Science and Society: Working Together for a Nature-Inclusive Energy Transition

David L. McCollum, Ph.D.
Senior Scientist

ORNL Buildings and Transportation Science Division
ORNL Transformational Decarbonization Initiative
ORNL Climate Change Science Institute
IPCC (Intergovernmental Panel on Climate Change)

Friends of Oak Ridge National Laboratory (FORNL)
Earth Day Lecture
April 11, 2023

Outline – Climate Change, Decarbonization, Sustainability

- The Enormous Challenge
- The Broader Context
- The Solution Space
- The Unique Opportunity

HISTORY | EVOLUTION OF THE IPCC

INTERGOVERNMENTAL PANEL ON climate change

THE ROLE OF THE IPCC IS...

"… to **assess** on a comprehensive, objective, open and transparent basis the **scientific, technical and socio-economic information** relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation."

"IPCC reports should be **neutral with respect to policy**, although they may need to **deal objectively with scientific, technical and socio-economic factors** relevant to the application of particular policies."

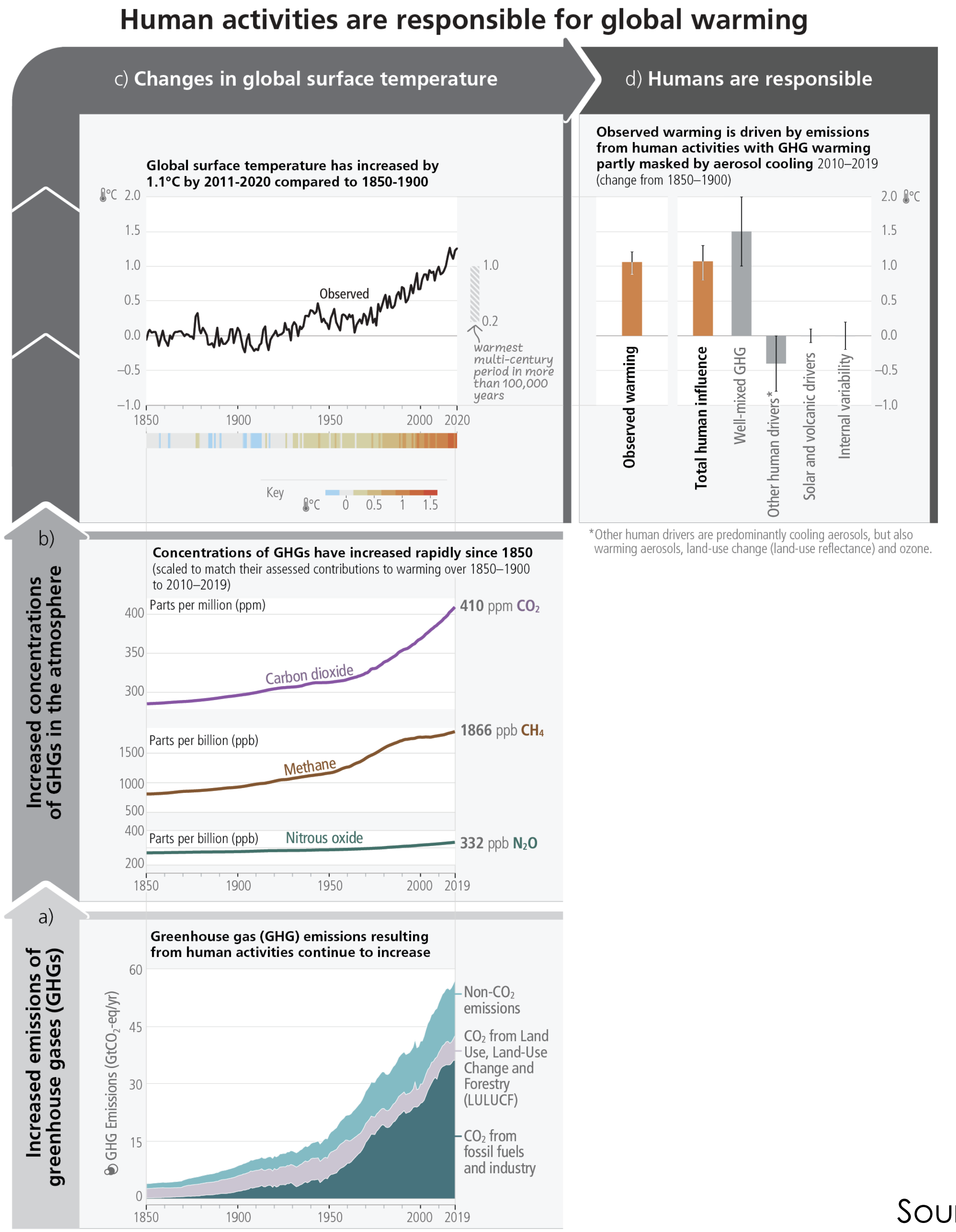
PRINCIPLES GOVERNING IPCC WORK, PARAGRAPH 2
SOURCE: HTTP://WWW.IPCC.CH/PDF/IPCC-PRINCIPLES/IPCC-PRINCIPLES.PDF

Oak Ridge National Laboratory

The Enormous Challenge

“Unequivocal that human influence has warmed the atmosphere, ocean and land”

Global surface temperatures reached 1.1°C above 1850–1900 in 2011–2020

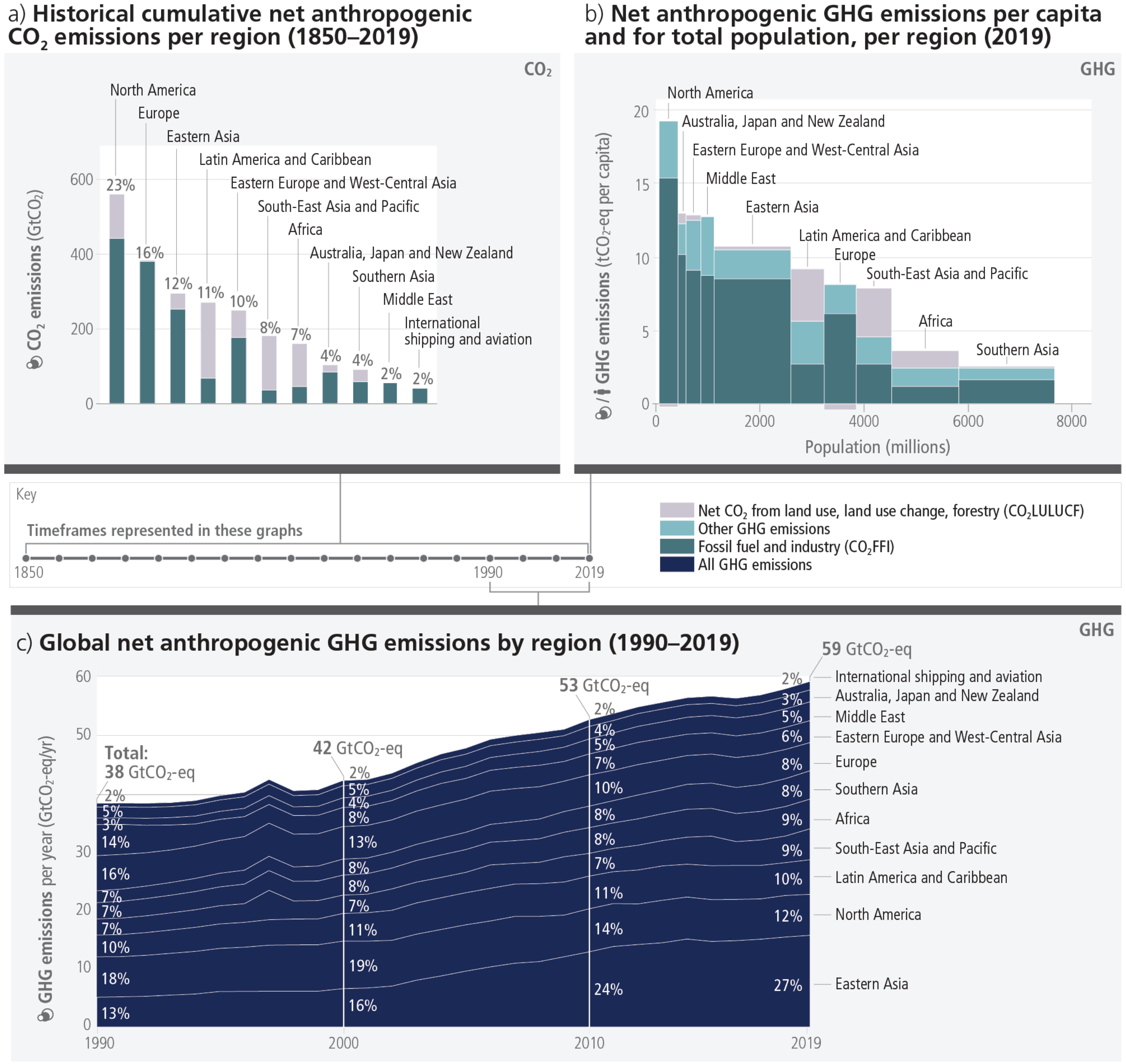


Source: IPCC AR6 Synthesis Report (Fig 2.1)

Historical contributions to global GHGs vary substantially across regions.

"The 10% of households with the highest per-capita emissions contribute 34-45% of global consumption-based household GHG emissions, while the bottom 50% contribute 13-15%."

Emissions have grown in most regions but are distributed unevenly, both in the present day and cumulatively since 1850

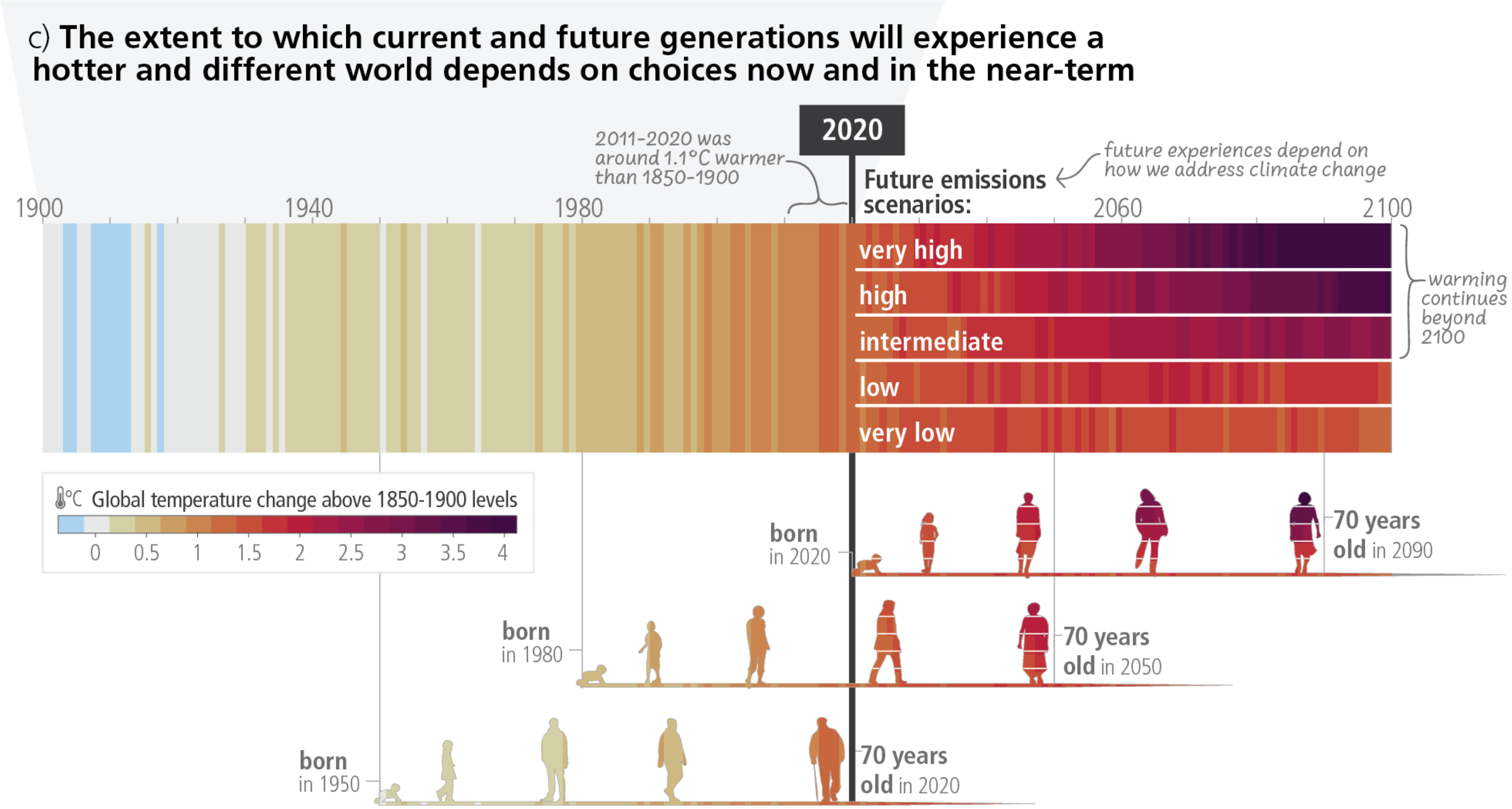


Source: IPCC AR6 Synthesis Report (Fig 2.2)

OAK RIDGE National Laboratory

Future warming will be driven by future emissions.

Past, current, and future generations will experience climate change, and its impacts, differently.



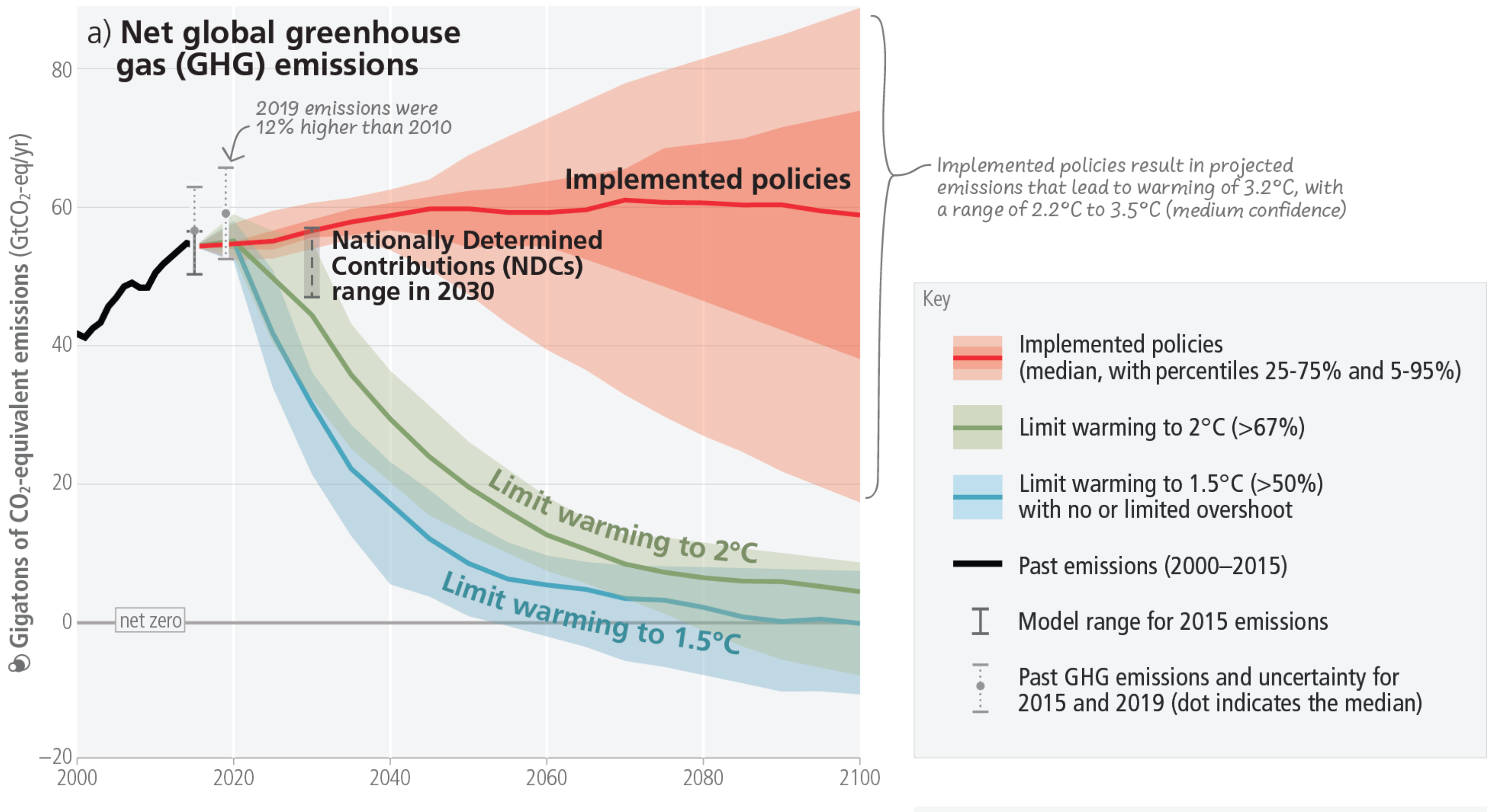
Source: IPCC AR6 Synthesis Report (Fig SPM.1)

Now is the ‘Decisive Decade’ (2021-2030)

“There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all…The choices and actions implemented in this decade will have impacts now and for thousands of years.”

Limiting warming to 1.5°C and 2°C involves rapid, deep and in most cases immediate greenhouse gas emission reductions

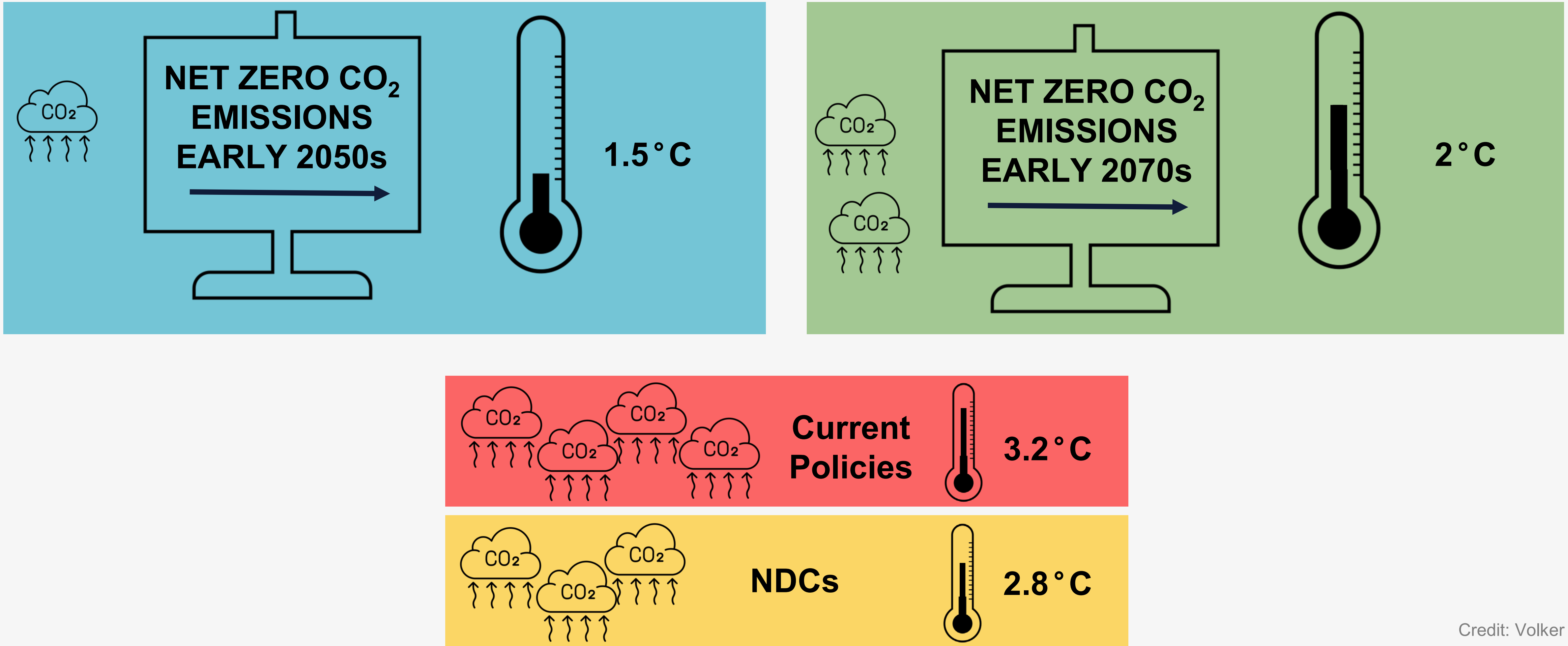
Net zero CO_2 and net zero GHG emissions can be achieved through strong reductions across all sectors



Source: IPCC AR6 Synthesis Report (Fig SPM.5)

Global temperatures will stabilize when the world reaches net zero carbon dioxide emissions (‘balance between sources and sinks’)

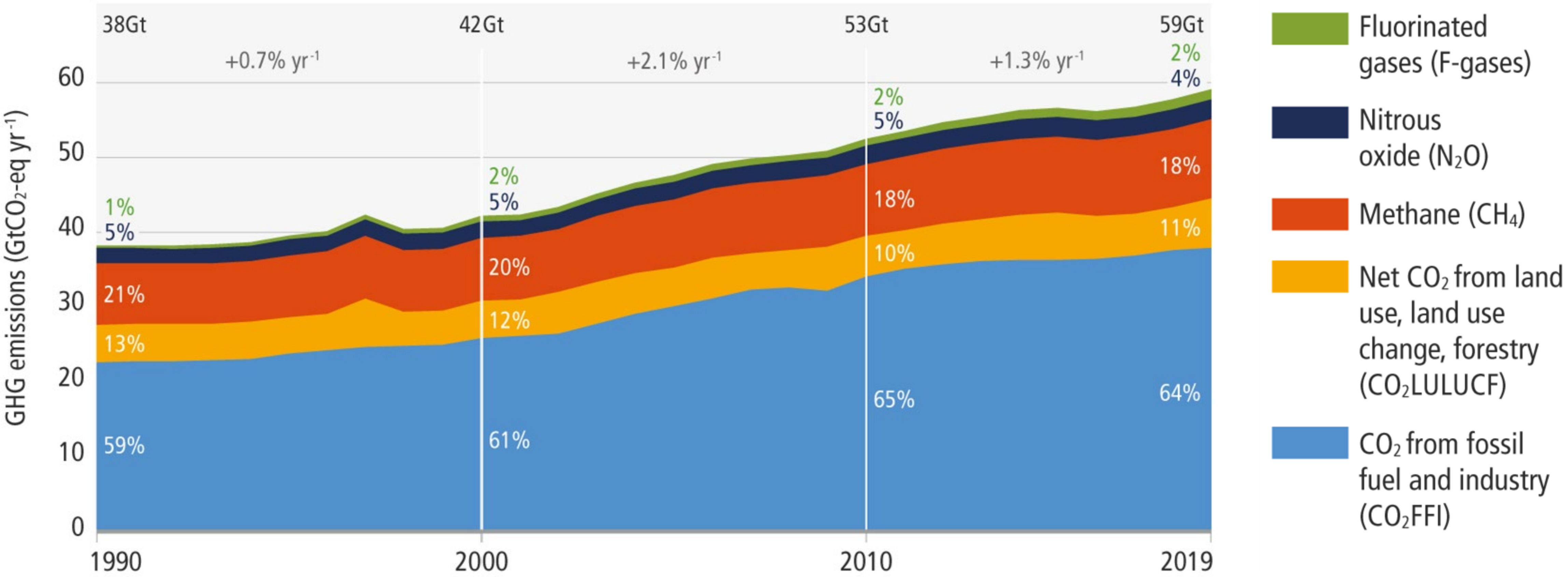
(based on IPCC-assessed scenarios)

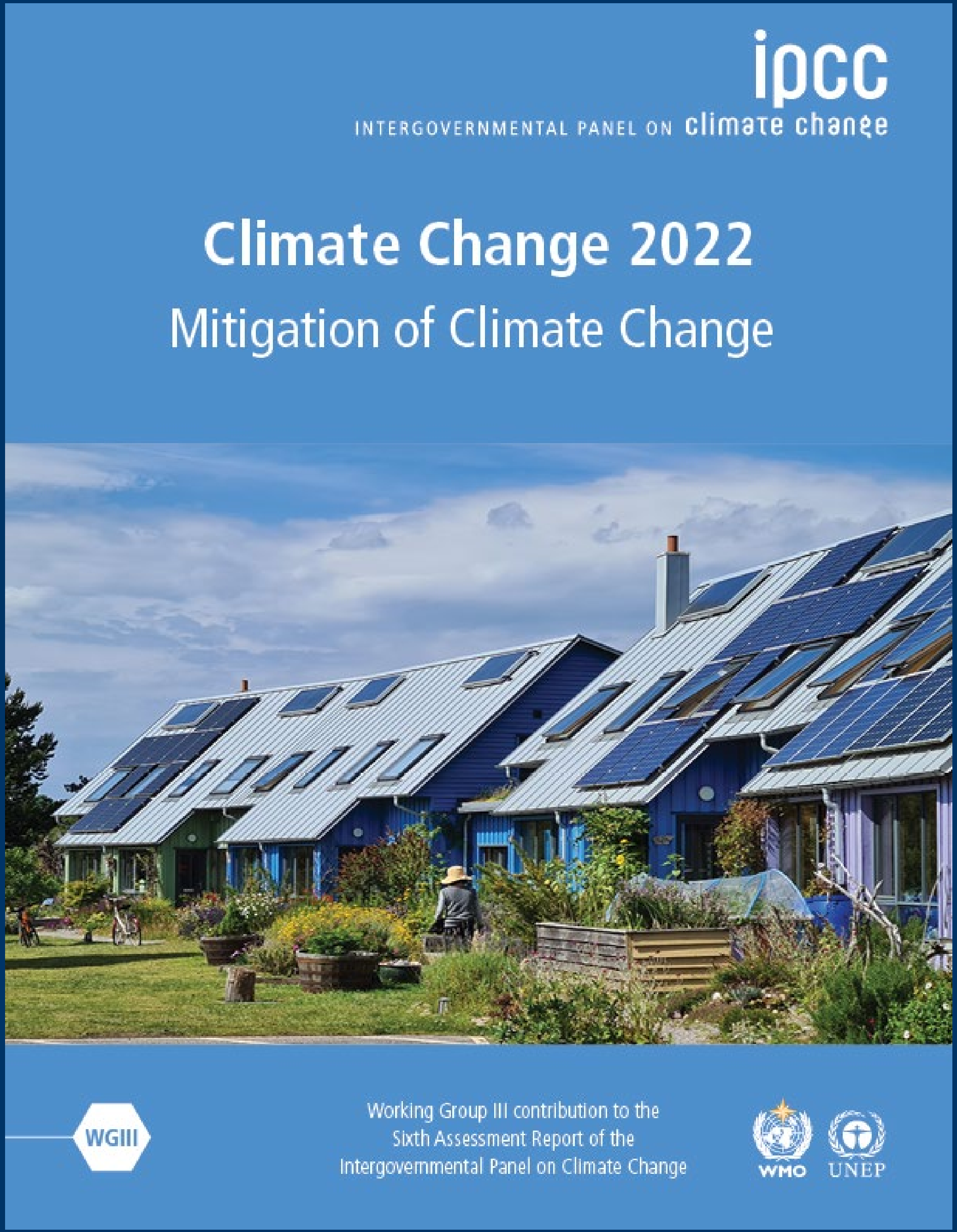


Credit: Volker Krey

The Broader Context

We are not on track to limit warming to 1.5 °C.





[Matt Bridgestock, Director and Architect at John Gilbert Architects]

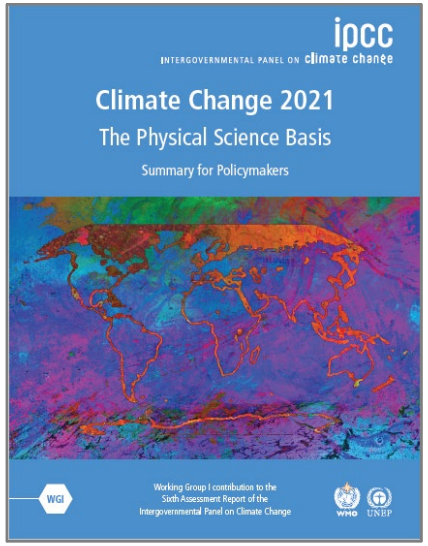
… but there is evidence of increased climate action

Evidence of increased climate action

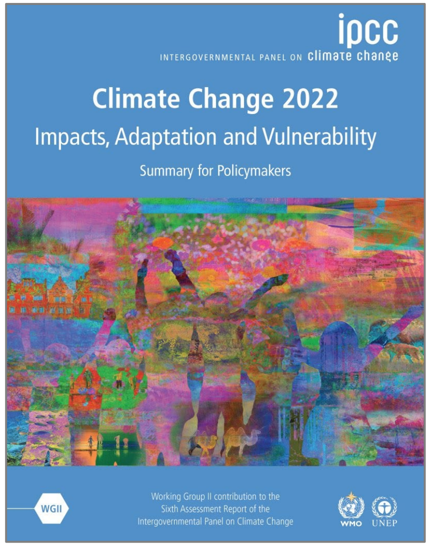
Some countries have achieved a **steady decrease** in emissions **consistent** with limiting warming to **2°C.**
Climate laws present in **56 countries**, covering **>50% of global emissions**.

Zero emissions targets have been adopted by at least **826 cities and 103 regions**

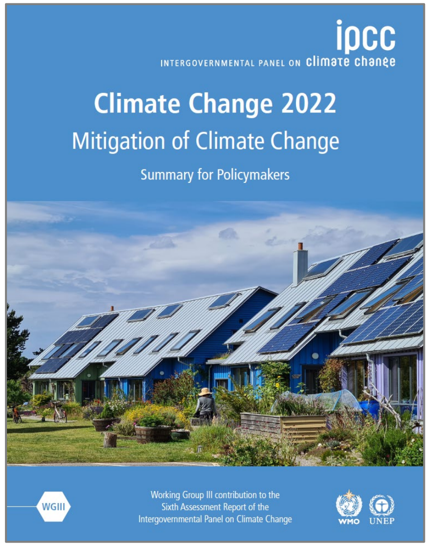
Climate Change and Energy Systems Transformation



Working Group I



Working Group II



Working Group III

International and national goals to keep global temperatures below 2 or 1.5 °C and achieve net-zero emissions by mid-century

Science generates knowledge and informs the possibility space

In USA…

- GHGs 50-52% below 2005 in 2030
- 100% carbon pollution-free power sector by 2035
- Net-zero emissions economy by 2050
- Bipartisan Infrastructure Law
- Inflation Reduction Act

(e.g., 500k EV chargers, high-quality jobs, clean water, broadband internet, …)

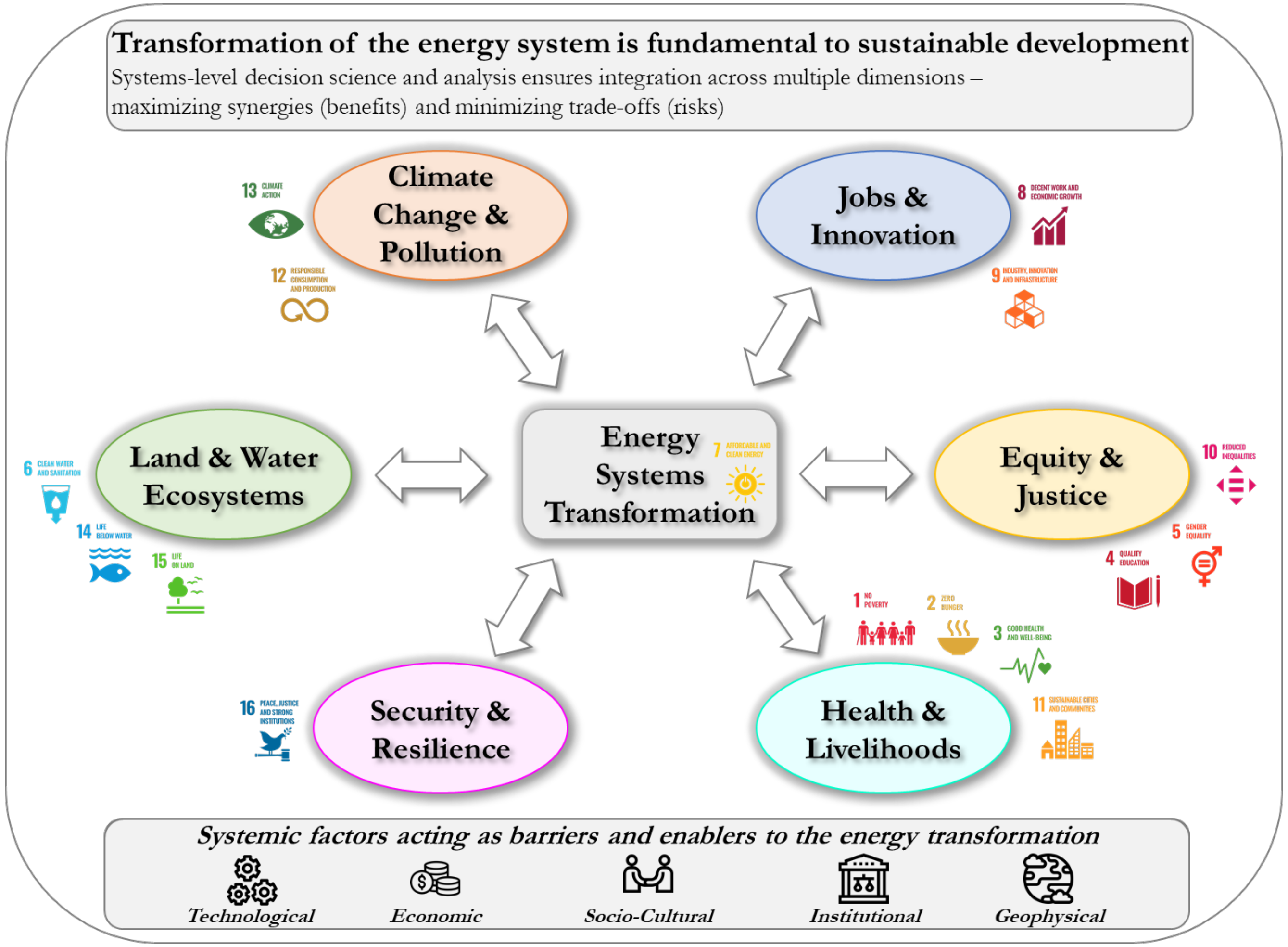
https://www.ipcc.ch/report/ar6/wg1/
https://www.ipcc.ch/report/ar6/wg2/
https://www.ipcc.ch/report/ar6/wg3/
https://www.politico.com/news/2022/03/01/biden-state-of-the-union-2022-missing-00013082

Many Societal Objectives to be Achieved

COP21 • CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

Toward a Nature-Inclusive Energy Transition

one that respects planetary boundaries and improves people's livelihoods



Identify barriers → Investigate enablers → Assess potential to be unlocked

- 'Whole-of-government' approach to the climate crisis
- Minimize tradeoffs (e.g., job losses; energy price rises; food shortages) => can be barriers to transition
- Maximize synergies (e.g., job gains; improved resilience; cleaner air; reduced water and ecosystem stress) => can accelerate transition
- Explore potential energy systems transition pathways from all sides
- Integrated, holistic perspective is needed
- Enormous potential at ORNL to marry basic science with applied R&D

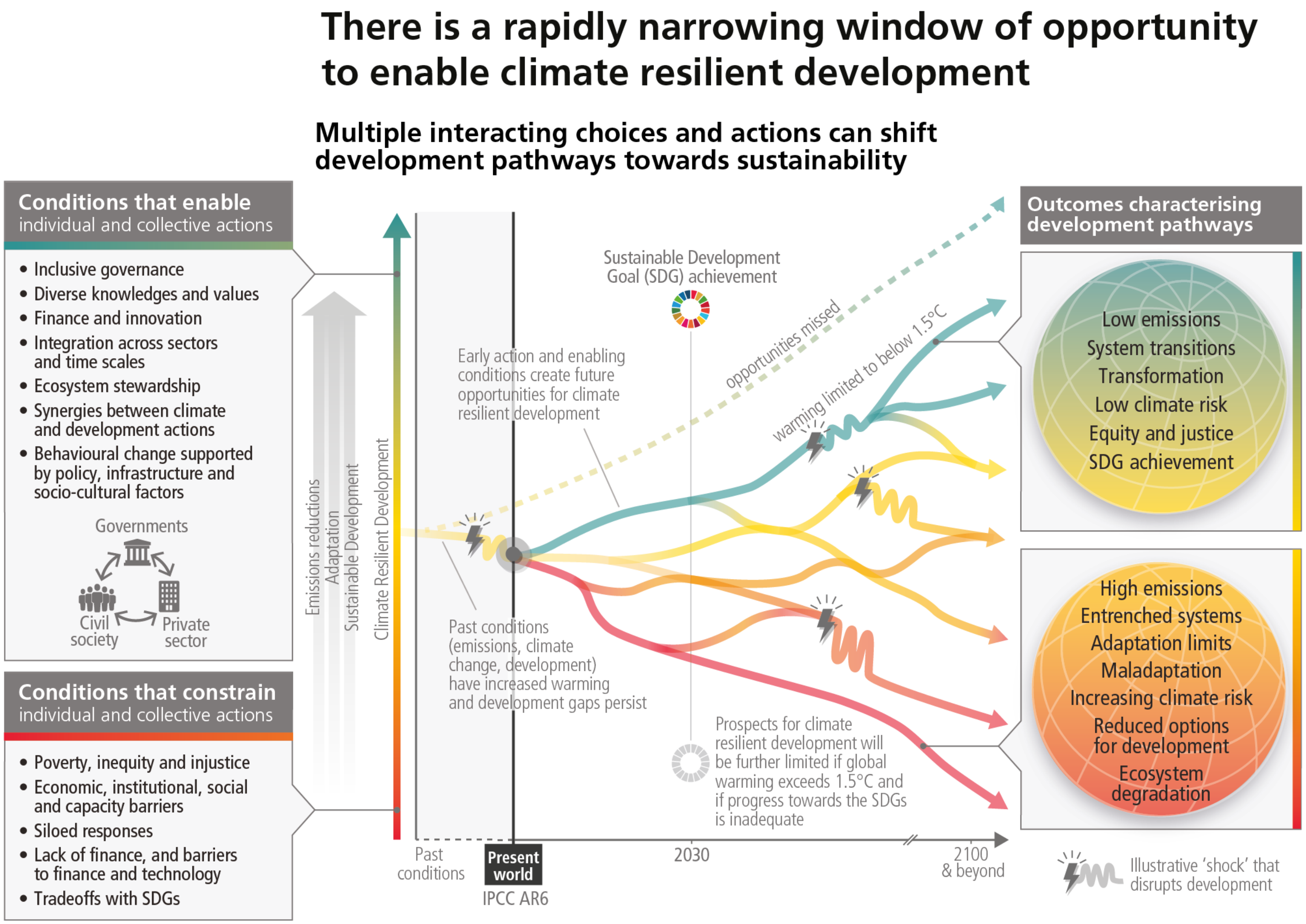
OAK RIDGE
National Laboratory

The Solution Space

Many pathways that society can take.

Pathways and opportunities for action are shaped by previous actions (or inactions and missed opportunities) and enabling and constraining conditions.

Diverse expertise to be relied upon includes: cultural values, Indigenous Knowledge, local knowledge, and scientific knowledge.



Source: IPCC AR6 Synthesis Report (Fig SPM.6)

Scenarios collected and assessed in IPCC AR6 WG III (Mitigation)

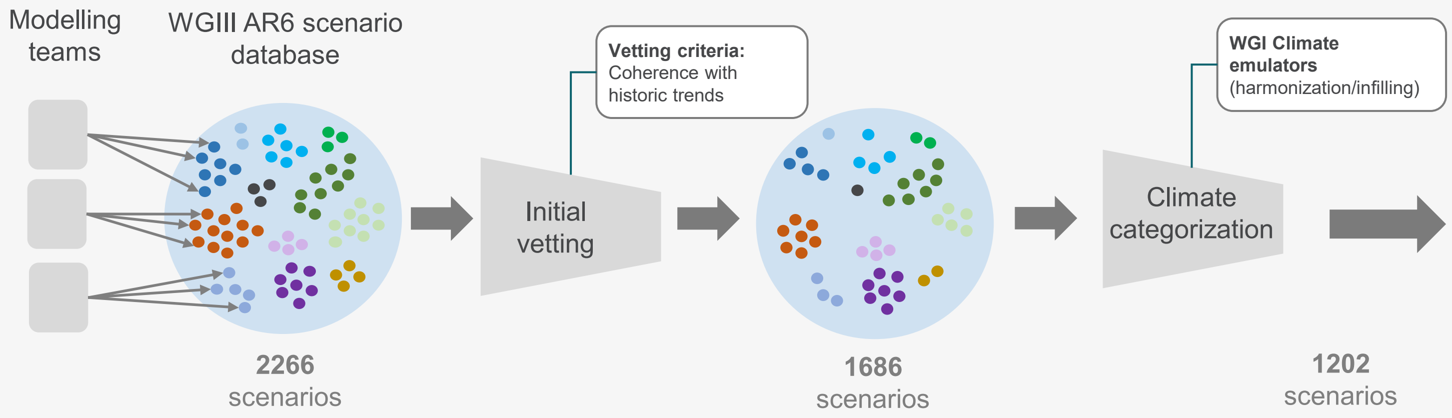


Table SPM1

p50 (p5-p95) [(1)] Global Mean Surface Air Temperature change			GHG emissions Gt CO_2-eq/yr			GHG emissions reductions from 2019 % [(7)]			Emissions milestones [(8,9)]			Cumulative CO_2 emissions Gt CO_2 [(12)]		Cumulative net-negative CO_2 emissions Gt CO_2	Temperature change 50% probability [(13)] °C		Likelihood of peak temperature staying below (%) [(14)]		
Category [(2, 3, 4)] [# pathways]	Category description	WG I SSP & WG III IPs/IMPs alignment [(5, 6)]	2030	2040	2050	2030	2040	2050	Peak CO_2 & GHG emissions [% peak before 2100]	net-zero CO_2 [% net-zero pathways]	net-zero GHGs [(10, 11)] [% net-zero pathways]	2020 to net-zero CO_2	2020-2100	year of net-zero CO_2 to 2100	at peak warming	2100	<1.5°C	<2.0°C	<3.0°C
A categorisation of pathways according to temperature outcomes. All Categories are with >50% probability of staying below the stated temeprature, with exception of C3 catgeories which are >=67% probability (likely). Alignment of the WG I SSP pathways and the WG III Illustrative (Mitigation) Pathways is also indicated			*Median annual GHG emissions in the year across the scenarios, with the 5th-95th percentile in brackets*			*Median GHG emissions reductions of pathways in the year across the scenarios compared to 2019, with the 5th-95th percentile in brackets*			*Median 5-year interval at which CO2 & GHG emissions peak, with the 5th-95th percentile interval in brackets. All pathways peak, unless a % is denoted in square brackets*	*Median 5-year interval at which CO2 & GHG emissions of pathways in this category reach net-zero, with the 5th-95th percentile interval in brackets. All pathways reach net-zero, unless a % is denoted in square brackets. ... denotes net-zero not reached for that percentile.*		*Median cumulative net CO2 emissions across the scenarios in this category until reaching net-zero or until 2100, with the 5th-95th percentile interval in brackets.*		*Median cumulative net-negative CO2 emissions of pathways that occur between the year of net-zero CO2 and 2100. More net-negative results in more temperature reductions after peak*	*Temperature change of pathways in this category (50% probability across the range of climate uncertainties), relative to 1850-1900, at peak warming and in 2100, for the median value across the scenarios and the 5th-95th percentile interval in brackets.*		*Median likelihood that the pathways in this catgeory stay below a given temperature, with the 5th-95th percentile interval in brackets*		
C1 [97]	Below 1.5°C with no or limited overshoot	SD, LD, SSP1-19, Ren	31 (21-36)	17 (6-23)	9 (1-15)	43 (34-60)	69 (58-90)	84 (73-98)	< 2025 [100%] (< 2025)	2050-2055 [100%] (2035-2070)	2095-2100 [53%] (2050-...)	510 (330-710)	320 (-210-570)	-200 (-560-0)	1.6 (1.4-1.6)	1.3 (1.1-1.5)	38 (33-58)	90 (86-97)	100 (99-100)
C2 [133]	Below 1.5°C with high overshoot	Neg	42 (31-55)	25 (17-34)	14 (5-21)	23 (0-44)	55 (40-71)	75 (62-91)	< 2025 [100%] (< 2030)	2055-2060 [100%] (2045-2070)	2070-2075 [87%] (2055-...)	720 (530-930)	400 (-90-620)	-330 (-620--30)	1.7 (1.5-1.8)	1.4 (1.2-1.5)	24 (15-42)	82 (71-93)	100 (99-100)
C3 [311]	Likely below 2°C	GS	44 (32-55)	29 (20-36)	20 (13-26)	21 (1-42)	46 (34-63)	64 (53-77)		2070-2075 [93%] (2055-2095)	...-... [30%] (2075-...)	880 (640-1130)	800 (500-1140)	-40 (-280-0)	1.7 (1.6-1.8)	1.6 (1.5-1.8)	20 (13-41)	76 (68-91)	99 (98-100)
C3a [204]	... with immediate action	SSP1-2.6	40 (30-49)	29 (21-36)	20 (14-27)	27 (13-45)	47 (35-63)	63 (52-76)	<2025 [100%] (<2025)	2070-2075 [91%] (2055-2100)	...-... [24%] (2080-...)	850 (630-1140)	790 (480-1150)	-10 (-280-0)	1.7 (1.6-1.8)	1.6 (1.5-1.8)	21 (14-42)	78 (69-91)	100 (98-100)
C3b [97]	... consistent with NDCs + accelerated action post 2030		52 (47-56)	29 (20-36)	18 (10-25)	5 (0-14)	46 (34-63)	68 (56-82)	< 2025 [100%] (< 2030)	2065-2070 [97%] (2060-2085)	...-... [42%] (2075-...)	910 (720-1100)	800 (560-1050)	-70 (-300-0)	1.8 (1.6-1.8)	1.6 (1.5-1.7)	17 (12-35)	73 (67-87)	99 (98-99)
C4 [159]	Below 2°C		50 (41-56)	38 (28-44)	28 (19-35)	10 (0-27)	31 (20-50)	49 (35-65)		2075-2080 [86%] (2065-2100)	...-... [31%] (2075-...)	1170 (960-1410)	1160 (700-1490)	-30 (-390-0)	1.9 (1.7-2.0)	1.8 (1.5-2.0)	11 (7-22)	59 (50-77)	98 (95-99)
C5 [212]	Below 2.5°C		52 (46-56)	45 (37-53)	39 (30-49)	6 (-1-18)	18 (4-33)	29 (11-48)	<2025 [100%] (<2035)	2090-2095 [41%] (2075-2100)	...-... [12%] (2090-...)	1610 (1340-1910)	1780 (1260-2360)	0 (-140-0)	2.2 (1.9-2.5)	2.1 (1.9-2.5)	4 (0-10)	37 (18-59)	91 (83-98)
C6 [97]	Below 3°C	SSP2-4.5 Mod-Act	54 (50-62)	53 (48-61)	52 (45-57)	2 (-10-11)	3 (-14-14)	5 (-2-18)	2030-2035 [97%] (<2085)				2790 (2440-3520)			2.7 (2.4-2.9)	0 (0-0)	8 (2-18)	71 (53-88)
C7 [164]	Below 4°C	SSP3-7.0 Cur-Pol	62 (53-69)	67 (56-76)	70 (58-83)	-11 (-18-3)	-19 (-31-1)	-24 (-41--2)	2070-2075 [57%] (2025-2095)	no net-zero		no net-zero	4220 (3160-5000)	no net-zero	temperature does not peak by 2100	3.5 (2.8-3.9)	0 (0-0)	0 (0-2)	22 (7-60)
C8 [29]	Above 4°C	SSP5-8.5	71 (69-81)	80 (78-96)	88 (82-112)	-20 (-34--17)	-35 (-65--29)	-46 (-92--36)	2080-2085 [90%] (2060-2095)				5600 (4910-7450)			4.2 (3.7-5.0)	0 (0-0)	0 (0-0)	4 (0-11)

190 Models (91+ modeling families):

- ✓ 98 globally comprehensive,
- ✓ 71 national or multi-regional,
- ✓ 20 sectoral models

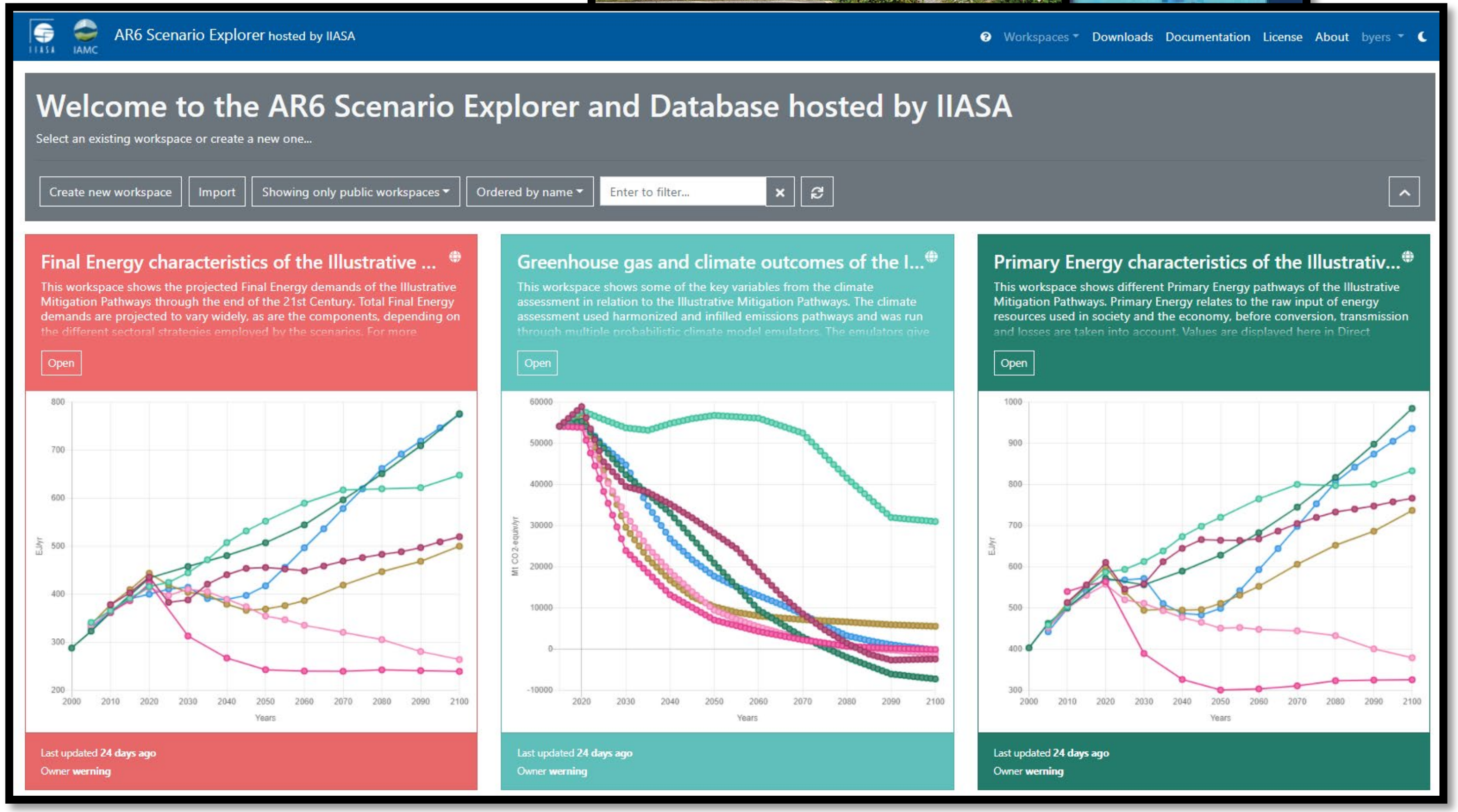
Scenarios :

- ✓ 3131 submitted scenarios (global, sectoral, national)
- ✓ 2266 with sufficient information for climate assessment
- ✓ 1686 scenarios passed the baseline vetting
- ✓ 1202 in final Ch 3 climate assessment

Credit: Ed Byers

IPCC AR6 WG III Scenario Database
(building on AR5 & SR1.5 experience)

- ✓ Facilitate collection of scenarios from the community
- ✓ Facilitates data sharing and analysis during report writing
- ✓ Establish internally consistent, quality-controlled and comparable datasets
- ✓ Data security during report writing
- ✓ Data transparency on publication

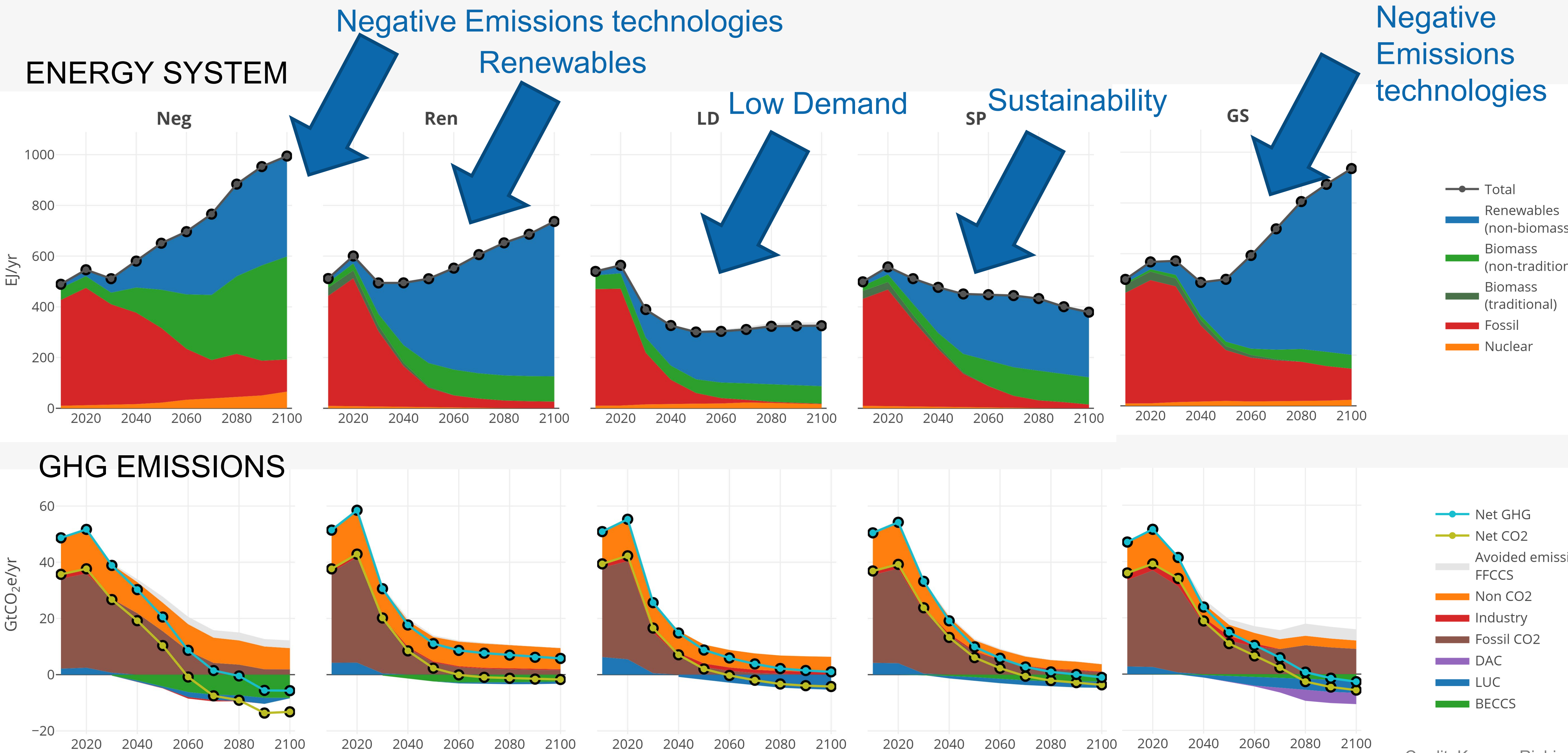


Visit the Scenario Explorer at https://data.ece.iiasa.ac.at/ar6/

Credit: Ed Byers

Illustrative Mitigation Pathways =>

Many Ways to Achieve Net Zero … Benefits and Risks of Each

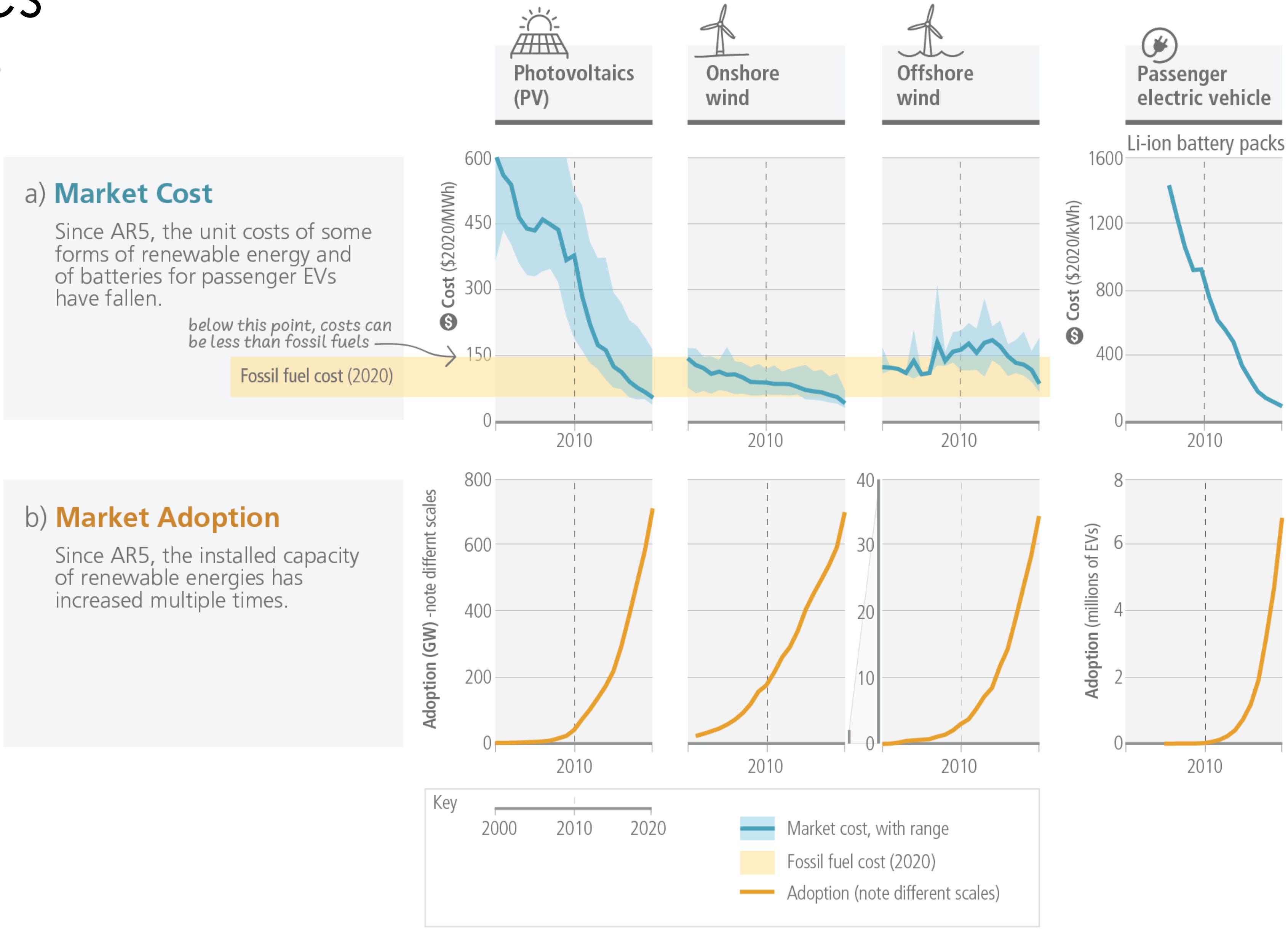


Credit: Keywan Riahi

The Unique Opportunity

Low-Carbon Technologies Continue to Mature

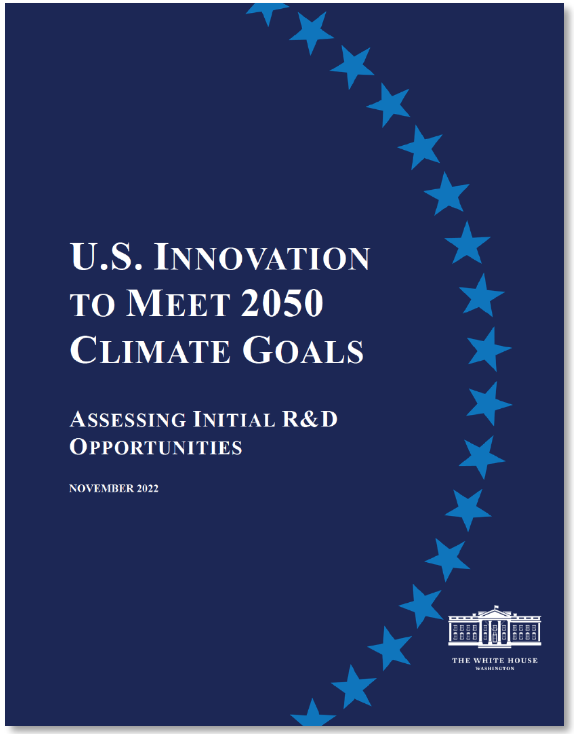
Renewable electricity generation is increasingly price-competitive and some sectors are electrifying



Source: IPCC AR6 Synthesis Report (Fig 2.4)

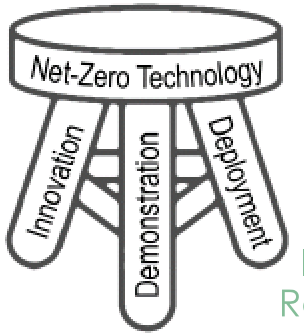
Oak Ridge National Laboratory

Net-Zero Game Changers


U.S. INNOVATION TO MEET 2050 CLIMATE GOALS

ASSESSING INITIAL R&D OPPORTUNITIES

NOVEMBER 2022



Threefold strategy for technologies needed to achieve net-zero emissions by 2050

CHIPS and Science Act

Bipartisan Infrastructure Law

Inflation Reduction Act

Transformational Impact	Broad Impact	Targeted Impact
Advanced Distribution Systems: Data, Optimization, & Controls	Circular Economy & Secure Supply Chains	Repurposing Pipelines for CO_2 and H_2Transport
CO_2 Capture, Utilization, & Storage	Efficient & Alternative Biofuel Production	Repurposing Transportation ROWs
Long Duration Energy Storage	Net-Zero Electrofuels	Electric & Hybrid Aircraft
Net-Zero Hydrogen & Ammonia	Connected & Automated Vehicles	Low-CO_2 Shipping
Net-Zero Power Grid: Advanced Transmission Planning & Operation	High-Speed & Electrified Rail	Low-CO_2 Aluminum
Advanced Batteries	Mobility on Demand	Low-CO_2 Cement
Low-CO_2 Heavy-Duty Vehicles	Advanced Nuclear Fission	Low-CO_2 Chemicals
Low-Cost Away-From-Home Charging	Advanced Solar	Low-CO_2 Steel
Fusion Energy	Advanced Wind	Low-CO_2 Greenhouses & Livestock Facilities
Low-GHG HVAC & Refrigerants	Enhanced Geothermal	
Engineered CDR	Low-CO_2 Industrial Heat & Clean Water	
Nature-Based CDR	Low-CO_2 Building Construction & Operation	
	Low-CO_2 Infrastructure Construction	
	GHG-Reducing Cropping Practices	
	Non-Agricultural Methane Reduction	
	Reduced Livestock GHGs	

Legend

Cross-Cutting Innovation	Transportation Technology	Electricity Generation	Industrial Processes	Buildings & Infrastructure	Agriculture & Methane Reduction	Carbon Removal

Note that the technologies are grouped by sector and appear in alphabetical order.

ORNL Efforts in Climate Change and Decarbonization

Examples (some established, others nascent) provided for illustration

- Transformational Decarbonization Initiative (LDRD)
- Climate Change Science Institute
- UT – Oak Ridge Innovative Institute (UT-ORII)
- Appalachian Carbon Forum
- Regional Decarbonization Project for the Southeast
- Net-Zero ORNL Campus (part of Sustainable ORNL)
- Decision Science and Global Change Analysis for Nature-Inclusive Energy Transitions

+ *Numerous individual projects (both large and small, many multi-lab)*

NET ZERO WORLD INITIATIVE

Accelerating Global Energy System Decarbonization

Net Zero World Overview

April 2023

USAID FROM THE AMERICAN PEOPLE

U.S. DEPARTMENT OF ENERGY

USTDA U.S. TRADE AND DEVELOPMENT AGENCY

DFC U.S. International Development Finance Corporation

EXIM EXPORT-IMPORT BANK OF THE UNITED STATES

MILLENNIUM CHALLENGE CORPORATION UNITED STATES OF AMERICA

The Net Zero World Initiative will partner with countries to help them implement climate ambition pledges and accelerate global transitions to net zero, resilient, and inclusive energy systems.

Net Zero World Will Harness Unique USG and Lab Assets in Partnership with Philanthropies

Whole of US Government Management Team

Country Partners: governments, private sector, academia, technical institutes, and civil society (including marginalized communities)

Federal Agency and DOE Lab Implementation Teams – Sector and Country-Specific

DOE – Energy Technology and Deployment Expertise

State Department – Energy and Climate Diplomacy

USAID – Integration with Development Assistance

EXIM/MCC/DFC/TDA/Commerce/Treasury – Investment and Business Partnerships

Initial Partner Governments

- **Argentina**
- **Chile**
- **Egypt**
- **Indonesia**
- **Nigeria**
- **Ukraine**
- **Thailand**
- **Singapore**

Philanthropies & Other Partners Support

- Breakthrough Energy
- Lynne and Marc Benioff
- Bloomberg Philanthropies
- MDBs, GIZ, others

KEY ENERGY SECTORS AND TOPICS AND INITIAL LAB TEAM

- **Buildings**
- **Industry**
- **Transport**
- **Power & Energy Storage**
- **Carbon Capture, Use, and Storage**
- **Agriculture**
- **Energy Systems**
- **Nuclear**

NREL Transforming ENERGY

Pacific Northwest National Laboratory

Berkeley Lab

Argonne National Laboratory

Oak Ridge National Laboratory

Brookhaven National Laboratory

Lawrence Livermore National Laboratory

Sandia National Laboratories

INL Idaho National Laboratory

NETL National Energy Technology Laboratory

Collaborative Action Areas

- Analysis and Road Maps
- RD&D – piloting, testing, incubators
- Policies and Regulations
- Deployment and Investment Programs
- Workforce Development

Mission

The Net Zero World Initiative will partner with countries to help them **implement climate ambition pledges** and accelerate global transitions to net zero, resilient, and inclusive energy systems.

The Net Zero World Initiative Offers Partners:

- **Immediate and sustained access to expert technical, deployment, and investment analysis and facilitation** from the U.S. government, including the U.S. DOE's world-class national laboratories.
- **Targeted support for in-country technical institutions** to build long-term, self-sustaining technical capacity.
- **Deep collaboration to develop technical and investment plans and support implementation** for technology project design and testing, infrastructure modernization, enabling policies and measures, investment analysis and facilitation, capacity building and workforce development, and other critical actions needed to achieve near- and long-term energy system decarbonization.

Timeline and Performance Metrics

By 2022	By 2023	By 2024
Assist with net zero energy technical and investment plans and support quick win measures	Provide deep cooperation to support priority policies and programs for countries to achieve net zero transitions	Continue implementation support, expand clean energy economies and jobs, and mobilize at least $10B in clean energy infrastructure and project investment

Example Technical Cooperation Areas to Support Net Zero Transitions

Transportation

- **Policies** supporting public-fleet **procurement** and **sustainable fuel** adoption
- **Low-carbon fuel standards** to drive deployment of zero-emissions vehicles
- **Modeling and analysis** of low and zero carbon options

Industry

- **Policies and standards** for energy and material efficiency
- **Modeling and analysis** to determine decarbonization opportunities
- Programs to support **clean energy entrepreneurship** and energy justice

Buildings

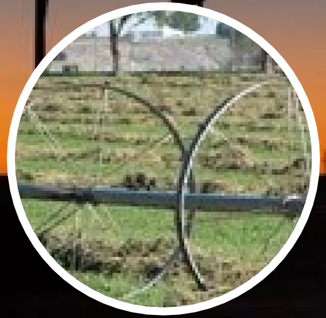
- **Policies** to attract **finance**
- **Codes and standards** for building and appliance efficiency
- **Technology demonstration** at building/community-level
- **Workforce development** for operators of net-zero buildings at scale
- **Modeling and analysis** of decarbonization options

Carbon Capture and Geologic Storage

- **Country-level assessments** to identify opportunities and technical assistance
- Regulatory assistance and best practices for **community engagement**
- Clean energy pathways that **link CCS and renewables**
- Assessment capacity building

Power and Storage

- Grid modernization **infrastructure and operational tools**
- High penetration **renewables deployment** options
- **Analysis and road mapping** to evaluate storage technologies
- **Policies and regulations** for grid planning, energy storage business models and market development



Energy System-Wide & Cross-cutting Topics

- **Energy system-wide analysis** to inform net zero technical and investment plans
- **Just transition** and **energy equity**
- Energy **investment** and **finance** mobilization
- Energy use for **agriculture**
- **Hydrogen** production, use in transportation, industry, etc.
- **Nuclear energy** for baseload electricity

LDRD Transformational Decarbonization Initiative (TDI)

TDI Initiative
(Lead: David Sholl)

=> TDI projects paired with DS@ORNL analysis

CO_2 Capture Thrust
(Thrust lead: Michelle Kidder)

Scalable, cost-efficient technologies

- CO_2 membrane contactor (PI – Islam)
- DAC with amino acids (PI – Custelcean)
- Electrothermal CO_2 adsorption (PI – Paul)
- CO_2 capture in cement(PI – BranAnleu)
- CO_2 capture with building infrastructure (PI – Nawaz)
- DAC with mineral looping (PI – Stack)

CO_2 Conversion Thrust
(Thrust lead: Shannon Mahurin)

Chemistry without aqueous solvents

- Molten salt CO_2 conversion to carbon (PI – Mahurin)
- Scalable CO_2 conversion using $scCO_2$ (PI – Veith)
- Nonaqueous CO_2 reduction using electron-proton mediators (PI – Nanda)
- Plasma-assisted urea synthesis (PI – Ivanov)

Decision Science Thrust
(Thrust lead: David McCollum)

Focusing R&D needs and priorities

- Planning future CO_2 infrastructure (PI – Uddin)
- Effects of CDR on carbon sinks (PI – Thornton)

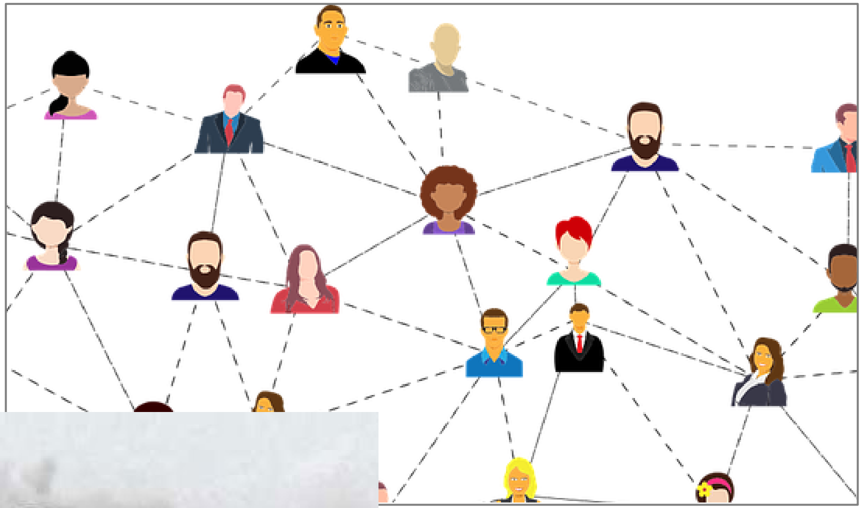
<u>TDI Objective</u>: Establish ORNL leadership in carbon negative technologies and economic sectors that will be challenging to decarbonize

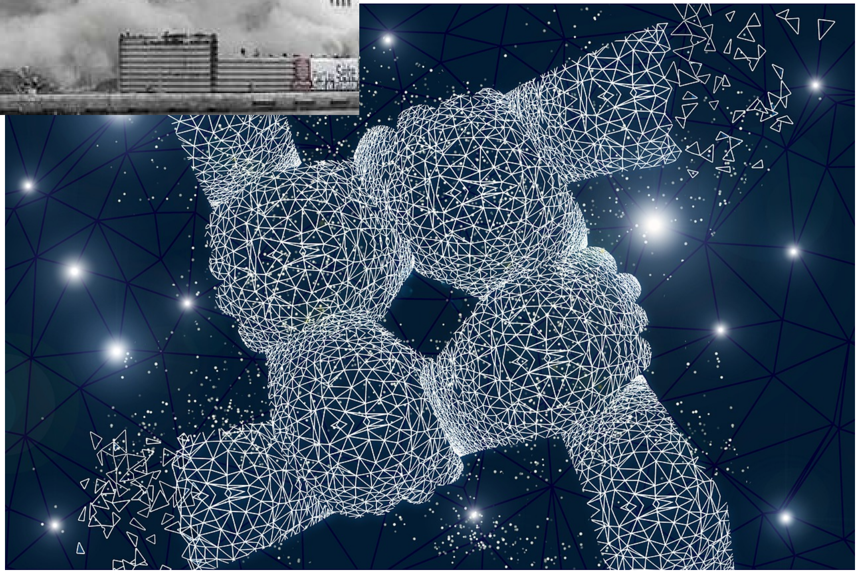
<u>DS@ORNL Objective</u>: Understand how novel experimental designs could potentially figure into the broader suite of decarbonization activities and assess where the opportunities and barriers may lie

DecisionScience@ORNL objectives

1. **<u>Promote networking</u>** of decision-science (DS) experts and enthusiasts at ORNL, including informing non-DS ORNL staff about the breadth and utility of decision-science methodologies

2. **<u>Integrate</u>** decision-science knowledge and tools throughout the laboratory's research portfolio, including establishing a pool of decision-science experts who can quickly come together for proposals and awarded projects





UrbanDAC: Distributed Direct Air Capture at the Urban Scale

PIs: Thomaz Carvalhaes, Nasir Ahmad (Built Environment Characterization Group, NSSD)

Goal: Data-driven framework to guide systems-level design and decision-making processes toward city-scale implementation of sustainable and resilient DAC technologies

Background:

DecisionScience@ORNL project

Inspired by and as a sub-effort to TDI project "*Intensified Carbon Capture Using Buildings Infrastructure*" by Kashif Nawaz (PI) et al.

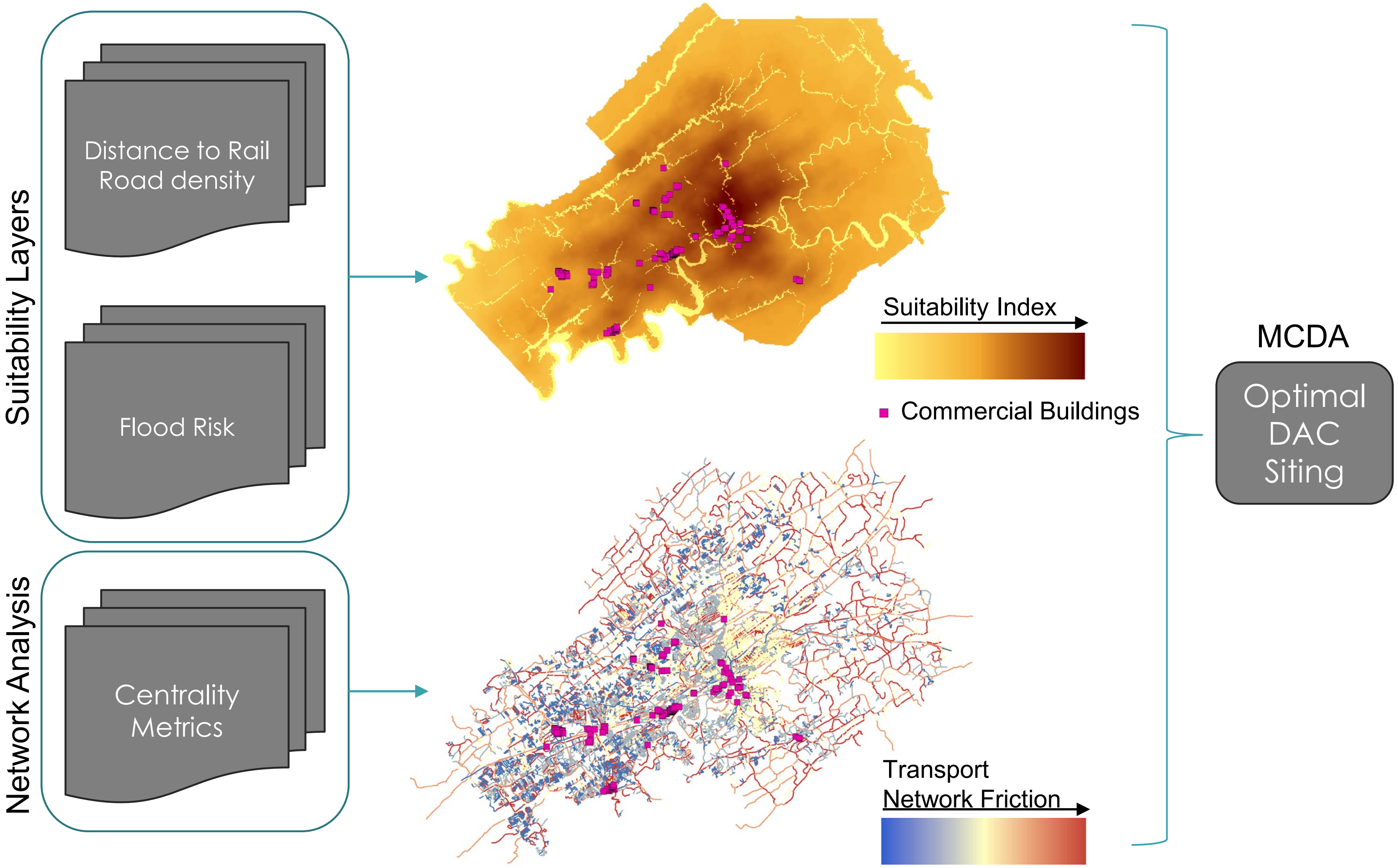
Methods:

Two-part geographic multi-criteria decision analysis (MCDA) approach:

- Suitability index for selecting candidate buildings for UrbanDAC;
- Network analysis that optimizes the resilience of the network

Preliminary Results:

- For mid-size city (Knoxville, TN), some candidates located in high-risk floodplains
- 20 optimal candidates initially identified for further analysis



Integrated perspective is needed to deliver on mission-critical challenges … and the mission continues to evolve

> Is anything really lost if a big laboratory becomes only a collection of weakly interacting little laboratories? To my mind, the laboratory's very essence is lost, in both applied and basic research … the strength of laboratories like ORNL lies in the interdisciplinary composition of their staffs.
>
> Over and over again it has been demonstrated that the whole can be greater than the sum of its parts, that good people from diverse fields working together can make major scientific discoveries that are denied geniuses working in isolation.
>
> – Alvin Weinberg (ORNL Director), 1967

21 July 1972, Volume 177, Number 4045

SCIENCE

Science and Trans-Science

Many of the issues that lie at the interface between science and politics involve questions that can be stated in scientific terms but that are in principle beyond the proficiency of science to answer. In a recent paper in *Minerva* [**10**, 209 (April 1972)], I proposed the term "trans-scientific" for such questions. For example, the biological effect on humans of very low level radiation (or of other physical insult, for that matter) will probably never be fully ascertained, simply because of the huge number of animals required to demonstrate an unequivocal effect. Estimates of extremely unlikely events (such as a serious reactor accident) can never be made with anything like the scientific validity that one can apply to estimates of events for which there are abundant statistics.

In the current attempts to weigh the benefits of technology against its risks, the protagonists often ask for the impossible: scientific answers to questions that are trans-scientific. What the scientist can do in clarifying matters of trans-science differs from what he can do in clarifying matters of science. In the latter case, he can bring to bear his scientific expertise to help establish scientific truth; in the former case, he can, at most, help delineate where science ends and trans-science begins. We scientists sometimes refuse to concede that science has limits. The debate on risks versus benefits would be more fruitful if we recognized these limits.

Scientific truth is established by the traditional methods of peer review: only what has value in the intellectual marketplace survives. By contrast, where trans-science is involved, wisdom (rather than truth) must be arrived at by some other mechanism. Our society is experimenting with procedures, either adjudicative or political, for making the delicate judgments of value that underlie the resolution of trans-scientific questions. These procedures are much in vogue now as a consequence of the National Environmental Policy Act. Although these procedures are often marred by their lack of discipline, even unruliness, such untidiness is, I suspect, inevitable in a democratic society.

We scientists value our republic of science with its rigorous peer group review. The uninformed public is excluded from participation in the affairs of the republic of science rather as a matter of course. But when what we do transcends science and impinges on the public, we have no choice but to welcome public participation. Such participation by the uninitiated in matters that have both scientific and trans-scientific elements may pose some threat to the integrity of the republic of science. To my mind, however, this is a lesser threat than is the threat to our democratic processes that would be posed by excluding the public from participation in trans-scientific debate.

We must strive to improve our procedures for conducting this debate in such a way that the issues can be aired fully and yet the procedures themselves cannot be easily abused. That this is easier said than done does not absolve us as scientists from contributing to the development of better institutions for conducting trans-scientific debate.—ALVIN M. WEINBERG, *Director, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830*

Weinberg (1972). "Science and Trans-Science." *Science*.

- Weinberg founded and directed the **Institute for Energy Analysis** at Oak Ridge Associated Universities (ORAU) from 1976 to 1984.
- Weinberg's Institute was:
  - … one of the first in the world to explore the **link between CO_2 in the atmosphere and its resulting effect on global warming**.
  - … a hub for inter- and trans-disciplinary **decision science and analysis**.

Oak Ridge National Laboratory

Thank you!

David L. McCollum, Ph.D.

mccollumdl@ornl.gov