e



Source: McKinsey Global MACC with regional/product estimations

100$/$tCO_2$ carbon tax would make most techs competitive

Estimated abatement costs, USD/tCO_2e



Source: McKinsey Global MACC with regional/product estimations

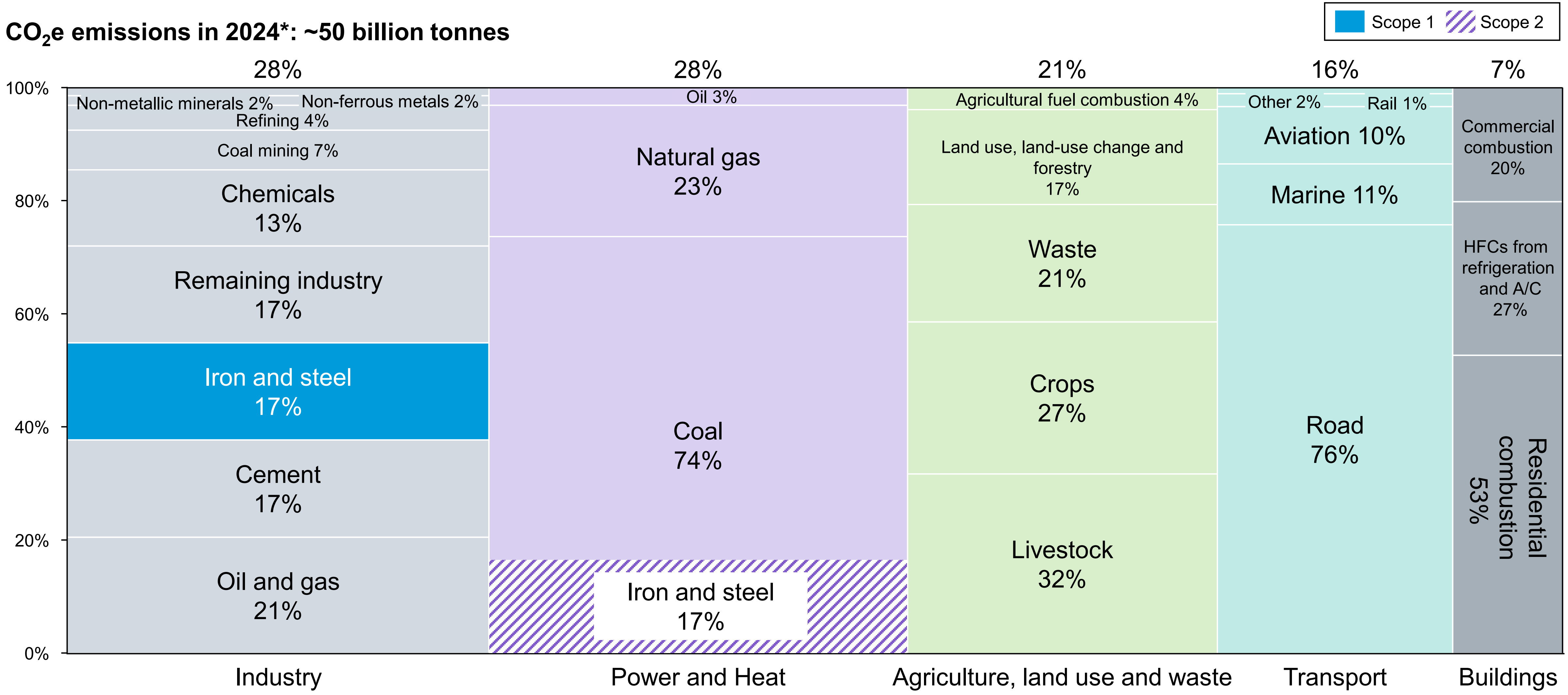
McKinsey & Company

Columbia Business School
AT THE VERY CENTER OF BUSINESS

Steel Sector Overview: The Problem

Steel sector Scopes 1 and 2 around 10% of global CO_2e emissions

CO_2e emissions in 2024*: ~50 billion tonnes



Sources: Scope 1 emissions from Rhodium Group ClimateDeck (September 2024); Scope 2 iron and steel estimate from IEA (2023); * 2024 emissions based on projections.
Credit: Theo Moers, Mimi Khawsam-ang, Max de Boer, Grace Frascati, Hyae Ryung Kim, and Gernot Wagner (27 September 2024); share/adapt with attribution. Contact: gwagner@columbia.edu

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At present, crude steel is produced through three main methods that all emit CO_2: BF-BOF, scrap EAF, and NG DRI-EAF

	1 Blast Furnace-Basic Oxygen Furnace (BF-BOF)	2 Scrap Electric Arc Furnace (Scrap EAF)	3 Natural Gas-Based Direct Reduced Iron – Electric Arc Furnace (NG DRI-EAF)
Description	**Iron ore, coke, and limestone** produce pure iron in a **blast furnace**, which **is turned into steel in an oxygen furnace**	**Scrap metal** is **melted in an EAF** using **electrical energy**	**Iron ore** is turned **into iron** using **natural gas**, which is then **melted in an EAF** to **produce steel**
Main inputs	**Iron ore, cooking coal**	**Scrap steel, electricity**	**Iron ore, natural gas**
% of global steel production	 72%	 21%	7%
CO2 per tonne of crude steel	**2.3 tonnes**	**0.7 tonnes**	**1.4 tonnes**
Energy intensity per tonne of crude steel	**~24 GJ**	**~10 GJ**	**~22 GJ**
Average cost per tonne of crude steel	**~$390**	**~$415**	**~$455**

Sources: World Steel Association; IEEFA (2022); IEA, Iron and Steel Technology Roadmap (2020); Steel Technology, Basic Oxygen Furnace Steelmaking; Recycling Today, Growth of EAF Steelmaking; Wildsight, Do We Really Need Coal to Make Steel. Credit: Mimi Khawsam-ang, Max de Boer, Grace Frascati, and Gernot Wagner (16 September 2024); share/adapt with attribution. Contact: gwagner@columbia.edu

Green H_2, electrolysis, and CCUS could reduce steelmaking CO_2 emissions by over 85% if implemented at scale

	1	2	3
	100% Green Hydrogen (H2) DRI-EAF	**Iron Ore Electrolysis**	**Carbon Capture, Utilization, and Storage (CCUS)**
Description	• **Green hydrogen** replaces **natural gas** as an iron ore reductant in DRI shaft; the rest of the process remains the same • Generates **water as a byproduct** instead of CO_2	• **Two different processes** are **possible:** **Molten oxide electrolysis:** High current runs through mixture of iron ore and liquid electrolyte to split ore into pure molten iron **Electrowinning-EAF:** Iron from iron ore is dissolved in acid. Iron-rich solution is then electrified to form pure solid iron	• **CCUS equipment** can be added to **existing steel-producing infrastructure** to **capture** emitted CO_2 • Captured CO_2 is then **sequestered underground** or **reused**
Real-time sector initiatives	HYBRIT/Stegra 100% fossil fuel-free DRI-EAF production with green H_2 used for DRI	Electra Electrowinning to produce high-purity iron plates ready for EAF input (no DRI or MOE step)	ArcelorMittal Carbalyst® captures carbon from a blast furnace and reuses it as bio-ethanol. However, technology not proven at scale
Applicability to conventional routes	**Applicable to existing DRI-EAF route**, with minor retrofitting	**Full overhaul** of BF-BOF equipment required; **replacement** of DRI shaft in DRI-EAF	**Retrofitting** of capture technology is possible on **conventional BF-BOF and DRI-EAF**
Decarbonization potential (vs. BF-BOF)	**~90%**	**~97%**	**~90%** ← Hypothetical best-case scenario
Estimated production cost (excl. CapEx)	**<$800 per tonne of steel**	**~$215 per tonne of iron + cost of 'stranded' iron ore**	**~$380 – 400 per tonne**

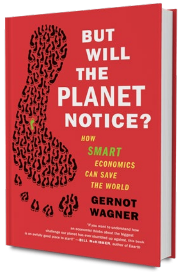
Sources: Columbia Center on Global Energy Policy (2021); IEA, Iron and Steel Technology Roadmap (2020); McKinsey (2020); Mining Technology (2023); Tata Steel; Primetals Technologies; Edie, ArcelorMittal accused of net-zero greenwashing (2023). Credit: Mimi Khawsam-ang, Max de Boer, Grace Frascati, and Gernot Wagner (13 March 2024); share/adapt with attribution.
Contact: gwagner@columbia.edu

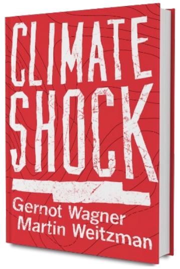
New energy supply chains need to be established to link energy-abundant regions and industrial centers

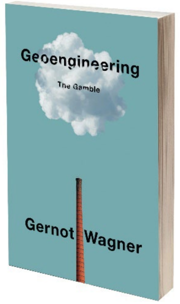
Source: Rich Lesser, Global Chair, Boston Consulting Group (2023)

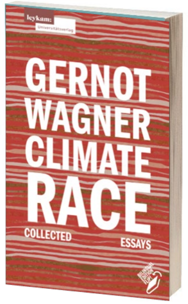
BlackRock.

Managing the net-zero transition









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