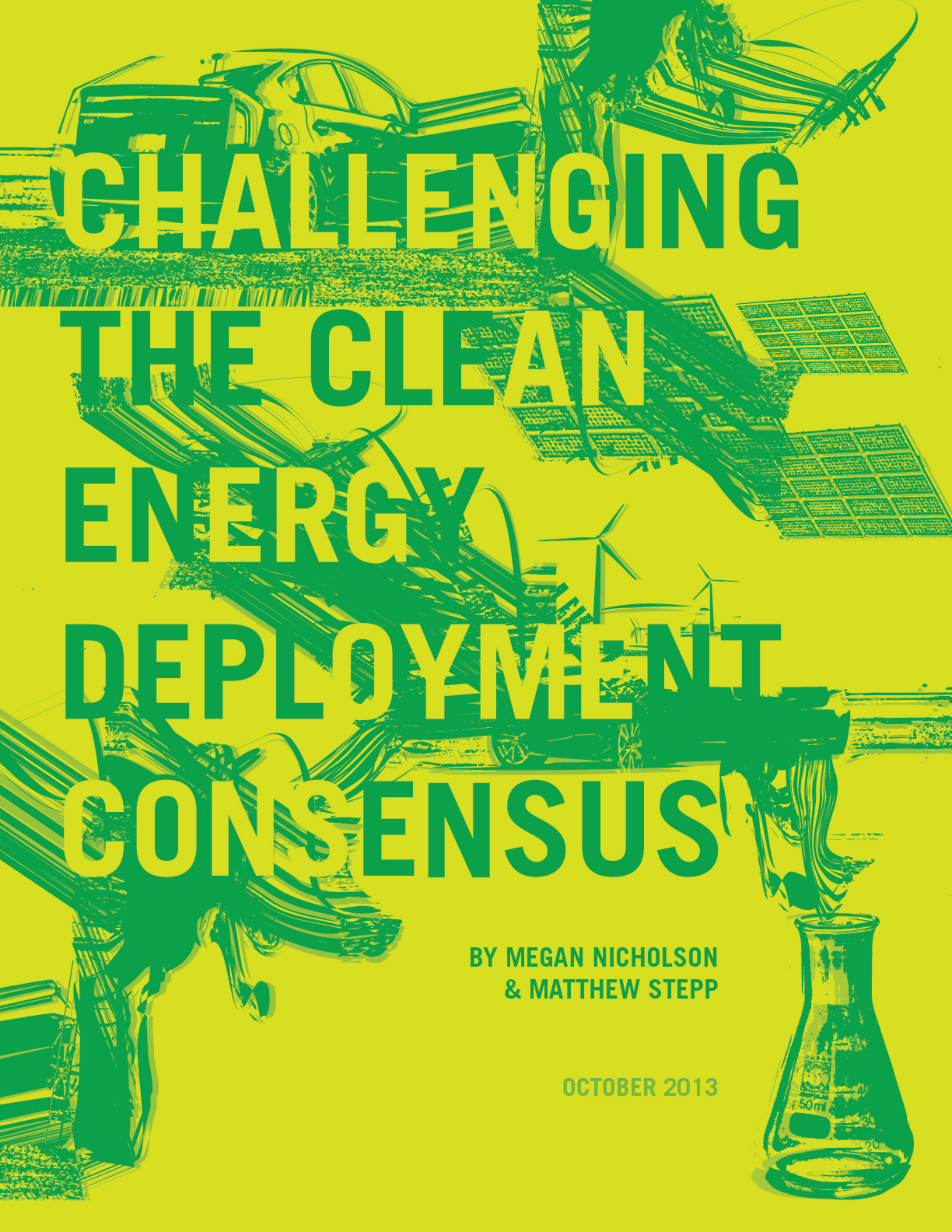

CHALLENGING THE CLEAN ENERGY DEPLOYMENT CONSENSUS

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OCTOBER 2013

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EXECUTIVE SUMMARY

Most clean energy advocates believe that the world has all the low-carbon technologies needed to effectively address climate change. In their view, we don't need technology breakthroughs; we need political breakthroughs that will establish regulatory mandates, subsidies for clean energy, and taxes on "dirty energy" that will drive widespread deployment of clean energy technologies. Unfortunately, this widely held "Deployment Consensus" is largely misguided: existing technologies still cost more, often substantially more, than fossil fuels, while exhibiting sub-optimal performance. Only when clean energy is cheaper than fossil fuels will it be massively deployed globally because countries, companies, and individuals will want to adopt it—not out of civic mindedness, but out of self-interest. And the only way for that to happen is through a robust global clean energy innovation strategy.

The Deployment Consensus is pervasive among environmentalists and climate advocates who contend that the urgency of climate change necessitates rapid deployment of existing renewable energy technologies. Citing a number of studies projecting the necessary scale-up of renewable energy capacity nationally and globally, supporters of the Deployment Consensus claim to have evidence that existing clean energy technologies can in fact meet total energy demand within the next 20 to 40 years. In fact, a careful analysis of these studies identifies four key problems with the Deployment Consensus interpretation of the literature:

While Deployment Consensus advocates are correct to that we need urgent action on climate change, the idea that the world has all the clean energy technologies it needs is fundamentally wrong.

- The Deployment Consensus downplays significant and possibly infeasible renewable power generation capacity scale-up in order to meet projected energy demand, often ignoring the high costs of infrastructure and systems changes the studies claim are needed.
- The Deployment Consensus overlooks or misrepresents persistent storage and integration challenges that will pose significant costs to consumers at high levels of renewables penetration.
- Some of the reviewed studies limit the technology options of a renewable future to wind, solar, and water resources, instead of incorporating other low- and zero-carbon solutions into the projections to maximize cost-effectiveness.
- The Deployment Consensus interpretation of the studies generally assumes that regulations and incentives are appropriate policy tools for encouraging the adoption of renewable energy technologies, and that these policies will likely induce the innovation necessary for a renewable future over time.

While Deployment Consensus advocates are correct to assume climate change is one of the most significant challenges of this century and action is needed now, the suggested costly—and in many cases infeasible—approaches to quickly mitigating the problem will not be effective in the short or long term for the simple reason that the world will not widely adopt more expensive energy sources or the policies needed to implement them, regardless of how loud the climate alarm bells are.

Rather, the key to mitigating climate change is to make clean energy cheap enough to replace conventional energy without mandates, subsidies, or carbon taxes. And the key to making this ideal a reality is to strategically invest in a comprehensive clean energy innovation ecosystem in the United States and internationally.

Unfortunately, most governments, including the United States, have prioritized policies supporting regulation and subsidies over clean energy innovation policies. Indeed, energy innovation policy—basic science, research and development, demonstration, prototyping, and "smart" deployment—is weakly supported in most nations, including in the United States. One key reason for this is that the dominant Deployment Consensus neglects the need for innovation and innovation policy at worst, or pays lip service for innovation at best. To the extent that the Deployment Consensus acknowledges the need for better technology, it emphasizes support for deployment alone as an innovation strategy; deploying more, they claim, will be enough to get clean energy cheaper than fossil fuel. But this assumption ignores the complexities of clean energy innovation. While deployment policies can incrementally lower costs of existing technologies, obtaining the dramatic cost declines necessary to make clean energy as cheap as fossil fuels requires an innovation strategy that invests throughout the innovation ecosystem, with a particular focus on significantly more funding for applied clean energy research. Policies supporting deployment can help support innovation, particularly if these policies tie the deployment of next-generation, breakthrough technologies to cost and performance improvements, called "smart" deployment. In short, advancing globally cost-competitive clean energy solutions to climate change requires a shift from a Deployment Consensus to an Innovation Consensus.

Building a new innovation consensus for climate and energy policy will not be simple, but it will be significantly easier than convincing nations to spend trillions of dollars more on high-cost clean energy than they would otherwise on "dirty" energy, if for no other reasons than nations want to build competitive clean energy industries. This goal would be even more accessible if environmental and climate advocates put their considerable political weight behind an innovation agenda. The report concludes with a number of recommendations for creating an innovation-driven energy policy strategy aimed at making a clean energy future a reality, including:

- Increase public investments in research, development, and demonstration globally. In the United States this would mean tripling existing investment to $15 billion annually.

- Create dedicated revenue streams to support public investment in energy innovation, such as through a carbon tax and/or re-directing revenue from oil and gas drilling on federal lands.

- Reform national laboratory systems to better support clean energy innovation. In the United States the Department of Energy National Laboratory system needs to better link federally funded research to the market to accelerate commercialization.

- Enact policies that address the “valleys of death” by strengthening regional energy innovation ecosystems and improving government clean energy demonstration and prototyping programs.

- Increase government procurement of next-generation clean energy technologies. In the United States this can be done through agencies such as the Department of Defense and the General Services Administration.

- Reform deployment incentives so that cost reductions and performance improvements are a prerequisite for obtaining incentives.

INTRODUCTION

The Clean Energy Deployment Consensus holds that existing clean energy technologies are sufficiently developed and able to replace most global fossil fuel energy use. Proponents of the Deployment Consensus acknowledge technology cost only as a problem that can be solved through government subsidies that bring the price of clean energy down, taxes that bring the cost of dirty energy up, or mandates that simply require its use. However, policy options like these are unsustainable in the long term. Existing clean energy technologies cost too much and are not performance-competitive with fossil fuels, and these limitations will not be fixed without an active clean energy innovation strategy.

The Clean Energy Deployment Consensus holds that deploying already existing clean energy technologies on a massive global scale is the optimal strategy for addressing climate change.

According to the Deployment Consensus, achieving high global penetration of existing renewable technologies only requires the right combination of subsidies, regulatory requirements, and political will. *Greentech Media* energy reporter Stephen Lacey described what he perceived to be the divide between global clean energy advocates: "There are two types of people in the climate action world. The first type—usually people focused on deploying clean energy projects—argues that we can reach very high penetrations with today's technologies. The second type—doubters, spin artists, cautious supporters, and well-intentioned futurists—argues that we can't do anything meaningful without major technology breakthroughs."[1]

Most clean energy policy stakeholders fall under the first category and have been outspoken in their support for deploying existing clean energy technologies. Because of its seemingly simple solution, the Deployment Consensus rhetoric is pervasive and continually referenced by climate and energy advocates, however incomplete or limited the supporting evidence.

- Former U.S. Vice President Al Gore spoke for many deployment proponents when he declared on Comedy Central's *The Daily Show with Jon Stewart* in 2009 that "we have all the tools we need" to solve the climate change crisis.[2]

- Former Sierra Club executive director and chairman Carl Pope decried President Barack Obama for presiding over a clean technology "deployment deficit," calling on members of his administration to prioritize "deploying climate solutions which don't require additional research."[3]

- Senior Fellow and climate blogger at the Center for American Progress Joseph Romm advocates a "deploy, deploy, deploy, research and develop, deploy, deploy, deploy" climate strategy.[4]

- Former Union of Concerned Scientists official Alan Nogee cited a 2011 report on the state of California's energy future, suggesting, "The analysis provides strong support for 'deploy, deploy, deploy' being the top priority."[5]

- Robert Collier, a visiting scholar at the Center for Environmental Public Policy at UC Berkeley's Goldman School of Public Policy argued, "What's important is to use government regulatory authority to push the deployment of existing carbon-reducing technologies."[6]

- In 2011, a group of the world's largest engineering organizations released a joint statement that claimed, "The technology needed to cut the world's greenhouse gas emissions by 85 percent by 2050 already exists." [7] The group refrained from defining what was meant by "existing technology" and did not support their claim with any evidentiary analysis.

- Jigar Shah, head of the Coalition for Affordable Solar Energy, wrote in 2012, "In solving our CO2 problem, we actually have all of the cost-effective technology need[ed]...and more to meet future goals. More R&D is always a good thing, but to suggest the current suite of technologies is not ready is just criminal."[8]

- Center for American Progress scholars Bracken Hendricks and Adam James commented about the National Renewable Energy laboratory's *Energy Futures Study*: "This detailed analysis makes clear that renewable energy is here, it is ready, and it can provide a very large share of the energy we need to run an advanced, prosperous and growing economy…We *don't* need some crazy cool new technology or some groundbreaking invention. We aren't waiting on the scientific community to make some breakthrough.[9]

- Kevin Knobloch, President of the Union of Concerned Scientists, noted that "the National Renewable Energy Laboratory concluded…that today's commercially available renewable technologies could adequately generate 80 percent of U.S. electricity by 2050" in his call to renew the wind production tax credit (PTC), pointing to the report as evidence of the "tremendous" potential of wind power deployment.[10]

- In a 2013 *Huffington Post* editorial co-authored with the former CEO of SunPower Corporation, Thomas Dinwoodie, Amory Lovins wrote: "Mr. President—our nation already has the technologies to protect the climate while advancing prosperity. Here's how. Your National Renewable Energy Laboratory showed just last June how to produce 80 to 90 percent of America's electricity from proven, reliable and increasingly competitive renewable sources like the sun and wind."[11]

- Environmental writer David Roberts contends, "If we are to stay within our carbon budget for the century, global emissions must peak and begin falling (quickly) within five years or so. To have a real chance at preventing catastrophe, we ideally ought to drive carbon emissions to zero, or even negative, well before the end of the century. There is simply no way to do that unless we rapidly deploy the technology we have today."[12]

The Deployment Consensus solution is appealing to policymakers and advocates alike because it suggests that we have already solved the most challenging part of climate change—developing effective alternatives to "dirty energy"— all that is left to do is to simply apply these technologies to transition from fossil fuels. Unfortunately, but unsurprisingly, the reality is much more complicated. It is unrealistic and unreasonable to expect the world to massively deploy expensive clean energy technologies as the Deployment Consensus demands. Even if it is technically possible, it is not economically sustainable or politically feasible on a global scale.

The cost and performance limitations of existing technologies cannot be adequately addressed through deployment-focused policies; however this is not to say that deployment policies are undesirable or unnecessary. All parts of the clean energy innovation systems, from support for basic research to deployment should drive innovation. At this stage of clean technology development more focus should be on research and development than on deployment. As technologies improve and get closer to fossil fuels in cost and performance characteristics, the focus should shift more toward deployment. Moreover, current deployment policies should be tied specifically to cost and performance improvements—otherwise known as "smart deployment" policies.

The policy prescriptions and goals of the Deployment Consensus are akin to attempting large-scale moon colonization using Apollo-age spacecraft technology.

The policy prescriptions and goals of the Deployment Consensus are akin to attempting large-scale moon colonization using Apollo-age spacecraft technology. Achieving widespread renewable energy adoption with existing technologies is technically feasible—the United States achieved multiple moon landings over the course of the Apollo program—and given enough funding, a colony could conceivably be established. But the amount of investment required for realizing this future would be astronomical and the performance of such a colony would not meet high-standards of health, food, water, and safety, similar to renewable energy intermittency not meeting the reliability standards of energy consumers. A significantly more effective long-term strategy is necessary to utilize improved technology generated by robust government support for innovation.

This debate is foundationally important. Climate change is a real, serious, and persistent challenge, but solving it will require policies that will enable clean energy technologies to be cost and performance competitive with fossil fuels. More policy focus on supporting the full lifecycle of clean energy innovation, from research and development through technology commercialization and maturation is necessary to reach this objective. While most supporters of the Deployment Consensus claim to also support innovation, this is often merely lip service; support is fleeting and lacks an organized advocacy commitment that translates into tangible policy action.

To challenge the Deployment Consensus, this report explores its conceptual roots and examines its impacts on energy and climate policy in the United States and internationally. It then analyzes the studies most frequently cited by the Deployment Consensus to defend their claims that we have all the tools we need to mitigate climate change. It clarifies some of the studies' conclusions and critiques the Deployment Consensus argument in four key areas: (1) assuming infeasible scale-up of renewable generation capacity while downplaying the massive costs involved; (2) ignoring critical energy storage and grid integration costs;

(3) limiting technology options for the future; and (4) erroneously assuming mandates, subsidies and carbon taxes will induce enough innovation to drive down costs below fossil fuel prices. This report then proposes an alternative policy framework supporting an innovation-focused global energy policy agenda that can get clean energy on part, if not better than, fossil fuels.

THE ROOTS OF THE CLEAN ENERGY DEPLOYMENT CONSENSUS

Support for the Deployment Consensus is motivated by a combination of urgency and ideology. Among other considerations, the sense of urgency regarding the threat of climate change, the popularity of the "Soft Energy Path" philosophy, and the long-standing U.S. environmental movement contribute to the pervasive and influential nature of the Deployment Consensus within the energy policy space.

The Urgency of Climate Change

Scientists estimate that rising concentrations of greenhouse gases in the atmosphere will result in serious and likely dangerous environmental and social impacts, including the destruction of critical ecosystems and endangerment of already vulnerable and less economically developed human populations.[13] In addition to these direct impacts, climate models also project that geological and atmospheric feedback cycles triggered by initial warming will produce further emissions, making mitigation of climate change even more difficult.[14] United Nations Secretary-General Ban Ki-moon noted at the 2012 international climate change conference in Qatar that "there is no time to waste, no time to lose for us. Climate change is happening much, much faster than one would understand."[15] At its core, the Deployment Consensus is rooted in an overwhelming sense of urgency among advocates to address climate change.

Effectively mitigating climate change demands the development of a comprehensive global strategy for reducing global GHG emissions as quickly as possible.

Effectively mitigating climate change demands the development of a comprehensive global strategy for reducing global greenhouse gas (GHG) emissions as quickly as possible. Deployment Consensus supporters, like environmental organizer Bill McKibben, warn of the existence of a planetary "tipping point." As McKibben stated, "With climate change, unless we act fairly soon in response to the timetable set by physics, there's not much reason to act at all."[16] Large-scale deployment of renewable technologies is logical in this situation because it asks for tangible action that can, according to McKibben, theoretically be achieved immediately.

Massachusetts Institute of Technology (MIT) professor John Sterman developed a theory called the "bathtub effect" to characterize this sense of urgency. It compares the Earth's atmosphere to a bathtub that has a partially open drain but is filling with water.[17] The water in the bathtub is analogous to atmospheric concentrations of carbon dioxide, while the drain is the equivalent of the natural removal of carbon dioxide by plants, soils, and the ocean. As long as water—global GHG emissions in this case—pours into the tub at a higher rate than it is being taken out, there is a risk of the tub overflowing and subsequent disaster: catastrophic and irreversible climate change. Climate scientists estimate that carbon dioxide can remain in the atmosphere for hundreds of years, which, coupled with the fact that many recognized carbon sinks are becoming saturated, means that the bathtub "drain" is beginning to clog.[18]

Since speeding up the drainage process is consequently not a feasible option, the only actionable path forward is to ideally turn the faucet off. Deployment Consensus proponents suggest that mitigating climate change depends on supporting policies that rapidly deploy existing renewable energy technologies to slow emissions immediately. However, this focus will not enable the global economy to adopt cheap clean energy technologies at the rate necessary to slow global temperature rise—deployment of existing clean technologies can only turn the faucet down. By encouraging policy and investment efforts to support innovation now, breakthroughs in clean energy technology and energy storage will eventually be able to turn off the faucet. The sense of urgency concerning climate change is important, but policies to address mitigation must incorporate a long-term view of the problem.

The "Soft Energy Path" Philosophy

Amory Lovins first identified the concept of the "soft energy path" in 1976. In contrast to a "hard energy path" characterized by a focus on large and centralized fossil fuel power plants, Lovins's "soft" path recommends energy conservation and widespread adoption of renewable energy technologies that decentralize energy supply.[19] The "soft energy path" essay, printed in *Foreign Affairs,* became the publication's most reprinted article and was expanded into a full-length book the following year.[20] Lovins's philosophical contribution continues to influence thinking within the Deployment Consensus.

The soft energy path thesis is best summarized as an energy policy addendum to economist E.F. Schumacher's 1973 book, *Small is Beautiful*, which calls for technology use that is both as small-scale and sustainable as possible.[21] In "Energy Strategy: The Road Not Taken?" Lovins emphasizes the importance of greater adoption of renewable energy in general, but greater adoption of simple, "off-the-grid," decentralized technologies such as solar water heaters and other small-scale renewables. Most significantly, Lovins eschews clean technology development in favor of massive deployment of these small-scale, existing renewable energy technologies, suggesting that the two options are mutually exclusive, as "the pattern of commitments of resources and the time required for the hard energy path and the pervasive infrastructure which it accretes gradually make the soft path less and less attainable."[22]

Lovins continues to lead contemporary calls for the deployment of existing renewable technologies based on his soft energy path thinking. His most recent book, *Reinventing Fire*, is even more explicit in its calls for renewable energy deployment on a large and rapid scale. As noted in the book's executive summary, "The key barrier to success is not inadequate technologies but tardy adoption."[23]

The Established Environmental Movement

The Deployment Consensus draws support from much of the environmental movement. Environmental groups in Washington are well heard and have become extremely influential and integrated into the political system in recent years. Matthew Nisbet, an associate professor at American University, suggested that the effort to pass cap-and-trade in the United States "may have been the best-financed political cause in American history."[24] In 2009, environmental groups outspent conservative and industry groups by 34 percent on activities related to climate and energy policy.[25] Environmental groups generally coordinate over congressional "asks," and despite their vocal support for energy innovation, advocacy for rapid deployment of existing technologies has historically taken priority.

An example: the heralded American Clean Energy and Security Act of 2009 (colloquially known as Waxman-Markey) would have dedicated just 1.5 percent of the revenue stream of a proposed cap-and-trade system to the R&D efforts of organizations like the Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) and the Energy Innovation Hubs, which represent key innovation programs within the Department of Energy (DOE).[26] Another example: Friends of the Earth, one of the oldest U.S. environmental organizations—initially headed by Amory Lovins—has partnered with Taxpayers for Commons Sense since 1995 on their *Green Scissors* series, which identifies "wasteful and environmentally harmful" annual federal spending on energy, agriculture, transportation, and land and water projects; in 2011 the report advocated for eliminating ARPA-E because its projects were reportedly "bad for the environment."[27] Modeled after the Defense Department's Advanced Research Projects Agency (DARPA), ARPA-E is considered to be one of the most promising federal government programs for accelerating breakthrough energy technologies and systems to market, and has consistently received bipartisan support since its creation in 2009.[28]

Environmental groups generally coordinate over congressional "asks," and despite their vocal support for energy innovation, advocacy for rapid deployment of existing technologies has historically taken priority.

The organizing power of the Clean Energy Deployment Consensus was evident within the environmental movement's focus on the U.S. wind PTC authorization fight in late 2012. Environmental organizations sided with the wind industry and emphasized the importance of the PTC as a necessary deployment policy. President of the League of Conservation Voters, Gene Karpinski, advocated that Congress should make reauthorization "a top priority," and Margie Alt, executive director of Environment America, put it even more clear-cut terms: "With wind power on the line, there's a lot at stake for our environment, our health, and the future of our planet."[29]

As one press release from McKibben's *350.org* declared, "The barrier towards a renewables powered future doesn't lay in a lack of renewable energy resources or technical limitations of rapidly deploying renewables all around the world—it lays with political will to quickly move towards a clean energy future as quickly as possible."[30] In fact, *350.org* has used the deployment of existing clean energy technologies as an organizing tool for years, calling for world leaders to install solar panels on the roofs of their residences and sponsoring competitions between students to see who can install more clean energy projects on their campuses, among many other initiatives.[31] The Obama administration's decision to put solar panels on the White House in 2010 was used as a rallying point by the Energy Action Coalition for a much broader clean energy deployment agenda. After the announcement, the organization's executive director declared: "We need something on the scale of an Apollo-style program…We need to invest quickly in the mass deployment of renewable energy, this will spark job creation and help communities that are most affected by our dependence on dangerous and unhealthy fossil fuels."[32] This pervasive messaging by environmental advocates fails to acknowledge the complexities and importance of understanding deployment as a stage in a broader energy innovation ecosystem.

POLICY IMPACT OF THE DEPLOYMENT CONSENSUS

The prevalence of the Deployment Consensus among leading thinkers, activists, and policymakers is most evident in today's global energy policy agenda. Specifically, adherence to the Consensus has had important impacts, as overwhelming focus on policies designed to advance the deployment of existing clean energy technologies at the expense of innovation policy has minimized the importance of innovation policy within the energy policy debate.

Prevailing Focus on Deployment

Between fiscal years 2009 and 2012, 71 percent of direct federal investments in clean energy went to deployment.

There is a clear link between energy policy priorities and government investment in energy technology research, development, and demonstration (RD&D) and deployment.[33] In the United States, substantial emphasis on regulation and subsidies translates to at least four times more spending annually on average on technology deployment than technology development. Figure 1 illustrates the overall emphasis of U.S. federal investment on deployment since FY2009, including the American Recovery and Reinvestment Act of 2009. In this case, technology innovation is defined as investments in basic science, research and development, and demonstration. Technology deployment encompasses installation and production subsidies as well as government procurement of clean energy technologies, along with supporting investments in siting and permitting and training and education.

Between fiscal years 2009 and 2012, 71 percent of direct federal investments in clean energy went to deployment, through energy efficiency grants, alternative fuel credits, and the energy production and investment tax credit programs for the domestic solar and wind industries. During the same period, public investment in deployment and procurement nearly tripled, while investment in research, development, and demonstration projects either remained steady or declined.[34] Post-American Recovery and Reinvestment Act, public investments in research, development, and demonstration projects declined by 30 percent to $5.1 billion, while investments in tax expenditures for clean energy almost tripled to $10.9 billion in FY2011 before falling to $6.5 billion in FY2012.[35] These expenditures are only part of the cost of supporting clean energy deployment and do not include the costs of clean energy and energy efficiency regulations and mandates, which are borne by energy consumers.[36]

Today's clean energy policies are suspect to significant—sometimes sensational—scrutiny in terms of public spending, and are pressured by growing deficits and fiscal austerity. It is unrealistically optimistic to suggest that policymakers do not need to make trade-offs between investing in energy innovation and investing in deployment, as public investment in clean energy is not unlimited.

The policy effects of the Deployment Consensus are global as well. Bloomberg New Energy Finance reports that both public and private clean energy investment amounted to $270 billion in FY2012, while only $30.2 billion, or 11 percent, was invested in research and development.[37] According to the International Energy Agency, the share of public investment in technology research, development, and demonstration invested in energy fell from a global average of 12 percent in 1980 to less than 4 percent in 2010.[38] This persistent investment imbalance is hollowing out the energy innovation ecosystems in the United States and globally.

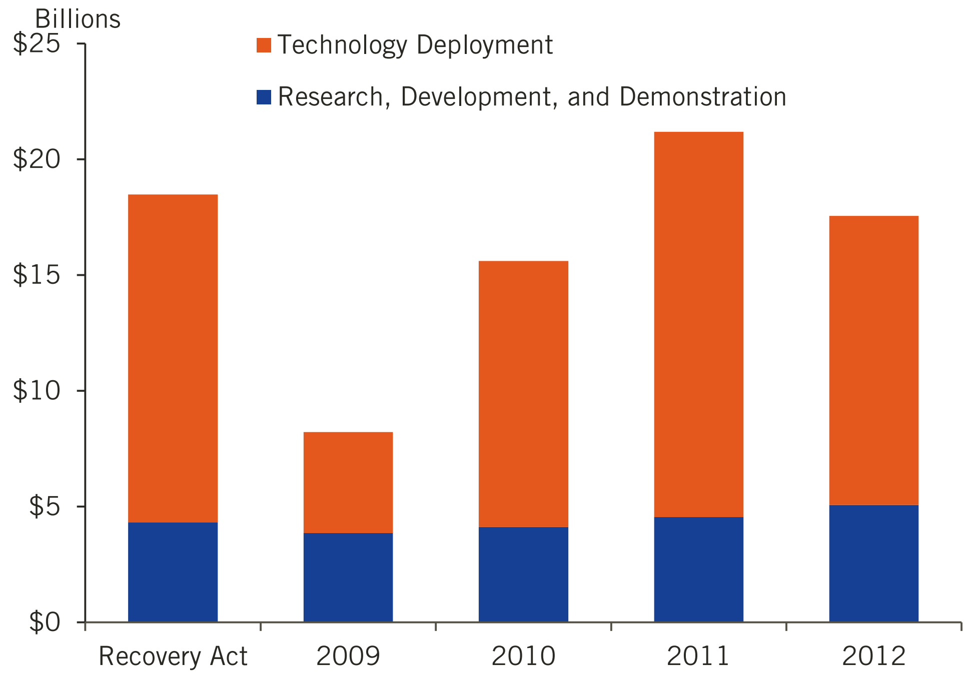

Figure 1: U.S. Federal Investments in Energy Research, Development, and Demonstration, and Deployment; Data in Billions[39]

The overwhelming policy focus on deployment has diluted public understanding of what innovation policy actually represents. "Innovation" has become a catch-phrase to promote all kinds of non-innovation-related policies.

Lip Service for Innovation

Supporters of the deployment consensus will argue that they too support the need for innovation, but for many, innovation is often assumed to happen of its own accord and seen as "manna from heaven."[40] *Grist* environmental writer David Roberts defines the debate between deployment and innovation: "Those who say we don't have the necessary technology focus on *innovation* [author's emphasis] and the need for 'breakthroughs.' Those who say we do have the necessary technology focus on *deployment*—accelerating the adoption of today's tech…as I see it, pretty much *nothing* hinges on the answer…this debate seems pointless to me."[41] Roberts contends, "Even the most enthusiastic fans of deployment acknowledge the need for innovation."[42] Unfortunately this acknowledgement is rarely translated into the commitment of scarce organizational and political capital to support clean energy innovation policies.

The overwhelming policy focus on deployment has diluted public understanding of what innovation policy actually represents. "Innovation" has become a catch-phrase to promote all kinds of non-innovation-related policies.[43] For example, an open letter to President Obama from the editors of *MIT Technology Review* in 2013 chided the administration for suggesting that support for innovation through the 2009 Recovery Act was justified by its job creation prospects, which lead to misplaced investments ultimately focused more on unsustainable economic development than on energy policy.[44] Even among policy experts, there is a tendency to simplify innovation policy by equating it simply to R&D, which distorts the necessary nature of an innovation ecosystem with many moving parts that must be comprehensively linked to lead to the development and commercialization of new technologies.

The full cycle of energy innovation emphasizes R&D, prototyping, technology demonstration, and smart deployment. As defined in the Breakthrough Institute's *Bridging the Clean Energy Valleys of Death* report, "Innovation is best described as a fluid and cyclical process, comprised of a myriad of actors and institutions whose actions and decisions will ultimately affect the development, deployment, maturation, and price of new technologies. Typically, new technologies pass through a series of five interlinked activities to drive an innovative idea from basic science to a fully developed business."[45] Those five stages of the energy innovation process are displayed in Figure 2.

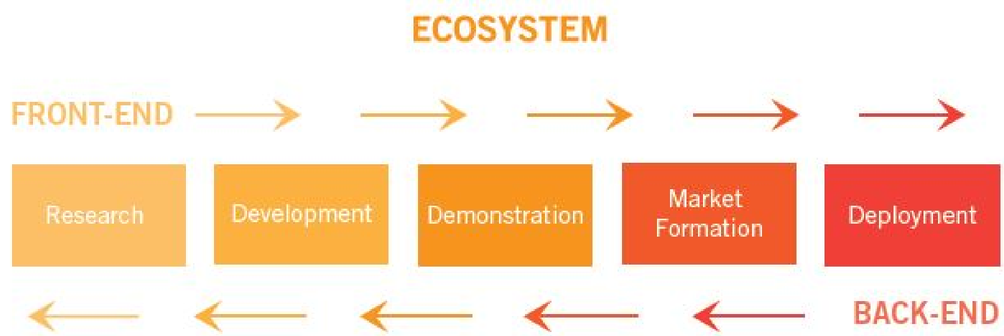

Figure 2: Conceptual Energy Innovation Lifecycle[46]

Defining energy innovation policy as research is thus oversimplified and incorrect; productive energy innovation requires an ecosystem of technology development stages, with inextricably linked policy and investment support. Solely emphasizing deployment as a solution to fixing national and global energy systems understates the necessary complexity of the system and results in unsupportive and disjointed policies outside the innovation lifecycle.

SURVEY OF ANALYSES UTILIZED BY THE DEPLOYMENT CONSENSUS

The central premise of the Deployment Consensus is that existing clean energy technologies can, if widely deployed, generate enough power to largely replace fossil fuels. If achieving high global penetration is technically feasible, then the most optimal policy solution is to support immediate and massive deployment of these existing technologies.

To defend their claims, supporters of the Deployment Consensus point to a number of reports presenting possible "renewable energy futures" that can be technically realized with significant deployment of existing technologies (see Table 1). According to the Deployment Consensus, these studies offer enough evidence to prove that the world has all the clean energy technology it needs to sufficiently reduce GHG emissions and mitigate climate change. However a review of this literature indicates two general conclusions. First, some of the studies base their projections on generous assumptions about the economic and political feasibility of massive deployment and the pace of energy technology innovation. These studies disregard cost as a significant issue, and do not acknowledge that energy consumers in the United States and internationally are not willing to pay much higher energy prices in support of the imagined renewable energy futures presented. Second, advocates often misinterpret evidence or "cherry pick" from conclusions to support assertions. This report does not aim to deliver a technical critique of the studies themselves, but instead discusses the Deployment Consensus interpretation and conclusions about the studies as "evidence" of the strength of clean energy deployment as adequate climate policy.

Report	Motivation	Projection
State Level		
California's Energy Future—the View to 2050[47]	California passed the *California's Global Warming Solutions Act of 2006* which sets strict greenhouse gas emissions standards for the state to meet by 2050. This study was conducted to help the state assess the ability of existing technologies and systems to meet energy demand under the emissions targets in 2050.	The state of California can achieve 60% reductions in greenhouse gas (GHG) emissions from 1990 levels with existing technologies by 2050; the state can reduce GHG emissions to 80% below 1990 levels with more significant policy changes and some innovation by 2050. Report finds that these goals are difficult or near-impossible to achieve cost-effectively without incremental and breakthrough innovation in clean energy technologies and particularly storage technologies.
Jacobson et al. (2013)[48]	The study is the first attempt at modeling a long-term and sustainable energy system powered only by wind, water, and solar technologies, consequently reducing air and water pollution and global warming impacts as significantly as possible.	New York state's energy demand can be met with 100% renewable energy by 2030.
National Level		
NREL *Renewable Electricity Futures Study*[49]	The study assesses the abilities and technical issues of significantly integrating renewable energy technologies into the U.S. electricity grid. The study models a number of scenarios considering operational challenges, energy demand growth, and levels of technology improvement.	Existing renewable energy technologies can provide 80% of U.S. electricity supply by 2050.
Budischak et al. (2013)[50]	The study models several different combinations of renewable electricity resources with electrochemical storage to calculate a minimal cost situation and to assess intermittency issues.	Existing renewable electricity technologies can power the U.S. grid 90% to 99.9% of the time at costs comparable to today's by 2030 by minimizing the use of energy storage technologies.

Global Level		
Mark Jacobson and Mark Delucchi (2011)[51]	The study models the feasibility of providing all national and global electricity with wind, water, and solar resources to address the three most significant challenges of the century: climate change, pollution, and energy insecurity.	Global energy demand can be met 100% with renewable energy technologies by 2030; there are no technical barriers to this future.
WWF *The Energy Report: 100% Renewable Energy by 2050*[52]	Motivated by the facts that much of the world still lacks energy access, and that sources of conventional fossil fuels are running out, this report models a possible scenario for global renewable power by 2050 as the most effective way to fight climate change.	Existing renewable energy technologies can provide 100% of global energy supply by 2050.
IPCC *Renewable Energy Sources and Climate Change Mitigation*[53]	The report assesses the six renewable energy resources and their ability to integrate into energy systems and suggests policy and technical strategies for enabling their deployment and application globally.	Existing and developing renewable energy technologies can meet 77% of global energy demand by 2050.

Table 1: Summaries of Commonly Cited Literature by Proponents of the Deployment Consensus

The subsequent sections introduce and explain four themes covered in seven studies frequently cited by supporters of the Deployment Consensus and reviewed in this report (see Table 2). These include:

- **Projecting economically infeasible renewable capacity build-up.** Each of the studies proposes scenarios of how much renewable power generation and infrastructure capacity build-up is necessary to meet different high GHG emission reduction goals. These projections are useful for visualizing the amount of renewable generation capacity necessary to meet future demand, but they also show how economically infeasible reaching high renewable penetration levels is using today's expensive renewable technologies.

- **Overlooking critical integration costs.** Many of the studies underestimate or altogether ignore the economic impacts of transitioning to a high-renewables scenario with existing technologies. The costs of integrating and transmitting electricity reliably to meet peak demand are still prohibitively high, especially considering the current state of storage and grid technology.[54]

- **Limiting technology options.** Most of the studies suggest that high-renewable penetration scenarios can be achieved without natural gas, biofuels, or even zero-carbon nuclear energy. These energy resources, among other low-carbon solutions, could enable a more cost-effective transition away from conventional fossil fuels in the short term. Exclusion of these technologies from a possible renewable energy scenario limits regional, national, and global opportunities to reduce GHG emissions as quickly and cheaply as possible.[55]

- **Erroneously assuming induced innovation through regulation and incentives.** Of the studies that recognize the limitations of existing technologies, some suggest that the best way to realize the proposed high-renewables-penetration scenario is to create policies that "induce innovation" through carbon taxes, cap-and-trade systems, or regulation. Studies suggest that deployment policies like these will encourage adequate private sector innovation, which will lead to needed breakthroughs. Unfortunately, this assumption is unfounded.

In 2012, renewable energy generated about 12 percent of total utility-scale electricity in the United States (about 56 percent attributed to hydropower), and 19.5 percent of globally generated electricity.

Report	Infeasible Capacity Build-Up	Integration and Storage Costs	Limited Technology Options	Induced Innovation
State Level				
California's Energy Future	X	X		X
Jacobson et al. (2013) [NY]	X	X	X	X
National Level				
***Delucchi & Jacobson (2011)**	X	X	X	
NREL *Renewable Electricity Futures Study*	X	X		
Budischak et al. (2013)	X	X	X	
Global Level				
***Delucchi & Jacobson (2011)**	X	X	X	
WWF *The Energy Report*	X	X		X
IPCC *Renewable Energy Sources*	X	X	X	X

Table 2: Common Assumptions Made in Frequently Cited Studies in Support of the Deployment Consensus[56]

Infeasible Renewable Capacity Build-Up

The primary purpose for many of the studies cited by the Deployment Consensus is to consider the additional renewable power generation capacity required to meet GHG emission reduction goals or high renewable penetration scenarios. The studies consider generation capacity build-up for a range of technologies to meet state, national, or global demand within either the next 20 or 40 years, making assumptions about plausible infrastructure and renewable power generation scale-up and potential costs.

Assuming Infeasible Scale-Up of Renewable Generation Capacity

In 2012, renewable energy generated about 12 percent of total utility-scale electricity in the United States (about 56 percent attributed to hydropower), and 19.5 percent of globally generated electricity.[57] The scenarios presented in the literature cited by Deployment Consensus advocates reflect radical acceleration of clean energy deployment to increase renewable generation capacity to near 100 percent. Table 3 summarizes the additional generation capacity suggested by five of the seven reviewed reports.[58]

	Additional Generation Capacity Required (GW)					
	State Level		National Level			Global Level
Technology	*California's Energy Future*	Jacobson et al. (2013) [NY]	*Delucchi & Jacobson (2011)	NREL *Futures Study*	Budischak et al. (2013)	*Delucchi & Jacobson (2011)
Biomass	1.5	-	-	45.3	-	-
Fossil Fuels	54	-	-	-	28.3	-
Geothermal	-	3.6	83	8.6	-	535
Hydroelectric	-	8.5	182	4	-	1,170
Nuclear	44	-	-	-	-	-
Solar: PV	22	116.4	795	87.9	16.2	17,100
Solar: CSP	65	38.7	2,280	0.5	-	14,700
Storage	-	-	-	140	51.9	-
Tidal	-	2.6	7.6	-	-	490
Wave	-	1.4	82.5	-	-	540
Wind	59	-	2,950	-	-	19,000
Wind: Offshore	-	63.6	-	56	89.7	-
Wind: Onshore	-	20.1	-	240	124	-

Table 3: Additional Generation Capacity Necessary to Meet Study Projections, in GW[59]

As *MIT Technology Review*'s Kevin Bullis comments, "Every once in a while someone will publish a roadmap for running the world (or a state) on 100 percent renewable energy by some date, say 2030 or 2050. But delve into these roadmaps, and you'll often find jaw-dropping numbers of solar panels and wind turbines, radical changes to existing infrastructure, and amazing assumptions about our ability to cut energy use that make switching to renewable energy seem more daunting."[60]

Several reviewed studies suggest that in order to meet electricity demand reliably with renewable energy— assuming the low availability of energy storage and grid technologies—it will be necessary to over-generate electricity by two to three times to meet peak demand. The capacity build-up in these studies is radical and would involve massive deployment efforts. Jacobson and Delucchi (2011) assume that to meet U.S. energy demand in 2030 with only wind, water, and solar power technologies, the country must deploy 590,000 5-MW wind turbines, 7,600 300-MW concentrated-solar plants, and 6,200 300-MW solar photovoltaic (PV) power plants.[61] This is the equivalent of installing 12.5 times more wind capacity and 50 times more solar capacity per year than was installed in 2012 until 2030.[62] The study projected under the same assumptions that to meet global energy demand in 2030, nearly four million 5-MW wind turbines, 49,000 300-MW concentrated-solar plants, and 40,000 300-MW of solar PV must be deployed.[63]

Jacobson et al. (2013) considers similarly high-level assumptions about deploying large amounts of renewable energy capacity in the state of New York. The report's plan calls for building 12,770 offshore 5-megawatt wind turbines and 4,020 onshore 5-MW wind turbines just to provide 50 percent of the state's electricity. There are obvious obstacles to this kind of deployment within state borders; according to *Bloomberg New Energy Finance*, the onshore wind turbines alone would cover 1,000 square miles—more than 2 percent of the entire state's land area and more than three times the area of New York City. The offshore wind turbines would require 4,903 square miles, or more than 10 percent of New York State's land area. As such, *Bloomberg New Energy Finance* senior analyst Angus McCrone fittingly labeled the report's plan "unrealistic," and *The New York Times*'s Andy Revkin characterized it as more of a "thought experiment" than a road map for renewable energy deployment "given the monumental hurdles—economic, political, regulatory and technical—that would hinder such a shift."[64]

The California Energy Future Study concludes that to achieve GHG emission reduction of any significance, further innovation in renewable power generation, energy storage, and grid technologies is necessary.

Compared with the New York state study, scaling up renewable generation capacity in California has similarly radical implications. The *California Energy Futures Study* suggests that to reduce GHG emissions 60 percent below 1990 levels, the state would need to add 22 GW of new nuclear power over 40 years, effectively necessitating the building of one new nuclear plant per year until 2050.[65] This recommendation accompanies additional scale-ups of renewable power generation and utilization of carbon capture and sequestration (CCS). Report co-author Jane Long, principal associate at the Lawrence Livermore National Laboratory, stated that if California could "very quickly replace cars, appliances, boilers, buildings and power plants with today's state-of-the art technology, replace and expand current electricity generation with non-emitting sources and produce as much biofuel as possible by 2050," the state would see significant emission reductions.[66] From the *California Energy Future Study*:

> If an average capacity factor of 37% is assumed, annual installed renewable energy generation would need to increase by an order of magnitude, from 16 GW in 2009 to 165 GW in 2050. To put this in perspective, this implies a growth rate for wind power of about 7.5% per year, and for solar power of about 12% per year, even with assumed increases in biomass and geothermal power and the assumption that California's large hydro resources remain in operation.[67]

The *California Energy Future Study* concludes that to achieve GHG emission reduction of any significance, further innovation in renewable power generation, energy storage, and grid technologies, as well as next-generation nuclear power is necessary; however, the study continues to be used by the Deployment Consensus as evidence of a well-constructed "plan" to decarbonize the state using existing technologies.[68] As California is one of the most renewable resource-rich states in the country, with strong policy support for renewable energy and climate change mitigation, it seems unlikely that New York state, which has a smaller land area, a smaller population, and a lower GDP, would be able to facilitate the above-mentioned renewable energy strategy by 2030 without the significant technology cost reductions and performance enhancements suggested in the California study.

The National Renewable Energy Laboratory's *Renewable Energy Futures Study* implies increasing U.S. geothermal capacity by almost three times, biomass energy by seven times, wind generation capacity by eight times, and solar energy by almost 42 times in its low-demand scenario.[69] In the high-demand scenario—which is closer to Energy Information Administration (EIA) predictions of future energy demand—the study assumes six times more geothermal energy, 13 times more wind and biomass energy, and 125 times more solar generation capacity by 2050.[70] The study's high-demand scenario also calls for doubling 2010 hydropower capacity, met with new river-run systems, which is the power-equivalent of adding the generation capacity of 45 new Hoover Dams in 40 years.[71] These capacity increases are ambitiously in pursuit of an 80 percent renewable penetration scenario, and the study acknowledges the significant obstacles in the way of its capacity building recommendations:

> Although this analysis suggests there are sufficient renewable resources to reach 80%-by-2050 renewable electricity even in a more-traditional higher demand growth scenario, there may be institutional challenges to deploying renewable energy at the rate required in that instance. In particular, approximately 20 GW–30 GW of renewable capacity is expected to be added each year through 2030 in order to achieve an 80% renewable electricity future under business-as-usual demand growth, compared to approximately 7 GW installed in 2010 and 11 GW installed in 2009, increasing to approximately 70 GW each year for the last decade of the period.[72]

The NREL *Futures Study* offers an extremely in-depth technical analysis of existing clean energy technologies' abilities to meet future energy demand, and models a large number of scenarios to consider many assumptions about energy growth, technology innovation, and transmission; however, Deployment Consensus advocates simplify the report's conclusions and generally rationalize the study as a well-planned roadmap for technology deployment.[73] After assessing scenarios assuming no technology improvement (NTI), incremental technology improvement (ITI) and evolutionary technology improvement (ETI), the study actually concludes that evolutionary improvements in renewable energy technologies are the most powerful driver for lowering technology costs. This piece of the report is often ignored by Deployment Consensus advocates.

When considering the economic and political implications of the capacity building recommendations put forth in the literature cited by the Deployment Consensus, it is clear that more innovation is necessary to develop cost effective and better-performing energy technologies to create an efficient, reliable, low-cost renewable energy system.

Assuming Costly Infrastructure Build-Up

Installation of millions of new wind turbines and tens of thousands of new solar plants required by the Deployment Consensus literature poses a weighty challenge, but building up renewable energy capacity is only part of the problem. Significant overhauls to the energy infrastructure at the state, national, and global level are required to meet these studies' goals, which would require billions, and even trillions, of dollars of investment, and higher consumer electricity prices.

For example, many of the studies demand significant innovation in the transportation sector to enable a complete transition away from fossil fuels to electric vehicles or hydrogen fuel cells, which add additional technical and economic challenges. The NREL *Futures Study* acknowledges that its low-demand growth scenario assumes a "substantial fraction" of passenger transportation—50 percent—will switch from conventional fuel vehicles to electric or hybrid-electric vehicles by 2050. As significantly more innovation in electric vehicle batteries is needed to lower cost and increase performance and range to make electric vehicles available to a broader population, 50 percent replacement of conventional fuel vehicles is likely overestimating electric vehicle deployment for the future.[74] Electric vehicle deployment assumptions serve studies like the NREL *Futures Study*, Jacobson et al. (2013), and Budischak et al. (2013), as an alternative option for energy storage and load balancing on the grid when vehicles are plugged in to charge. Access to this modus of energy storage, however, hinges on national and international ability to innovate affordable, efficient, and safe electric vehicle batteries within the next 20 to 40 years.

Report	Estimated Cost of Projected Scenario	Cost Per Household Per Year	GDP (State, National, and World)	Percent of GDP Per Year
State Level				
Jacobson et al. (2013) [NY]	$533 billion	$3,641	$1.1 trillion	3 percent
National Level				
***Delucchi & Jacobson (2011)**	$13 trillion	$5,664	$15.7 trillion	5 percent
Global Level				
***Delucchi & Jacobson (2011)**	$100 trillion	$3,571	$71.6 trillion	8 percent

Table 4: Estimated Cost of Additional Generation Capacity Between 2013 and 2030[75]

Infrastructure conversion costs are challenging to estimate, since these changes often involve behavioral and technology changes outside of a reasonably predictive scope.[76] Some studies simply suggest that total electricity and transportation system transformation will result in "large initial cost increases to consumers," leaving additional details and further estimates vague.[77] By comparison, Jacobson et al. (2013) estimate that one simple way to calculate the costs of adding power generation capacity is to consider that every MW of installed capacity costs an average of about $2.1 million, across all renewable technologies.[78] Table 4 considers this methodology to estimate the scale-up costs for three of the reviewed studies, compared to GDP. These estimates represent conservative approximations of total cost, as they exclude the costs of overhauling transportation systems and other relevant factors. By this methodology, Delucchi and Jacobson (2011) project a plan for powering the world on 100 percent renewable energy by 2030 that costs $100 trillion, which is equivalent to 8 percent of global GDP per year for 20 years, or asking every household in the world to pay an additional $3,571 per year for renewable energy.[79]

Overlooking Storage and Integration Costs

In transitioning from a fossil fuel-based energy system to a low-carbon energy future, costs will likely determine worldwide deployment. As acknowledged in Budischak et al. (2013), any renewable electricity future must meet the same consumer expectations of today's electricity system—in other words, any electricity system of the future must be highly reliable, low cost, and environmentally safe.[80]

Impact of Falling Levelized Costs

Many studies cited by the Deployment Consensus address falling levelized costs of renewable energy in support of their deployment goals. Levelized cost is a measure of the cost of an energy generation system over the course of its lifetime, which according to the IPCC is "calculated as the per-unit price at which energy must be generated from a specific source in order to break even."[81] The levelized cost of an energy generation system reflects capital and operating and management costs, and it serves as an opportune measure for comparing the generation cost of say, a solar photovoltaic plant to an offshore wind turbine.

Technology	Levelized Cost of Energy (LCOE)
Natural Gas (Conventional Combined Cycle)	$63-$67/ MWh
Coal	$89-$118/ MWh
Nuclear	$104-$108/ MWh
Wind	$74-$99/ MWh
Geothermal	$81-$100/ MWh
Biomass	$98-$130/ MWh
Solar PV-Utility Scale	$113-$224/ MWh
Battery Storage*	$216-$329/ MWh

Table 5: Levelized Costs of Conventional and Renewable Energy Sources (data in dollars per megawatt hour)[82]

As part of its *Annual Energy Outlook 2013* report, the U.S. Energy Information Administration (EIA) forecasts the range of levelized domestic electricity generation for different sources beginning operation in 2017.[83] The data, based on a 30-year cost recovery period, indicates that among nuclear, solar, and wind, only wind—in certain situations—can be considered cost-competitive with coal, with an average levelized cost of $87 per megawatt-hour, compared to $100/ MWh for conventional coal. Natural gas, with an average levelized cost of $67/ MWh, is considerably cheaper than other clean and conventional energy sources (see Table 5).[84]

Many studies suggest that levelized costs for solar PV and wind power generation are approaching competitiveness with other electricity sources in niche markets—usually in resource-favorable regions.[85] Real costs of some renewable energy technologies like onshore wind and solar PV have fallen considerably during the last few decades because of a combination of technology improvements and evolving policy environments.[86] However, additional feedbacks are also supporting these cost declines. For example, research scientist Schalk Cloete's analysis of a GTM Research study suggests that subsidies for wind and solar still support the industries substantially, and that cost declines can be traced back to "margin erosion" thanks to "government support and desperate cost cutting across the board."[87] Cloete continues: "Even though it is conceivable that solar PV could eventually achieve grid parity with fossil fuel electricity through third generation technologies like organic PV, the chances of first generation panels (for which an enormous overcapacity has been subsidized into existence) ever achieving this milestone are slim to none."[88]

If continued technology innovation is not identified and emphasized to policymakers as the key to achieving renewable grid parity, clean energy costs will not fall to necessarily low levels to compete with fossil fuels.

Not only is it necessary to understand why costs have fallen in previous years, it is critical to target cost reductions for the future and leverage policy to ensure it occurs. For instance, Near Zero, a nonprofit organization that facilitates dialogue on energy policy, solicited the perspective of leading energy experts in the United States on the future of solar costs.[89] It found that the solar industry requires breakthroughs in materials, installation methodology, manufacturing, and electrical conversion efficiency to continue driving down the cost of solar in the coming decades.[90] It is not enough to just focus on so-called "soft-costs"—non-hardware costs such as permitting and labor—that many advocates focus on; it is also necessary to target technical costs to drive up efficiencies and lower the overall balance of costs of renewables.

In other words, if continued technology innovation is not identified and emphasized to policymakers as the key to achieving renewable grid parity, clean energy costs will not continue to fall to necessarily low levels to compete with fossil fuels.[91] Surely, deployment subsidies—if aimed at driving clean energy innovation—are one part of a cohesive policy response to ensure that renewable cost curves continue to fall. But perpetual subsidies in absence of an aggressive innovation policy are unsustainable and may not allow cost curves to dip below that of fossil fuels, or for new cost curves to emerge.

Energy Storage and Integration Challenges

The Deployment Consensus cites falling levelized cost as a sign that renewable energy technologies are becoming cheap enough to be cost-effectively deployed. However, levelized cost is an incomplete measure of cost-competitiveness, as it does not account for regional variation in costs, and does not factor in storage and integration costs of renewables.[92] The former is important because the EIA indicates that energy policymakers and stakeholders can continue to expect substantial regional variation in the levelized cost of wind and solar, which translates into considerable uncertainty for policymakers.[93] The latter is important because storage, load balancing, and grid integration technologies are obviously critical to ensuring electricity reliability. Many of these technologies are still in development and continue to have significantly high costs.[94]

NREL's *Futures Study*, which models 80 percent renewables penetration in the United States by 2050, requires increasing existing storage capacity by at least seven times current capacity, from around 20 GW in 2010 to 140 GW in 2050.[95] A recent study by the U.S. Department of Energy and the Electric Power Research Institute (EPRI) calculates that depending on system size, levelized costs of pumped hydro and compressed air energy storage systems are over $200/ MWh.[96] In its "low-demand" scenario, which assumes that national electricity demand does not increase between now and 2050, the *Futures Study* also requires the deployment of 28 GW–48 GW of additional load balancing by 2050, compared to 15.6 GW in 2009. Additionally, the *Futures Study* requires installing 30 million to 180 million new MW-miles in transmission capacity, which would effectively double current capacity and cost between $6.4 billion and $8.1 billion per year between 2010 and 2050.[97] The *Futures Study* maintains that while this additional storage and transmission capacity is ambitious, it is still technically feasible, but possibly constrained by "institutional obstacles" like siting and coordination between governing entities.[98] While this study and others refer to policy and technical improvements that would make implementing the high-renewables scenario more readily attainable, the Deployment Consensus fails to recognize many of these recommendations. As a technical review of the capability of renewable technologies to meet future energy demand, the *Futures Study* does not assess consumer willingness to pay for these infrastructure changes.

Significantly more battery, smart-grid, and power electronics innovation is needed to satisfy this white space before large-scale, deployed renewable energy can meet peak load balancing demand at the statewide, national, or global level.

Other studies confront the problem of reliable energy supply by oversizing renewable energy capacity to minimize the need for load balancing altogether. The model created by Budischak et al. (2013) relies on oversizing the renewable electricity supply to accommodate peak demand using very little storage—in other words, the study claims that over-generation of power solves the reliability problem more cheaply than using existing storage and load balancing technologies. The study asserts that meeting 90 percent to 99.9 percent of energy demand in the United States with renewable technologies necessitates generating between two and three times that much electrical energy—the study's "least cost" scenario requires generating double the amount of electricity needed in order to satisfy peak demand.[99] Budischak et al. (2013), also assume perfect transmission to "simplify" the study, however this assumption is unrealistic if applied to an actual transmission system.[100] While this scenario skirts the storage technology problem, it also assumes the deployment of two to three times the necessary generating capacity as an alternative to developing better storage and load balancing technologies (see Table 4 for estimated costs of generating capacity).

The *California Energy Future Study* directly recognizes the inefficiencies and cost barriers of storage technologies, stating that while there are a number of energy storage technologies in development, "few or none of these would be able to manage multiple GW-days of storage which might be required in the case where wind and solar are used for a substantial (>50 percent) fraction of the state's energy mix."[101] Additionally, the study finds that systems management technology and other smart grid alternatives are still in development and not widely commercially available, and consequently considers fossil fuel-fired plants with CCS to manage about half of all renewable generation load balancing.[102] The study finds that nuclear energy could most efficiently manage load balancing without additional carbon emissions. California Institute of Technology Professor Nate Lewis reiterated the incongruity of Deployment Consensus interpretation of the *California Energy Futures Study* during an interview with *New York Times* columnist Andrew Revkin about his participation in a 2009 National Academy of Sciences study on the readiness of renewable technologies:

> Everybody agreed that if we were going to get more than half of our electricity in our country from renewables by 2050 we were going to have to do things that we simply don't know how to do today at all and fundamentally change the way we use, generate, and consume energy. That is completely in agreement with the California report. And it's different than people who would tell you that we have all the technology we need and we just need the political will and let's be done with it. That's not what any technically knowledgeable panel concludes.[103]

Energy storage and carbon-free load balancing technologies are needed to accommodate high renewable energy generation capacities, but are still in development and demonstration phases and must see further cost declines. Significantly more battery, smart-grid, and power electronics innovation is needed to satisfy this white space before large-scale, deployed renewable energy can meet peak load balancing demand at the statewide, national, or global level. Although many of the reviewed studies acknowledge this reality, the need is generally overlooked by Deployment Consensus advocates.

Limited Technology Options

At least four of the seven reports examine future scenarios of 100 percent renewable energy supply. These studies in particular are simply based on evaluating necessary new renewable installation capacity to replace fossil energy with zero-carbon technologies. This "evidence" is thought to prove the insignificance of technical barriers to the widespread adoption of renewable energy without consideration for the massive cost hurdles of this kind of deployment.

These four studies emphasize building a 100 percent renewables future and consequently are modeled around a portfolio of zero-carbon energy technology options to be widely deployed and scaled. This portfolio generally includes solar PV and concentrated solar power (CSP), onshore and offshore wind, hydroelectric power, wave power, and tidal power, and occasionally geothermal energy. Two of the reports, Jacobson et al. (2011) and Jacobson and Delucchi (2011), specifically pursue future scenarios that rely solely on wind, water, and solar energy, suggesting that transportation systems should also be electrified.[104]

Scenarios like these ultimately exclude alternative zero- and low-carbon technologies from projections in order to achieve high renewable market penetration, instead of prioritizing the maximization of GHG emission reduction as quickly, efficiently, and cost-effectively as possible.[105] Despite nuclear energy's standing as an available, carbon-free energy source, six of the seven studies exclude it from their projections.[106] While there are still technical, cost, and regulatory barriers, innovation in next-generation nuclear technologies and small modular nuclear reactors (SMRs) has accelerated technology development and lowered costs, signifying substantial opportunity to integrate nuclear energy into a low-carbon energy future.[107] Biofuels, natural gas, and other unconventional fossil fuels—along with carbon capture and sequestration (CCS) technology—were also excluded from most of the studies, despite their potential usefulness as transition energy sources.

	State Level		National Level		Global Level		
Technology	California Energy Future (2012)	Jacobson et al. (2013) [NY]	NREL Futures (2012)	Budischak et al. (2013)	Delucchi & Jacobson (2011)	WWF (2011)	IPCC (2012)
Biomass	X		X			X	X
Biofuels	X		X				
CCS	X		X				
Energy Efficiency			X				
Fossil Fuels	X		X			X	
Geothermal		X	X		X	X	X
Hydroelectric		X	X		X		X
Hydrogen Fuel Cells	X	X		X		X	
Nuclear	X		X			X	
Ocean							X
Solar: PV	X	X	X	X	X	X	X
Solar: CSP	X	X	X		X	X	X
Electric Vehicles		X		X			
Tidal & Wave		X			X	X	
Onshore Wind	X	X	X	X	X	X	X
Offshore Wind	X	X	X	X	X	X	X

Table 6: Technologies Considered by Deployment Consensus Report[108]

As a more affordable, less polluting, and less carbon intense fuel, natural gas has already started to displace coal in the U.S. electricity generation mix.[109] Its potential for further carbon emission reductions in this country and around the world within the next few decades will be significant until other renewable energy sources become cost competitive with fossil fuels worldwide.

Additionally, in a zero-carbon future powered by renewable energy, load balancing of intermittent power supply will be necessary to reliably meet peak demand. As most of the studies conclude, energy storage technologies and smart-grid power management are still in development, and the cost barriers remain prohibitively high.[110] Natural gas turbines and nuclear energy both have significant potential as low-carbon sources of base load electricity, and should not be excluded from future plans when considering economically feasible futures.[111]

The Breakthrough Institute's Ted Nordhaus and Michael Shellenberger termed this low-carbon future tunnel-vision—one that must be powered solely by water, wind, and solar—"technology tribalism." They write,

> If you cut past particular technologies and instead go to values, you find a large percentage of Americans—and, we would venture to say, of all humans as well—who want energy that is increasingly cheap, clean, reliable, and safe. This is an embrace not of a particular thing—solar panels, nuclear reactors, fracking, wind farms—but rather of a process of human development. It's an embrace of technological innovation, not of particular technologies as they exist today.[112]

Determining future technology scenarios dependent on a select few technologies ignores the innovation potential of other technologies that could have revolutionary impacts on lowering greenhouse gas emissions in the United States. The NREL *Futures Study* also investigates a number of technology scenarios, including nuclear, fossil fuels, CCS, and natural gas, focusing on the extent to which U.S. electricity needs can be supplied by renewables with other energy resources in the mix. The *California Energy Future Study* models scenarios to enable the state to reduce carbon emissions by 60 percent below 1990 levels; as the study does not focus on maximizing renewable energy market penetration, it recommends dramatically scaling up the state's nuclear and CCS resources, along with its renewable energy capacity.[113] Ultimately, given the significant challenge of global climate change, no potential technology solution should be ignored.

Erroneously Assuming Significant Induced Innovation Through Deployment

Although some of the reports, namely Budischak et al. (2013) and Jacobson and Delucchi (2011), do not prescribe any policy changes to realize their projected scenarios, some studies advise "first steps," and consider policy options to strengthen the possibility of ensuring large-scale renewables deployment. Unfortunately, the policy emphasis suggested in these studies predictably favor deployment policies like mandates, subsidies, financing mechanisms, and carbon prices or cap-and-trade systems, which raise the price of energy, rather than comprehensive investment in clean energy technology innovation.

The *California Energy Futures Study* and Jacobson et al. (2013)'s study on New York State's renewable energy future offer interesting but contrasting examples of how the "evidence" of the Deployment Consensus should be applied to policymaking. The ambitious deployment scenario described in Jacobson et al. (2013) identifies a number of short-term policy actions to enable the energy transition within the state, including ensuring that the state meets its already established 33 percent Renewable Portfolio Standard (RPS) by 2020, extending the RPS to 50 percent by 2050, determining and enforcing retirement dates for state coal-fired power plants, and setting up a Green Bank to operate as a state-based loan guarantee resource focused specifically on financing wind, water, and solar technology projects.[114] The report suggests that to electrify all transportation, state policymakers should adopt legislative mandates for electric vehicle adoption for short- and medium-distance government transportation, as well as leverage assistance from the U.S. Department of Energy's Clean Cities program supporting the deployment of electric vehicles.[115] Recommendations also include insuring that the new electric vehicle charging infrastructure is operable and "integrated into a statewide smart grid system," but additional support for how to secure this technology is not discussed.[116]

Report	Policy Recommendations
State Level	
California's Energy Future	▪ Established carbon price and aggressive performance standards aligned with price signals ▪ High efficiency standards for buildings, appliances equipment, and vehicles ▪ Support level of innovation needed from universities, national labs, small businesses, innovation hubs, and regional clusters
Jacobson et al. (2013) [NY]	▪ Extend RPS ▪ Establish a Green Bank as a vehicle for public-private financing and long-term contracts for renewable energy development ▪ Retire coal plants ▪ Implement feed-in tariffs for small-scale energy systems
National Level	
***Delucchi & Jacobson (2011)**	▪ Adopt economic policies to stimulate production of renewable energy, including feed-in tariffs, output and investment subsidies, and output quotas ▪ Eliminate fossil fuel subsidies or tax fuel production and use to internalize environmental damage ▪ Reduce energy demand
Global Level	
IPCC *Renewable Energy Sources*	▪ Couple R&D investment with deployment incentives ▪ Provide fiscal incentives (grants, rebates, tax credits), public finance (loans, guarantees, procurement), and regulations (quotas, green labeling, net metering, feed-in tariffs)

Table 7: Policy Prescription Summaries for Reviewed Deployment Consensus Reports[117]

In contrast, the *California Energy Futures Study* recognizes upfront the technical challenges to transitioning to a low-carbon economy with only existing technologies, and recommends supporting a level of innovation in zero-carbon energy technologies and storage that would enable the state to make even deeper cuts to GHG emissions in the future. The report reads:

> The State of California, working where appropriate with the U.S. Federal Government and industry, should foster, support and promote an innovation ecosystem in energy including universities, national laboratories, small businesses,

> innovation hubs, regional clusters, etc. The California delegation should support federal funding for this activity and the CEC should work with California institutions to develop successful proposals to harness and nucleate efforts around the energy R&D capability of the state.[118]

These recommendations, while vague in their prescriptive value, at least identify that reducing GHG emissions in the state is fundamentally a technology problem that should be addressed by utilizing and improving the state's research, development, and demonstration potential. California's energy innovation ecosystem is one of the strongest in the country, but investments like these across all states, including New York, could especially impact the feasibility of renewable technology improvements and commercial competitiveness.

The reality that energy innovation is at the heart of successfully confronting our global climate change problem often comes secondary to advocacy for conventional climate and energy policies focused around subsidies, taxes, or mandates.

Regrettably, the reality that energy innovation is at the heart of successfully confronting our global climate change problem often comes secondary to advocacy for conventional climate and energy policies focused around subsidies, taxes, or mandates. The Intergovernmental Panel on Climate Change's *Renewable Energy Sources and Climate Change Mitigation* report concludes that a mix of deployment and innovation policies to drive less mature technologies to market is important to any global renewable energy strategy. The IPCC report makes a point of highlighting the host of improvements needed in renewable technologies to enable high energy sector penetration:

> Examples of important areas of potential technological advancement include: new and improved feedstock production and supply systems, biofuels produced via new processes (also called next-generation or advanced biofuels, e.g., lignocellulosic) and advanced biorefining; advanced PV and CSP technologies and manufacturing processes; enhanced geothermal systems (EGS); multiple emerging ocean technologies; and foundation and turbine designs for offshore wind energy. Further cost reductions for hydropower are expected to be less significant than some of the other RE technologies, but R&D opportunities exist to make hydropower projects technically feasible in a wider range of locations and to improve the technical performance of new and existing projects.[119]

Although the study is upfront about the benefits of technology improvements through innovation, it also suggests that "public R&D investments are most effective when complemented by other policy instruments, particularly renewable energy deployment policies that simultaneously enhance demand for renewable energy technologies."[120] Beyond noting the merits of a healthy innovation ecosystem, however, the report mentions no other specific innovation policies, but does list 19 different fiscal incentives, public finance measures, and regulatory policy options to support technology deployment, including feed-in tariffs, tax credits, and rebates.[121] As noted in the 2011 ITIF report, *Inducing Innovation: What a Carbon Price Can and Can't Do*, market-based price signals of this nature "tend to be better suited for inducing incremental technological improvements," while what is necessary to encourage widespread deployment of renewable energy in the U.S. and globally is radical, cost-reducing breakthroughs.[122]

CHALLENGING THE CLEAN ENERGY DEPLOYMENT CONSENSUS

Despite the "evidence" advocates of the Deployment Consensus point to, the reality is that massive global deployment of existing clean energy technologies to high penetration levels is neither feasible nor the optimal climate change mitigation strategy. Existing clean energy continues to be more costly than fossil fuels outside of niche markets, and consumers in the United States and the rest of the world are largely unwilling to pay the economically necessary and hefty cost premium. Without a doubt, renewable cost curves have fallen dramatically, but climate and energy stakeholders must be realistic as to what is necessary to ensure that costs curves continue fall globally to below the cost of fossil fuels. Global warming is a global challenge, so clean energy must be accessible to developing and developed countries alike to mitigate the effects of climate change. As inadvertently proven by studies that are highlighted by supporters of the Deployment Consensus, innovation is required to make clean energy truly cost- and performance-competitive with fossil fuels.

Unwillingness to Pay a Premium for Clean Energy

The Deployment Consensus often cites declining levelized costs of existing clean energy, allowing supporters to downplay cost concerns associated with existing technologies. For example, Adam James of the Center for American Progress dismisses the need for cost improvements in regard to massive deployment as the optimal climate strategy. "Would there be costs? Yes. But do we need a technological breakthrough to do it…? No."[123] Yet despite ongoing gains, existing clean energy technologies still face significant cost challenges undermining the assumption that massive deployment is realistic from a cost perspective. The fact is that global consumers are largely unwilling to pay a premium for clean energy, even in the face of the urgency of climate change.

A wide body of evidence suggests that U.S. consumers' willingness to pay a premium for clean energy and climate change mitigation is limited. A March 2012 Gallup poll found that while 55 percent of Americans worry a great deal or a fair amount about global warming, Americans nevertheless prioritize economic growth over environmental protection, by a 49 percent to 41 percent margin, and have done so since 2009.[124] Similarly, a *HuffPost/YouGov* poll conducted in October 2012 asked respondents, "If it meant we could stop climate change, would you personally be willing to pay 50 percent more on your gas and electricity bills?" Only 21 percent of respondents answered in the affirmative.[125] As Roger Pielke, Jr. postulates in his book *The Climate Fix*, there is an "Iron Law of Climate Policy" which states that "even if people are willing to bear some costs to reduce emissions, they are only willing to go so far."[126]

A 2010 survey of economic estimates of Americans' specific willingness to pay for climate change mitigation by Evan Johnson and Gregory Nemet of the University of Wisconsin-Madison indicated that the average willingness to pay was somewhere between $100 and $300 a year per household.[127] Two more recent surveys peg Americans' willingness to pay extra for costlier clean energy, however, at much closer to the $100 value. As related by *The Financial Times*, a 2011 poll on the increased use of clean energy found that when respondents were "asked to rank themselves on a 1–10 scale for willingness to pay more for those forms of energy, only 21 percent reported a score of eight or more." Poll respondents were on average prepared to pay a premium of only $9.74 a month, or "about 10 percent of the average U.S. (monthly) electricity bill."[128] Similarly, a trio of researchers from Harvard and Yale conducted a survey in 2012 that found that the average U.S. citizen is willing to pay $162 per year, or $13.50 a month, in higher electricity bills in support of a hypothetical national clean energy standard that would require 80 percent clean energy by 2035.[129] That figure would be the equivalent of a 13 percent increase in the 2009 average annual U.S. household energy bill of $1,250.[130]

The best demonstration of Americans' low cost threshold for clean energy is their participation in "green pricing" programs. More than half of American consumers have the option to pay a premium on their electric bill for more renewable energy at an average cost of less than 10 percent of their utility bill.[131] Nevertheless, according to the Energy Information Administration, less than 1 percent of residential customers participated in a green pricing program in 2011.[132] Options for participating in green pricing programs, and consequently program participation rates, vary across the country; green power sales have reportedly been highest in California, Illinois, Maryland, Oregon, Texas, and Washington.[133] An NREL study on green pricing concluded that the average participation rate for the largest 20 green pricing programs was only 2.9 percent in 2011.[134]

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It's Global Warming, Not America Warming

The challenge of deploying clean energy at cost is magnified when looking at the world beyond just the United States. Climate change is a global phenomenon requiring globally impactful solutions. While many developed countries are implementing climate and energy policies within national boundaries, these efforts will have little effect on mitigating global climate change even if they are successful in cutting emissions, as developing countries are growing in population and economic prosperity and continue to rely on fossil fuels to power economies. Given the fact that clean energy is essentially a luxury good in its current state, it is difficult to envision the world—and more specifically developing nations—deploying enough clean energy to mitigate climate change absent substantial innovation to make clean energy cheap.

Close to 300 million Indians—almost all in rural areas and representing roughly 25 percent of the nation's population—do not have regular access to electricity. In order to expand access, the country increasingly relies on coal for energy; domestic electricity production from coal sources rose by 7 percent between 2009 and 2010.[135] The country was rocked by protests in the fall of 2012 in response to reduced diesel subsidies, which challenges the Deployment Consensus expectation that there is willingness to pay higher costs for energy if it comes from renewable sources.[136] The International Energy Agency estimated the number of people without access to electricity in 2009 to be 1.3 billion, or almost 20 percent of the world's population, yet developing nations will have the highest energy demand and greenhouse gas emissions in the future.[137] While some scientists cite the optimistic conclusion that carbon intensity of global energy supply has remained stagnant for the past 20 years, the impacts of dramatically increasing global energy demand make this look like a small victory.[138]

It is hypocritical and insensitive for developed countries to expect developing countries, struggling to expand access to energy in general, to pay a premium for clean energy, especially when developed countries lack the willingness to do so themselves. Germany achieved a high renewables penetration of roughly 26 percent in the first half of 2012 and 22 percent for the whole year, but the country accomplished the feat with and the help of a robust feed-in-tariff. Despite the country's success in increasing renewable grid penetration, however, Germany will start up more coal-fired power plants in 2013 than at any time in the past 20 years. *Bloomberg* reports that greenhouse gas emissions in Germany actually "rose 1.6 percent last year as more coal was burned to generate power."[139]

As seen in several European countries, when faced with fiscal austerity challenges, renewable energy subsidies are unsustainable. To reduce its budget deficit, Germany cut solar subsidies by as much as 29 percent in March 2012.[140] Similarly, Italy began regularly cutting its solar feed-in tariff—which provides producers with long-term compensation contracts—in 2011 due to cost concerns, and Spain started cutting renewable energy subsidies at the beginning of 2012.[141] Earlier this month the chief executives of ten energy companies in charge of half of Europe's electricity production asked for an end to wind and solar subsidies, which are reportedly putting pressure on industry and low-income rate-payers; in Europe electricity prices have risen 17 percent since 2009.[142] High electricity costs such as these are politically unsavory and are forcing governments to revisit clean energy subsidy strategies.

When clean energy is genuinely cost- and performance-competitive with fossil fuels, developing nations—and the world as a whole—will not have to choose between higher energy costs and climate change mitigation.

If the world is to mitigate climate change, clean energy must ultimately be cheap enough to be deployed everywhere, not just in the United States. As physics Nobel Laureate Burton Richter explained, "the developing world, which will be using by far the largest fraction of energy by the end of the century, will not cripple itself economically with expensive systems only to control emissions…What the industrialized part of the world has to do is to develop the technology that everyone can use in a cost effective manner to run their economies and to limit emissions."[143] When clean energy is genuinely cost- and performance-competitive with fossil fuels, developing nations—and the world as a whole—will not have to choose between higher energy costs and climate change mitigation.

Deployment Alone Does Not Make Clean Energy Competitive

A greater commitment to improving innovation ecosystems is necessary to enable clean technology to compete with conventional alternatives on both a cost and performance basis without relying on subsidies or mandates. As the International Energy Agency's comprehensive review of energy technology, *Energy Technology Perspectives 2012*, indicates, "despite technology's potential, progress in clean energy is too slow." The report summary notes:

> Nine out of ten technologies that hold potential for energy and CO2 emissions savings are failing to meet the deployment objectives needed to achieve the necessary transition to a low-carbon future. Some of the technologies with the largest potential are showing the least progress…Particularly worrisome is the slow uptake of energy efficiency technologies, the lack of progress in carbon capture and storage (CCS) and, to a lesser extent, of offshore wind and concentrated solar power (CSP)...

> Promising renewable energy technologies (such as offshore wind and CSP) and capital-intensive technologies (such as CCS and integrated gasification combined cycle [IGCC]), have significant potential but still face technology and cost challenges, particularly in the demonstration phase.[144]

Some Deployment Consensus supporters acknowledge the need for clean technology cost and performance improvements, but these supporters also view deployment as sufficient impetus for innovation. *New York Times* columnist Thomas Friedman captured the sentiment of Deployment Consensus advocates when he opined, "Breakthroughs come from deployment, and driving prices down come from deployment. Those two together are what give you scalable responses to our climate problem."[145] Environmental writer David Roberts also equates research and development to innovation: "Deployment *is* R&D. There is no more reliable way of bringing costs down and uncovering new efficiencies than deploying at scale."[146]

The history of technology development indicates that deployment alone cannot adequately spur innovation, but that it must instead be a part of a robust and well-funded innovation ecosystem that emphasizes public support and investment at all stages of the technology development process. A number of analyses have identified a significant difference between an assumed "linear" innovation model and an actual "chain-link" model. Gallagher et al. (2006) characterizes the chain-link innovation system as one with "collective activity involving many actors and knowledge feedbacks."[147] Much of the innovation literature concludes that public investment and support at every "link" in the chain within the innovation ecosystem have been historically integral to bringing breakthrough technologies to market.[148]

University of Wisconsin-Madison Professor Gregory Nemet has conducted substantial research on the relative effects of "technology push" policies, such as R&D investment, and "demand pull" policies, a proxy for deployment policies such as pricing and adoption subsidies, with the conclusion being that "demand-pull ignores technological capabilities."[149] Specifically, Nemet finds investment in R&D to be a far more effective driver of clean technology advancement than subsidies.[150] Furthermore, he finds deployment-centric policies to have been ineffective in driving innovation since the 1980s; "inventors," he notes, "filed almost all of the highly cited wind power patents well before there was any substantial market for wind power equipment and before the important details of strong policy instruments could have been anticipated."[151] After compiling a database of more than 73,000 energy-related patents, the Massachusetts Institute of Technology and the Santa Fe Institute were able to observe a "clear" correlation between the rise in clean energy technology patents and prior government and industry investments in research and development.[152] The report noted that patents for renewable technologies increased from about 200 patents per year between 1975 to 2000 to more than 1,000 patents in 2009; the authors credit this dramatic increase to significant research funding for clean energy after the oil shocks of the 1970s and 1980s.[153] The authors' conclusion matches the experience of the shale gas revolution, which has been proven to be the result of not only billions in federal tax credits for the deployment of emerging drilling technologies, but also billions more for research and development, testing, and demonstration projects.[154]

As ITIF has written a number of times, scaling up the production of renewable technologies might move them down the cost curve, but the significant problem is that these cost curves are still much higher than that of fossil fuel alternatives. The incremental improvements of deploying technologies at a massive scale will not lead to breakthroughs in cost or performance competitiveness—in other words, they won't lead to new and cheaper cost curves. To dramatically affect the competitiveness of renewable energy technologies, innovation is needed to create a completely new and lower cost curve.[155] As stated in ITIF's 2011 report, *Inducing Innovation: What a Carbon Price Can and Can't Do*:

> Truly disruptive innovation comes, not from price-based demand-pull, but from focused (and occasionally, not-so-focused) technology supply-push, in the form of research-driven technological development. Demand-pull, in the form of lower relative prices and expanding markets offering the premise of greater payoff, is best suited for inducing incremental innovations and diffusion in mature technologies where market barriers apart from price are minimal.[156]

Scaling up the production of renewable technologies might move them down the cost curve, but the significant problem is that these cost curves are still much higher than that of fossil fuel alternatives.

A frequently used analogy to illustrate the potential of breakthrough innovation to generate cost declines is the exponential growth in processing power for computing by the semiconductor industry. Recently there is renewed debate over whether the industry will be able to sustain such rates of progress, which is a comparable conversation to that happening within the renewable energy sector, as solar and wind technologies have seen significant cost declines in recent years.[157] The main difference, however, is that while the energy industry continues to emphasize deployment as the key to cost declines, the semiconductor industry is again engaging in a conversation about how to effectively improve innovation systems and processes to stimulate new and cheaper breakthroughs in computer chip technologies.[158]

Economists David Mowery and Nathan Rosenberg detailed as far back as 1979 that demand-pull and technology-push are "necessary, but not sufficient, for innovation to result; both must exist simultaneously."[159] Ultimately, smart deployment policies are necessary to facilitate technology scale-up but are most effective in concert with smart innovation policies, which strengthen the entire energy innovation ecosystem as a whole.

CONCLUSION: BUILDING A CLEAN ENERGY INNOVATION CONSENSUS

Deployment Consensus thinking has led to an overwhelming policy emphasis on deploying existing clean energy technology at the expense of building support for a cohesive, well-funded energy innovation agenda. But Deployment Consensus supporters are wearing rose-tinted glasses—the major clean energy studies reviewed in this report point to innovation as the key path to an affordable low-carbon future, not just policy support for massive deployment of existing technologies. Unfortunately, today's clean energy policies are being shaped by this rose-colored view, and political advocacy is dramatically skewed towards deploying existing renewable energy technologies, advocating for even greater deployment support even as the suite of energy innovation policies are annually cut.

It is paramount for policymakers and climate advocates to move past the clean energy deployment doctrine toward a more inclusive and cohesive Energy Innovation Consensus. Policymakers should consider the full spectrum of innovation policies to develop and deploy next-generation technologies and recognize the limitations of the technologies widely available today. This specifically includes greatly expanding public investment in early-stage clean energy innovation, such as basic science, R&D, and demonstration projects of a range of low-carbon and zero-carbon technologies. Advocacy and policy support for these critical public investments have waned and are being slashed through sequestration and budget cuts. But an energy innovation agenda doesn't stop there. It should also seek to implement smart deployment and early commercialization reforms and incentives that drive next-generation technologies to market rather than supporting the same existing technologies year-after-year.

The goal of an energy innovation agenda is straightforward: cheaper and better performing clean energy technologies are fundamentally required to mitigate global climate change. More expensive renewable energy pathways are not a solution. Specifically, key characteristics of a sophisticated energy innovation agenda include:

- **Significantly more public investment in R&D.** According to ITIF's Energy Innovation Tracker, the federal government invests roughly $5 billion per year in clean energy research, development, and demonstration (RD&D). In comparison to other leading innovation challenges, clean energy is at the bottom of the list: the U.S. invests $9.5 billion annually in space exploration, $30 billion in healthcare research, and $70 billion to develop new weapons. To fully fund clean energy RD&D, public investments must increase to at least $15 billion per year. While fiscal austerity in the United States threatens to hollow out the country's already limited energy innovation ecosystem, commitment to funding institutions like the National Labs, the Energy Innovation Hubs, and Energy Frontier Research Centers, and the offices and agencies within the Department of Energy—the Office of Energy Efficiency and Renewable Energy (EERE) and the Advanced Research Projects Agency-Energy (ARPA-E) in particular—is integral to preserving the country's innovation strengths and improving on its weaknesses.

- **A dedicated revenue stream for clean energy innovation.** Innovation requires consistent public investment rather than the boom-and-bust budgets innovation programs face today.[160] Historic technological breakthroughs have utilized long-term consistent funding—a surcharge on gas prices secured funding for the development of shale natural gas technologies decades ago, and this innovation has enormously impacted the price of natural gas.[161] Providing the same level of support for renewable energy technology innovation is crucial to the development of next-generation clean energy, and a number of options for generating this revenue exist, including raising revenue from increased royalty rates on oil and gas drilling and implementing a modest carbon tax to fund innovation.[162]

- **Institutional reform of public research enterprises to better link research to market.** An innovation ecosystem is only as good as its institutional base. U.S. public energy innovation institutions differ in age, structure, support, and engagement, and all have strengths that make them unique, but weaknesses that should be addressed. Every institution within the innovation ecosystem should ensure that new innovations have a clear path from the research stage to the commercialization stage. Sweeping but detailed strategies for institutional reform should be at the forefront of policymaking discussions on how to comprehensively improve the depth of U.S. innovation competence and international competitiveness. For example, policymakers should immediately focus on accelerating institutional changes at the Department of Energy to ensure that it is best equipped to support clean technology innovation.[163] In addition, policymakers should also take up the complex but necessary task of bringing the DOE National Laboratory system from its cold war roots and into the 21st century innovation economy through more flexible management and better links to market.[164]

- **Policies that drive research through the "valley of death."** Strengthening the energy innovation ecosystem also means elevating policy support for bridging the clean energy valleys of death. Programs and facilities for testing and demonstration of prototype technologies must be sustained and encouraged. Additionally, enhancing regional innovation networks through collaboration between researchers, public institutions, entrepreneurs, centers of commercialization, and business incubators can establish innovation "hotspots" across the country that can serve as models for addressing white spaces and weaknesses in the system at the national level.

- **Increased government procurement of next-generation technologies.** The opportunity for the federal government to affect energy innovation through procurement of next-generation technologies is extensive; harnessing the procurement power of the Department of Defense and the General Services Administration, for example, presents ideal opportunities for demonstration and early commercialization of energy technologies still not ready for market. The Department of Defense has consistently been a leader in the space because of its own comprehensive innovation ecosystem, and recently the department's need for energy technologies like breakthrough alternative fuels and independent battery systems have led it to increase its procurement of next-generation energy technologies and systems to $376 million in FY2012.[165] These efforts should be supported and scaled to meet the energy needs of other departments throughout the federal government.

- **Reformed deployment incentives that make cost reductions and performance improvements a prerequisite for obtaining federal support.** Today's clean energy deployment incentives are blunt tools rather than targeted instruments. For example, the Wind Production Tax Credit has offered the same value per kilowatt-hour since 1992, making it a guaranteed subsidy for any wind technology, regardless of its future cost reduction and performance improvement potential.[166] It simply does not incentivize breakthrough innovation. That is not to say deployment incentives are not useful. Most recently, targeted tax credits were successfully used to advance shale natural gas commercialization, and Japan's Top Runner approach has driven energy efficiency innovation in the appliance market by prioritizing performance goals for deployment.[167] Renewed efforts to reform existing or implement new, temporary, and innovative deployment incentives are needed. This could mean significant reforms, such as tying tax credits to cost, performance, or deployment milestones that are reassessed annually, or interim improvements, such as carving out a portion of existing tax credits to specifically go to the most innovative clean energy designs entering the market.

Structuring the optimal energy innovation ecosystem is not an easy task, nor does it fit in a simple policy reform package. Nonetheless, it is still fundamentally important. Addressing climate change most effectively requires nothing less than an aggressive energy innovation strategy. Advocates' insistence on supporting only parts of the innovation ecosystem or just today's costly technologies gets the world no closer to a global solution. To address the urgency of climate change most effectively, the United States—and the rest of the world—must put supporting clean energy innovation at the center of any energy and climate strategy.

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ACKNOWLEDGEMENTS

The authors wish to thank Alex Key, Bethany Imondi, Kathryn Angstadt, and William Dube of ITIF, and Elizabeth Stewart for editorial and production assistance. The authors would also like to acknowledge and thank Clifton Yin for assisting with initial report research. Any errors or omissions are the authors' alone.

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