Ten Scalable Solutions for Bending the Climate Change Curve the California Way

V. Ramanathan[1a*], D. M. Kammen[2a*], F. Forman[1b], J. Christensen[3a,b,c], L. Chiang[4], J. Allison[5], M. Auffhammer[2b], D. Auston[7], A.D. Barnosky[2b], W.D. Collins[2d,6], S.J. Davis[8], S.B. Hecht[3a,d], C.-Y. C. Lin Lawell[9], T. Matlock[10], D. Press[11], D. Rotman[12], S. Samuelsen[8], G. Solomon[13], B. Washom[1c].

Submitted to the Policy Forum of Science
March 07, 2016

[*]Corresponding Authors: vram@ucsd.edu; kammen@berkeley.edu

[1] University of California at San Diego, (a) Scripps Institution of Oceanography, (b) Department of Political Science, (c) Resource Management & Planning
[2] University of California at Berkeley, (a) Energy & Resources Group & Goldman School of Public Policy, (b) Department of Agricultural and Resource Economics, (c) Department of Integrative Biology and Museums of Paleontology and Vertebrate Zoology, (d) Earth & Planetary Science.
[3] University of California at Los Angeles, (a) Institute of the Environment and Sustainability, (b) Department of History, (c) Center for Digital Humanities, (d) Department of Urban Planning
[4] University of California Office of the President, Research Strategy & Portfolio Management
[5] University of California at Riverside, Gender and Sexuality Studies
[6] Lawrence Berkeley National Laboratory, Climate and Ecosystem Sciences Division
[7] University of California at Santa Barbara, Institute for Energy Efficiency
[8] University of California at Irvine, (a) Department of Earth System Science, (b) Department of Mechanical & Aerospace Engineering, (c) Advanced Power and Energy Program
[9] University of California at Davis, Department of Economics
[10] University of California at Merced, Cognitive & Information Sciences Program
[11] University of California at Santa Cruz, Department of Environmental Studies
[12] Lawrence Livermore National Laboratory, Office of Deputy Director for Science & Technology
[13] University of California at San Francisco, School of Medicine

The post-Paris euphoria has worn off. Truth be told, we knew it wouldn't last long. Although the agreement[1] was a landmark achievement, even as it was being signed, it was clear that the real work was just beginning. The emissions-reduction commitments[2] in hand could allow warming to exceed 4°C, much more than the "well below 2°C" limit set in the agreement. As many observers noted even before the Paris summit, we need a path forward beyond Paris, and urgently now more than ever.

The 195 signatory nations[2] have made voluntary pledges to reduce greenhouse gas emissions, monitor the results, report back in five years, and revise their goals. We've seen such agreements work in California, where the state has made great strides reducing pollution, cleaning the air[3], steadily setting the bar higher through ambitious greenhouse-gas-reduction goals, and forging voluntary agreements to cooperate with other national and subnational entities[4].

Pope Francis has done much to urge us on the road through Paris, focusing on the poor and immediate benefits to people's health, well-being, and equity[5]. And this past year, California's Governor Jerry Brown showed how effective communication about climate change can combine realistic, even apocalyptic warnings about the dangers of continuing with business-as-usual, along with concrete steps we can take now to curb emissions to avoid that undesirable future, and adapt and cope with warming that is already locked in. The University of California system stepped up, with its president, Janet Napolitano, pledging that all 10 campuses—collectively a community of half a million people—will become carbon neutral by 2025[6]. The resulting living laboratory for reducing emissions will reveal scalable solutions for the world, while training a new generation of leaders in effective stewardship of Earth's future[6].

As part of these efforts, 50 researchers from a wide variety of disciplines across the University of California system mapped out a set of pragmatic solutions that can be scaled up regionally, nationally, and globally to achieve the chief goal of the Paris summit: keeping global warming well below 2°C. The result is a report entitled *Bending the Curve: Ten Scalable Solutions for Carbon Neutrality and Climate Stability*[7], which is a "kit of parts" that can be used around the world, differently in different places.

Many of the technologies needed are at hand or are emerging now. To be sure, further investments, innovations, and improvements are urgently required to accelerate technical innovation. New carbon sequestration technologies will be helpful in the long run[8] to remove up to 1 trillion tons of CO_2 from Earth's atmosphere. But there is no single silver bullet. We will need a diverse technological portfolio.

We need more adaptive institutions, too, but we don't need totally new policies. Incentives for accelerating the deployment of renewable energy and laws to promote greater fuel efficiency and lower emissions are already on the books in California and elsewhere, and have proven effective and scalable.

What we urgently need are better ways of educating, engaging, and communicating with people and their leaders for climate actions. We've learned a lot about what to do—and not to do—on

that front over the past several decades. Our 10 scalable solutions recognize[9] that fundamental changes in human attitudes and behaviors are critical for achieving public support for policies and actions to get our diverse world on pragmatic paths to achieve the Paris goals within the next decade.

Our 10 scalable solutions are guided by the knowledge that intra-regional, intra-generational, and inter-generational equity and ethical responsibilities are inherent in climate change and must be central to any solution set. Consumption by around 1 billion of the world's population contributes more than 50 percent of greenhouse gas emissions, while the poorest 3 billion contribute very little to this climate pollution[9] and are likely to suffer the worst consequences of climate disruption[9,10]. In addition to reducing emissions, these solutions can help meet global sustainable development goals, enhance public health, improve air and water quality, and reduce the likelihood of large-scale mortality, population displacement, and civil unrest.

The parts in this diverse solution set are already being put to use productively in different places around the world. Eventually, everyone, everywhere in the world will need to use all of the parts, but this solution set is adaptable over time to fit into the "Paris way," voluntarily setting goals, measuring progress, and raising the bar, until we get to climate stability together.

The 10 Scalable Solutions[7]:

1. A) Bend the warming curve immediately by reducing four short-lived climate pollutants (SLCPs): black carbon, methane, tropospheric ozone, and hydrofluorocarbons. And B) Bend the emissions curve sustainably by replacing current fossil-fueled energy systems with carbon neutral technologies over the next several decades. 1A addresses the near-term problem of keeping global warming well below 2°C by 2050, while 1B addresses the long-term problem of climate stability in this century and beyond. Mitigating emissions of the super pollutants (SLCPs), whose life times range from a week to a decade, with a warming potency of 100 to 2,000 times that of CO_2, can cut the rate of warming by nearly 50 percent within a few decades. Immediate benefits of 1A and 1B also include saving as many as 100 million lives lost to air pollution by 2050 (See table for other co-benefits)[7]. To limit long-term global warming to well below 2°C, cumulative net CO_2 emissions for this century must be less than 1 trillion tons and approach zero emissions post-2050. Solutions #7, 8, and 9 cover technological solutions to accomplish 1A and 1B.

2. Combine technology and policy solutions with innovative approaches to changing institutions, social attitudes, and behaviors. Foster a culture of climate action through coordinated public communication and education at local to global scales. Use what we have learned about the successes and failures of communicating about climate change to reach people where they are, respect their values, and lower the barriers to taking action.

3. Deepen the global culture of climate collaboration with the goal of initiating collaborative actions to mitigate climate disruption. Create venues where community members and political, business, NGO, and religious leaders can converge around concrete problems with researchers and scholars from all academic disciplines to find and implement solutions.

4. Scale up subnational models of governance and collaboration around the world to embolden and energize national and international action. Use examples of success from California and elsewhere to help other state, regional, and city-level jurisdictions become living laboratories for renewable technologies and for regulatory as well as market-based solutions. Build cross-sector collaborations among urban and rural stakeholders, because creating sustainable cities and working landscapes will be key to global change.

5. Adopt market-based instruments to create efficient incentives for businesses and individuals to reduce CO_2 emissions. These can include cap-and-trade or carbon pricing and should employ mechanisms to contain costs. Adopt the high quality emissions inventories, monitoring, and enforcement mechanisms necessary to make these approaches work. In settings where these institutions do not credibly exist, alternative approaches such as direct regulation may be the better approach, although often at higher cost than market-based systems.

6. Narrowly target direct regulatory measures and incentives—such as rebates and renewable-energy-portfolio and efficiency standards—at high emissions sectors not adequately covered by market-based policies. Continually reward improvements to bring down emissions while building political coalitions in favor of climate policy. Terminate subsidies that encourage emission-intensive activities. Expand subsidies that encourage innovation in low emission technologies.

7. Promote immediate widespread use of mature technologies such as photovoltaics, wind turbines, battery and hydrogen-fuel-cell electric light-duty vehicles, and more efficient end-use devices, especially in lighting, air conditioning, appliances, and industrial processes. These technologies will have greater impact if they are targets of market-based or regulatory solutions such as those described in solutions #5 and 6. This solution has the potential to achieve 30 to 40 percent reductions in fossil fuel CO_2 emissions by 2030.

8. Aggressively support and promote innovations to establish a zero-carbon electric grid, accelerate the complete electrification of transportation and freight systems, improve building efficiency, and develop and deploy battery and hydrogen-fuel-cell electric medium- and heavy-duty vehicles. Support the development of lower-cost energy storage for applications in transportation, resilient large-scale and distributed micro-scale grids, and residential uses. Support the development of new energy storage technologies, including batteries, super-capacitors, compressed air, hydrogen and thermal storage, as well as advances in heat pumps, efficient lighting, fuel cells, smart buildings and systems integration, and carbon sequestration. These innovative technologies are essential for meeting the target of carbon neutrality by 2050 and sustaining climate stability thereafter.

9. Immediately make maximum use of available technologies combined with regulations to reduce methane emissions by 50 percent and black carbon emissions by 90 percent. Phase out hydrofluorocarbons (HFCs) by 2030 by amending the Montreal Protocol. In addition to the climate and health benefits[11,12] (See table), this solution will provide access to clean cooking for the poorest 3 billion people who still depend on firewood and biomass for cooking and heating—the largest source of black carbon. Three million lives are lost each year to the cooking smoke[7].

10. Reduce deforestation to zero net clearing and support forest recovery through natural and regenerative farming and forestry systems to restore biomass and soil organic carbon and improve natural and managed sinks for carbon. Implement food waste reduction programs and energy recovery from food waste. Global deployment of these measures has the potential to reduce at least 20 percent of the current 50 billion tons of emissions of CO_2 and other greenhouse gases.

Global climate change is already ravaging our cities, countryside, livelihoods, and health. This set of solutions builds on California's success in encouraging sub-national governance and climate agreements between cities, regions, and states; the use of regulations and market-based instruments to reduce emissions; and innovative approaches in education, communication, and incentives to encourage attitudinal and behavioral changes. Ultimately, this strategy will require new and much broader global solidarities, ranging from disenfranchised communities to the most powerful corporate and governmental institutions on Earth, to move us forward along pragmatic paths to effective solutions[7].

Breakthrough approaches and technologies would greatly accelerate and facilitate this process[13], but a steady, long-term strategy has served California exceedingly well to combine actions across the state and build a sustainable climate plan. But we also recognize that a fundamental challenge with this approach—and the California way, the Pope's way, and the Paris way, for that matter—is that it will depend on people and their leaders, on all of us. Together, using solutions at hand, while investing in new ones, we just might accomplish what we need to urgently bend the climate change curve.

TEN SOLUTIONS FOR BENDING THE CURVE

Ten Solutions	Estimated Climate Benefits	Population, Health & Economic Indicators
Science Solutions Cluster		
Solution 1: SLCPs and carbon neutrality	The SLCPs solution can keep warming below 2°C until 2050; carbon neutrality is necessary to keep it below 2°C beyond 2050.	Co-Benefits: ▪ 7 M lives saved each year ▪ 100 M tons of food staples saved per year. ▪ Strong biodiversity co-benefits
Societal Transformations Solutions Cluster	*Solutions 2 - 6 are essential to obtain public support for the decisive actions required for carbon neutrality. These can variably work in tandem with solutions #1, 7, 8, 9, and 10 to achieve emissions reductions.*	
Solution 2: Attitudinal and behavior change		
Solution 3:Climate collaboration		
Governance Solutions Cluster		
Solution 4: Governance		
Market- and Regulation-Based Solutions Cluster		
Solution 5: Market-based instruments		
Solution 6: Targeted regulatory measures		
Technology-Based Solutions Cluster		
Solution 7: Mature technologies	Together solutions #7 and 8 are necessary for achieving carbon neutrality post-2050.	▪ Eliminate air pollution-related mortalities of 7 million deaths per year ▪ Improved energy access for the bottom 3 billion ▪ Positive effects on biodiversity and agricultural productivity ▪ Reduction in severe climate-related events that produce periodic or permanent displacement or migration
Solution 8: Energy and transit electrification; building efficiency		
Solution 9: Reduce Methane and black carbon & phase out HFCs	Immediate reductions in greenhouse effects and avoid crossing over tipping points within next three decades	▪ Provides access to clean cooking for the bottom 3 billion people ▪ Reduce ozone pollution and crop damages and yield reductions ▪ Slow down melting of glaciers and sea level rise ▪ Improve fresh water supply by enhancing precipitation
Natural and Managed Ecosystem Cluster		
Solution 10: Control deforestation, support forest recovery and agroforestry production systems, reduce food waste and energy recovery	A. U.S. forests can offset 20% of U.S. fossil fuel emissions (*14*) B. Controlling Amazon deforestation by 70% avoids emitting 3.2 gigatons CO_2 (*15*) C. Tropical forest regrowth absorbs 1.64 gigatons of carbon per year (*16*); rates of regrowth can be 12-20 times that of old growth *(17)* D. Range of agroforestry benefits depends on management*(18)* E Any woody component improves carbon storage in pastures (*19*)	Multiple co-benefits: ▪ Forest recovery and urban afforestation ▪ Biodiversity and microclimate improvements (urban heat island, windbreaks, local water balances, storm surge, flood control) ▪ Enhances livelihoods of rural poor ▪ Helps meet sustainable development goals

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