Control for Climate Change Mitigation and Adaptation

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Questions to the Panelists and Community

- What are the most important problems in the climate change mitigation and adaptation space for three different time horizons: 2030, 2040, and 2050? Why?

- What are the unique opportunities for control to make impactful contributions for the technology goals for these timeframes? Can the goal(s) be achieved without contribution from controls field?

- What are the novel technical challenges that need to be overcome for various specific goals to be achieved?

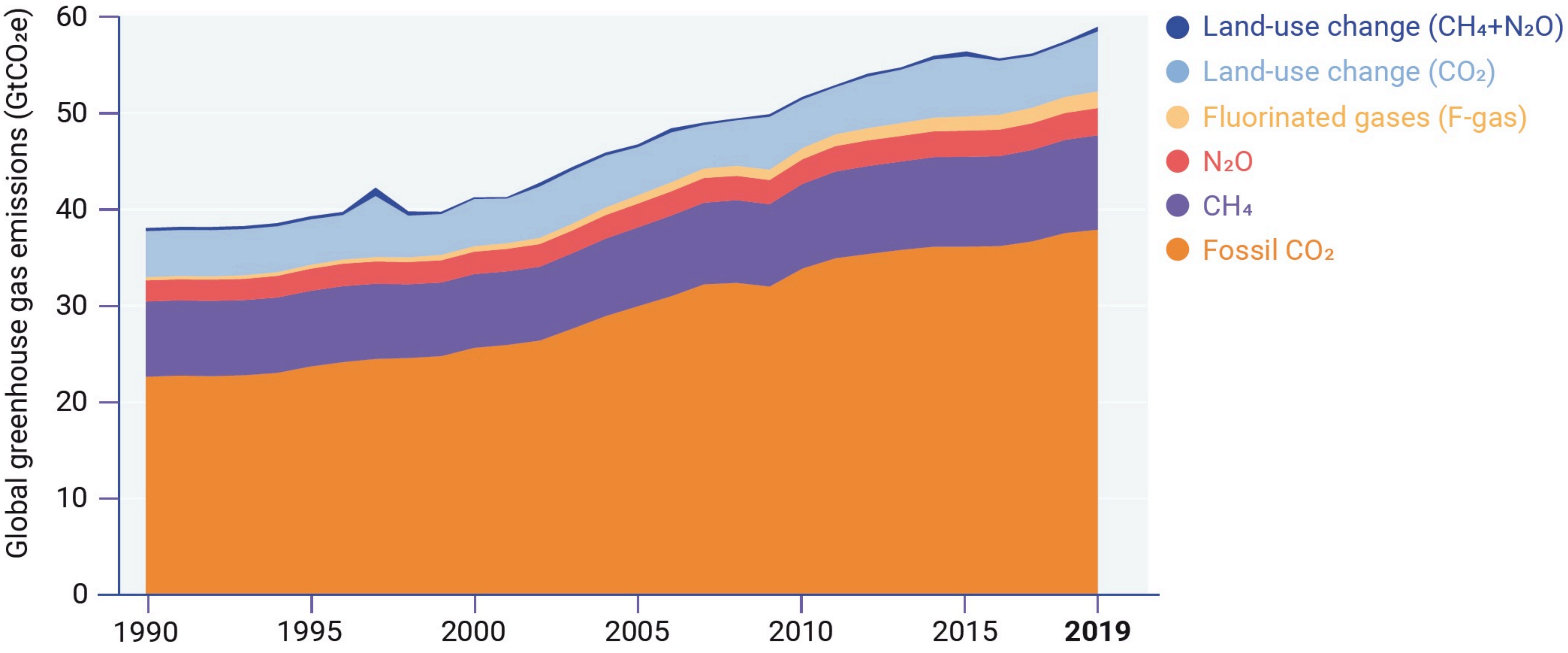
- What collaborating fields and technologies are needed to overcome the challenges and achieving the goals?

- What are the key barriers, technical and non-technical, for controls to achieve full participation and recognition in solving these problems? How can we overcome them as a community?

- Any additional comments or suggestions are also welcome.

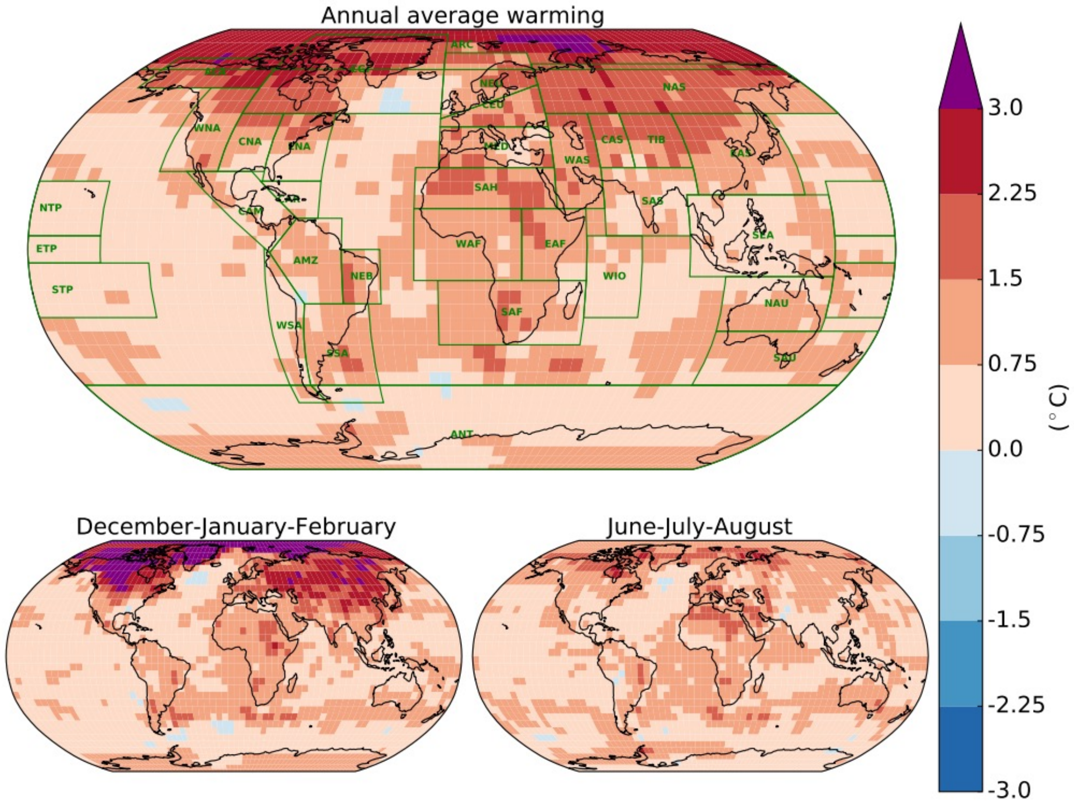
Global GHG Emissions: 1990-2019

Figure ES.1. Global GHG emissions from all sources

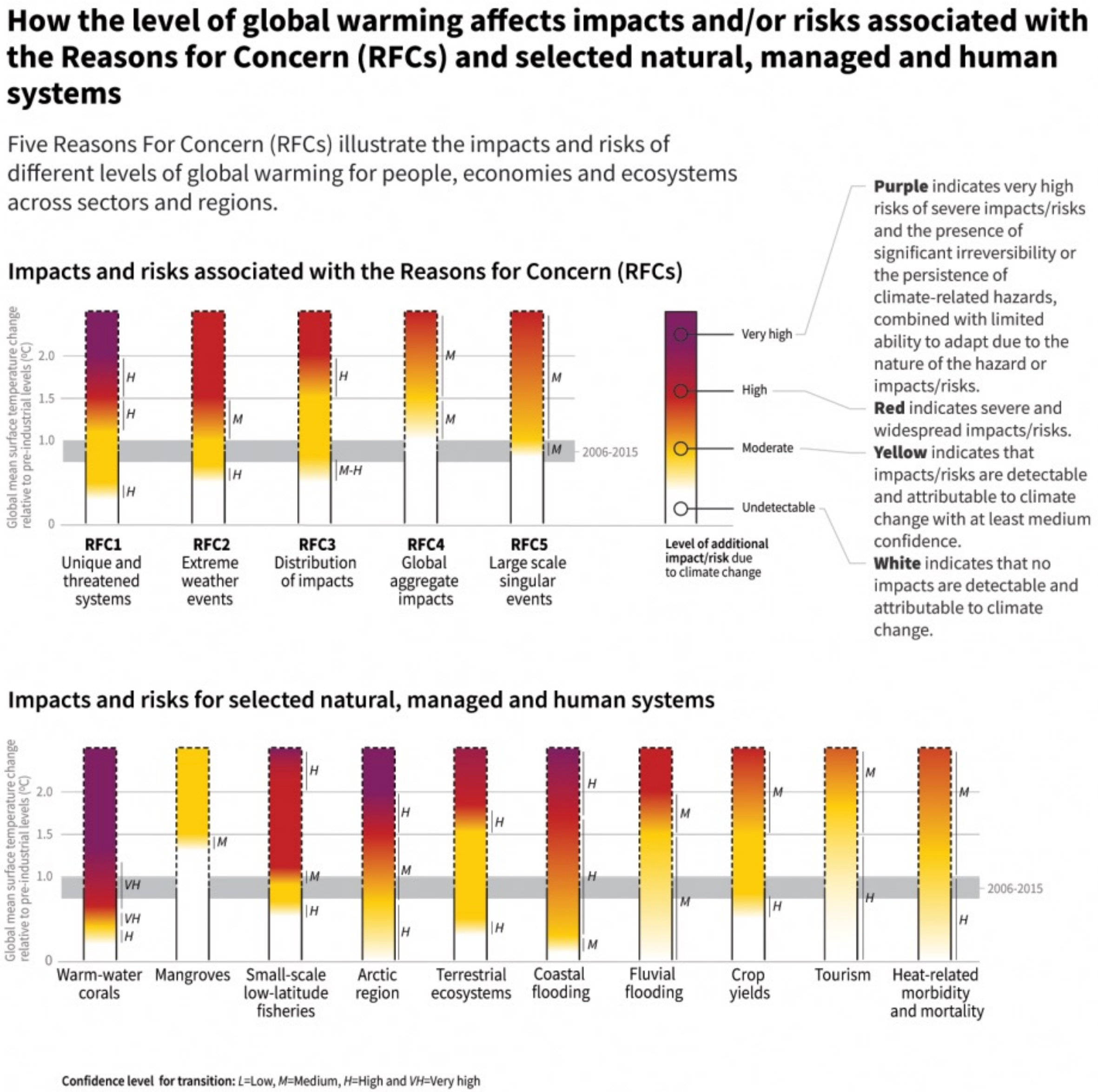


Source: [UNEP Emissions Gap Report 2020]

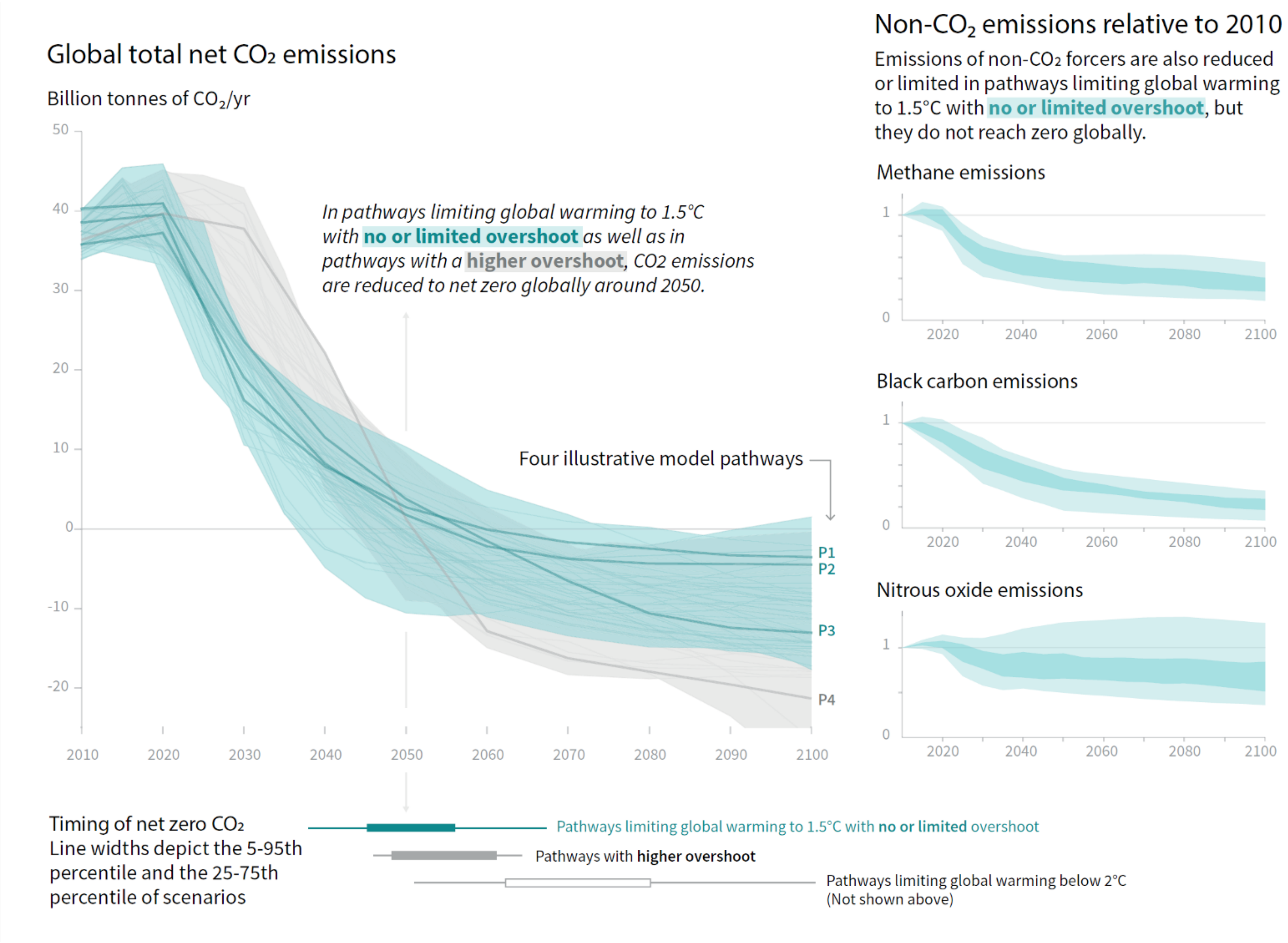
Global Warming During 2006-15



Maps of regional human-caused warming for 2006-15, relative to 1850-1900, annual average (top), the average of December, January and February (bottom left) and for June, July and August (bottom right). Shading indicates warming (red and purple) and cooling (blue). Source: IPCC



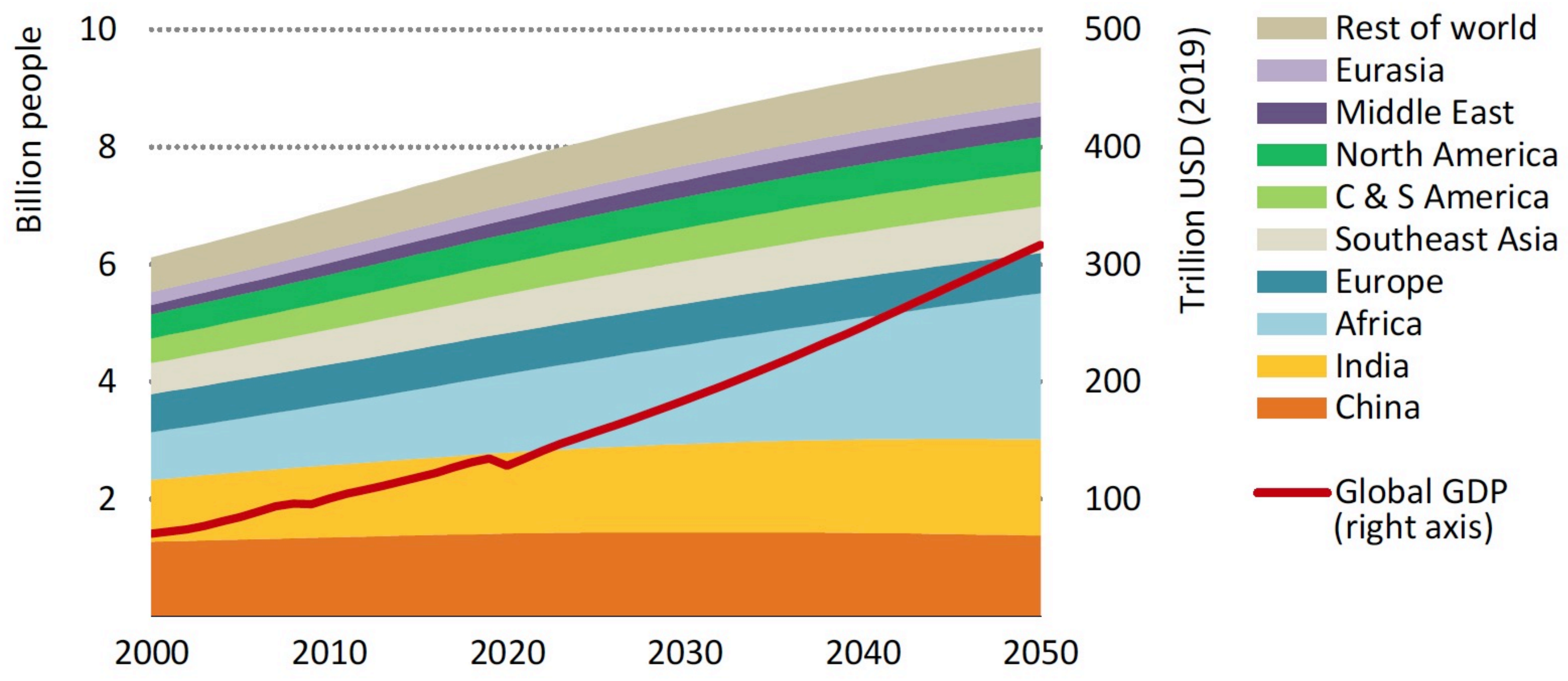
Global Emissions Pathway Characteristics



Source: [IPCC Global Warming to 1.5 degrees C]

World Population and Economy will Continue to Grow

Figure 2.1 ▹ World population by region and global GDP in the NZE

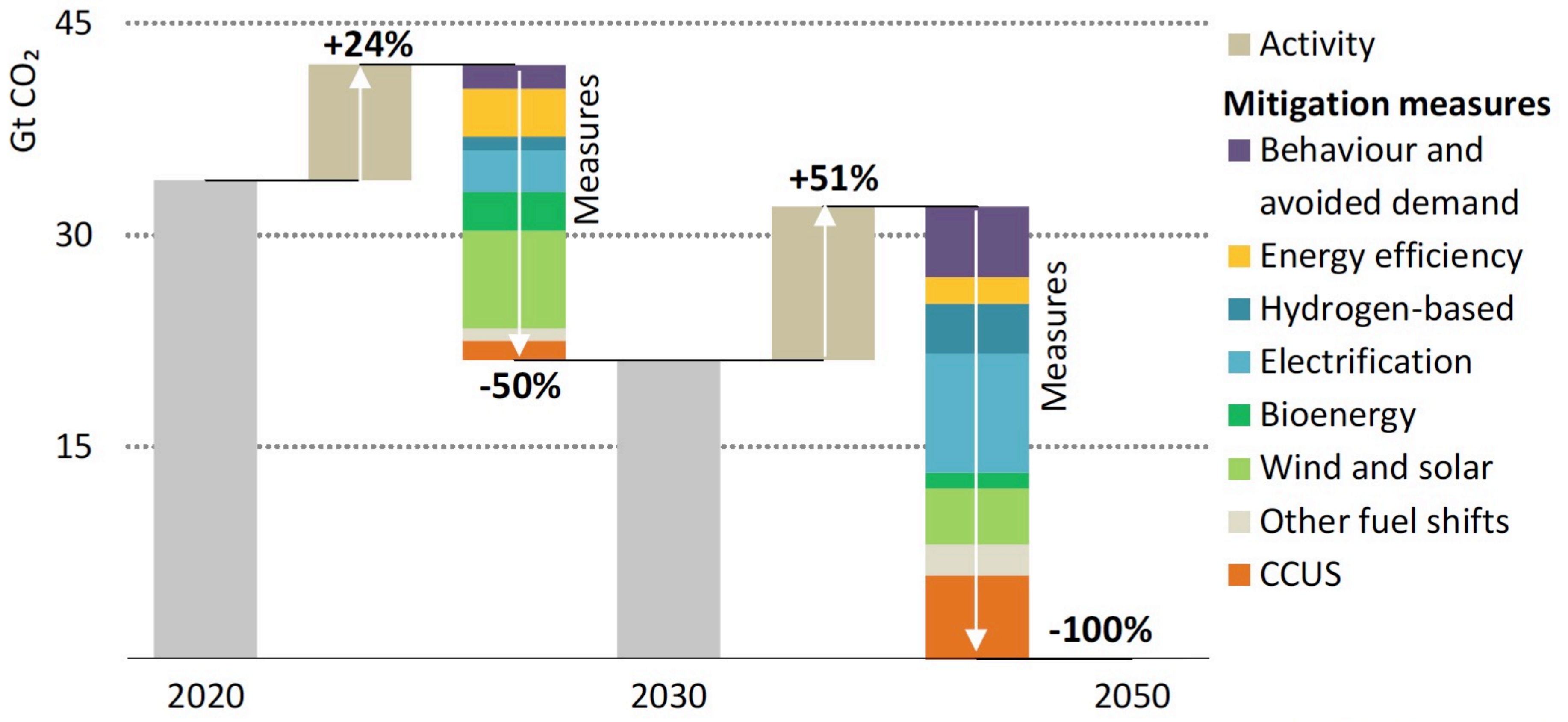


By 2050, the world's population expands to 9.7 billion people and the global economy is more than twice as large as in 2020

Source: [IEA]

IEA Net Zero Emissions Measures

Figure 2.12 ▻ Emissions reductions by mitigation measure in the NZE, 2020-2050

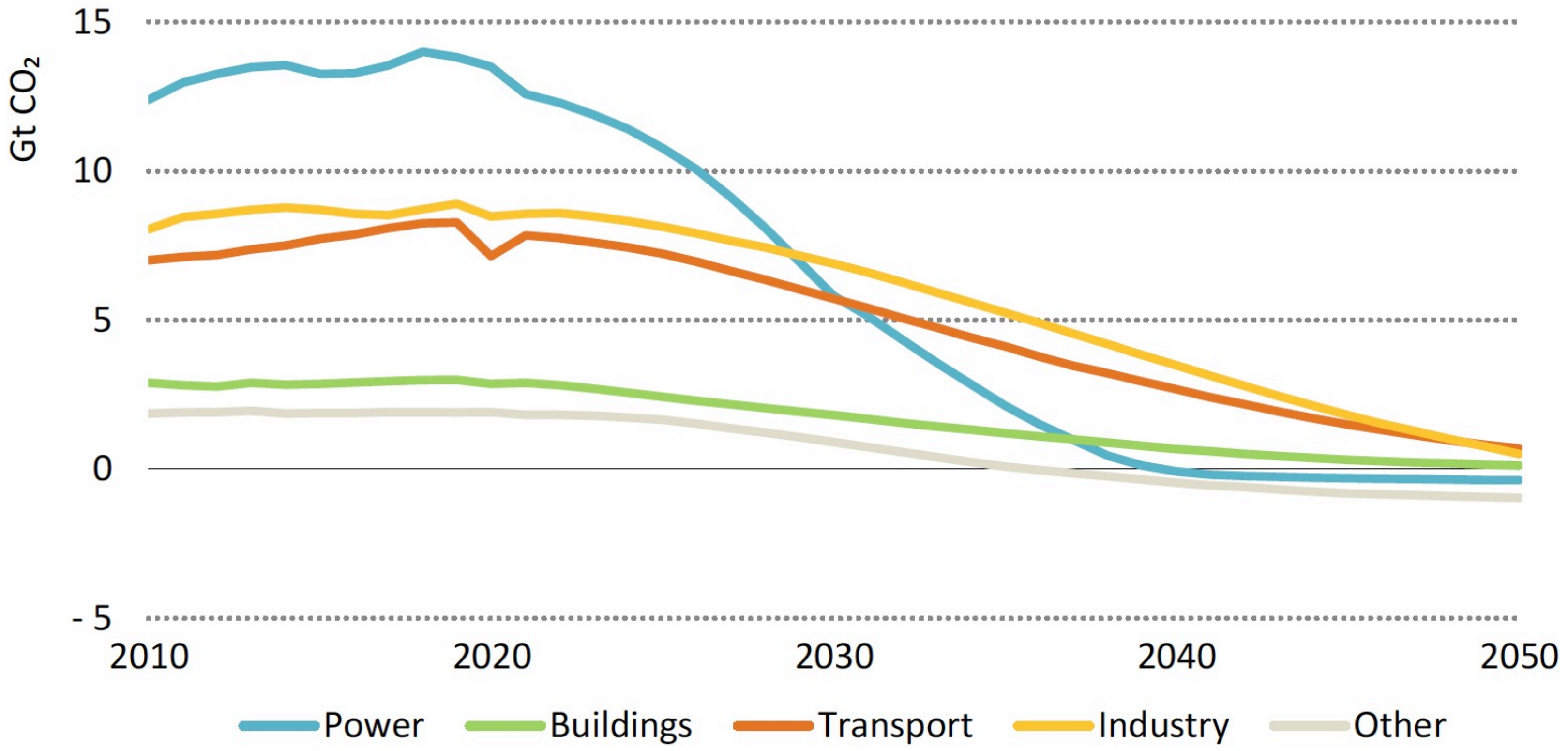


Solar, wind and energy efficiency deliver around half of emissions reductions to 2030 in the NZE, while electrification, CCUS and hydrogen ramp up thereafter

Source: [IEA]

CO2 Emissions by Sector

Figure 3.1 ▷ CO_2 emissions by sector in the NZE



Emissions fall fastest in the power sector, with transport, buildings and industry seeing steady declines to 2050. Reductions are aided by the increased availability of low-emissions fuels

Source: [IEA]

Big Picture Global Warming and Climate Change Outlook

Decarbonization of the energy system is essential to mitigate climate change

- Energy efficiency must be a big target
- Electric energy sector is likely to be the easiest to decarbonize due to falling wind and solar generation costs
- Transportation sector is much harder to decarbonize. Electrification of transportation offers the best path forward
- Industrial and manufacturing emissions are much harder to reduce
- Negative emissions solutions will be necessary
- Climate change impacts are already here and adaptation is necessary
- It is not an engineering or technology problem alone – public policy and human behavior will play very large roles
- Younger generations see this as their big problem

Energy/climate system is immense, multiscale, distributed, interconnected and slow to change

Selected Targets for Climate Change Mitigation and Adaptation

- Electric energy system
- Energy Efficiency and Productivity
- Industrial and manufacturing
- Hydrogen, ammonia, renewable fuels
- Carbon capture and storage
- Resilience in energy, transport, agriculture, social systems to global warming driven disruptions

Control systems community will need to work on multidisciplinary teams to make a significant contribution

Many of these problems may require new modelling, analysis, and control theory and design methodologies

Renewable Electric Energy Generation

- Modeling, prediction, decision and controls for optimization of renewable energy production
- On-shore and off-shore wind forecasting, controls, diagnostics, and optimization
  - Turbine level prediction, controls, diagnostics, and optimization
  - Farm level prediction, controls, and optimization
- PV solar forecasting, control and optimization
  - Grid scale farms
  - Distributed, roof-top solar
- Wave energy technologies
- Geothermal technologies

Control of Electric Power Systems

- Novel grid architectures and controls
  - Rethinking of grid control and management architectures
  - Pervasive role for control and optimization at various temporal and spatial scales for various information and communication architectures
  - Recent NASEM report

- Controls for deep integration of wind and solar into power systems
  - Utility scale as well as distributed solar
  - Prediction and forecasting
  - Demand side management in electric grids
  - Day-ahead to real-time distributed controls
  - Energy storage management and control
  - Interdependence of electric and gas infrastructures

- Controls for vehicle charging as transportation sector is electrified

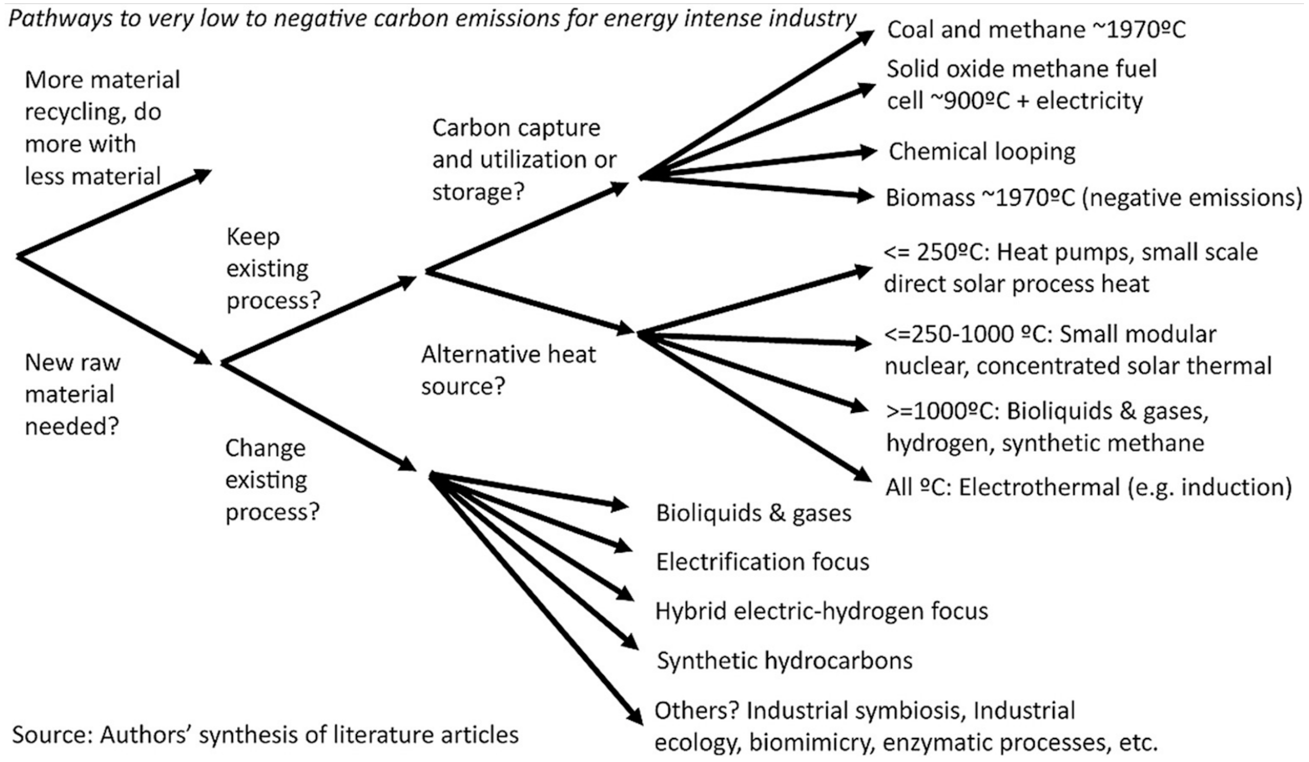
- Planning and control with deep uncertainty for transmission expansion

Building Energy Efficiency

- Sensors and controls for efficiency in building HVAC
- Combined heat and power
- Net zero buildings
- Heat pumps

Industrial and Manufacturing Sector

- Manufacturing of chemicals, metals, cement is very energy intensive
- New processes will be needed to decarbonize these sectors
- Process control for increasing energy efficiency of existing processes
- Process co-design and optimization to enable novel manufacturing processes
- Process controls and optimization for new energy materials



Source: Battaile et al (2019)

Hydrogen, Ammonia, Renewable Fuels

- Hydrogen and ammonia are potential choices as energy carriers
- Control, optimization, and co-design of electrolyzers for economic green hydrogen production
- Process controls for ammonia production from renewable electricity
- Hydrogen for long duration storage in electric grids management and control
- Hydrogen as heat source in industrial processes
- Process control for sustainable fuels production for aviation and marine

Carbon Capture, Utilization, and Storage

- All pathways for climate change mitigation require negative carbon technologies
- Modeling, controls, and optimization to enable carbon capture, utilization, and storage processes

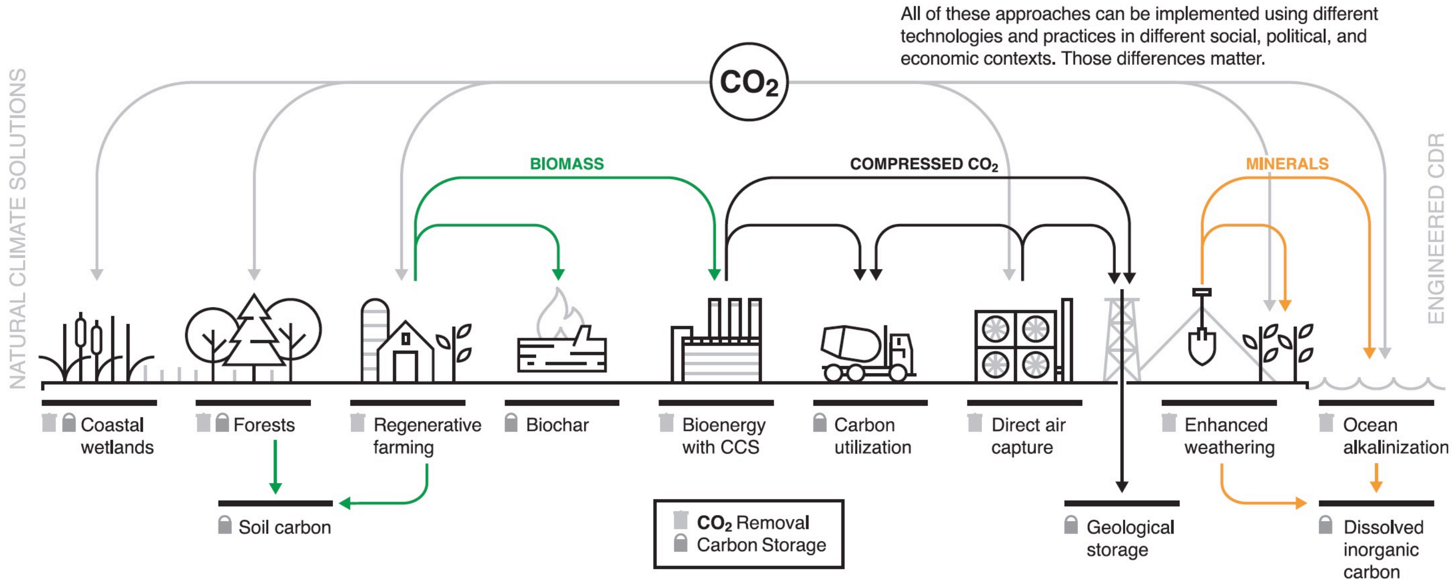


Figure 1. Some Proposed Methods of Carbon Dioxide Removal
Some of the many approaches that people have proposed for removing carbon dioxide from the atmosphere and storing it are presented here without assessment of their respective potential for removing or storing carbon or their social, environmental, or economic sustainability, which will vary between methods and depend on the details and context of implementation. These methods are often divided into "natural climate solutions" and "engineered" approaches, although the precise boundary between these categories is contested and somewhat vague. Illustration by Matt Twombly.

Source: [Morrow et al. 2020]

Adaptation to Climate Change: Control for Interdependent Systems

- Climate change will increase severity and frequency of extreme events such as storms, hurricanes, wildfires, droughts, and floods
- Controls to address interconnectedness and interdependence of infrastructures and increase their resilience
    - Gas and electric grids
    - Energy and transportation
    - Water and energy
    - Water-energy-food nexus
- Drought and heat resilient smart agriculture systems

Cross Cutting Methodological Themes

- Control and optimization as a new, cross-cutting operational paradigm

- Integration of controls with data science, IoT, and related technologies is a very large opportunity

- Collaboration of controls and behavioral, economic, and social sciences in climate change mitigation and adaptation problems is essential

- More generally, controls experts will need to collaborate on multidisciplinary, multi-sector teams to make useful contributions. How can such collaborations be promoted and supported?

- Research needed across the board for 2030, 2040, and 2050 goals

  - 2030 climate change goals focus on the electric energy sector
  - 2040 allows for focus on hard to decarbonize sectors
  - 2050 allows for negative emissions technologies

Other Themes

- Sensing, control, optimization for existing fossil fuel driven problems, e. g. methane as a critical short lived climate pollutant.
- Finance, insurance, and risk management are likely to be big drivers. Control and modeling may have a significant role to impact these decisions.
- Energy and infrastructure system decisions have multi-decade time frames, lock-ins, with very large uncertainties. This presents an opportunity for new formulations for decision problems under deep uncertainty.
- Modeling, control and optimization for smart, sustainable, resource efficient cities, communities, and circular economies as ways to create better, sustainable, alternative societal futures that support human flourishing.
- Equity and social justice considerations are crucial in energy system transitions, climate change mitigation and adaptation pathways

Future Steps

- What have we missed?
- How can you help in the development of these ideas and visions?
- Should we hold future workshops to discuss these challenges and opportunities?

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Breakout Session Summary Slides

Aranya Chakrabortty and Dennice Gayme

Control for Climate Change

1. Globality of the problem:

- A gigantic canvas: power systems, control, chemistry, biology, climate science, sociologists, city-planning, economics

- different time-scales and spatial-scales: from fast device-level controls to societal-scale issues such as population growths and investments for infrastructure expansion

- Concrete ways by which communities can come close to each other – for example, how control+power systems + power electronics community can collaborate with environmental engineers to address energy related control problems for coastal resilience, wind and wave energy, natural hazards and emulation/testing testbeds

- Interconnected infrastructures such as power, water, food, transportation, with associated questions on social justice

- Technical language barrier - take an outside-in approach for addressing the grand challenge of sustainability, take effort to communicate to other communities that what will be the final end product of control theory

2. Socio-Economic- Environmental aspects of climate change:

- Adaptation versus mitigation, we need to work with anthropologists and economists, new qualitative cost functions that represent social justice and equity

3. Investments
- investments drives the economy
- sustainability is about the right investment in the middle of total uncertainty in determining the technology that wins the market
- Technology development needs to account for aspirations of the developing world
- Western world has the investment capital
- Energy access to under-developed countries

4. **Domain-specific questions:**
- new control architectures for power grids with renewables – hierarchical, distributed, combinations
- shared mobility, Mobility DNA
- policy makers need to collaborate with academics
- control co-designs for infrastructures (eg. microgrid controls)
- new technologies for carbon capture such as nature-based solutions such as reforestation, gentrification
- mathematical modeling of dynamic interdependence between big cities and rural areas in terms of energy, agriculture, irrigation, population growth, finance, transportation
- collaboration with anthropology, political science, and economics for formulating “setpoint regulation to social prosperity”
- creation of shared experimental testbeds, computational tools and simulations