Well Under 2 Degrees Celsius:

Fast Action Policies to Protect People and the Planet from Extreme Climate Change

Report of the Committee to Prevent Extreme Climate Change
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Summary for Global Leaders

Climate change is becoming an existential threat with warming in excess of 2°C within the next three decades and 4°C to 6°C within the next several decades. Warming of such magnitudes will expose as many as 75% of the world's population to deadly heat stress in addition to disrupting the climate and weather worldwide. Climate change is an urgent problem requiring urgent solutions. This report lays out urgent and practical solutions that are ready for implementation now, will deliver benefits in the next few critical decades, and places the world on a path to achieving the long-term targets of the Paris Agreement and near-term sustainable development goals. The approach consists of four building blocks and 3 levers to implement ten scalable solutions described in this report by a team of climate scientists, policy makers, social and behavioral scientists, political scientists, legal experts, diplomats, and military experts from around the world. These solutions will enable society to decarbonize the global energy system by 2050 through efficiency and renewables, drastically reduce short-lived climate pollutants, and stabilize the climate well below 2°C both in the near term (before 2050) and in the long term (post 2050). It will also reduce premature mortalities by tens of millions by 2050. As an insurance against policy lapses, mitigation delays and faster than projected climate changes, the solutions include an Atmospheric Carbon Extraction lever to remove CO_2 from the air. The amount of CO_2 that must be removed ranges from negligible, if the emissions of CO_2 from the energy system and SLCPs start to decrease by 2020 and carbon neutrality is achieved by 2050, to a staggering one trillion tons if the carbon lever is not pulled and emissions of climate pollutants continue to increase until 2030.

There are numerous living laboratories including 53 cities, many universities around the world, the state of California, and the nation of Sweden, who have embarked on a carbon neutral pathway. These laboratories have already created 8 million jobs in the clean energy industry; they have also shown that emissions of greenhouse gases and air pollutants can be decoupled from economic growth. Another favorable sign is that growth rates of worldwide carbon emissions have reduced from 2.9% per year during the first decade of this century to 1.3% from 2011 to 2014 and near zero growth rates during the last few years. The carbon emission curve is bending, but we have a long way to go and very little time for achieving carbon neutrality. We need institutions and enterprises that can accelerate this bending by scaling-up the solutions that are being proven in the living laboratories. We have less than a decade to put these solutions in place around the world to preserve nature and our quality of life for generations to come. The time is now.

Foreword

Transition to a Safe Anthropocene

We are clearly living in the Anthropocene–but then, what exactly is the Anthropocene? Even after thinking about that for many years, it still is not really clear to me. We have not yet found a clean, quasi-mathematical definition, which is also reflected by the extensive discussions about what starting point to assign. The idea of the Anthropocene–the age of Humans–all started from the simple idea that humanity has moved out of the Holocene and taken over from nature in shaping the face of the planet. But then it quickly becomes more abstract than one might think at first. And it becomes more complicated and extensive than only the scientific discourse: the Anthropocene concept is being used socially and culturally, for example in Art, and even in the context of what it means for religions. A fun question to consider is: how would the world look if we had never brought about the Anthropocene? What if our global society had grown in a way that was built from the beginning on renewable energy, on circular economies and on environmentally and societally low-impact consumption? We rarely think about such an alternate present, but maybe that can give us insight into how we can go about pursuing the noble goal of Sustainable Development–which in many ways is just as abstract as the Anthropocene, maybe even more so.

Climate change, one of the main indicators of the Anthropocene, is also an abstract concept for many – something "out there", in the future predicted by complicated climate models. But sadly, it is becoming less abstract with every passing year, given the mounting evidence ranging from temperature records to melting glaciers and ice sheets to sea level rise. And within the Anthropocene, climate change is intricately linked to many of the other grand challenges that we face. For example, rising temperatures and shifting precipitation patterns can affect agriculture, animal husbandry, and fisheries, severely threatening food security. Climate change is also a challenging justice issue, since the poor and future generations are mostly the ones who will be worst affected. Furthermore, climate change can lead to immigration and conflicts or wars over borders and resources like water, which in turn can hinder international efforts towards disarmament and peace. Even education is affected by climate change, since in farming regions where the changing climate is leading to water scarcity, we are already seeing children not going to school because they have to spend hours a day helping the families carry water from far away. And in turn, issues like hunger, poverty, lack of education and cultural and national conflicts make it challenging to put the attention needed into transitioning to technologies and lifestyles that cause less emissions of CO_2 and other climate-forcing gases and particles. A viscious cycle can develop within these connections.

The enormity of these challenges is reflected in the first impression I got in looking through this report: it just feels as though it's too much, far beyond the simple, elegant, mathematics-based solution that I would like as a scientist. Probably many people feel this way when they first look at a

report like this. But don't give up too easily! After I looked through it again, and another time, then found it actually got very easy to go through and get an overview, not only of the problems, but also of the pathways to solving them. The report is very nicely structured, with its four building blocks, three levers, and 10 scalable solutions. It creates an appetite for reading it, and at the same time, provides valuable food for thought. And one thought I had while reading the report is that in many ways, it's like reading about the Anthropocene, due to how it all fits together and its grand scope–even though it's really about climate change, and not much is explicitly said about the Anthropocene. But it doesn't really need to be mentioned much explicitly, since it's woven in the fabric of the report: the authors did not have on blinders, looking only at climate change and its physical, chemical, and biological basis, but kept their eyes on the broader humanistic and societal aspects that are so central to the Anthropocene.

Nevertheless, despite the best effort of the authors to make an understandable and convincing case, I'm very concerned that humanity collectively will not be wise enough to follow the straightforward solutions to the extent laid out here. Of course, it's not black and white: doing some is better than doing none. And in the course of this, it will be very important to continue to lay out this scientific basis, so that we know better and better how to apply the full constructive talents of human beings (which, sadly, are harder to apply than the destructive talents). In order to do this well, we're going to have to learn to make better use of that great gift we are given: the human brain. Supplied with the right conditions, a healthy human brain can think much better than under challenging conditions and massive stress. We still need to learn new and better ways to think, to apply our minds–especially to be able to really get our minds around such massive issue as climate change in the larger context of the Anthropocene. This may require taking a serious step back, and becoming more reflective about how our own thoughts work. If we can learn to do this, then not only will we be able to forecast a safe Anthropocene, but perhaps even more importantly: a beautiful Anthropocene.

Paul Crutzen

Nobel Laureate, Chemistry 1995 (shared with Mario J. Molina and F. Sherwood Rowland)

* I thank Mark Lawrence for his collaboration in this foreward

High Level Summary

The Paris Agreement is an historic achievement. For the first time, effectively all nations have committed to limiting their greenhouse gas emissions and taking other actions to limit global temperature change. Specifically, 197 nations agreed to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels," and achieve carbon neutrality in the second half of this century.

The climate has already warmed by 1°C. The problem is running ahead of us, and under current trends we will likely reach 1.5°C in the next fifteen years and surpass the 2°C guardrail by mid-century with a 50% probability of reaching 4°C by end of century. Warming in excess of 3°C is likely to be a global catastrophe for three major reasons:

- Warming in the range of 3°C to 5°C is suggested as the threshold for several tipping points in the physical and geochemical systems; a warming of about 3°C has a probability of over 40% to cross over multiple tipping points, while a warming close to 5°C increases it to nearly 90%, compared with a baseline warming of less than 1.5°C, which has only just over a 10% probability of exceeding any tipping point.
- Health effects of such warming are emerging as a major if not dominant source of concern. Warming of 4°C or more will expose more than 70% of the population, i.e. about 7 billion by the end of the century, to deadly heat stress and expose about 2.4 billion to vector borne diseases such as Dengue, Chikengunya, and Zika virus among others.
- Ecologists and paleontologists have proposed that warming in excess of 3°C, accompanied by increased acidity of the oceans by the buildup of CO_2, can become a major causal factor for exposing more than 50% of all species to extinction. 20% of species are in danger of extinction now due to population, habitat destruction, and climate change.

The good news is that there may still be time to avert such catastrophic changes. The Paris Agreement and supporting climate policies must be strengthened substantially within the next five years to bend the emissions curve down faster, stabilize climate, and prevent catastrophic warming. To the extent those efforts fall short, societies and ecosystems will be forced to contend with substantial needs for adaptation—a burden that will fall disproportionately on the poorest three billion who are least responsible for causing the climate change problem.

Here we propose a policy roadmap with a realistic and reasonable chance of limiting global temperature to safe levels and preventing unmanageable climate change—an outline of specific science-based policy pathways that serve as the building blocks for a three-lever strategy that could limit warming to well under 2°C. The projections and the emission pathways proposed in this summary are based on a combination of published recommendations and new model simulations conducted by the authors of this study (see Figure 1). We have framed the plan in terms of four building blocks and three levers, which are implemented through 10 solutions.

The first building block would be fully implementing the nationally determined mitigation pledges under the Paris Agreement of the UN

Framework Convention on Climate Change (UNFCCC). In addition, several sister agreements that provide targeted and efficient mitigation must be strengthened. Sister agreements include the Kigali Amendment to the Montreal Protocol to phase down HFCs, efforts to address aviation emissions through the International Civil Aviation Organization (ICAO), maritime black carbon emissions through the International Maritime Organization (IMO), and the commitment by the eight countries of the Arctic Council to reduce black carbon emissions by up to 33%. There are many other complementary processes that have drawn attention to specific actions on climate change, such as the Group of 20 (G20), which has emphasized reform of fossil fuel subsidies, and the Climate and Clean Air Coalition (CCAC). HFC measures, for example, can avoid as much as 0.5°C of warming by 2100 through the mandatory global phasedown of HFC refrigerants within the next few decades, and substantially more through parallel efforts to improve energy efficiency of air conditioners and other cooling equipment potentially doubling this climate benefit.

For the second building block, numerous sub-national and city scale climate action plans have to be scaled up. One prominent example is California's Under 2 Coalition signed by over 177 jurisdictions from 37 countries in six continents covering a third of world economy. The goal of this Memorandum of Understanding is to catalyze efforts in many jurisdictions that are comparable with California's target of 40% reductions in CO_2 emissions by 2030 and 80% reductions by 2050—emission cuts that, if achieved globally, would be consistent with stopping warming at about 2°C above pre-industrial levels. Another prominent example is the climate action plans by over 52 cities and 65 businesses around the world aiming to cut emissions by 30% by 2030 and 80% to 100% by 2050. There are concerns that the carbon neutral goal will hinder economic progress; however, real world examples from California and Sweden since 2005 offer evidence that economic growth can be decoupled from carbon emissions and the data for CO_2 emissions and GDP reveal that growth in fact prospers with a green economy.

The third building block consists of two levers that we need to pull as hard as we can: one for drastically reducing emissions of short-lived climate pollutants (SLCPs) beginning now and completing by 2030, and the other for decarbonizing the global energy system by 2050 through efficiency and renewables. Pulling both levers simultaneously can keep global temperature rise below 2°C through the end of the century. If we bend the CO_2 emissions curve through decarbonization of the energy system such that global emissions peak in 2020 and decrease steadily thereafter until reaching zero in 2050, there is less than a 20% probability of exceeding 2°C. This call for bending the CO_2 curve by 2020 is one key way in which this report's proposal differs from the Paris Agreement and it is perhaps the most difficult task of all those envisioned here. Many cities and jurisdictions are already on this pathway, thus demonstrating its scalability. Achieving carbon neutrality and reducing emissions of SLCPs would also drastically reduce air pollution globally, including all major cities, thus saving millions of lives and over 100 million tons of crops lost to air pollution each year. In addition, these steps would provide clean energy access to the world's poorest three billion who are still forced to resort to 18th century technologies to meet basic needs such as cooking.

For the fourth and the final building block, we are adding a third lever, ACE (Atmospheric Carbon Extraction, also known as Carbon Dioxide Removal, or "CDR"). This lever is added as an insurance against surprises (due to policy lapses, mitigation delays, or non-linear climate changes) and would require development of scalable measures for removing the CO_2 already in the atmosphere. The amount of CO_2 that must be removed will range from negligible, if the emissions of CO_2 from the energy system and SLCPs start to decrease by 2020 and carbon

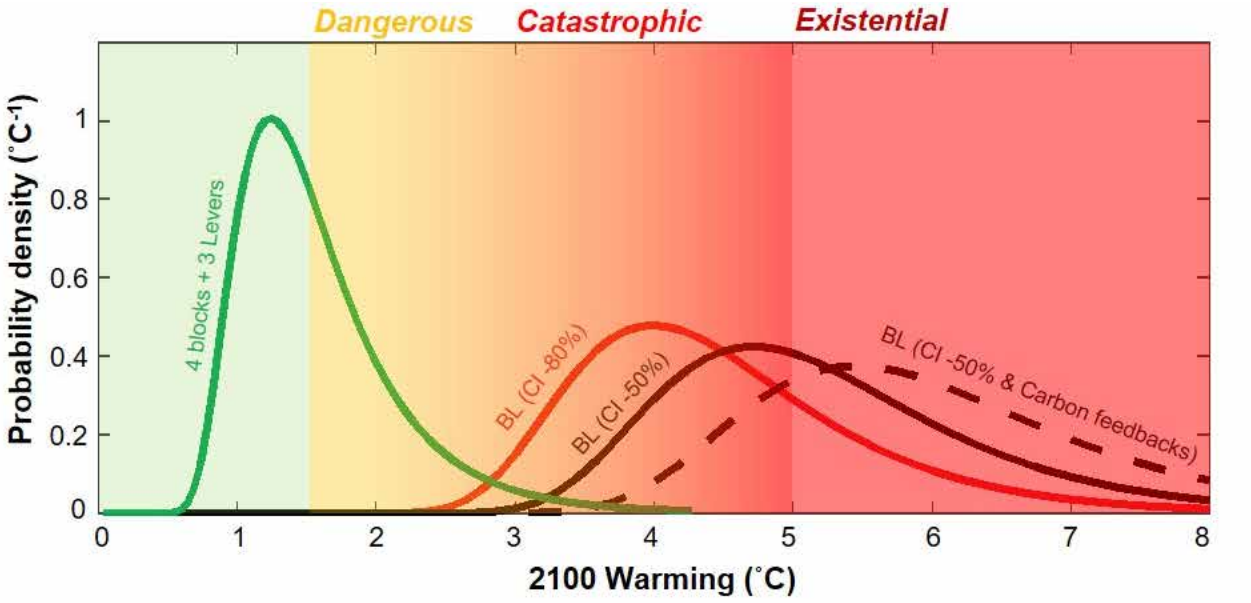

Figure 1: Projected warming for 4 different scenarios from pre-industrial to 2100 as adopted from Xu and Ramanathan (2017). The warming is given in terms of probability distribution instead of a single value, because of uncertainties in climate feedbacks, which could make the warming larger or smaller than the central value shown by the peak probability density value. The three curves on the right side indicated by BL (for baseline), denote projected warming in the absence of climate policies. The BL (CI-80%) is for the scenario for which the energy intensity (the ratio of energy use to economic output) of the economy decreases by 80% compared with its value for 2010. For the BL (CI-50%), the energy intensity decreases by only 50%. These scenarios bound the energy growth scenarios considered by IPCC–WGIII (2014). The right extreme curve, BL (CI-50% & C feedback), includes the carbon cycle feedback due to the warming caused by the BL (CI-50%) case. The carbon cycle feedback adopts IPCC recommended values for the reduction in CO_2 uptake by the oceans as a result of the warming; the release of CO_2 by melting permafrost; and the release of methane by wetlands.

The green curve adopts the 4 building blocks and the 3 levers proposed in this report. There are four mitigation steps:

1. Improve the energy efficiency and decrease the energy intensity of the economy by as much as 80% from its 2010 value. This step alone will decrease the warming by 0.9ºC (1.6ºF) by 2100.
2. Bend the Carbon emission curve further by switching to renewables before 2030 and achieving carbon neutrality in 3 decades. This step will decrease the warming by 1.5ºC (2.7ºF) by 2100.
3. Bend the Short-Lived Climate Pollutants curve, beginning 2020, following the actions California has demonstrated. This step will decrease the warming by as much as 1.2ºC (2.2ºF) by 2100.
4. In addition, extract as much as 1 trillion tons (about half of what we have emitted so far) from the atmosphere by 2100. This step will decrease the warming by as much as 0.3ºC to 0.6ºC (0.5ºF to 1ºF).

The 50% probable warming for the 4 scenarios are respectively from left to right: 1.4ºC (2.5ºF); 4.1ºC (7.4ºF); 5ºC (9ºF); 5.8ºC (10.4ºF). There is a 5% probability, the warming for the 4 scenarios can exceed respectively (left to right): 2.2ºC (4ºF); 5.9ºC (10.6ºF); 6.8ºC (12.2ºF); 7.7ºC (14ºF).

The risk categories shown at the top largely follow Xu and Ramanathan (2017) with slight modifications. Following IPCC and Xu and Ramanathan (2017), we denote warming in excess of 1.5°C as *Dangerous*. Following the burning embers diagram of IPCC as updated by Oneill et al. (2017), warming in excess of 3°C is denoted as *Catastrophic*. We invoke recent literature on health effects of warming >4°C, impacts on mass extinction of warming >5°C and projected collapse of natural systems for warming in excess of 3°C, to denote warming >5°C as exposing the global population to *Existential* threats.

neutrality is achieved by 2050, to a staggering one trillion tons, if CO_2 emissions continue to increase until 2030, and the carbon lever is not pulled until after 2030. This issue is raised because the NDCs (Nationally Determined Contributions) accompanying the Paris Agreement would allow CO_2 emissions to increase until 2030. We call on economists and experts in political and administrative systems to assess the feasibility and cost-effectiveness of reducing carbon and SLCPs emissions beginning in 2020 compared with delaying it by ten years and then being forced to pull the third lever to extract one trillion tons of CO_2.

The fast mitigation plan of requiring emissions reductions to begin by 2020, which means that many countries need to cut now, is urgently needed to limit the warming to well under 2°C. Climate change is not a linear problem. Instead, we are facing non-linear climate tipping points that can lead to self-reinforcing and cascading climate change impacts. Tipping points and self-reinforcing feedbacks are wild cards that are more likely with increased temperatures, and many of the potential abrupt climate shifts could happen as warming goes from 1.5°C in 15 years to 2°C by 2050, with the potential to push us well beyond the Paris Agreement goals.

Box 1: Aggressive mitigation actions have already begun

The four building blocks to be implemented through the 10 solutions may appear ambitious and formidable, but there are numerous living laboratories ranging from cities such as Stockholm to a large state like California, the sixth largest economy in the world, already embarked on mitigation actions such as 40% reductions in CO_2 emissions by 2030 and 50% to 80% reductions in SLCPs. CO_2 emissions curves in the U.S. and E.U. have already started to bend since 2005. G7 and G20 countries have agreed to accelerate access to renewables. The world now adds more renewable power capacity annually than it adds (net) capacity from all fossil fuels combined. By the end of 2015, there was enough installed renewable capacity in place to supply an estimated 23.7% of global electricity demand, with hydropower providing about 16.6%. In part due to these advances and innovations, worldwide CO_2 emissions, which grew at a rate of 2.9% per year from 2000 to 2011, slowed to 1.3% per year from 2012 to 2014 and was down at near zero growth for 2015 and into 2016. While these are encouraging signs, aggressive policies still needed to achieve carbon neutrality and climate stability by mid-century.

The progress of the past several years can be accelerated by immediately ending all fossil fuel subsidies and expanding incentives for renewables as has been called for by the G20 and others. Global energy efficiency gains are accelerating. In 2015, global energy intensity improved 1.8%, three times the annual average of the last decade and investment in energy efficiency increased by 6%. Quickly ratifying and implementing the Kigali Amendment to the Montreal Protocol to phase down HFCs while pursuing parallel efforts to improve affordable appliance efficiency by at least 30% is an immediate opportunity to drive global energy efficiency improvements even farther. There is also more hope for increased public support due to religious declarations—including the Pope's sustainability encyclical, 'Laudato Si', as well as inter-faith declarations on climate change—calling on their billions of followers to commit to a low-carbon future through renewable energy. Businesses are also stepping up. Twenty-five worldwide business networks speaking for 6.5 million companies from over 130 countries have pledged to help foster a low-carbon and climate resilient economy. We are not starting from a blank page. The climate change mitigation train has already left the station. What we must do is scale up what is already happening in many parts of the world.

Box 2: Climatological Pearl Harbor

Walter Munk, Centenarian Oceanographer

Walter Munk, fourth from the left

I recall a previous time when academics from three campuses of the University of California system joined forces to combat a global crisis.

It was 1940 and we were losing the war. My homeland, Austria, had been taken over by Germany in 1938 and the Axis-powers had overrun much of Europe. It appeared that U.S. military action was imminent, so I enlisted in the newly formed Ski Troops at Fort Lewis, WA.

Our Allies were desperate for help. We were shipping food and arms in merchant ships sailing in protected convoys, but German U-boats were very effective in sinking them. In response, the U.C. Regents directed President Sproul to form the University of California Division of War Research (UCDWR). Scripps Director Harald Sverdrup and recent SIO graduate Lt.(jg) Roger Revelle arranged for my discharge from the Army. I had served eighteen months and there had been no military action, so I was anxious to join the UC effort. One week later on 7 December 1941, the Japanese attacked Pearl Harbor; all Army discharges were canceled. My unit was dispatched to Papua New Guinea and virtually wiped out.

There was no initial grand solution on the horizon of how to respond to the German submarine attacks (like in the present challenge for Carbon Neutrality). As it turned out, many of today's concepts about operations on and under the sea go back to that early effort. I think back to this period with great satisfaction; we worked purposefully together to do a job that had to be done.

Three and a half years later on D-Day, 6 June 1944, at spring low tide, our troops came ashore on Omaha Beach.

The combined resources of our University have proven a formidable resource in times of national needs. I welcome this opportunity to participate in the effort towards protecting our planet, before we are faced with a climatological Pearl Harbor.

Where Do We Go from Here?

A massive effort will be needed to stop warming at 2°C, and time is of the essence. With unchecked business-as-usual emissions, global warming has a 50% likelihood of exceeding 4ºC and a 5% probability of exceeding 6ºC in this century, raising existential questions for most, but especially the poorest three billion people. A 4ºC warming is likely to expose as many as 75% of the global population to deadly heat. Dangerous to catastrophic impacts on the health of people including generations yet to be born, on the health of ecosystems, and on species extinction have emerged as major justifications for mitigating climate change well below 2ºC, although we must recognize that the uncertainties intrinsic in climate and social systems make it hard to pin down exactly the level of warming that will trigger possibly catastrophic impacts. To avoid these consequences, we must act now, and we must act fast and effectively. This report sets out a specific plan for reducing climate change in both the near- and long-term. With aggressive urgent actions, we can protect ourselves. Acting

quickly to prevent catastrophic climate change by decarbonization will save millions of lives, trillions of dollars in economic costs, and massive suffering and dislocation to people around the world. This is a global security imperative, as it can avoid the migration and destabilization of entire societies and countries and reduce the likelihood of environmentally driven civil wars and other conflicts.

Staying well under 2°C will require a concerted global effort. We must address everything from our energy systems to our personal choices to reduce emissions to the greatest extent possible. We must redouble our efforts to invent, test, and perfect systems of governance so that the large measure of international cooperation needed to achieve these goals can be realized in practice. The health of people for generations to come and the health of ecosystems crucially depend on an energy revolution beginning now that will take us away from fossil fuels and toward the clean renewable energy sources of the future. It will be nearly impossible to obtain other critical social goals, including for example the UN agenda 2030 with the Sustainable Development Goals, if we do not make immediate and profound progress stabilizing climate, as we are outlining here.

10 Scalable Solutions to Bend the Curve

Achieving success will require the global mobilization of human, financial, and technical resources. For the global economy and society to achieve such rapid reductions in SLCPs by 2030 and carbon neutrality and climate stability by 2050, we will need multi-dimensional and multi-sectoral changes and modification, which are grouped under Ten Scalable Solutions in the table below. We have adapted the solutions with some modifications from the report: Bending the Curve written by fifty researchers from the University of California system. These solutions, which often overlap, were in turn distilled from numerous publications and reports.

Table 1: Ten Scalable Solutions

Science Solutions

1. Show that we can bend the warming curve immediately by reducing SLCPs, and long-term by replacing current fossil fuel energy systems with carbon neutral technologies.

Societal Transformation Solutions

2. Foster a global culture of climate action through coordinated public communication and education at local to global scales.
3. Build an alliance among science, religion, health care, and policy to change behavior and garner public support for drastic mitigation actions.

Governance Solutions

4. Build upon and strengthen the Paris Agreement. Strengthen sister agreements like the Montreal Protocol's Kigali Amendment to reduce HFCs.
5. Scale up subnational models of governance and collaboration around the world to embolden and energize national and international action. California's Under 2 Coalition and climate action plans by over 50 cities are prime examples.

Market- and Regulation-Based Solutions

6. Adopt market-based instruments to create efficient incentives for businesses and individuals to reduce CO_2 emissions.
7. Target direct regulatory measures—such as rebates and efficiency and renewable energy portfolio standards—for high emissions sectors not covered by market-based policies.

Technology-Based Solutions

8. Promote immediate widespread use of mature technologies such as photovoltaics, wind turbines, biogas, geothermal, batteries, hydrogen fuel cells, electric light-duty vehicles, and more efficient end-use devices, especially in lighting, air conditioning and other appliances, and industrial processes. Aggressively support and promote innovations to accelerate the complete electrification of energy and transportation systems and improve building efficiency.
9. Immediately make maximum use of available technologies combined with regulations to reduce methane emissions by 50%, reduce black carbon emissions by 90%, and eliminate high-GWP HFCs ahead of the schedule in the Kigali Amendment while fostering energy efficiency.

Atmospheric Carbon Extraction Solutions

10. Regenerate damaged natural ecosystems and restore soil organic carbon. Urgently expand research and development for atmospheric carbon extraction, along with CCUS.

** Adapted from Ramanathan et al. (2016) and modified by authors of this report.*

The report can be downloaded at *http://www-ramanathan.ucsd.edu/about/publications.php* and *www.igsd.org/publications/*

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