Climate Risks, Uncertainties, and Opportunities

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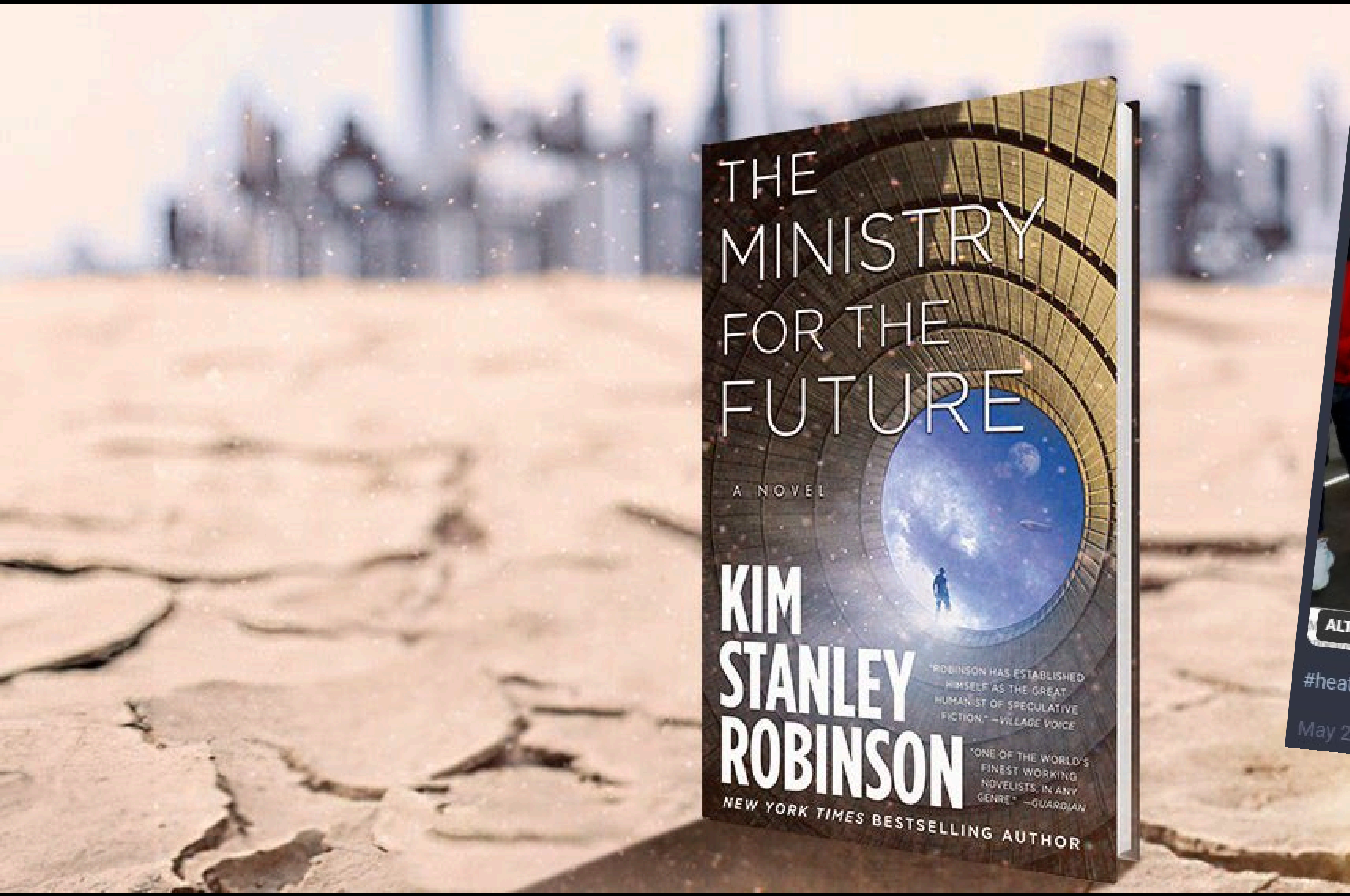
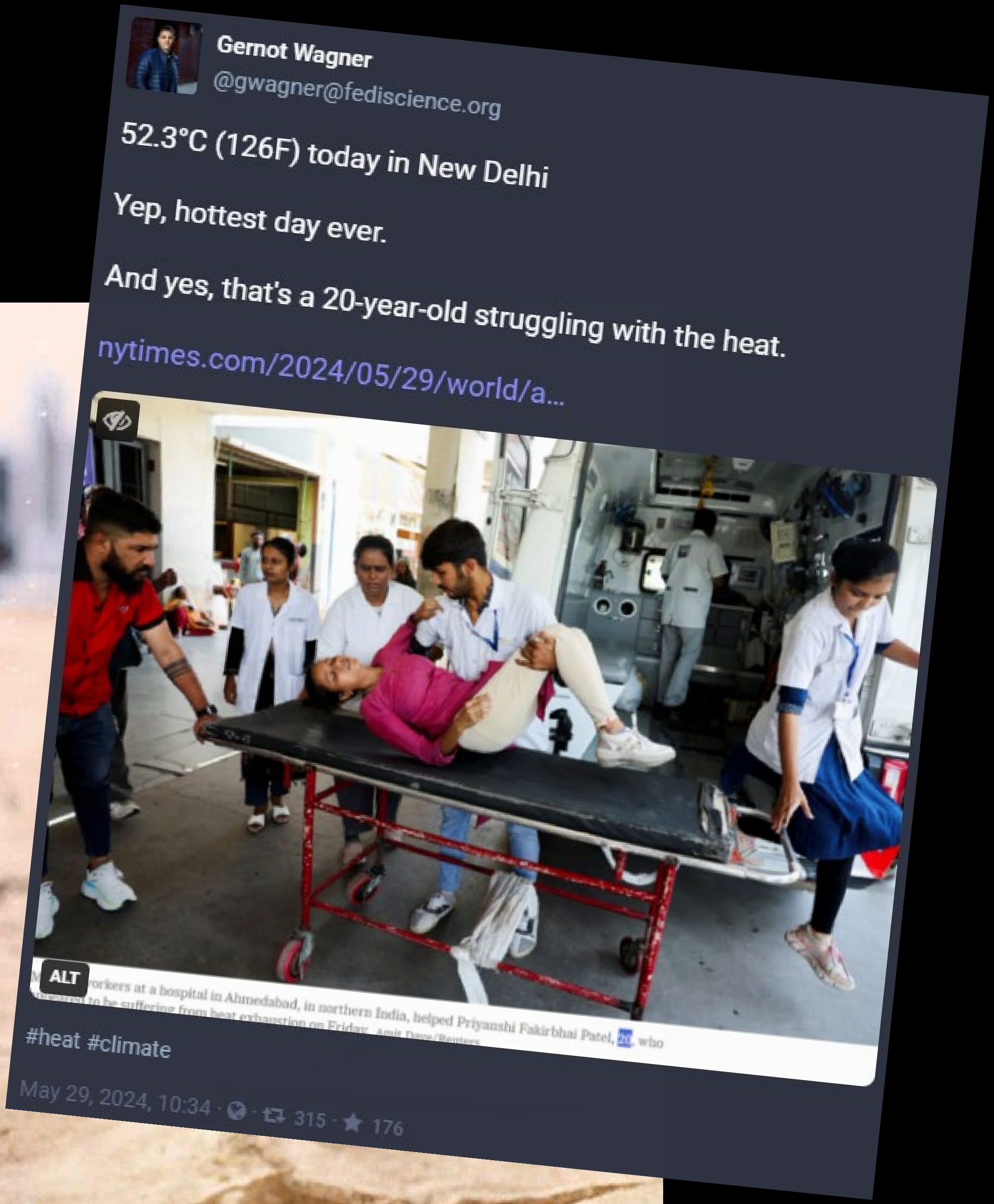
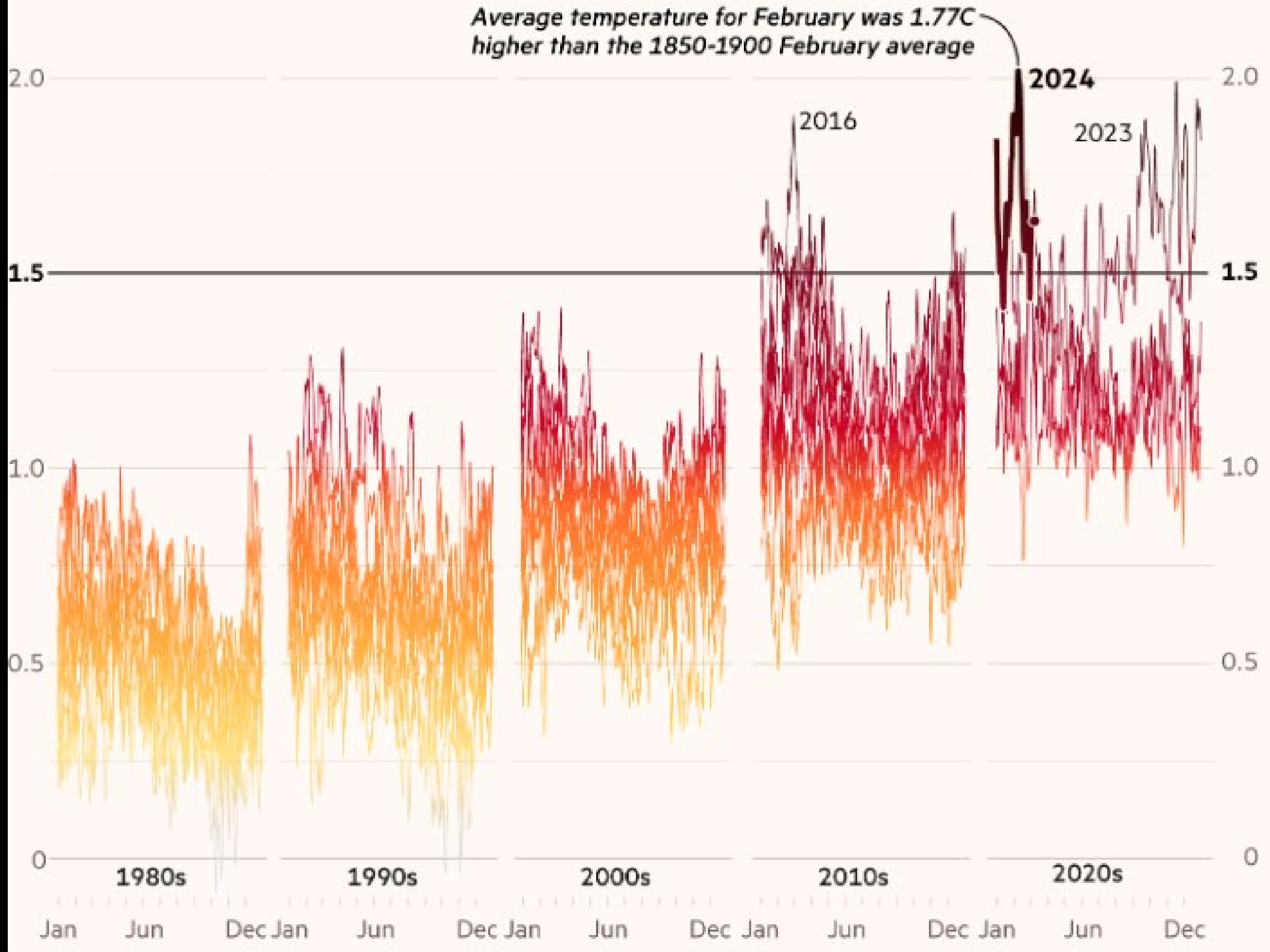

THE MINISTRY FOR THE FUTURE
A NOVEL
KIM STANLEY ROBINSON
"ROBINSON HAS ESTABLISHED HIMSELF AS THE GREAT HUMANIST OF SPECULATIVE FICTION." —VILLAGE VOICE
"ONE OF THE WORLD'S FINEST WORKING NOVELISTS, IN ANY GENRE." —GUARDIAN
NEW YORK TIMES BESTSELLING AUTHOR


Gernot Wagner
@gwagner@fediscience.org
52.3°C (126F) today in New Delhi
Yep, hottest day ever.
And yes, that's a 20-year-old struggling with the heat.
nytimes.com/2024/05/29/world/a…
ALT
#heat #climate
May 29, 2024, 10:34 · 315 · 176

Climate graphic of the week

Global temperatures continue run of record highs in February

Difference between global 2-metre temperatures from 1980 to 2024 and pre-industrial average (C)



Source: C3S/ECMWF

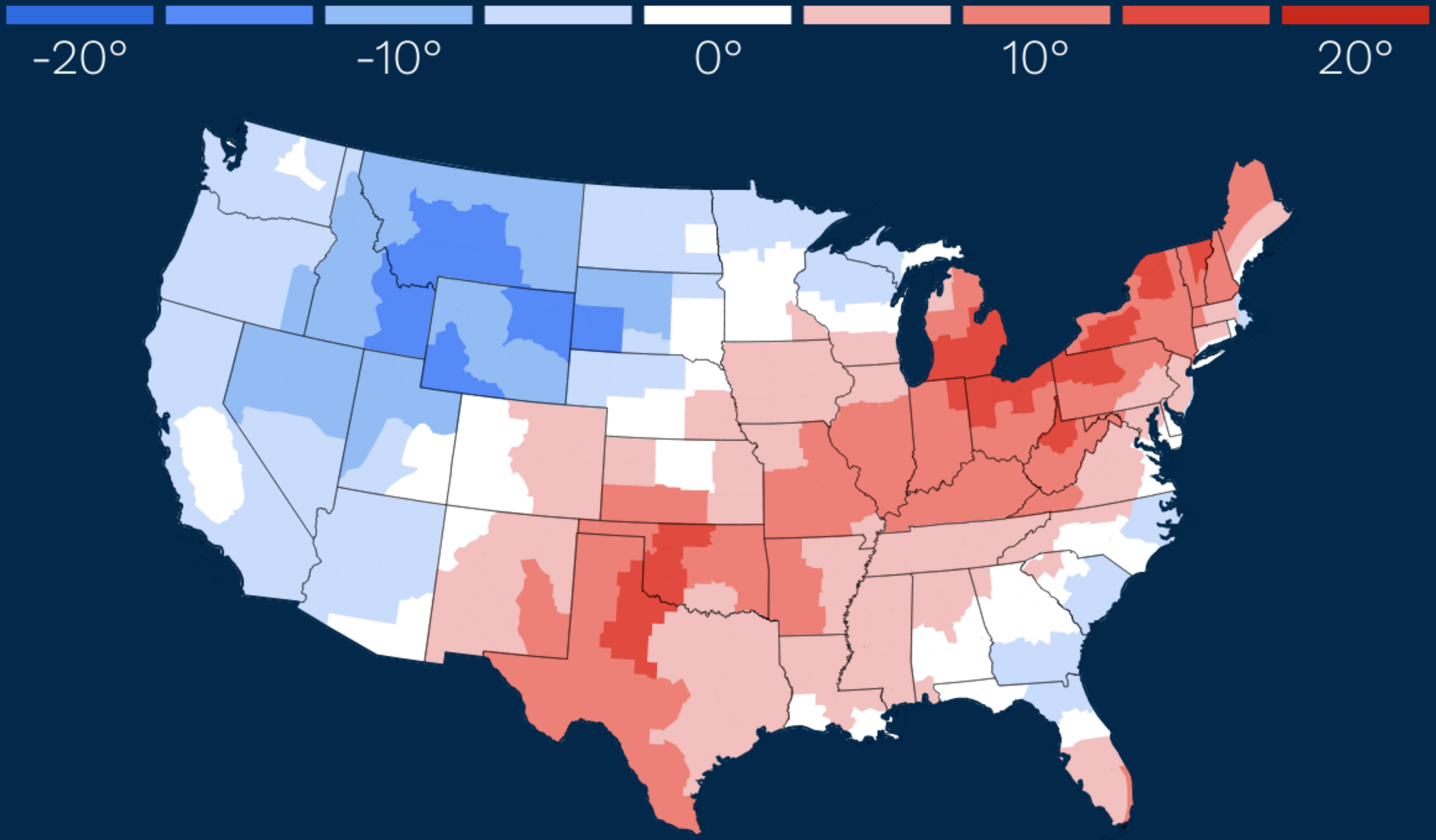
Warmer, wetter, hotter, drier – February caps unending stretch of record temperatures

Global average temperature rise in February reaches 1.77C above pre-industrial levels

Source: *Financial Times* (10 March 2023)

Temperature Anomaly

For High Temperature on May 20, 2024



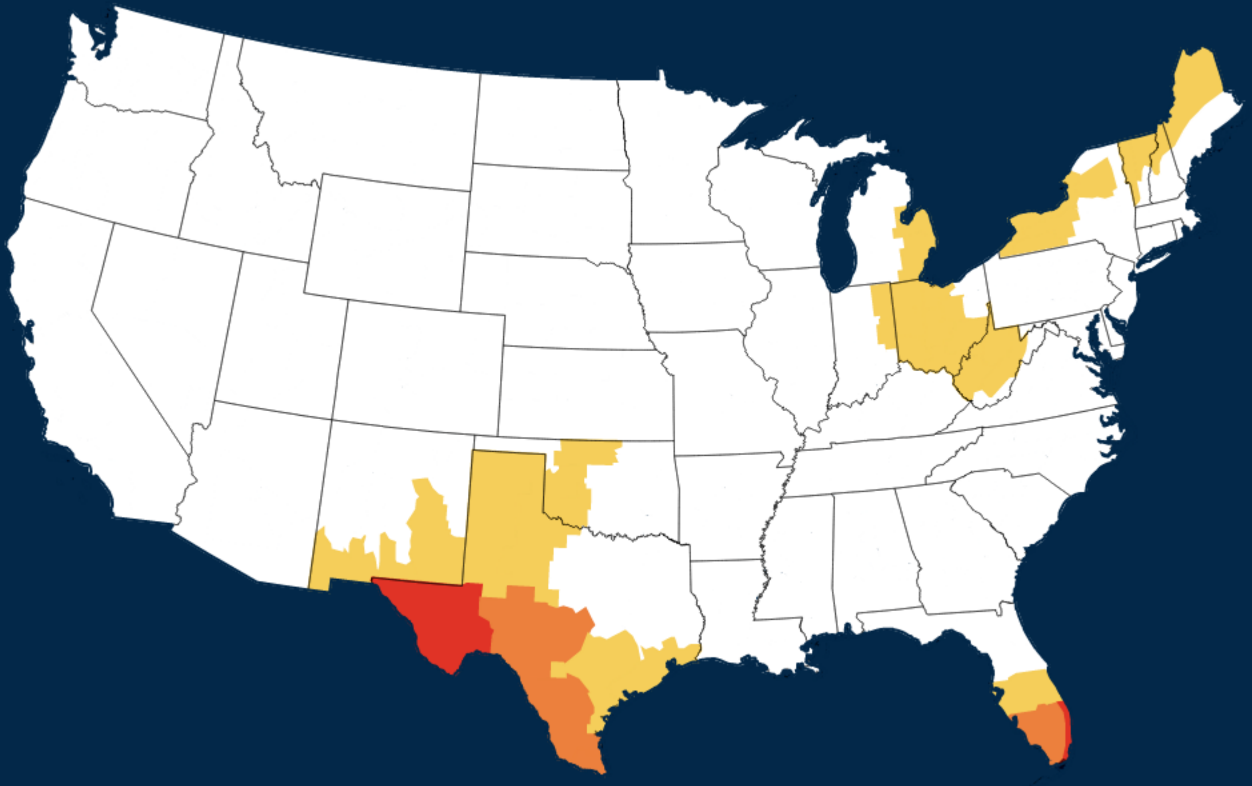
Source: Climate Central analysis based on NOAA data. Produced 5/20/2024.

CLIMATE CENTRAL

Climate Shift Index™ For High Temperature on May 20, 2024

Less likely — More likely

-5 -4 -3 -2 -1 0 1 2 3 4 5



Source: Climate Central analysis based on NOAA data. Produced 5/20/2024.

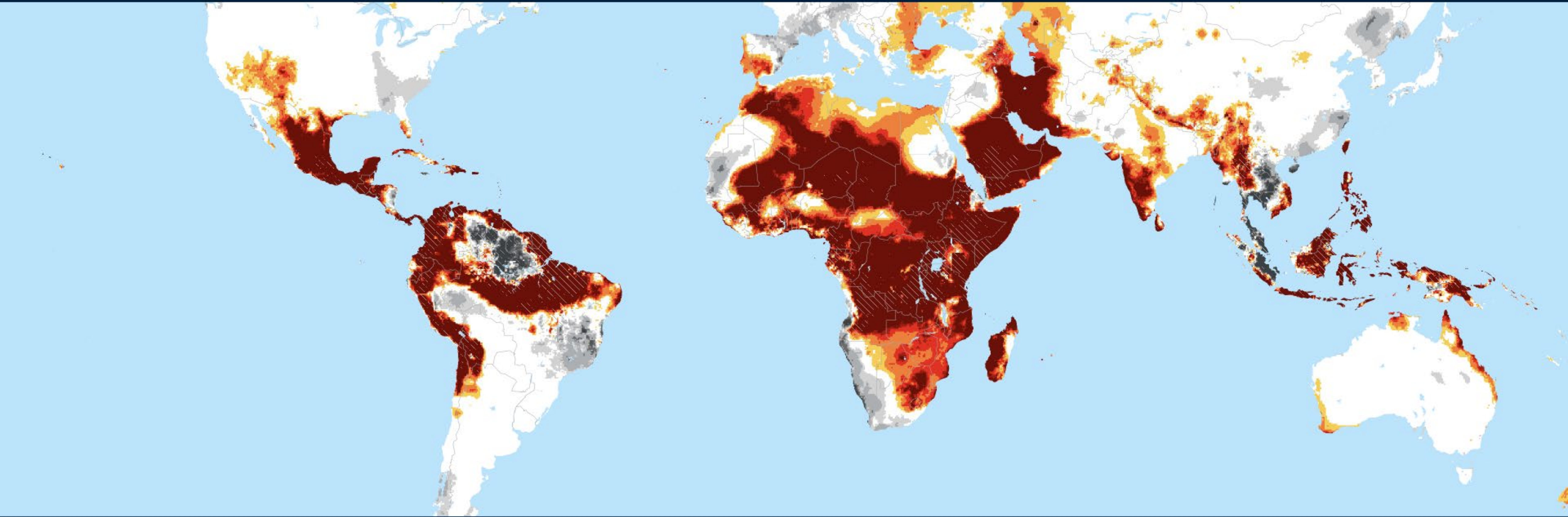
CLIMATE CENTRAL

Climate Shift Index

Jun 1, 2024

Change in likelihood due to climate change

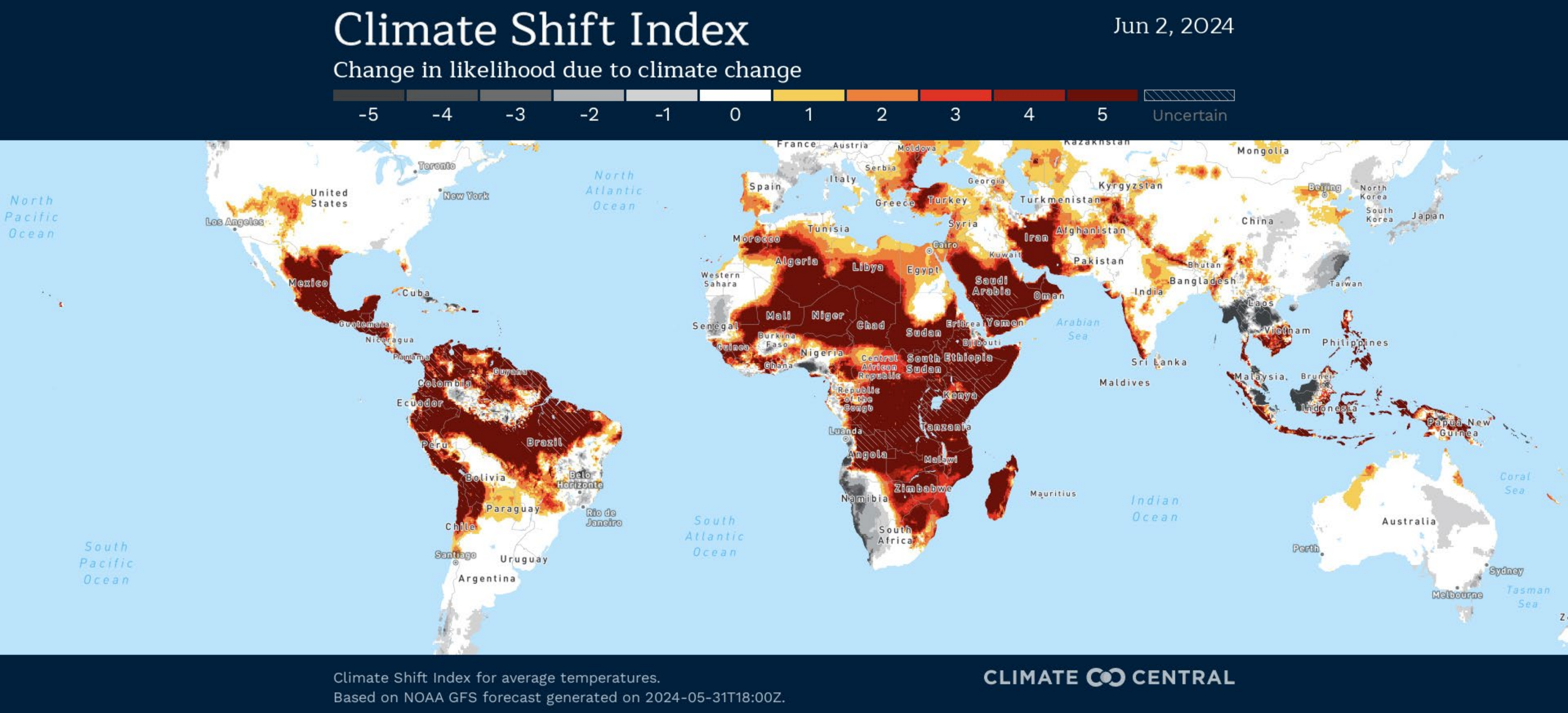
-5 -4 -3 -2 -1 0 1 2 3 4 5 Uncertain



Climate Shift Index for average temperatures.
Based on NOAA GFS forecast generated on 2024-05-31T18:00Z.

CLIMATE CENTRAL

Source: climatecentral.org/climate-shift-index



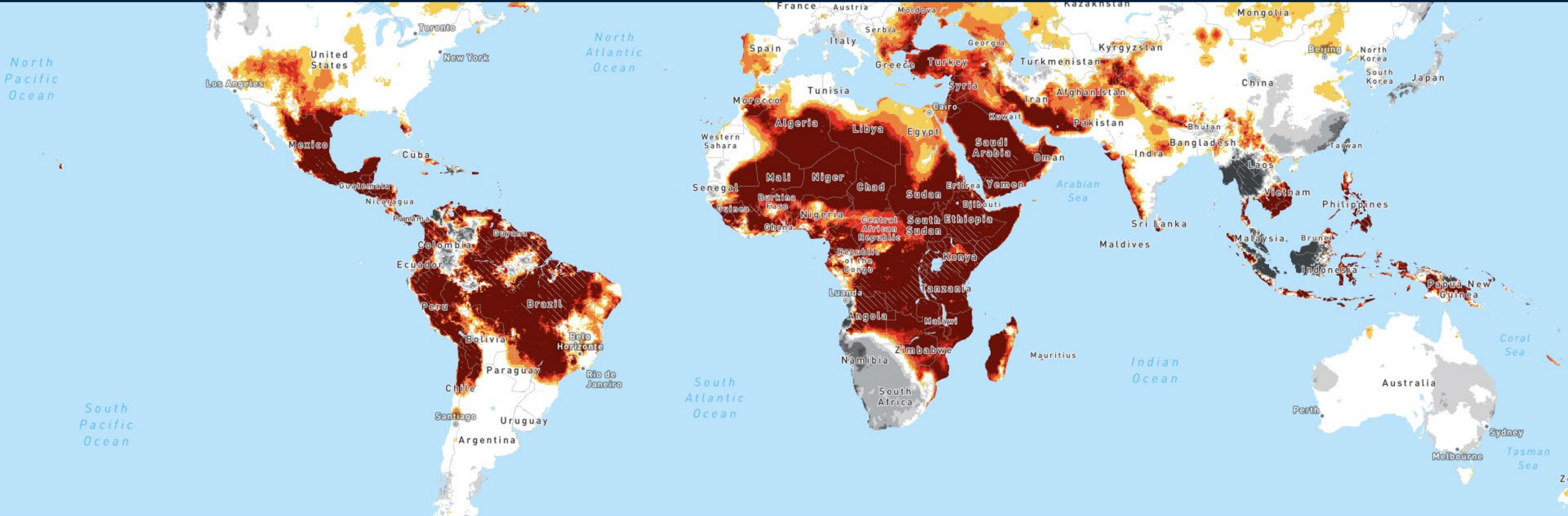
Source: climatecentral.org/climate-shift-index

Climate Shift Index

Jun 3, 2024

Change in likelihood due to climate change

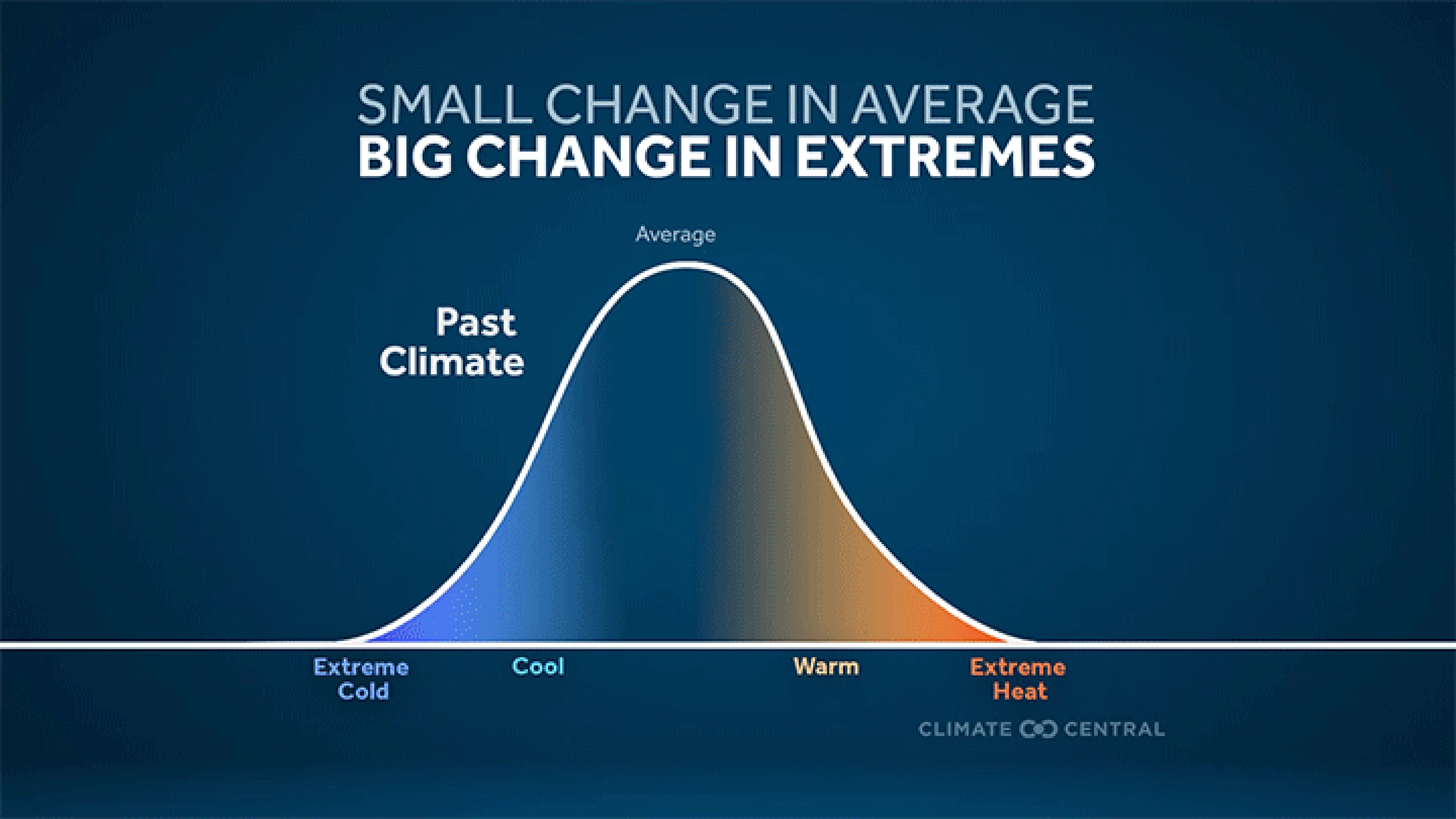
-5	-4	-3	-2	-1	0	1	2	3	4	5	Uncertain

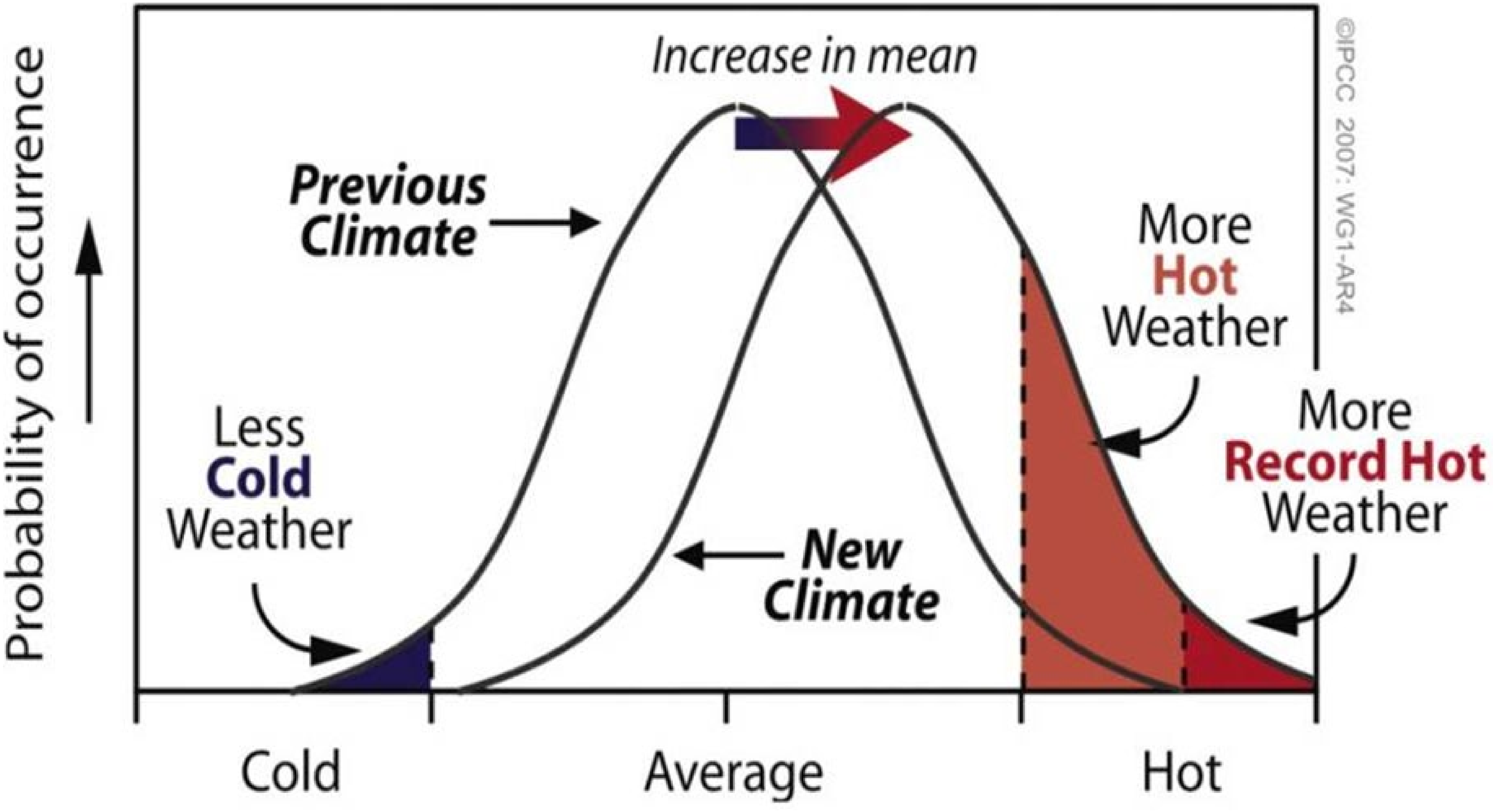


Climate Shift Index for average temperatures.
Based on NOAA GFS forecast generated on 2024-05-31T18:00Z.

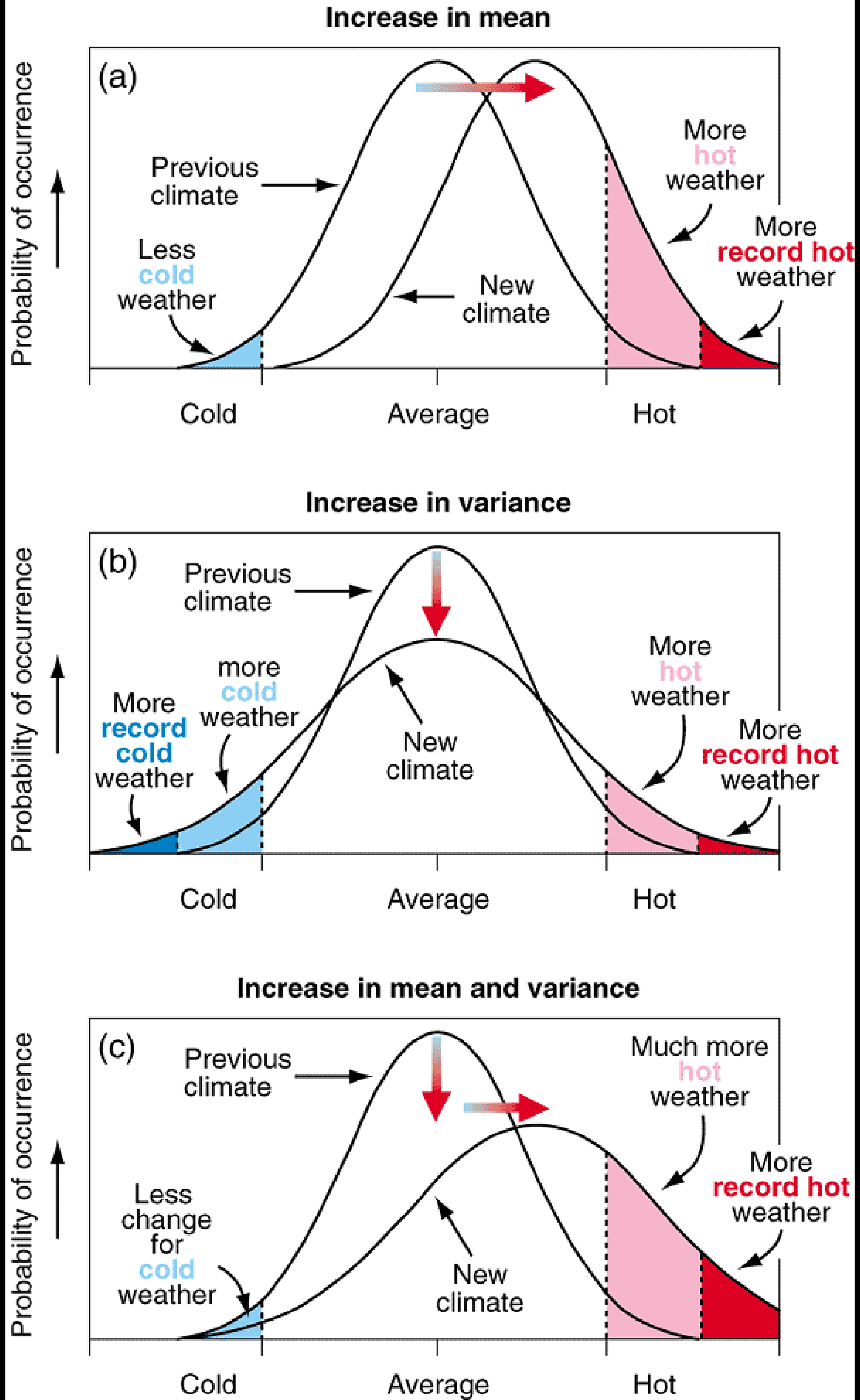
CLIMATE CENTRAL

Source: climatecentral.org/climate-shift-index


SMALL CHANGE IN AVERAGE
BIG CHANGE IN EXTREMES
Average
Past Climate
Extreme Cold
Cool
Warm
Extreme Heat
CLIMATE CENTRAL



Probability of occurrence
Increase in mean
Previous Climate
New Climate
Less Cold Weather
More Hot Weather
More Record Hot Weather
Cold
Average
Hot
©IPCC 2007: WG1-AR4


Increase in mean
(a)
Probability of occurrence
Previous climate
New climate
Less cold weather
More hot weather
More record hot weather
Cold
Average
Hot
Increase in variance
(b)
Probability of occurrence
Previous climate
New climate
more cold weather
More record cold weather
More hot weather
More record hot weather
Cold
Average
Hot
Increase in mean and variance
(c)
Probability of occurrence
Previous climate
New climate
Less change for cold weather
Much more hot weather
More record hot weather
Cold
Average
Hot

Leaders | A $25trn hit

Global warming is coming for your home

Who will pay for the damage?

The potential costs stem from policies designed to reduce the emissions of houses as well as from climate-related damage. They are enormous. By one estimate, climate change and the fight against it could wipe out 9% of the value of the world's housing by 2050—which amounts to $25trn, not much less than America's annual GDP. It is a huge bill hanging over people's lives and the global financial system. And it looks destined to trigger an almighty fight over who should pay up.

Known knowns are bad

Unknowns, unknowables, risks & uncertainties make it worse

~\$200 / tCO_2

~$200 Social Cost of CO_2

Based on 2% discount rate

Table ES.1: Estimates of the Social Cost of Greenhouse Gases (SC-GHG), 2020-2080 (2020 dollars)

	SC-GHG and Near-term Ramsey Discount Rate								
	SC-CO_2 (2020 dollars per metric ton of CO_2)			SC-CH_4 (2020 dollars per metric ton of CH_4)			SC-N_2O (2020 dollars per metric ton of N_2O)		
Emission Year	2.5%	2.0%	1.5%	2.5%	2.0%	1.5%	2.5%	2.0%	1.5%
2020	120	190	340	1,300	1,600	2,300	35,000	54,000	87,000
2030	140	230	380	1,900	2,400	3,200	45,000	66,000	100,000
2040	170	270	430	2,700	3,300	4,200	55,000	79,000	120,000
2050	200	310	480	3,500	4,200	5,300	66,000	93,000	140,000
2060	230	350	530	4,300	5,100	6,300	76,000	110,000	150,000
2070	260	380	570	5,000	5,900	7,200	85,000	120,000	170,000
2080	280	410	600	5,800	6,800	8,200	95,000	130,000	180,000

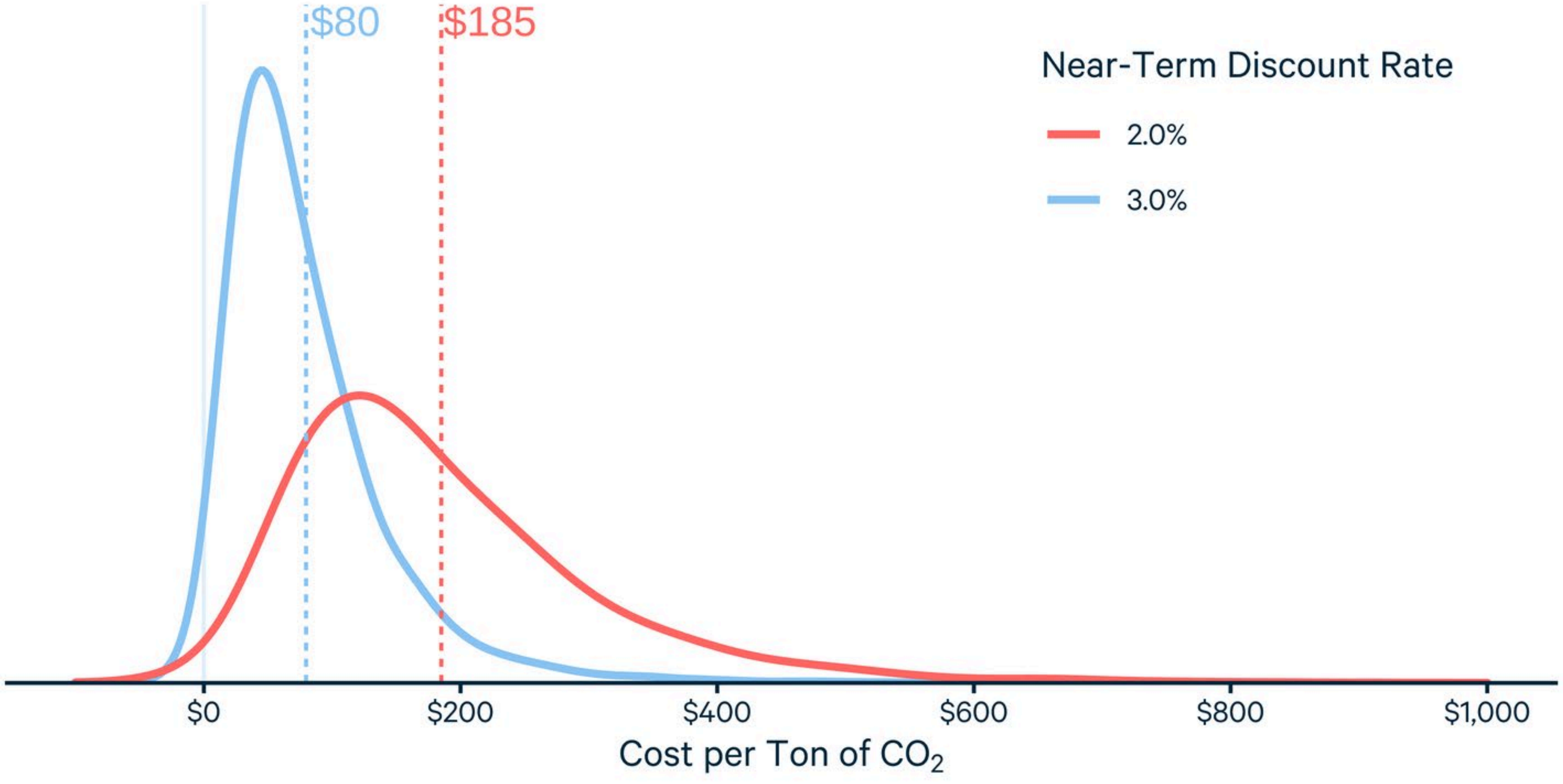
Values of SC-CO_2, SC-CH_4, and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available in Appendix A.4 and at: www.epa.gov/environmental-economics/scghg.

~$200 U.S. EPA SC-$CO_2$, up from ~$50

Source: EPA External Review Draft of Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances (September 2022)

~$185 Social Cost of CO_2

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

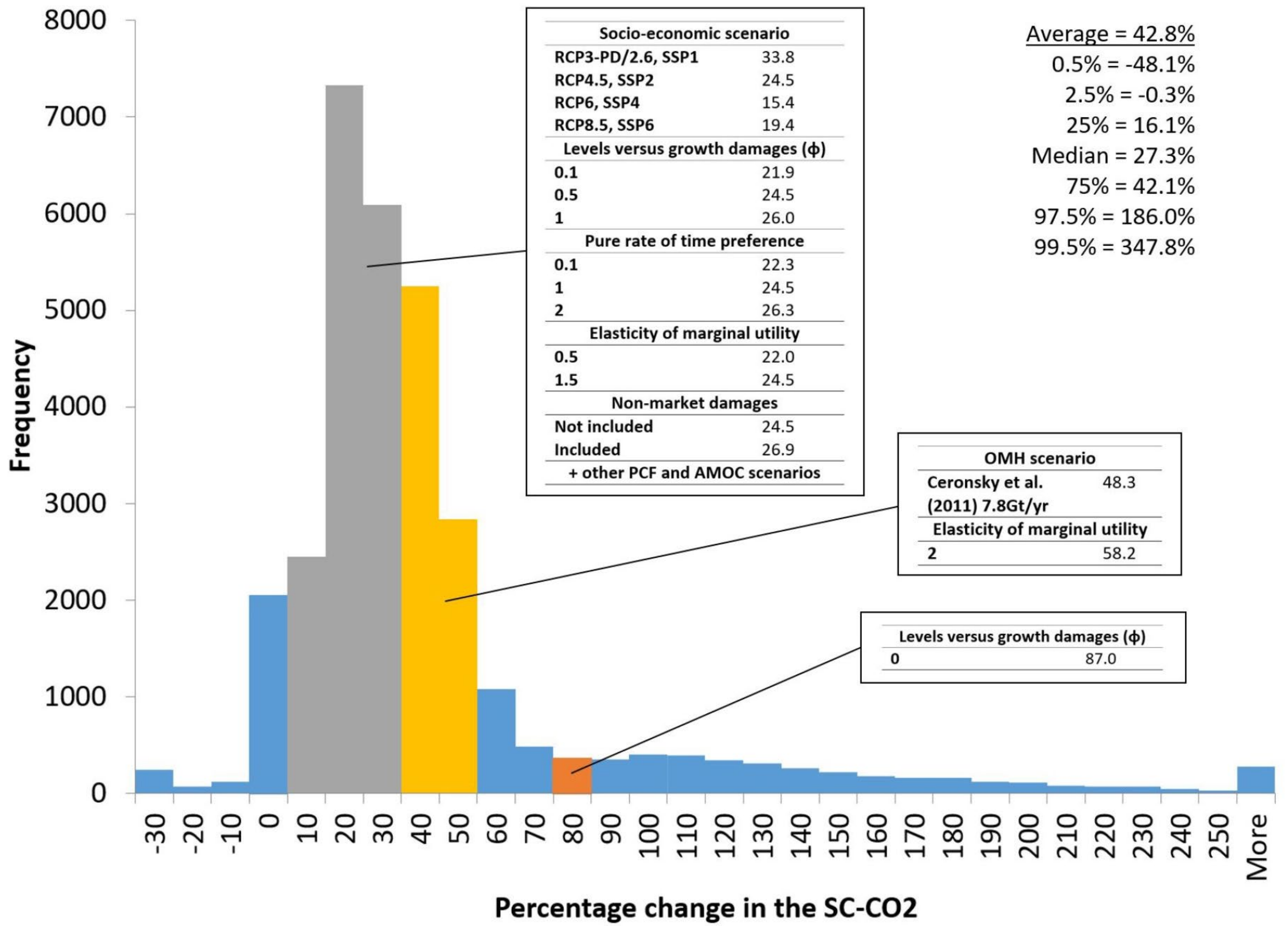


~$50 to ~$80 from updated damages,
~$80 to ~$185 from discounting

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

Economic impacts of tipping points in the climate system

Tipping points increase SCC by between ~27-43%, with large, right-skewed distribution



Source: Dietz, Rising, Stoerk & Wagner (*PNAS* 2021), gwagner.com/tipping-economics

> $200 / tCO_2

~ $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

The New York Times

There's Only One Way to Fix New York's Traffic Gridlock

June 8, 2023

Congestion pricing is the only durable antidote to persistent traffic congestion. The Columbia University economist and Nobel laureate William Vickrey demonstrated 60 years ago that there's no way out of gridlock without making drivers pay for taking up limited street space. Otherwise, there will always be more car owners wanting to use the available space than there is space to accommodate them.

Komanoff & Wagner, *NYT* (8 June 2023)

The New York Times

Our City Could Become One of the World's Greenest, but It Won't Be Easy

Feb. 7, 2023

The rewards the city reaps will not only be reputational. If New York cracks this decarbonization nut (as it started to do under Mayor Michael Bloomberg with transport and especially bike lanes), the city's hard-to-bear summers, when the asphalt, steel and brick absorb the sun's rays and turn the city into a heat island will mellow. The noise from air-conditioners and boilers will ebb.

It will be a much nicer place to live.

Greenberg & Wagner, *NYT* (7 February 2023)

Tail risks dwarf all else

Climate policy = insurance

Climate policy = opportunity

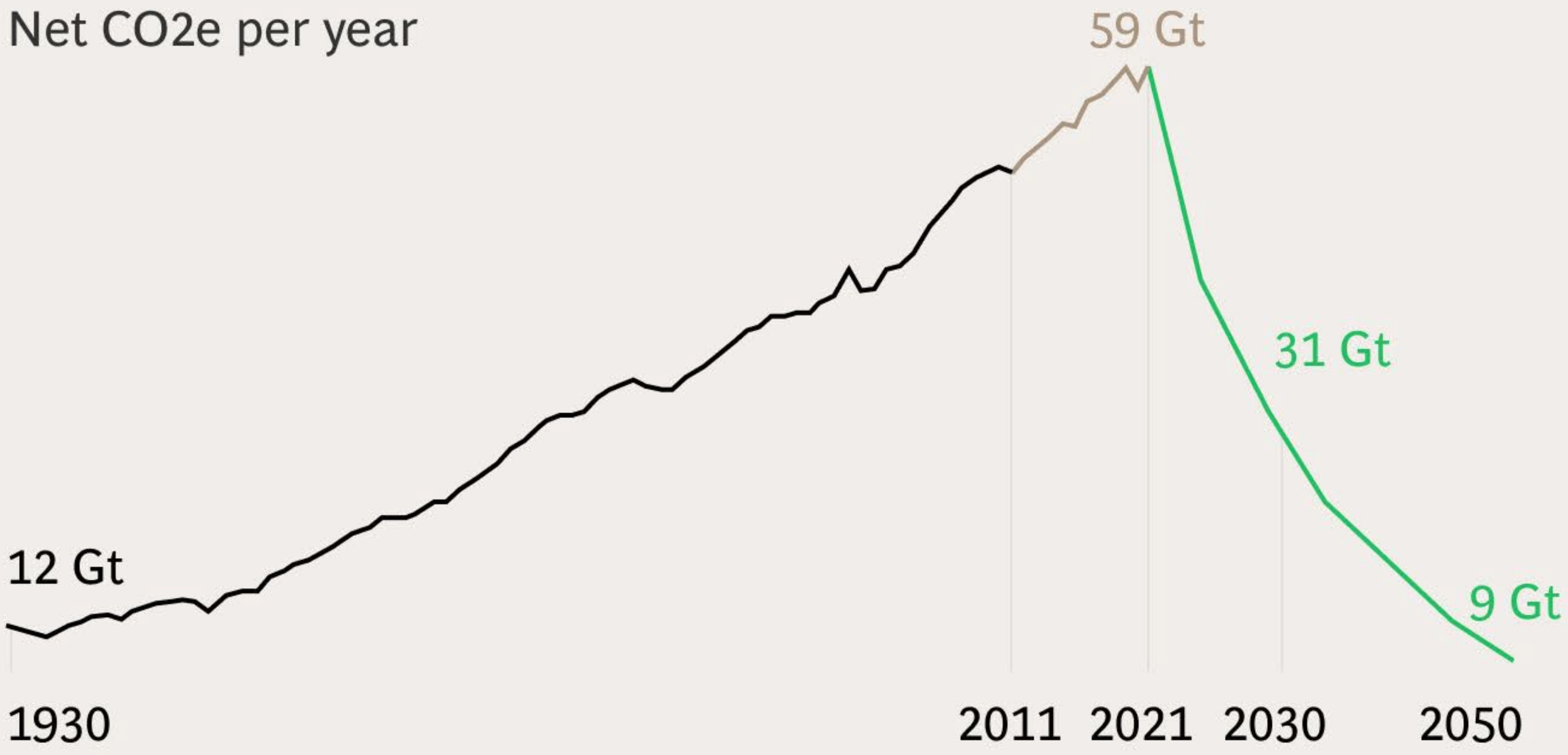
Negative climatic tipping points, meet the positive socio-economic ones the IRA is jumpstarting

- The challenge: Addressing ‘fossilflation’ while keeping ‘greenflation’ in check
- Direct effects are important
  - e.g. get $8k rebate for your heat pump, $2.5k to improve electric wiring, … $250b in DOE loans
  - adding up to $1.2 trillion in federal spending over first decade, spurring $2.9 trillion in total spending over first decade, >$10 trillion by 2050, per Goldman Sachs Research,

  But:
- It’s the external effects, norm changes, positive socio-economic tipping points that will make the real difference

Rich Lesser, Global Chair, Boston Consulting Group, at Columbia Business School, 2022

Major course correction needed to achieve the 1.5°C ambition

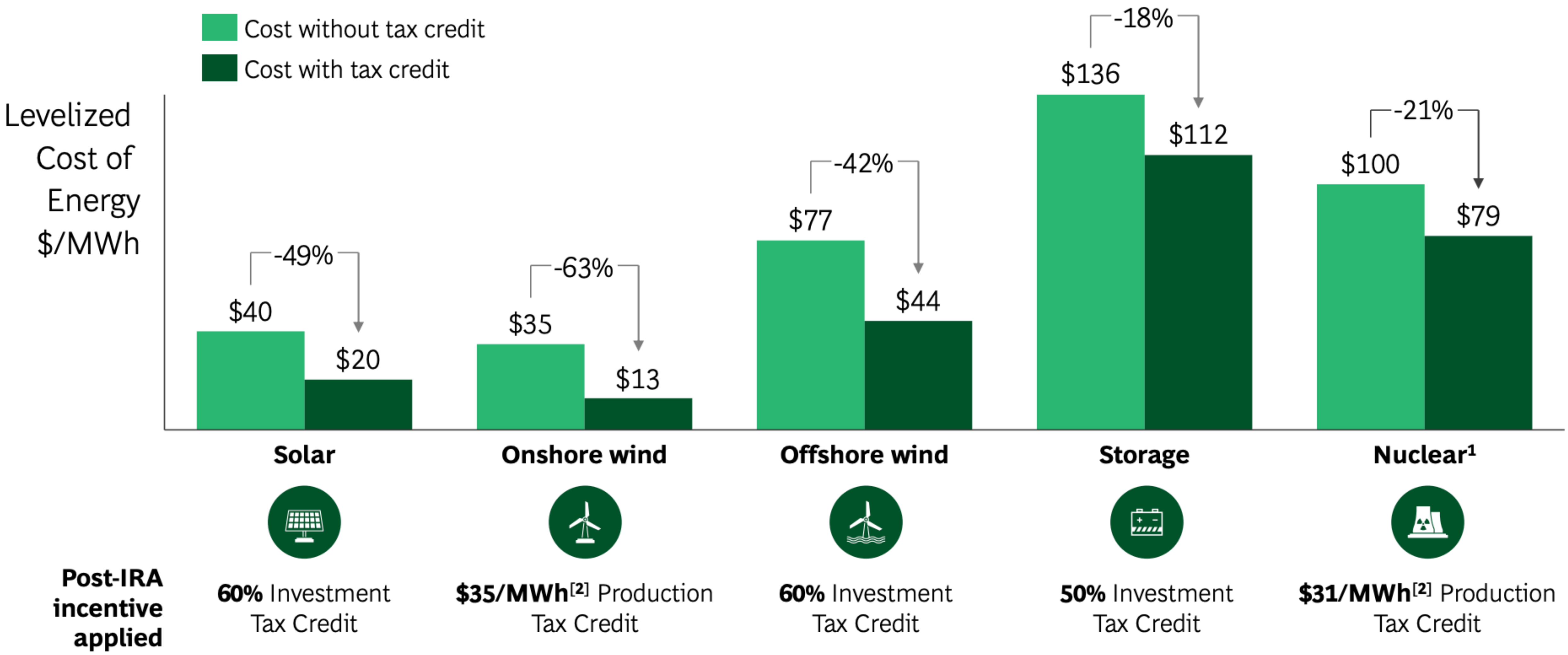


-7%
annual reduction in emissions needed by 2030 to meet the 1.5°C pathway

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

Sources: IPCC, PIK, BCG analysis

Impact of IIJA + IRA on Climate Solutions



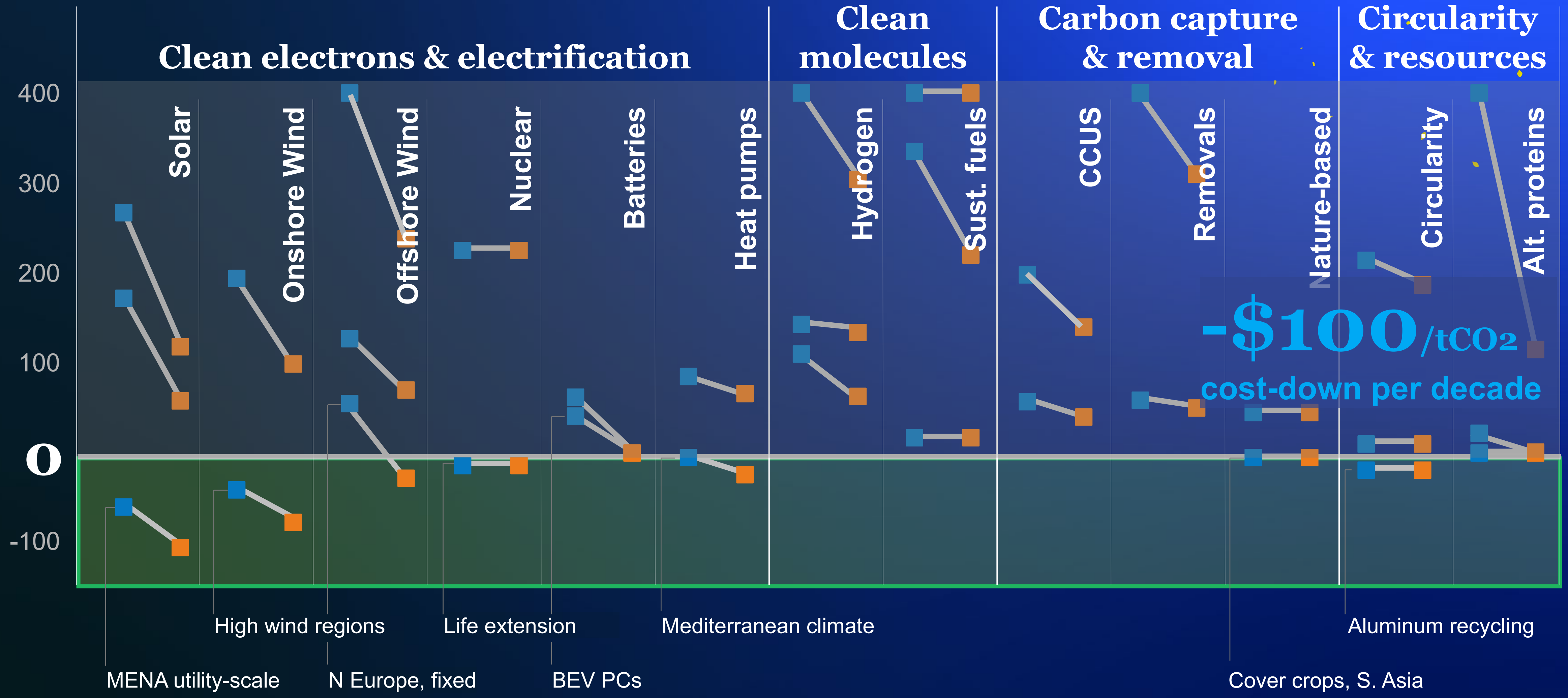
1. New small-modular reactor; 2.Assumes $15/MWh incentive, inflation adjusted and with bonuses; Note: all technologies assume base + prevailing wage bonus + domestic production bonus + energy community bonus, and wind and solar also include low-income bonus Source: Lazard, BCG analysis

Source: BCG

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

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

Estimated abatement costs, USD/tCO_2e

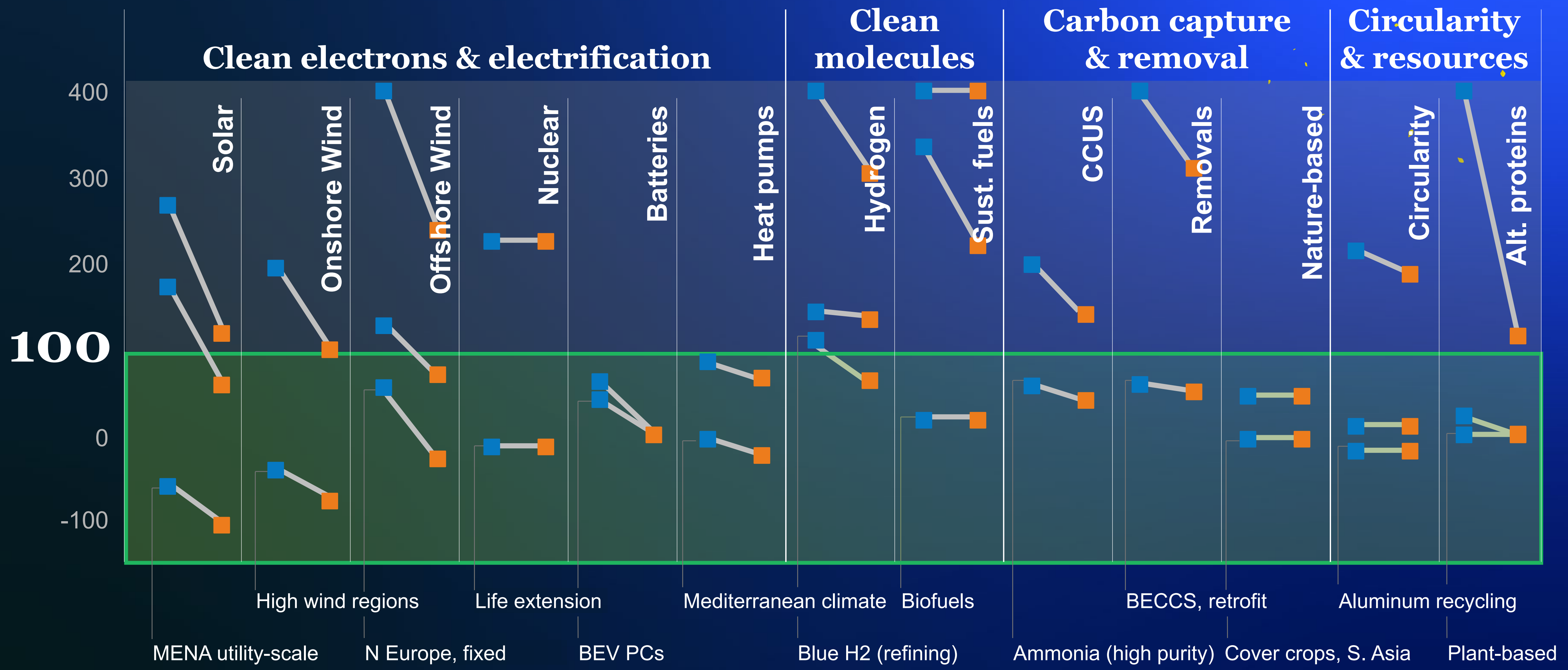


Source: McKinsey Global MACC with regional/product estimations

McKinsey & Company

100$/t$CO_2$ carbon tax would make most techs competitive

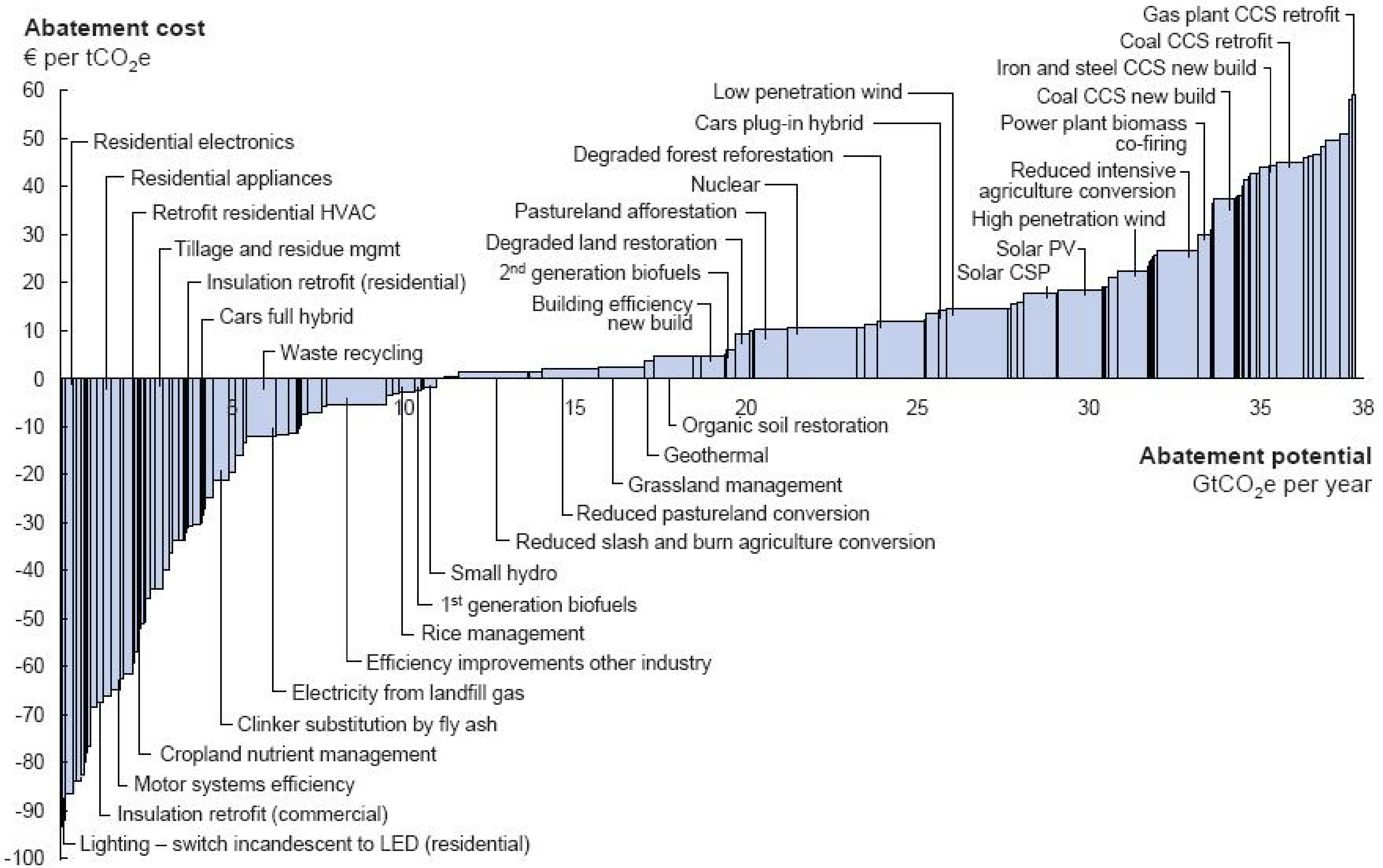
Estimated abatement costs, USD/tCO_2e



Source: McKinsey Global MACC with regional/product estimations

Large abatement opportunities available at low or no cost

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



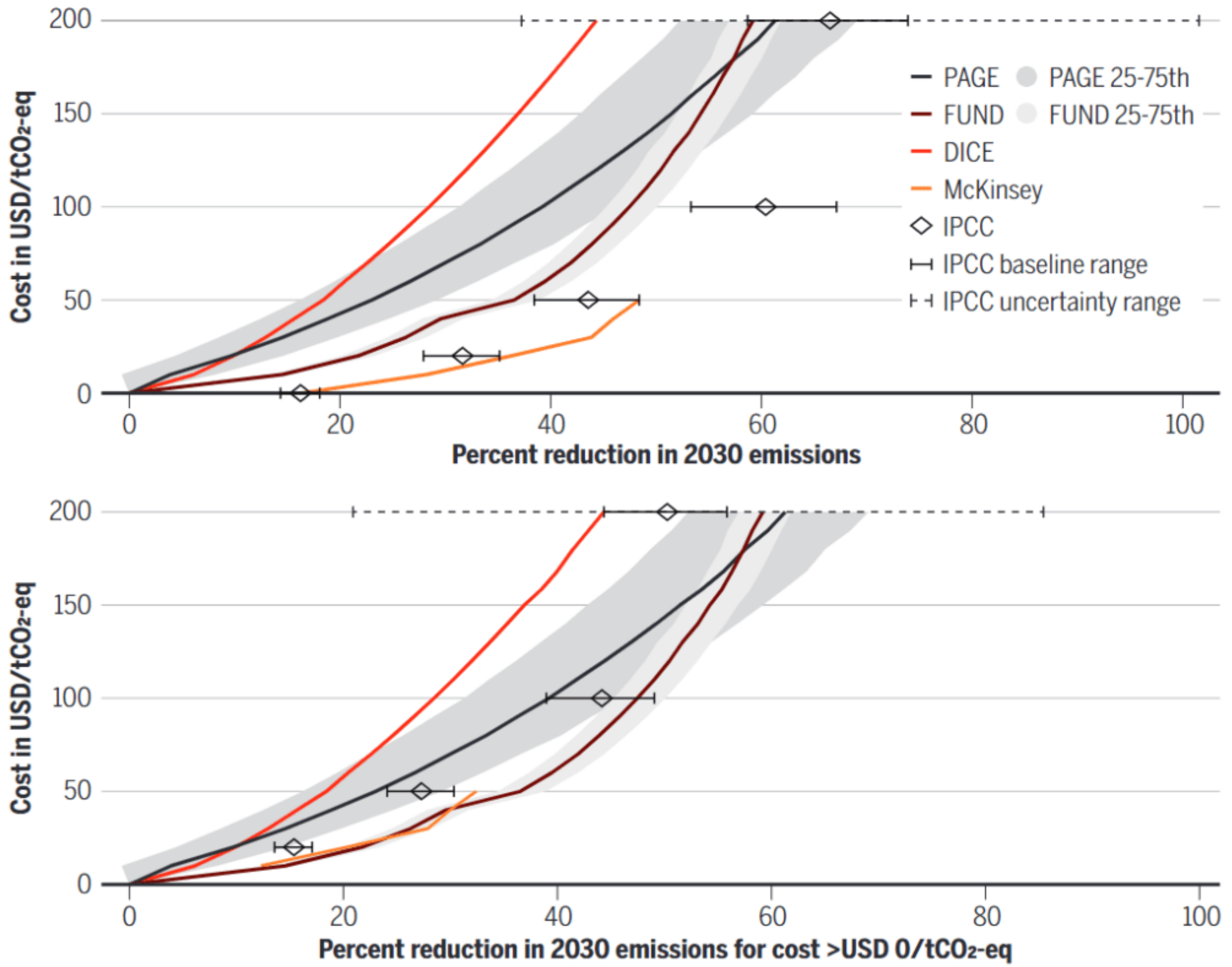
Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Global GHG Abatement Cost Curve v2.0

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

Comparison of global mitigation potentials at different costs

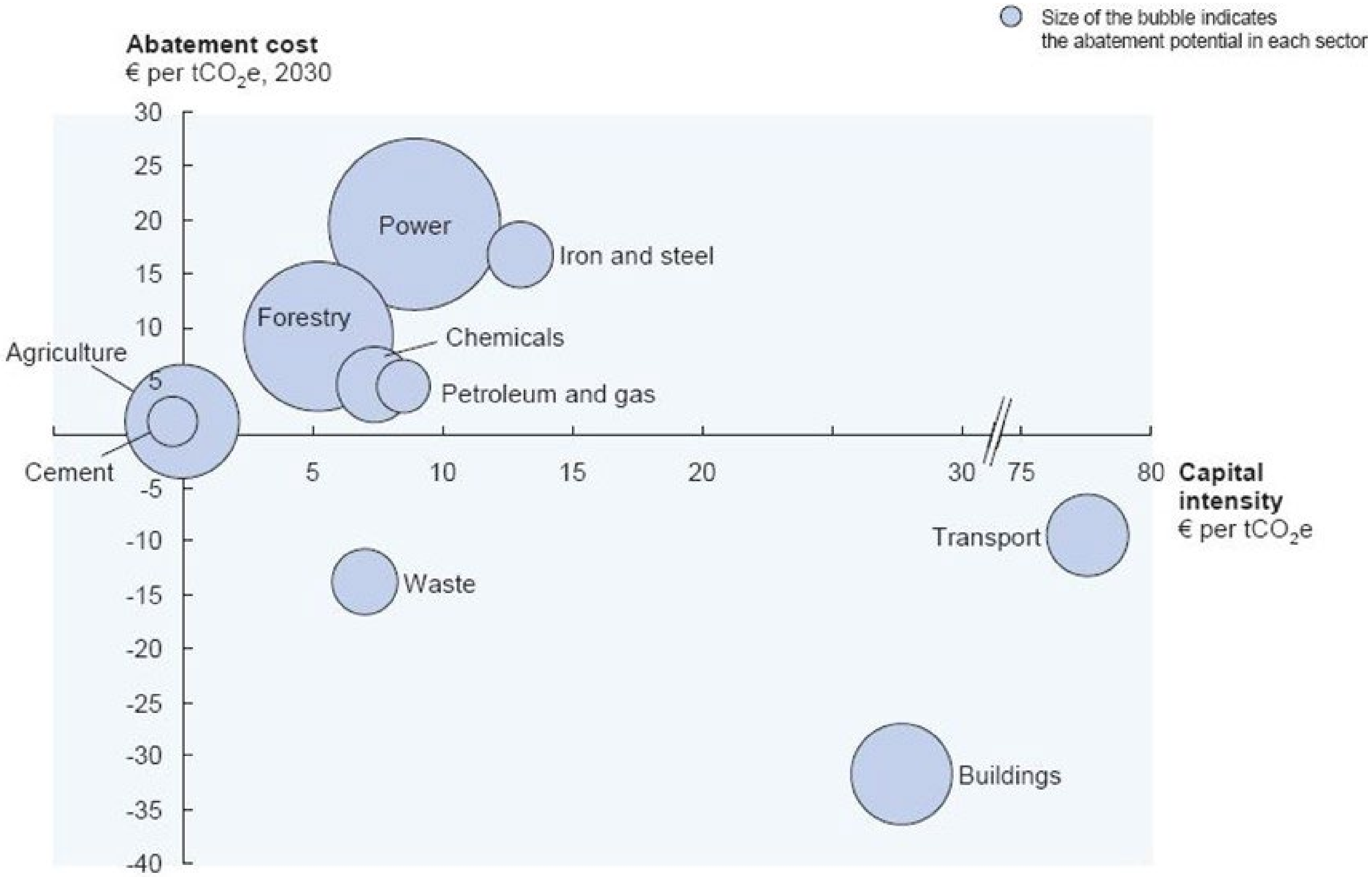
The IPCC results use different baseline emissions to calculate the range of mitigation potentials. The top panel reports the full set of results, and the bottom panel reports only the mitigation potentials with costs >$0 per tonne of CO_2 equivalent (tCO_2-eq). USD reported in 2020 dollars. See supplementary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



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

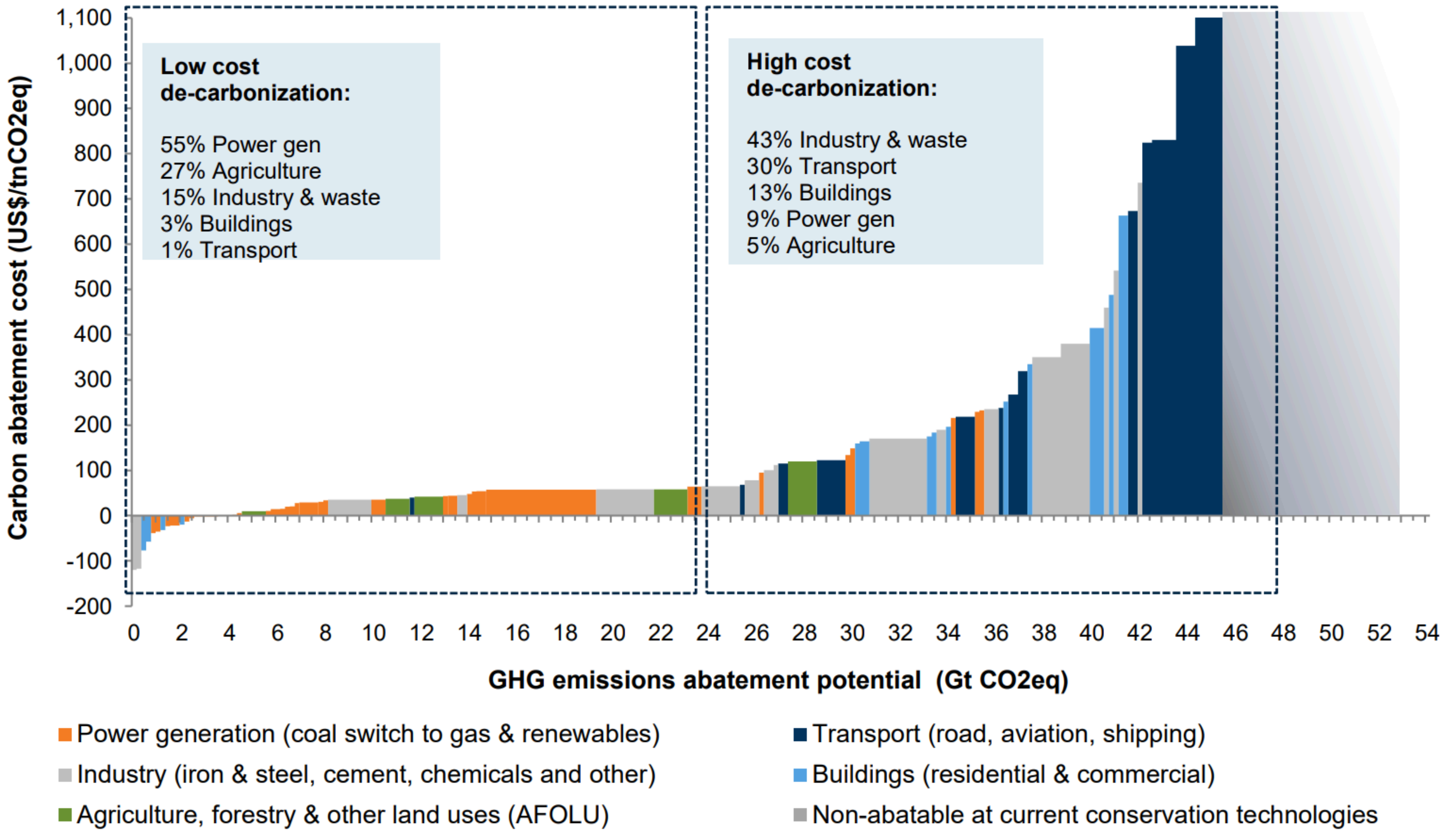
Capital intensity varies widely across sectors

Transport and buildings with largest up-front capital expenditure requirements



Source: Global GHG Abatement Cost Curve v2.0

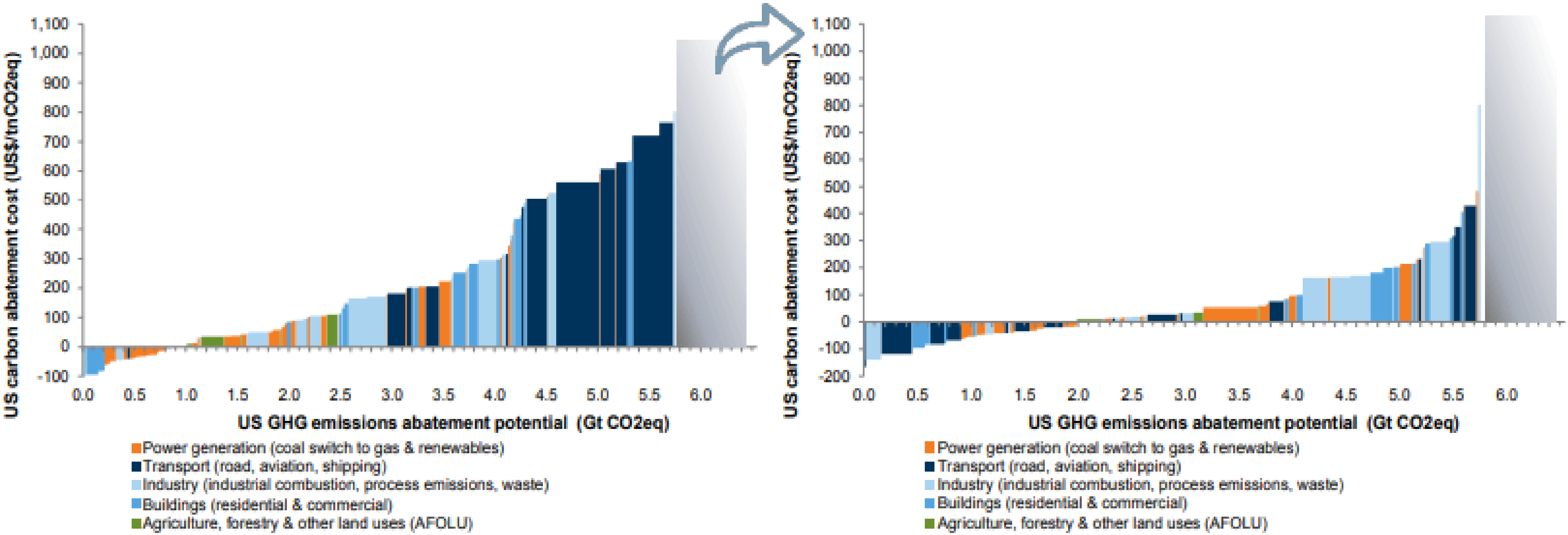
Goldman Carbon Abatement Cost



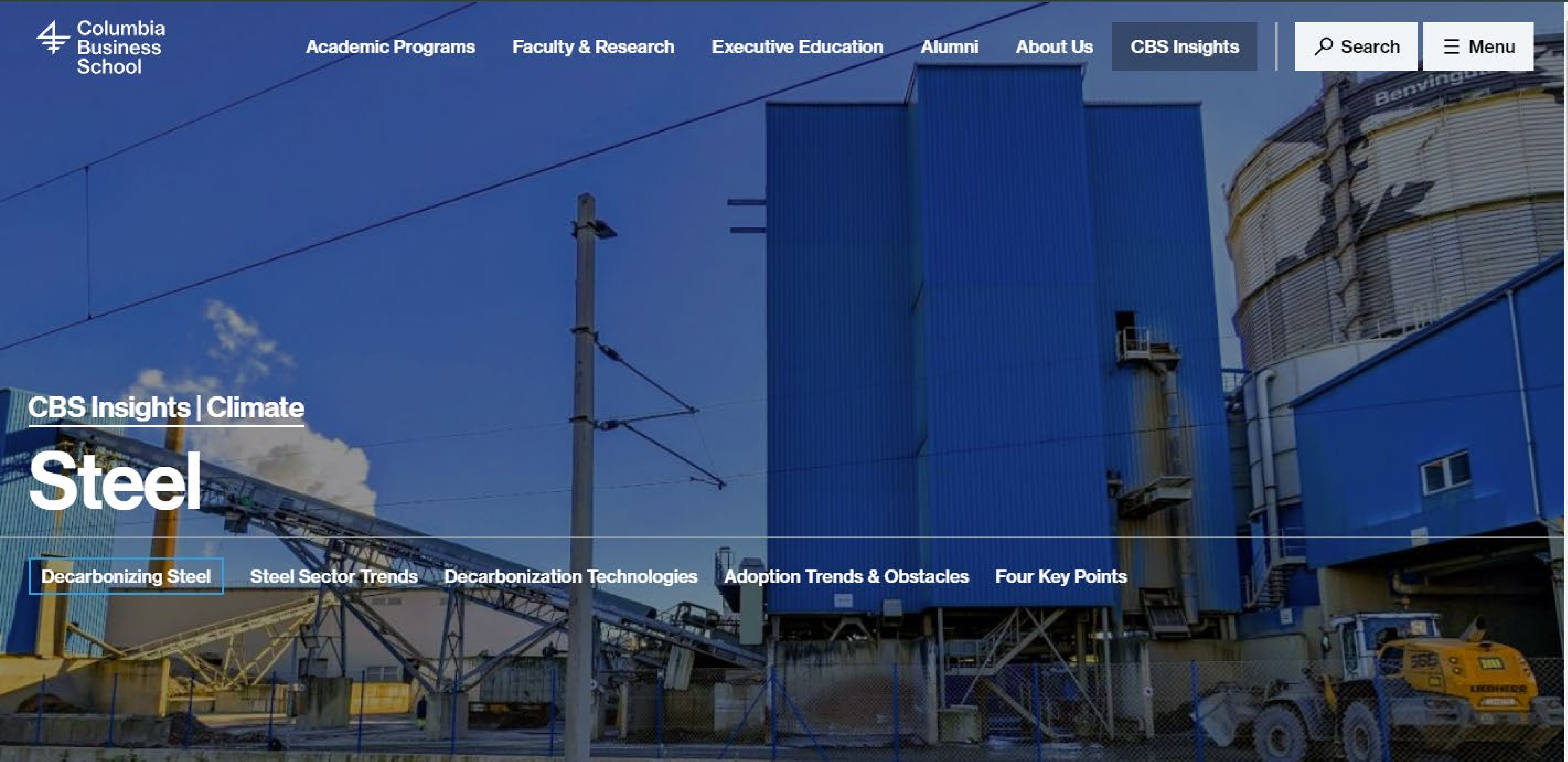
Source: Goldman Sachs Global Investment Research

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

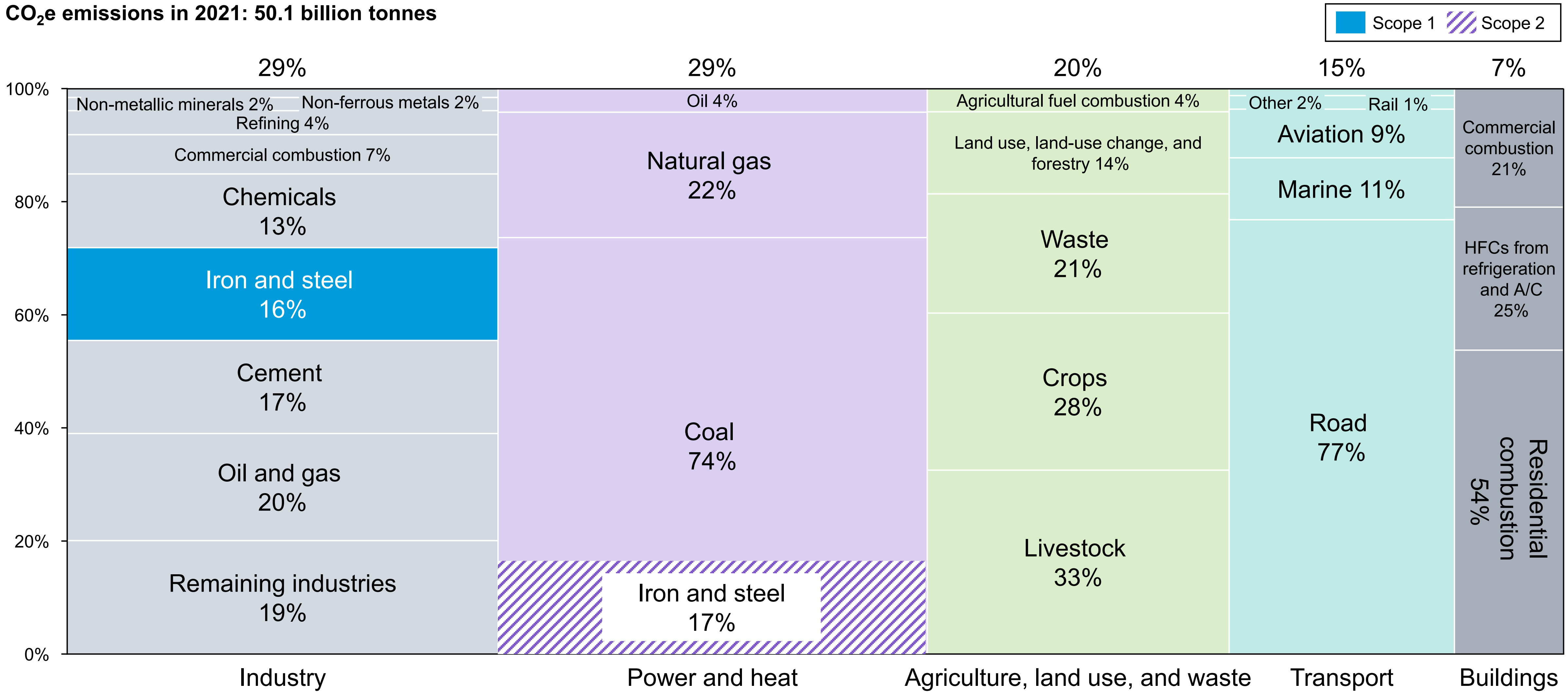


CBS Insights | Climate

Steel

Decarbonizing Steel | Steel Sector Trends | Decarbonization Technologies | Adoption Trends & Obstacles | Four Key Points

Steel sector scope 1 and 2 emissions are ~10% of global emissions

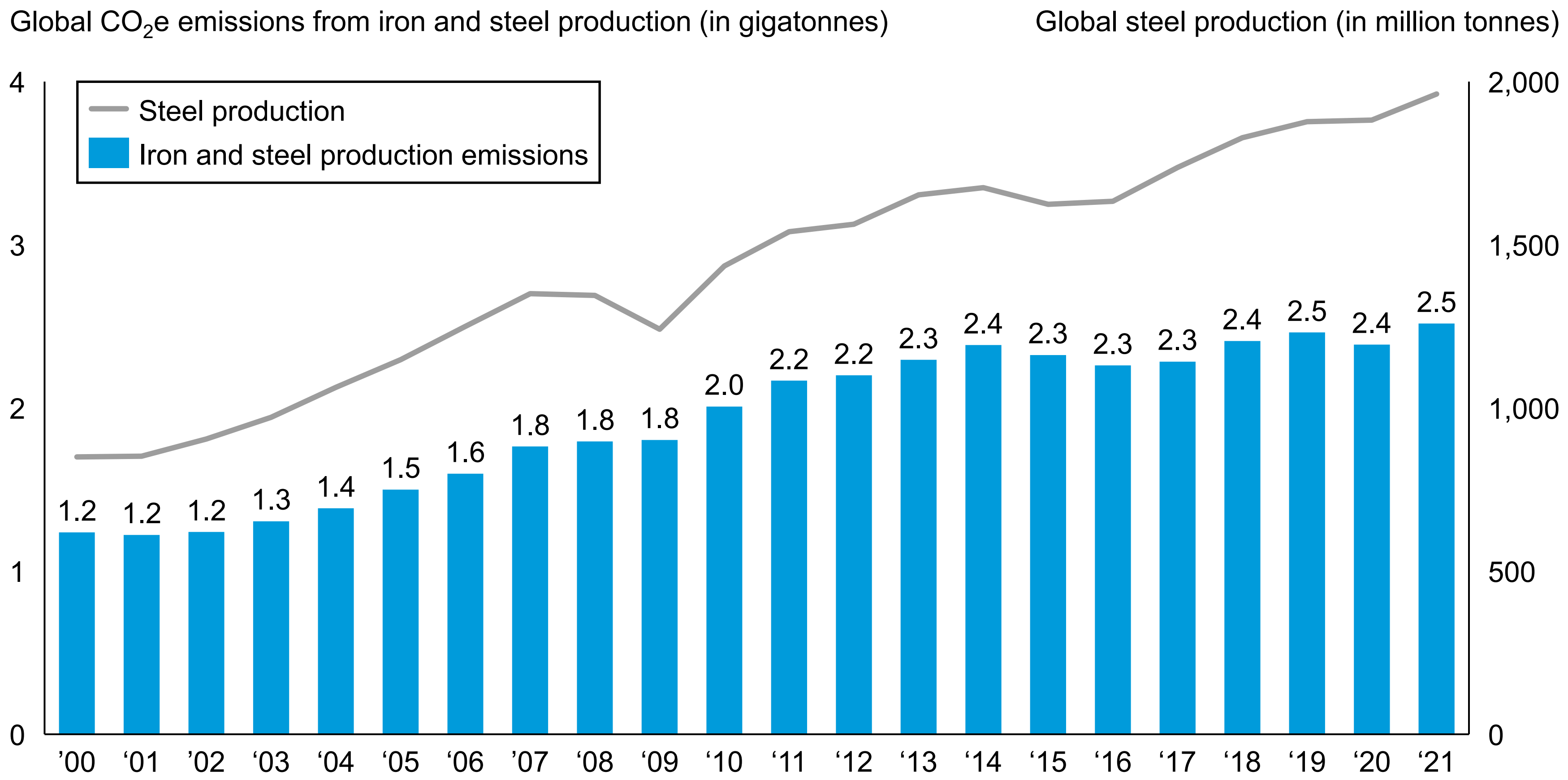


Sources: Scope 1 emissions from Rhodium Group ClimateDeck (September 2023); Scope 2 iron and steel estimate from IEA (2023).
Credit: Mimi Khawsam-ang, Max de Boer, Grace Frascati, and Gernot Wagner (22 February 2024); share/adapt with attribution. Contact: gwagner@columbia.edu

Columbia Business School

Global steel emissions have more than doubled since 2000, with emission growth decoupled from production growth after 2016

Global CO_2e emissions decoupled from steel production post-2016



Observations

- In recent years, the steel industry has made efforts to **reduce its carbon footprint** with **more energy-efficient processes and technologies**
  - Though not enough by itself, recycling rates **have improved** (sitting around 80%-90% globally)
  - **Better manufacturing yields** have made supply chains more efficient
  - **Enhanced control processes** and **predictive maintenance strategies** have led improvements in **operational efficiency**
- **China**, the largest steel producer in the world, saw a **3% decline in steel output** in 2021 and a similar decline in the years since

Note: The majority of the world's iron is used to make steel. Sources: Rhodium Group ClimateDeck (September 2023); World Steel Association; McKinsey, Decarbonization Challenge for Steel; IEA, CO_2 Emissions in 2022, Reuters, China 2021 Crude Steel Output. Credit: Mimi Khawsam-ang, Max de Boer, Grace Frascati, and Gernot Wagner (22 February 2024); share/adapt with attribution.
Contact: gwagner@columbia.edu

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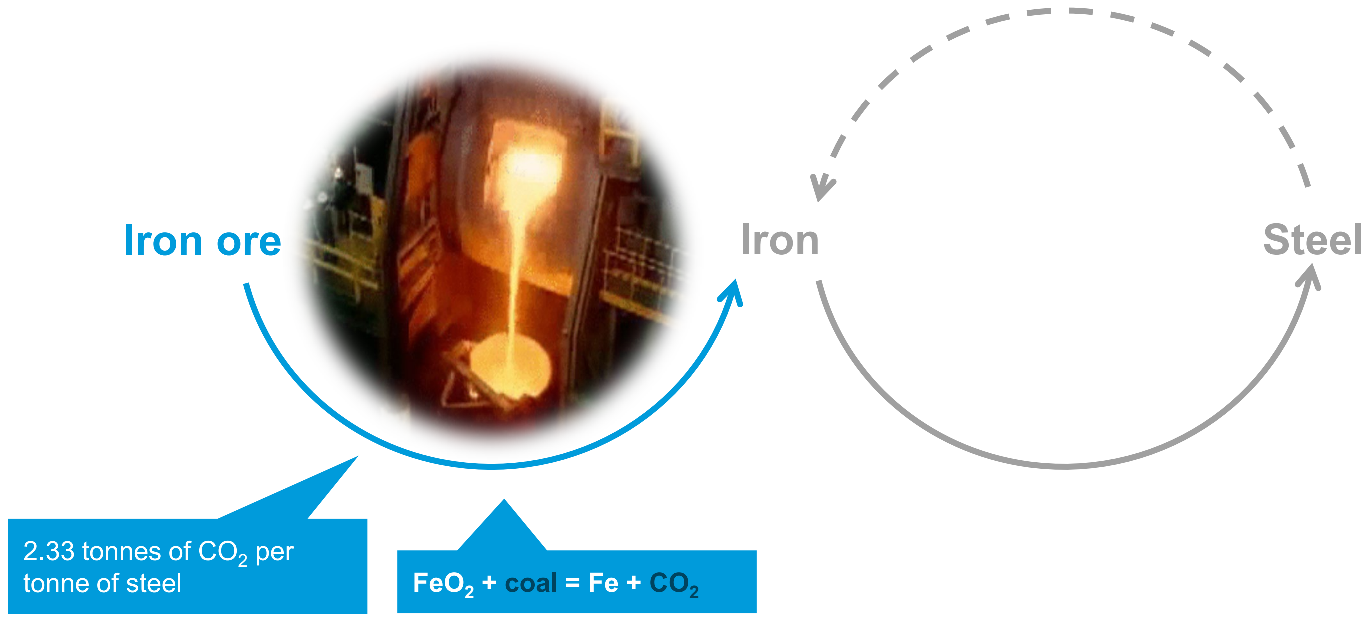
❶ Of three main steelmaking methods, blast furnace-basic oxygen furnace (BF-BOF) is the cheapest, most popular, and most polluting

BF-BOF ~73% of global steel production and ~80% of iron and steel CO_2 emissions



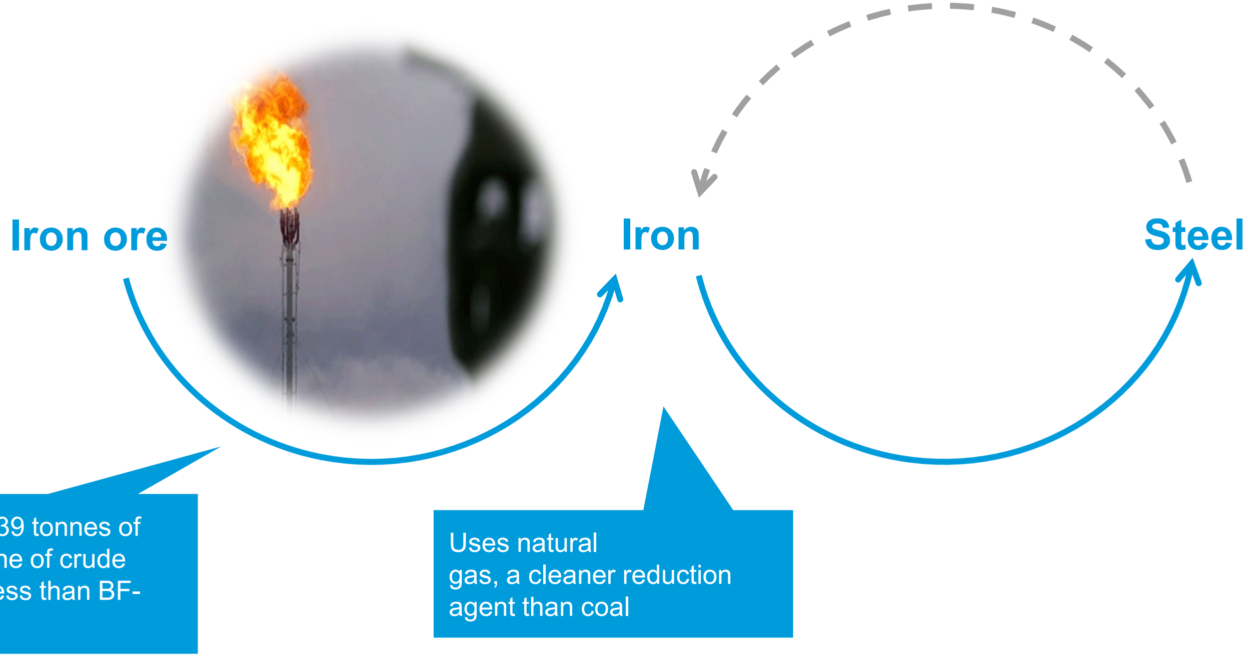
Observations

- **BF-BOF:** Iron ore, coke, and limestone produce iron in a blast furnace, which is turned into steel in an oxygen furnace

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 (22 February 2024); share/adapt with attribution. Contact: gwagner@columbia.edu

3 Of the three main steelmaking methods, natural gas-based direct reduced iron-electric arc furnace (NG DRI-EAF) is the most expensive and least used

BF-BOF ~73% of global steel production and 80% of iron and steel CO_2 emissions

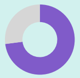


Observations

- **BF-BOF:** Iron ore, coke, and limestone produce iron in a blast furnace, which is turned into steel in an oxygen furnace
- **Scrap EAF:** Scrap metal is melted in an EAF using electrical energy
- **NG DRI-EAF:** Iron ore turns into iron using natural gas, which is then melted in an EAF to produce steel

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 (22 February 2024); share/adapt with attribution. Contact: gwagner@columbia.edu

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 ton of crude steel	**~24 GJ**	**~10 GJ**	**~22 GJ**
Average cost per tonne of crude steel	**~$390**	**~$415**	**~$455**

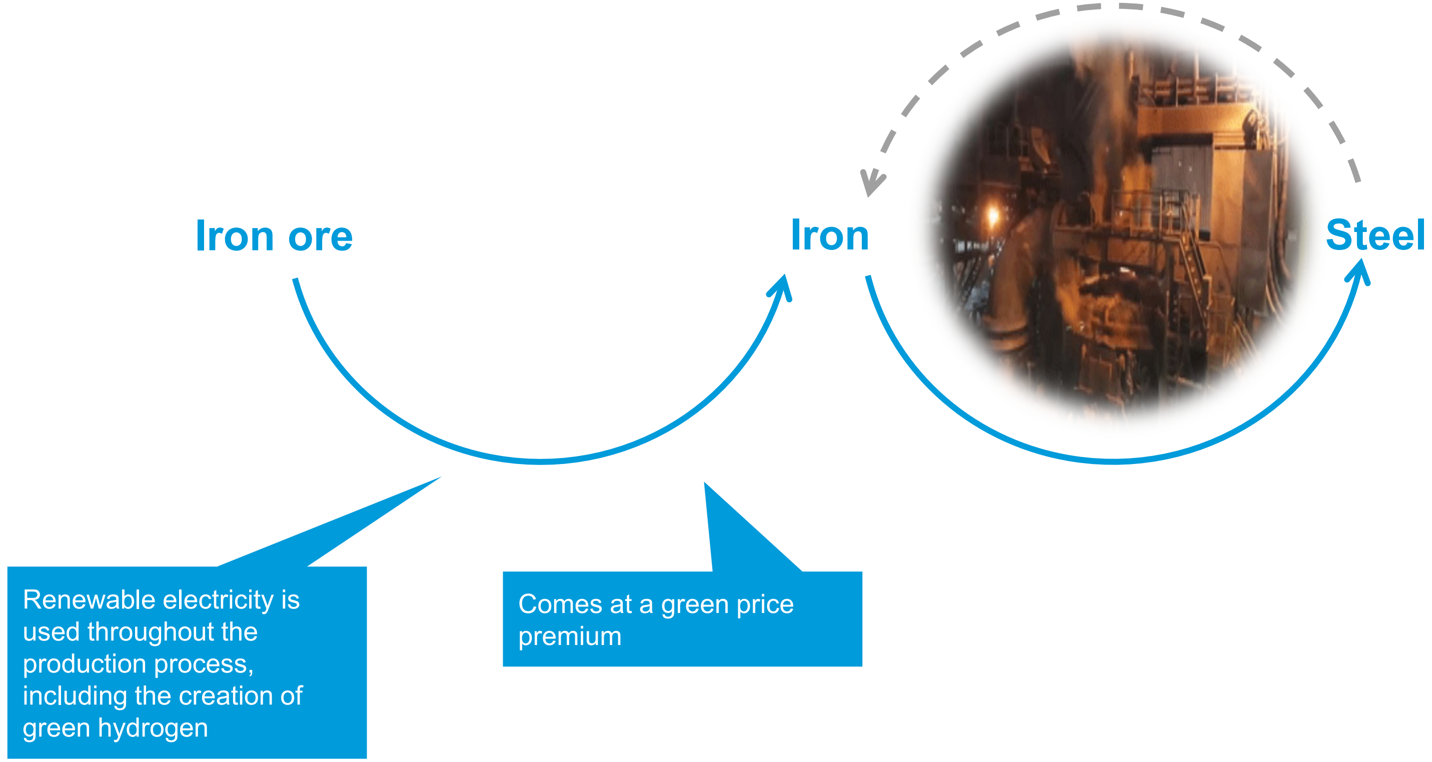
Sources: World Steel Association; IEEFA (2022); IEA, Iron and Steel Technology Roadmap (2020); Steel Technology, Basic Oxygen Furnace Steelmaking; Recycling Today, Growth of EAF Steelmaking; Wildsight, Do We Really Need Coal to Make Steel. Credit: Mimi Khawsam-ang, Max de Boer, Grace Frascati, and Gernot Wagner (22 February 2024); share/adapt with attribution. Contact: gwagner@columbia.edu

Columbia Business School
AT THE VERY CENTER OF BUSINESS

Steel Decarbonization Technologies

1 Green H_2 DRI-EAF is an emerging technology using green hydrogen instead of natural gas as an iron ore reductant with standard electric arc furnaces

Green H_2 direct reduced iron-EAF has an average cited decarbonization potential of ~90%



Observations

- **BF-BOF:** Iron ore, coke, and limestone produce iron in a blast furnace, which is turned into steel in an oxygen furnace
- **Scrap EAF:** Scrap metal is melted in an EAF using electrical energy
- **NG DRI-EAF:** Iron ore turns into iron using natural gas, which is then melted in an EAF to produce steel
- **Green H_2 DRI-EAF:** Green hydrogen replaces natural gas as an iron ore reductant; byproduct is water vs. CO_2

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 (22 February 2024); share/adapt with attribution. Contact: gwagner@columbia.edu

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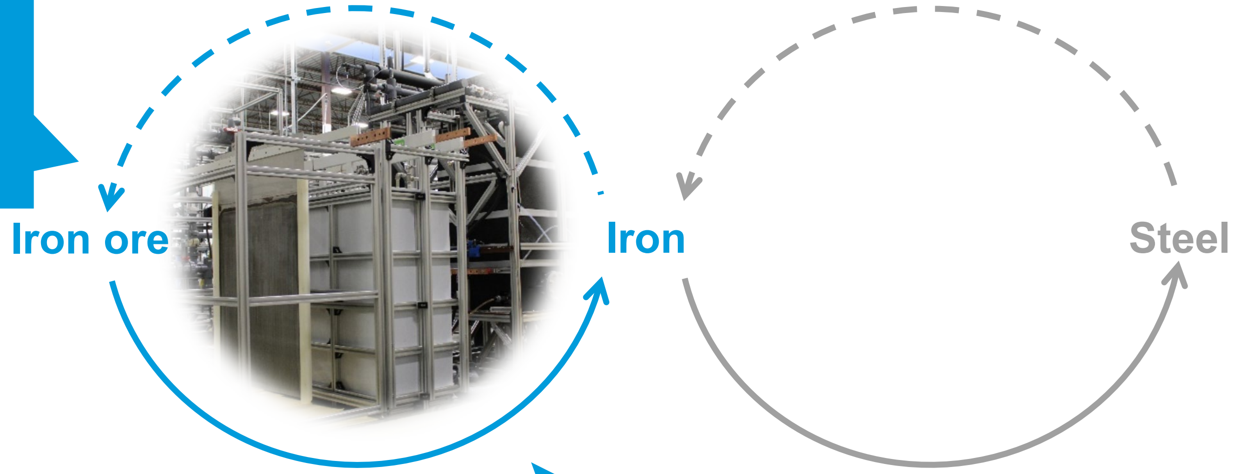
2 Iron ore electrolysis is an emerging technology that uses an electric current to drive a chemical reaction, producing molten iron or pure solid iron

Iron ore electrolysis has an average cited decarbonization potential of ~97%

Iron is now akin to solid-state battery, allowing for a reversed process that *produces* electricity



Electrowinning-EAF dissolves iron from iron ore in acid, then electrifies it to form pure solid iron; molten oxide electrolysis runs a current through iron ore and liquid electrolyte to split ore into pure molten iron

May be cheaper than conventional processes but has not yet been proven at scale

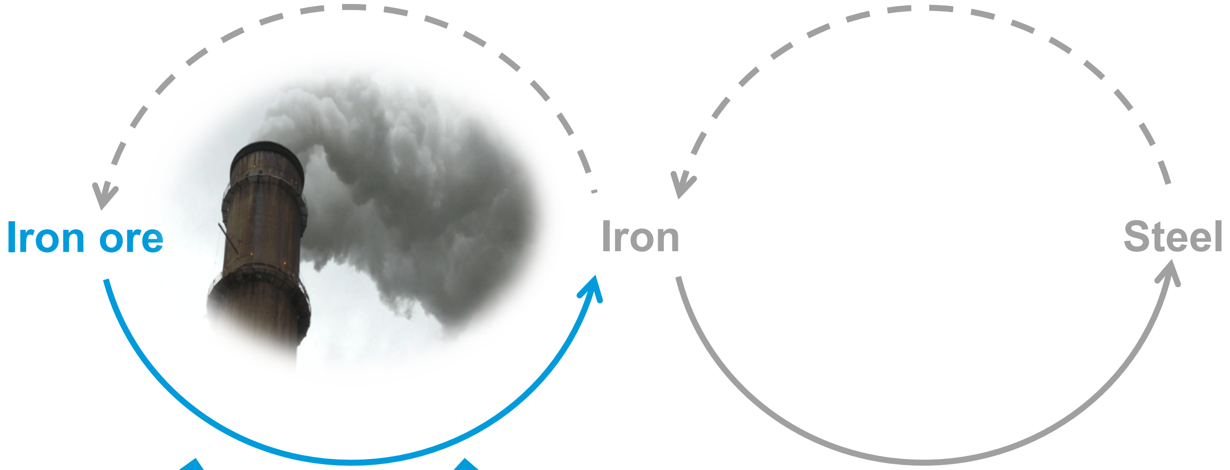
Observations

- **BF-BOF:** Iron ore, coke, and limestone produce iron in a blast furnace, which is turned into steel in an oxygen furnace
- **Scrap EAF:** Scrap metal is melted in an electric arc furnace (EAF) using electrical energy
- **NG DRI-EAF:** Iron ore turns into iron using natural gas, which is then melted in an EAF to produce steel
- **Green H_2 DRI-EAF:** Green hydrogen replaces natural gas as an iron ore reductant; byproduct is water vs. CO_2
- **Iron ore electrolysis:** Molten oxide electrolysis runs a current through iron ore and liquid electrolyte to split ore into pure molten iron; electrowinning-EAF dissolves iron from iron ore in acid, then electrifies it to form solid iron

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 (13 March 2024); share/adapt with attribution. Contact: gwagner@columbia.edu

3 Carbon capture, utilization, and storage (CCUS) is an emerging technology that reduces steel's carbon footprint by capturing released CO_2

Despite a cited ~90% decarbonization potential, CCUS technology is largely unproven



Less viable for the blast furnace route given difficulty of capturing all carbon released

Capture rates range from 50%-90%, and viability is debated due to the lack of a single capture point

Observations

- **BF-BOF:** Iron ore, coke, and limestone produce iron in a blast furnace, which is turned into steel in an oxygen furnace
- **Scrap EAF:** Scrap metal is melted in an electric arc furnace using electrical energy
- **NG DRI-EAF:** Iron ore turns into iron using natural gas, which is then melted in an EAF to produce steel
- **Green H_2 DRI-EAF:** Green hydrogen replaces natural gas as an iron ore reductant; byproduct is water vs. CO_2
- **Iron ore electrolysis:** Molten oxide electrolysis runs a current through iron ore and liquid electrolytes to split ore into pure molten iron; electrowinning-EAF dissolves iron from iron ore in acid, then electrifies it to form solid iron
- **CCUS:** Equipment is added to existing steel-producing infrastructure to capture emitted CO_2, to then sequester or reuse

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 (22 February 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 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

Columbia Business School


H2 green steel

Investors:

- Altor Equity Partners
- AMF
- Andra AP-Fonden
- Ane & Robert Maersk Uggla
- BILSTEIN GROUP
- Cristina Stenbeck
- Daniel Ek
- EIT InnoEnergy
- Exor
- FAM
- GIC
- Hitachi Energy
- Hy24
- IMAS Foundation
- Just Climate
- Kingspan
- Kinnevik
- Kobe Steel
- Marcegaglia
- Mercedes-Benz AG
- Scania
- Schaeffler
- SMS Group
- Stena Metall Finans
- Swedbank Robur Alternative Equity
- Temasek
- Vargas

When we launched, only 2-3mt DRI steel had been announced in Europe

DRI announced in Europe 2021, *mt liquid steel*

2025	H2 green steel	2.5mt
2026	HYBRIT – FOSSIL-FREE STEEL	~1mt
2027		
2028		
2029	LKAB SSAB	2.0mt
2030	H2 green steel	2.5mt

Since our announced, more than ~40mt green steel projects have been promised by 2030

DRI announcements in Europe today, *mt liquid steel*

2025
- H2 green steel – 2.5mt
- ArcelorMittal – 2.3mt

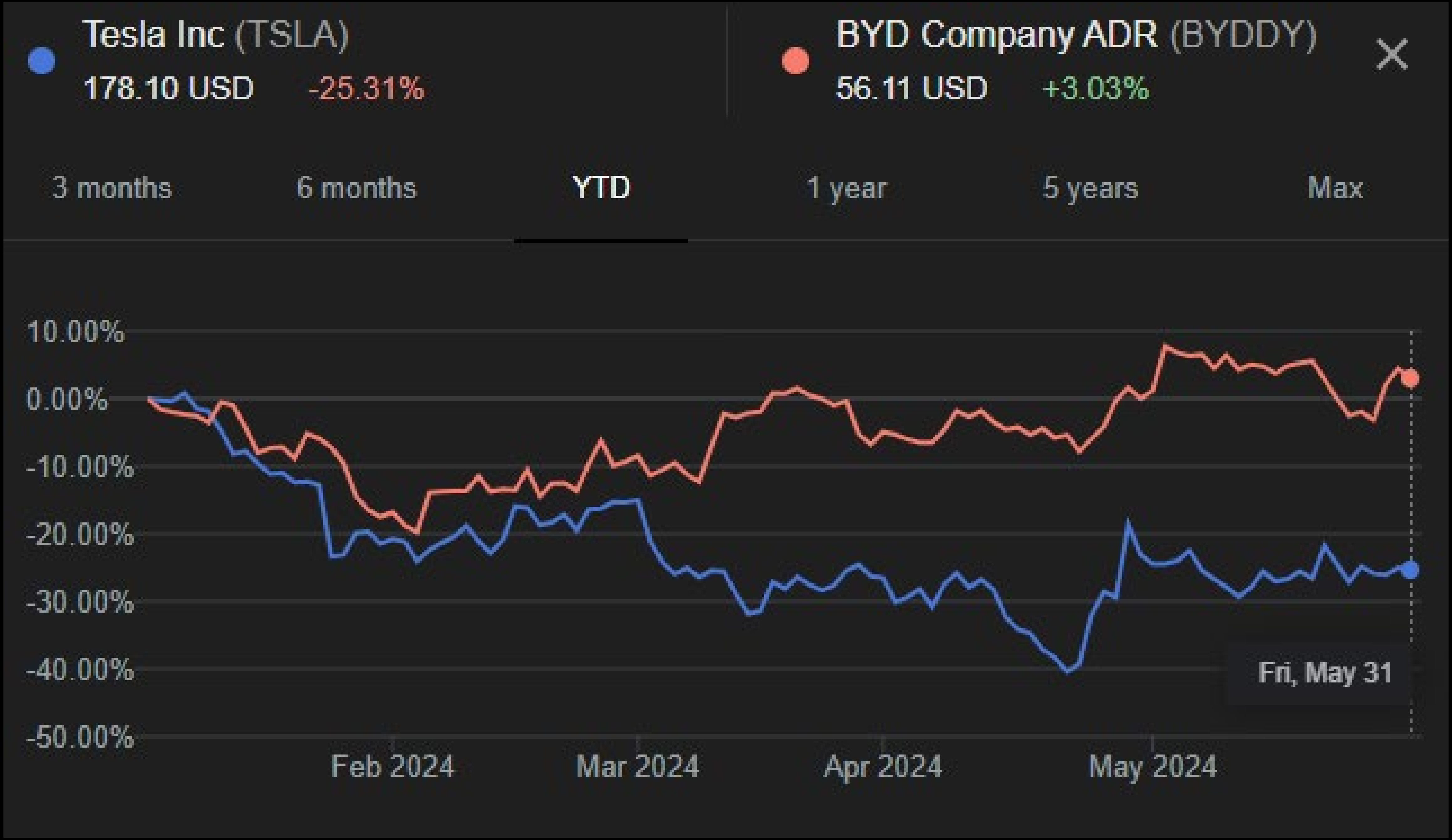
2026
- HYBRIT ▶▶▶ FOSSIL-FREE STEEL – 1.3-2.7mt
- thyssenkrupp – 2.5mt
- SALZGITTER AG Stahl und Technologie – 1.9mt
- BLASTR Green Steel – 2.5mt
- LIBERTY – 3.0mt
- GravitHy – 2.0mt

2027
- ArcelorMittal – 2.3mt
- voestalpine ONE STEP AHEAD. – 1.9mt

2028
- SHS - STAHL-HOLDING-SAAR – 2.0mt
- TATA STEEL – 4.5mt

2029
- LKAB SSAB – 5.0mt
- ArcelorMittal – 7.0mt

2030
- H2 green steel – 2.5mt
- SALZGITTER AG Stahl und Technologie – 1.9mt


Tesla Inc (TSLA)
178.10 USD -25.31%
BYD Company ADR (BYDDY)
56.11 USD +3.03%
3 months
6 months
YTD
1 year
5 years
Max
10.00%
0.00%
-10.00%
-20.00%
-30.00%
-40.00%
-50.00%
Feb 2024
Mar 2024
Apr 2024
May 2024
Fri, May 31

Clean Growth*

Costas Arkolakis
Yale University

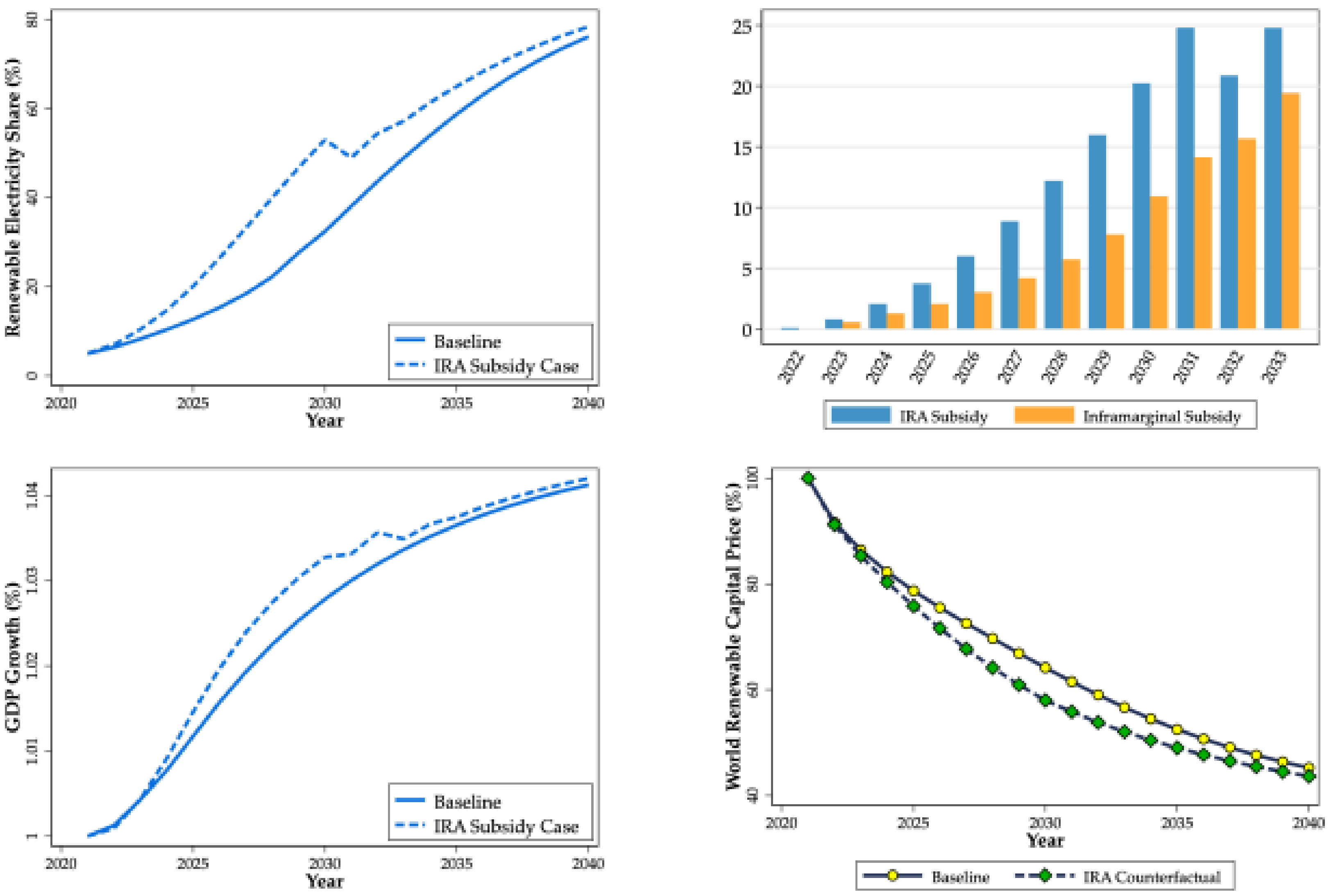
Conor Walsh
Columbia University

February 2023

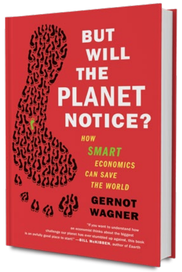
Abstract

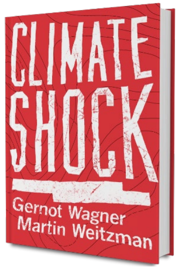
We provide a spatial theory of clean growth to assess the global impact of the rise of renewable energy. We model the details of the combined production and transmission network of electricity ("the grid") that determine the supply and losses of energy in space. The local rate of clean energy adoption depends on learning-by-doing, the global electricity and trade network, and regional comparative advantage in renewable resources. To quantify the contribution of renewable adoption to global growth, we collect and harmonize global data on transmissio lines, power stations, trade, and regional output. We use the model to measure the aggrega and spatial implications of clean growth, as well as the role of the Inflation Reduction Act affecting the transition.

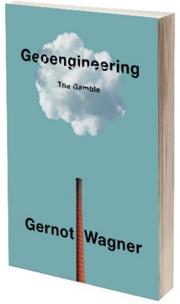
Figure 7: The Impact of the Inflation Reduction Act

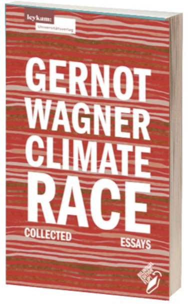


Notes: The top left panel shows the model's projection for renewable power share under the IRA production tax credit, and without. The top right panel shows the total cost of the bill (in blue), and subsidies going to capital that would be installed in the absence of the subsidy. The bottom left shows GDP growth in both scenarios, and the bottom right shows the renewable capital price.









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