

USING RENEWABLE PORTFOLIO STANDARDS TO ACCELERATE DEVELOPMENT OF NEGATIVE EMISSIONS TECHNOLOGIES

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ABSTRACT

As society continues to emit greenhouse gases, the likelihood of dangerous climate change occurring increases.¹ Indeed, most analyses project that we must utilize negative emission technologies (“NETs”) to avoid dangerous warming.² Even the Paris Agreement anticipates the implementation of such carbon dioxide (“CO₂”) removal technologies.³ Unfortunately, NETs are not ready for large-scale deployment. In many instances, their technologies remain uncertain; in others, their ability to operate at the scale required is unknown. Other uncertainties, including their costs, effectiveness, and environmental impacts have yet to be determined.

A means to accelerate the development and implementation of NETs is a policy that already did the same for renewable energy—Renewable Portfolio Standards (“RPSs”). RPSs require that providers source a predetermined amount of their electricity from renewable energy.⁴ RPSs have an established track record of stimulating investment in renewable energy in the United States and elsewhere.⁵ These policies incorporate a number of requirements that jurisdictions can tailor to accommodate local resources, industries, and objectives.⁶

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¹ *WMO Greenhouse Gas Bulletin*, WORLD METEOROLOGICAL ORGANIZATION, Oct. 30, 2017, at 1.

² See Guy Lomax et al., *Investing in Negative Emissions*, 5 *NATURE CLIMATE CHANGE* 498 (2015).

³ Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 13, 2015, in Rep. of the Conference of the Parties of the Twenty-First Session, art. 10, ¶ 4, U.N. Doc FCCC/CP/2015/10/Add.1 (2016) [hereinafter Paris Agreement].

⁴ WARREN LEON, *THE STATE OF STATE RENEWABLE PORTFOLIO STANDARDS* iii (2013).

⁵ *Id.*

⁶ *Id.* at 21.

Similarly, RPSs can facilitate the investment in and development of NETs. RPSs create markets for technologies that encourage compliance with low-cost alternatives. This incentivizes innovation, which lowers costs. Furthermore, jurisdictions can utilize other tools of RPSs, such as technology carve outs and credit multipliers, to encourage development of specific technologies. Using these provisions, states have incentivized the development and installation of renewable energy, generally, and solar power, specifically.

However, current RPSs are too limited to develop NETs. States need to expand the technologies that satisfy RPS mandates to include NETs, thereby fostering RPS development. Over time, states should also expand the economic sectors required to comply with their RPSs to encompass the agriculture, aviation, and manufacturing industries—sectors with emissions that are expensive or difficult to mitigate.

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I. DEVELOPMENT OF NETS IS CRUCIAL

Scientists project that greenhouse gas emission mitigation is occurring too slowly to avert dangerous climate change.⁷ Since CO₂ remains in the atmosphere for centuries, we cannot rely solely upon earth systems to remove it from the atmosphere.⁸ Instead, we will need to use

⁷ Chris Mooney, *We only have a 5 percent chance of avoiding ‘dangerous’ global warming, a study finds*, WASH. POST (July 31, 2017), https://www.washingtonpost.com/news/energy-environment/wp/2017/07/31/we-only-have-a-5-percent-chance-of-avoiding-dangerous-global-warming-a-study-finds/?utm_term=.faafe61370c0 [<https://perma.cc/KKV4-SSWV>].

⁸ Duncan Clark, *How long do greenhouse gases stay in the air?*, THE GUARDIAN (Jan. 16,

technological means. Scientists recognize that a number of such CO₂ removal technologies may be possible.⁹

A. *Dangerous Climate Change Is Becoming Unavoidable*

Despite approval of the 2015 Paris Agreement, the climate is increasingly likely to exceed the Agreement's targets. Regarding temperature rise, the parties to the Paris Agreement pledged themselves to pursue certain objectives. First, they agreed to increase efforts to hold the rise in global average temperature to "well below 2°C above pre-industrial levels."¹⁰ Second, they also pledged to pursue efforts to limit the temperature increase to 1.5°C.¹¹ To accomplish these objectives, the parties agreed to "aim to reach global peaking of greenhouse gas emissions as soon as possible."¹²

Despite the growing concern about climate change reflected by these pledges, emissions—and the consequent warming—are on track to blow past these levels. During the first fifteen years of this century, CO₂ emissions grew at an average rate of 2.6 percent.¹³ This contrasts with an average rate of growth of 1.72 percent during the previous three decades.¹⁴ Furthermore, for every year-on-year period this century, except for 2008 to 2009, emissions have increased.¹⁵ Continuing these trends, atmospheric CO₂ hit an all-time high in 2017 of 403.3 ppm, increasing at an unprecedented rate.¹⁶

Policymakers have targeted the 1.5–2.0°C range because scientists consider this to be the threshold of "dangerous" climate change.¹⁷ A rise of 2.0°C is the level at which they anticipate "nonlinear and potentially irreversible disruptions" to the environment may begin.¹⁸ These changes

2012, 2:00 PM), <https://www.theguardian.com/environment/2012/jan/16/greenhouse-gases-remain-air> [<https://perma.cc/7PUN-TEAW>].

⁹ See C. H. Greene et al., *Geoengineering, Marine Microalgae, and Climate Stabilization in the 21st Century*, 5 *EARTH'S NATURE* 278, 278 (2017).

¹⁰ Paris Agreement, *supra* note 3, at art 2, ¶ 1(a).

¹¹ *Id.*

¹² *Id.* at art. 4, ¶ 1.

¹³ Niall MacDowell et al., *The Role of CO₂ Capture and Utilization in Mitigating Climate Change*, 7 *NATURE CLIMATE CHANGE* 243, 243 (2017).

¹⁴ *Id.*

¹⁵ *Id.*

¹⁶ *WMO Greenhouse Gas Bulletin*, *supra* note 1, at 8.

¹⁷ Mooney, *supra* note 7.

¹⁸ Greene et al., *supra* note 9, at 278–84.

may include the complete loss of Arctic sea ice during the summer and deglaciation of the Greenland ice sheet, the West Antarctic Ice Sheet, and most mountain glaciers.¹⁹ As a result, oceans would rise to a level that would jeopardize many coastal cities, and droughts, floods, and other extreme weather would threaten food sources and biodiversity.²⁰

Even a now-expected rise of 1.5°C will cause significant disruptions. Asia's glaciers, for instance, will lose nearly half of their mass.²¹ Peak sea levels will rise by one meter.²² Other changes will include longer heat waves, heavier precipitation, and increasing risk of coral reef bleaching.²³ Scientists also project that restricting warming to a 1.5°C rise will be critical to protecting small island states.²⁴

Because society has failed to rein in its greenhouse gas emissions, the likelihood of staying below the 2°C target, let alone the 1.5°C target, is disappearing rapidly. A study released in 2017 concluded that only a five percent chance remains that we can hold warming to 2°C; for 1.5°C, the likelihood is down to one percent.²⁵ Furthermore, the authors calculate that the likely range of warming will be 2.0 to 4.9°C, with a mean anticipated warming of 3.2°C.²⁶ Contemporaneously, a separate study concluded that likely committed warming (the warming which would still

¹⁹ *Id.*

²⁰ *Id.* at 278–79.

²¹ P. D. A. Kraaijenbrink et al., *Impact of a Global Temperature Rise of 1.5 Degrees Celsius on Asia's Glaciers*, 549 NATURE 257, 257–58 (2017).

²² Greene et al., *supra* note 9, at 278–79.

²³ Carl-Friedrich Schleussner et al., *Differential climate impacts for policy-relevant limits to global warming: the case of 1.5°C and 2°C*, 7 EARTH SYS. DYNAMICS 344, 345 (2016). Actually, scientists have conducted few analyses of the consequences of a 1.5°C warming. Daniel Mitchell et al., *Realizing the Impacts of a 1.5 °C Warmer World*, 6 NATURE CLIMATE CHANGE 735, 735–36 (2016). Consequently, the Intergovernmental Panel on Climate Change is preparing a special report on the impacts of a 1.5°C warming, which it plans to complete before the end of 2018. *Global Warming of 1.5 °C*, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, <http://www.ipcc.ch/report/sr15> [<https://perma.cc/G9S2-DVNJ>] (last visited Nov. 17, 2018).

²⁴ Laurie Goering, *Carbon-sucking technology needed by 2030s, scientists warn*, REUTERS (Oct. 10, 2017), <https://www.reuters.com/article/us-climatechange-geoengineering/carbon-sucking-technology-needed-by-2030s-scientists-warn-idUSKBN1CF2KY> [<https://perma.cc/Z26P-6ZU5>].

²⁵ Adrian E. Raftery et al., *Less Than 2°C Warming by 2100 Unlikely*, 7 NATURE CLIMATE CHANGE 637, 637–40 (2017).

²⁶ *Id.* Moreover, even though non-binding commitments made by the parties to the Paris Agreement reduce expected warming below business as usual levels, researchers at MIT project temperatures to a similar rise of 3.1 to 5.2°C by 2100. Burns & Nicholson, *infra* note 126, at 528.

occur if anthropogenic greenhouse gas emissions were to cease immediately)²⁷ already has reached 1.5°C.²⁸

Another form of analysis reaches a similar conclusion. Climate scientists calculate a “carbon budget,” the amount of CO₂ that society can emit with global temperature rise still remaining below a targeted level.²⁹ Nearly all estimates³⁰ suggest that the budget remaining to stay under a rise of 1.5°C is nearly exhausted, while the budget to hold to a 2°C rise will run out in a matter of decades.³¹ For instance, one representative calculation suggests that between four and fifteen years remain before the 1.5°C budget will expire; for a 2°C rise, the time remaining ranges from nineteen to thirty-two years.³²

B. Staying Below Dangerous Global Temperature Levels Will Require Substantial Utilization of NETs

Utilizing technologies that can reverse the increase of CO₂ in the atmosphere will be necessary to avoid a 2°C rise in temperature. Nearly every analysis demonstrates that mitigation alone cannot keep temperatures below this level. Unlike mitigation, these technologies can also help to reverse warming should society fail to mitigate sufficiently to avoid the 2°C level.

Because of the level of anticipated warming and its dire consequences, policymakers have begun directing more attention to removing CO₂ after it has already entered the atmosphere. Indeed, in addition to the

²⁷ K.C. Armour & G.H. Roe, *Climate Commitment in an Uncertain World*, 38 GEOPHYSICAL RES. LETTERS 1, 1 (2011).

²⁸ Thorsten Mauritsen & Robert Pincus, *Committed Warming Inferred from Observations*, 7 NATURE CLIMATE CHANGE 652, 652–54 (2017).

²⁹ *Understanding the IPCC Reports*, WORLD RESOURCES INST., <http://www.wri.org/ipcc-in-fographics> [<https://perma.cc/G8QK-B9UT>] (last visited Nov. 17, 2018).

³⁰ Recently, Millar et al., calculated that holding warming to less than 1.5°C “is not yet a geophysical impossibility.” Richard J. Millar et al., *Emission Budgets and Pathways Consistent with Limiting Warming to 1.5 °C*, 10 NATURE GEOSCIENCE 741, 741–47 (2017); Ben Sanderson, *1.5°C: Geophysically impossible or not?*, REAL CLIMATE (Oct. 11, 2017), <http://www.realclimate.org/index.php/archives/2017/10/1-5oc-geophysically-impossible-or-not/> [<https://perma.cc/9PWY-397A>].

³¹ Robert McSweeney & Rosamund Pearce, *Analysis: Just four years left of the 1.5C carbon budget*, CARBON BRIEF (Apr. 5, 2017), <https://www.carbonbrief.org/analysis-four-years-4-left-one-point-five-carbon-budget> [<https://perma.cc/VP62-QDLM>].

³² *Id.* The range results from the probability of staying within the targeted level that is applied to the calculation. *Id.* Thus, a higher probability of staying below a given target produces a shorter timeframe before the budget will expire, while a lower likelihood of staying below the target allows a longer timeframe. *Id.*

setting of targets for warming, the Paris Agreement parties also set goals concerning carbon sinks. Specifically, they agreed to act “to conserve and enhance” greenhouse gas sinks and reservoirs.³³ Furthermore, they set a target of balancing carbon emissions and sinks by the second half of this century.³⁴ In light of the hard-to-control emissions from agriculture and other sectors, the balancing sought by the Paris Agreement can only be accomplished with net negative CO₂ emissions.³⁵ Thus, the implication of the Paris Agreement is that countries will need to develop CO₂ removal technologies to accomplish their goals.

Nevertheless, few countries have included NETs in their Intended Nationally Determined Contributions (“INDCs”). INDCs identify the steps the parties to the Paris Agreement intend to take after 2020 to achieve the Agreement’s goals.³⁶ In their INDCs, no countries have included bio-energy with carbon capture and sequestration (“BECCS”), the technology most ready for implementation,³⁷ and only a few nations have included carbon capture and storage.³⁸

A number of analyses indicate that NETs will be essential to achieve the Paris Agreement’s 2°C goal. Anthropogenic emissions of carbon are overwhelming the ability of natural sources to remove carbon from the atmosphere.³⁹ This will almost certainly necessitate the deployment of NETs.⁴⁰ Indeed, most analytical scenarios in which warming stays within 2°C, and nearly all in which it stays below 1.5°C, incorporate NETs.⁴¹ For instance, for its Fifth Assessment Report, the Intergovernmental Panel on Climate Change analyzed nearly 900 scenarios from integrated assessment

³³ Paris Agreement, *supra* note 3, at art. 5, ¶ 1.

³⁴ Glen P. Peters & Olive Geden, *Catalysing a Political Shift from Low to Negative Carbon*, 7 NATURE CLIMATE CHANGE 619, 619 (2017).

³⁵ J. Rockström et al., *The World’s Biggest Gamble*, 4 EARTH’S FUTURE 465, 465–70 (2016).

³⁶ *What is an INDC?*, WORLD RES. INST., <http://www.wri.org/indc-definition> [<https://perma.cc/G55K-N3F4>] (last visited Nov. 17, 2018).

³⁷ See discussion *infra* Section I.C.

³⁸ Peters & Geden, *supra* note 34, at 619. As a result, even after the effect of the INDCs is considered, planetary warming is still anticipated to approach between 2.6 and 3.1°C. Rob Bellamy, *Incentivize Negative Emissions Responsibly*, 3 NATURE ENERGY 532, 532–34 (2018).

³⁹ NATIONAL RESEARCH COUNCIL (NRC), CLIMATE INTERVENTION: CARBON DIOXIDE REMOVAL AND RELIABLE SEQUESTRATION 110–11 (2015).

⁴⁰ *Id.*

⁴¹ David P. Keller et al., *The Carbon Dioxide Removal Model Intercomparison Project (CDR-MIP): Rationale and Experimental Design*, 11 GEOSCIENTIFIC MODEL DEV. 1133, 1133–34 (2018). As discussed later in this Section, even these scenarios anticipate that global temperatures will actually exceed, or overshoot, these targets before returning to the 2.0°C or 1.5°C levels. *Id.*

models.⁴² One hundred sixty-six of the scenarios had a 66 percent chance or better that warming would stay below 2°C by the year 2100. Of these, 101 included some form of NETs.⁴³ Typically, they included NETs on a “massive” scale.⁴⁴ Similarly, prior to the 2015 Conference of the Parties in Paris, researchers were tasked with developing emissions scenarios demonstrating the viability of still holding warming to 2°C.⁴⁵ They found that this goal cannot be achieved through plausible and cost-effective mitigation efforts.⁴⁶ It requires NETs.⁴⁷ Of course, scenarios holding warming to 1.5°C require even greater commitments to NETs.

Even if society were to mitigate its emissions sufficiently to stay within a 1.5°C or 2°C rise, NETs will still play a critical role. CO₂ has a long atmospheric life. Once emissions cease, natural systems will remove greenhouse gases from the atmosphere, but CO₂ will remain at an elevated level for centuries or even a millennia.⁴⁸ Even though global temperatures will remain flat (but elevated), over centuries, regional changes in temperature and precipitation may be substantial, and sea level will continue to rise.⁴⁹ Thus, actual removal of anthropogenic CO₂ will be essential to reverse climate change and its consequences “on timescales relevant to human civilization.”⁵⁰

In reality, most projections conclude that the global temperature will exceed the 2°C target, and we will need to remove CO₂ from the atmosphere to return it to the targeted level.⁵¹ In these scenarios, warming

⁴² Christopher B. Field & Katharine J. Mach, *Rightsizing Carbon Dioxide Removal*, 356 SCIENCE 706, 707 (2017). Integrated assessment models (“IAMs”) incorporate approaches from two or more fields into a single framework. Gilbert Metcalf & James Stock, *The Role of Integrated Assessment Models in Climate Policy: A User’s Guide and Assessment*, THE HARVARD PROJECT ON CLIMATE AGREEMENTS, Mar. 2015, at 5. IAMs have become the standard methodological approach in climate change research. Zili Yang, Yi-Ming Wei & Zhifu Mi, *Integrated Assessment Models (IAMs) For Climate Change*, OXFORD BIBLIOGRAPHIES ONLINE (Oct. 11, 2018), <http://www.oxfordbibliographies.com/view/document/obo-9780199363445/obo-9780199363445-0043.xml> [https://perma.cc/KSM9-TYRM].

⁴³ Field & Mach, *supra* note 42, at 707.

⁴⁴ Lomax et al., *supra* note 2.

⁴⁵ Edward A. Parson, *Climate Policymakers and Assessments Must Get Serious About Climate Engineering*, 114 PROC. NAT’L ACAD. SCI. U.S. 9227, 9228 (2017).

⁴⁶ *Id.*

⁴⁷ *Id.*

⁴⁸ Mauritsen & Pincus, *supra* note 28, at 652.

⁴⁹ Katarzyna B. Tokarska & Kirsten Zickfeld, *The effectiveness of net negative carbon dioxide emissions in reversing anthropogenic climate change*, 10 ENVIRON. RES. LETT. 1 (2015).

⁵⁰ *Id.* at 2.

⁵¹ *Id.* at 1.

for at least some period of time exceeds the targeted level.⁵² By 2100, however, after using CO₂ removal, the temperature returns to the targeted level; scientists call these “overshoot” scenarios.⁵³ Some scenarios indicate that temperatures can still be held under 2°C without overshoot.⁵⁴ All 1.5°C scenarios contemplate at least a temporary overshoot.⁵⁵ Overshoot scenarios require CO₂ removal to reverse such a rise in CO₂.⁵⁶ In fact, these efforts can help compensate for as much of an overshoot as 0.5°C.⁵⁷

NETs consist of “anthropogenic activities that deliberately extract CO₂ from the atmosphere.”⁵⁸ Typically, NETs and CO₂ removal⁵⁹ (“CDR”) are used interchangeably,⁶⁰ as they will be here. These technologies remove CO₂ from the atmosphere via sequestration.⁶¹ Broadly speaking, NETs fall into two categories. First, some approaches increase the natural removal of CO₂ by amplifying these processes.⁶² Second, some methods utilize mechanical means to capture CO₂ from the atmosphere, concentrate it, and sequester it underground by injecting it under high pressure.⁶³

⁵² *Id.* at 2.

⁵³ Joeri Rogelj et al., *Energy System Transformations for Limiting End-of-Century Warming to Below 1.5 °C*, 5 NATURE CLIMATE CHANGE 519, 520 (2015).

⁵⁴ S. Fuss et al., *Research Priorities for Negative Emissions*, 11 ENVTL. RES. LETTERS 4 (2016).

⁵⁵ *Id.* at 2.

⁵⁶ *Id.*

⁵⁷ *Id.* at 4. Even if temperatures are brought back to below the target, some of the consequences of the overshoot will continue. *Id.* For instance, sea levels will continue to rise for several centuries. Tokarska & Zickfeld, *supra* note 49, at 9. Furthermore, as NETs remove CO₂ from the atmosphere, oceanic and terrestrial sinks will eventually reverse and actually release CO₂, thereby increasing the amount of carbon dioxide removal necessary to overcome this outgassing. Keller et al., *supra* note 41, at 1337.

⁵⁸ Fuss et al., *supra* note 54, at 1.

⁵⁹ *Geoengineering*, HARVARD'S SOLAR GEOENGINEERING RESEARCH PROGRAM, <https://geoengineering.environment.harvard.edu/geoengineering> [<https://perma.cc/GN68-XSVA>] (last visited Nov. 17, 2018) (explaining that carbon dioxide removal (“CDR”) traditionally appears as one of two branches under the label of geoengineering or climate engineering). The other branch consists of albedo modification, often called solar radiation management (“SRM”). See NRC, *supra* note 39, at 20 (explaining that since CDR reduces the amount of CO₂ in the atmosphere, it is more akin to mitigation than to SRM); see also *Geoengineering*, *supra* (explaining that CDR thus seeks to “address the root cause of climate change”); NRC, *supra* note 39, at 20 (noting that SRM attempts to provide symptomatic relief from only some of the consequences of anthropogenic CO₂); Fuss et al., *supra* note 54, at 4 (noting that besides methodology and effect, substantial differences also abound concerning, among others, the nature of their associated risks, costs to implement, governance, and research needs).

⁶⁰ Peter Psarras et al., *Slicing the Pie: How Big Could Carbon Dioxide Removal Be?*, 6 WIRES ENERGY & ENV'T 1, 1 (2017).

⁶¹ NRC, *supra* note 39, at 33.

⁶² *Id.*

⁶³ *Id.*

NETs can serve several useful functions. Crucially, they “decouple emissions and emissions control in space and time.”⁶⁴ Decoupling in space refers to their ability to compensate for CO₂ emissions from sectors where they are difficult or expensive to reduce.⁶⁵ Such “recalcitrant” emissions include those from the agricultural sector generated by livestock.⁶⁶ Another source is the transportation sector, especially the aviation and marine subsectors.⁶⁷ Other difficult to capture emissions derive from cement production⁶⁸ and residential heating and cooling.⁶⁹ The ability to compensate for emissions from these sectors will be critical, since they account for a significant portion of global emissions.⁷⁰

NETs decouple emissions in time by providing a means to address previously released emissions.⁷¹ This buys time to develop and install clean energy technologies and to replace locked-in emissions sources.⁷² This has important intergenerational implications, too. Scientists estimate that emission mitigation costs later in the century will rise rapidly as society begins to impose stronger reductions on difficult to address emissions, such as in the transportation sector,⁷³ which would be more

⁶⁴ Elmar Kriegler et al., *Is Atmospheric Carbon Dioxide Removal a Game Changer for Climate Change Mitigation?*, 118 CLIMATE CHANGE 45, 46 (2013).

⁶⁵ Lomax et al., *supra* note 2, at 498.

⁶⁶ Duncan McLaren, *Negatonnes—An Initial Assessment of the Potential for Negative Emission Techniques to Contribute Safely and Fairly to Meeting Carbon Budgets in the 21st Century*, 1 FRIENDS OF THE EARTH 1, 8 (2011). See also Eloise Gibson, *Cutting Down on Cow Burps to Ease Climate Change*, BLOOMBERG BNA ENV'T & ENERGY REP. (Nov. 27, 2017), <https://www.bloomberglaw.com/news/articles/2017-11-29/cutting-down-on-cow-burps-to-ease-climate-change> [<https://perma.cc/59J2-2QAN>] (explaining that the share of global warming directly caused by livestock is approximately 25 percent).

⁶⁷ Mark Workman et al., *An Assessment of Options for CO₂ Removal from the Atmosphere*, 4 ENERGY PROCEDIA 2877, 2877 (2011).

⁶⁸ *Id.*

⁶⁹ Adriana Marcucci, Socrates Kypreos & Evangelos Panos, *The Road to Achieving the Long-Term Paris Targets: Energy Transition and the Role of Direct Air Capture*, 144 CLIMATE CHANGE 181, 182 (2017).

⁷⁰ *Global Manmade Greenhouse Gas Emissions by Sector*, CENTER FOR CLIMATE CHANGE AND ENERGY SOLUTIONS, <https://www.c2es.org/content/international-emissions/> [<https://perma.cc/Q6WT-3D77>] (last visited Nov. 17, 2018). For instance, the entire agriculture sector accounted for 11 percent of global greenhouse gas emissions in 2013, while the entire transportation sector emitted 15 percent.

⁷¹ Lomax et al., *supra* note 2, at 498.

⁷² *Id.* Carbon emissions and their sources are “locked in” when investments in emitting technologies, infrastructure, and supporting networks constrain future paths, thereby rendering lower-emission alternatives more costly, consequently diminishing the likelihood of their adoption. Peter Erickson et al., *Assessing Carbon Lock-in*, 10 ENVIRON. RES. LETTER 1 (2015).

⁷³ Kriegler et al., *supra* note 64, at 54.

expensive to control.⁷⁴ Energy modeling studies consistently find that limiting warming to 2°C without NETs will be two to three times more expensive than if they are utilized.⁷⁵ Thus, NETs will play a critical role in providing a future least-cost energy system.⁷⁶ Decoupling in time also enables society to compensate for excessive previous emissions that might cause overshoot.⁷⁷ NETs can help to remediate historic emissions, too.⁷⁸

C. *NETs Incorporate a Number of Distinct Technologies*

NET is an umbrella term which encompasses a range of methods. These technologies vary in a number of aspects, including their effectiveness, costs, scalability, physical limitations, and stage of development.

Scientists organize NETs in several different ways. As noted previously, one approach distinguishes between methods that amplify natural processes and those that use technological means to capture and sequester CO₂.⁷⁹ Another grouping organizes the methods into land based, air capture, and sinks enhancement.⁸⁰ Perhaps the most telling division organizes the methods as mature ecosystem-based, less mature biomass-based, and immature nonbiological.⁸¹

The label of NETs typically incorporates eight methods. These consist of the following:

Enhanced weathering—this method spreads minerals that naturally absorb CO₂ to accelerate the absorption process.⁸² Normally, CO₂ released into the atmosphere turns into carbonate ions which dissolve in the oceans.⁸³ Eventually, the carbonate settles on the ocean floor.⁸⁴ The natural weathering process will remove atmospheric carbon, but it will require 100,000 years to return the climate to its pre-industrial level.⁸⁵

⁷⁴ Pete Smith, *Biophysical and Economic Limits to Negative CO₂ Emissions*, 6 NATURE CLIMATE CHANGE 42–50 (2016).

⁷⁵ Myles Allen et al., *Certificates for CCS at Reduced Public Cost: Securing the UK's Energy and Climate Future, Energy Bill 2015* (SCCS Working Paper No. 2015-04).

⁷⁶ MacDowell et al., *supra* note 13.

⁷⁷ Lomax et al., *supra* note 2, at 498.

⁷⁸ Charles-Francois de Lannoy et al., *Indirect ocean capture of atmospheric CO₂: Part I. Prototype of a negative emissions technology*, 70 INT'L J. OF GREENHOUSE GAS CONTROL 243, 243 (2018).

⁷⁹ NRC, *supra* note 39, at 33.

⁸⁰ Tokarska & Zickfeld, *supra* note 49, at 2.

⁸¹ Field & Mach, *supra* note 42, at 706.

⁸² Fuss et al., *supra* note 54, at 3.

⁸³ NRC, *supra* note 39, at 47.

⁸⁴ *Id.*

⁸⁵ Jeremy Deaton, *Earth's "Weathering Thermostat" Keeps Climate in Check Over Very*

Accordingly, this method seeks to accelerate the weathering reaction by increasing the rate of exposure of CO₂ to the requisite minerals.⁸⁶ This might occur in situ among rock formations, in industrial settings, or on the oceans by releasing ground-up minerals.⁸⁷

A limiting factor will be the ratio of minerals required to the amount of CO₂ to be removed. The amount of minerals required will need to exceed the amount of CO₂ to be removed by ratios ranging from 1.3 to 3.6 times.⁸⁸ To deploy this method at scale would require 100 billion tons per year to offset current emissions.⁸⁹ In contrast, global coal production is approximately 8 billion tons per year.⁹⁰ Limitations on the land suitable for use will further restrict this process.⁹¹ Consequently, scientists project that weatherization can remove only 0.7 to 3.7 gigatons (billion tons) of CO₂ (GtCO₂) per year.⁹² For perspective, current anthropogenic emissions approximate 40 GtCO₂ per year.⁹³ The cost of weatherization will likely range between \$20 and \$40 per tCO₂ removed.⁹⁴ This estimate, however, incorporates only the costs of grinding and transportation and not the costs of spreading the ground minerals.⁹⁵

Afforestation and Reforestation—afforestation involves the restoration of forests on land without forests for at least fifty years, while reforestation restores forests on lands more recently deforested.⁹⁶ The

Long Periods of Time, CLEANTECHNICA (Sept. 18, 2017), <https://cleantechnica.com/2017/09/18/earths-weathering-thermostat-keeps-climate-check-long-periods-time/> [<https://perma.cc/4NZ7-2T8Q>].

⁸⁶ NRC, *supra* note 39, at 47.

⁸⁷ *Id.* at 46–47.

⁸⁸ *Id.* at 41.

⁸⁹ *Id.*

⁹⁰ *Id.* at 48.

⁹¹ McLaren, *supra* note 66, at 12. Indeed, studies concerning the environmental impact of dispersion at scale are still in their infancy. Psarras et al., *supra* note 60, at 13–14.

⁹² U.N. ENVIRONMENTAL PROGRAMME, *The Emissions Gap Report 2017: A UN Environment Synthesis Report* 64 (2017).

⁹³ European Academies Science Advisory Committee, *Negative emission technologies: What role in meeting Paris Agreement targets?*, 35 EASAC POL'Y REP. 1, 4 (2018) [hereinafter EASAC] (noting that we had emitted more than 200 GtCO₂ in the past five years). *But see* J.C.J. Olivier et al., *Trends in global CO₂ and total greenhouse gas emissions* 4 (PBL Netherlands Environmental Assessment Agency, 2017) (measuring the emissions of CO₂ equivalents, which is a broader, but more meaningful, calculation than just the amount of CO₂ emissions, and asserting that 2016 emissions were nearly 50 GtCO₂eq).

⁹⁴ NRC, *supra* note 39, at 66–67.

⁹⁵ McLaren, *supra* note 66, at 12.

⁹⁶ U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 60. These processes are necessitated by deforestation, which causes approximately 10 percent of anthropogenic greenhouse gas emissions. NRC, *supra* note 39, at 29.

ability of forestation to remove CO₂ from the atmosphere depends upon a number of factors, including the type and age of the trees,⁹⁷ temperature, precipitation, and CO₂ concentration.⁹⁸ Scientists project possible sequestration from these activities as ranging from 1.5 to 14 GtCO₂ by 2030.⁹⁹ Considerations that limit this approach include the availability of suitable land and sufficient water.¹⁰⁰ Although scientists calculate the costs of these activities to range from as low as \$7.50 per tCO₂ to as high as \$100 per tCO₂, most estimates do not exceed \$40 per tCO₂.¹⁰¹ Because of its comparatively low cost, afforestation can serve as a substitute for, or at least a complement to, other NETs methods or mitigations.¹⁰²

Agricultural land management practices—agricultural practices have released terrestrial carbon to the atmosphere.¹⁰³ In fact, agricultural practices have released 10 to 12 percent of anthropogenic greenhouse gases.¹⁰⁴ These practices reverse that flow. They either increase soil carbon inputs or reduce soil carbon losses.¹⁰⁵ Methods that increase soil carbon include growing cover crops,¹⁰⁶ leaving crop residues to decay, and applying manure or compost.¹⁰⁷ Soil tends to lose carbon through oxidation, such as when it is plowed.¹⁰⁸ Accordingly, practices that reduce carbon releases include no- or low-till farming.¹⁰⁹ Possible sequestration from agricultural land management practices may be as high as 5.2 GtCO₂, but food production and other uses may lower this amount.¹¹⁰ Some of these practices (such as no-till) may already be cost-competitive with traditional practices. Anticipated costs range from \$20 to \$100 per tCO₂.¹¹¹

⁹⁷ NRC, *supra* note 39, at 40. In general, net CO₂ removal peaks within 30–40 years, and then it declines to zero as the forest matures.

⁹⁸ *Id.*

⁹⁹ *Id.*

¹⁰⁰ McLaren, *supra* note 66, at 20.

¹⁰¹ *Id.*; NRC, *supra* note 39, at 41–42.

¹⁰² Ulrich Kreidenweis et al., *Afforestation to Mitigate Climate Change: Impacts on Food Prices Under Consideration of Albedo Effects*, 11 ENVTL. RES. LETTERS 1, 1 (2016).

¹⁰³ NRC, *supra* note 39, at 42–43.

¹⁰⁴ Stefan Frank et al., *Reducing Greenhouse Gas Emissions in Agriculture without Compromising Food Security?*, 12 ENVTL. RES. LETTERS 1, 2 (2017).

¹⁰⁵ U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 61.

¹⁰⁶ NRC, *supra* note 39, at 43, n.2 and accompanying text. Farmers plant these crops (such as bean, lentil, and alfalfa) when they are not using their fields to grow market crops. *Id.* Cover crops increase carbon sequestration. *Id.*

¹⁰⁷ *Id.* at 43.

¹⁰⁸ McLaren, *supra* note 66, at 21.

¹⁰⁹ NRC, *supra* note 39, at 43.

¹¹⁰ *Id.* at 44.

¹¹¹ Psarras et al., *supra* note 60, at 16.

Biochar—this involves storing stable biomass in soil. Without using oxygen, pyrolysis combusts biomass at low temperatures to form biochar.¹¹² Biochar resists decomposition, thereby stabilizing biomass buried in soil.¹¹³ It constitutes a NET because it fixes atmospheric CO₂ in a stable form that can be easily sequestered.¹¹⁴ Biochar also can provide several benefits, including increasing soil fertility and improving water and nutrient retention.¹¹⁵ Scientists project that biochar can sequester as much as 1 GtCO₂ by 2030, and possibly up to 9.5 GtCO₂, by 2100.¹¹⁶ Costs of biochar range from \$18 to \$166 per tCO₂.¹¹⁷

Bioenergy with Carbon Capture and Sequestration (“BECCS”)—this system uses conventional power plants to burn biomass and capture the resulting emissions.¹¹⁸ The process begins with growing biomass—plants or trees—for fuel; the biomass consumes CO₂ to grow.¹¹⁹ Mature biomass provides fuel for electricity generation or process heat; it can also serve as the basis for liquid fuels such as ethanol or methanol or gas fuels such as hydrogen.¹²⁰ When used with power or manufacturing plants fitted with carbon capture and storage technology, the system traps the released CO₂ for sequestration.¹²¹ Since bioenergy is in theory carbon neutral and in practice low carbon, the capture and sequestration of the process’s emissions results in net negative emissions.¹²²

BECCS benefits from several advantages over other NETs. It “has the greatest technological maturity and [can] be introduced relatively easily into today’s energy system.”¹²³ Indeed, BECCS could contribute significantly to emissions reductions as soon as 2030.¹²⁴ BECCS is scalable, too,¹²⁵ though extensive expansion may conflict with other land uses.¹²⁶

¹¹² NRC, *supra* note 39, at 45.

¹¹³ U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 62.

¹¹⁴ Niall McGlashan et al., *High-Level Techno-Economic Assessment of Negative Emissions Technologies*, 90 PROCESS SAFETY & ENVTL. PROTECTION 501, 504 (2012).

¹¹⁵ U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 62.

¹¹⁶ McGlashan et al., *supra* note 114, at 503.

¹¹⁷ U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 62.

¹¹⁸ McGlashan et al., *supra* note 114, at 503.

¹¹⁹ *Id.*

¹²⁰ NRC, *supra* note 39, at 63.

¹²¹ McGlashan et al., *supra* note 114, at 503–04.

¹²² McLaren, *supra* note 66, at 17.

¹²³ McGlashan et al., *supra* note 114, at 505.

¹²⁴ *Id.* at 508.

¹²⁵ McLaren, *supra* note 66, at 17.

¹²⁶ Wil Burns & Simon Nicholson, *Bioenergy and carbon capture with storage (BECCS)*:

Integrated assessment models estimate that it can satisfy from 15 to 45 percent of global energy needs.¹²⁷ At these levels, BECCS sequester between 2 and 18 GtCO₂ per year.¹²⁸ While significant, society is already adding about 40 GtCO₂ to the atmosphere every year.¹²⁹ A critical advantage of BECCS is that, in addition to the value of its negative emissions, it also produces a salable product, electricity.¹³⁰ Finally, most studies project BECCS to cost \$50 to \$100 per tCO₂.¹³¹

If BECCS operates at scale, it may produce several negative consequences. BECCS produced at scale would require 500 million hectares of land, about 1.5 times larger than India.¹³² It would likely compete with other land uses, such as food and fiber production, forestry, and biodiversity protection.¹³³ Using the 500 million hectares as a benchmark, BECCS would require fifty times the amount of land dedicated to United States bioethanol production, 50 percent of global fertilizer production, and more than double current global water withdrawals for irrigation.¹³⁴ These impacts would serve as an effective cap on the extent of BECCS use, necessitating that society use BECCS in conjunction with other NETs.¹³⁵

Direct Air Capture with Carbon Capture and Sequestration (“DACCS”)—this method collects CO₂ from the ambient air, processes it, and then buries it.¹³⁶ It uses a chemical or physical scrubbing process to separate CO₂ from the ambient air. Similar processes operate in submarines and the International Space Station.¹³⁷ DACCS systems generate a

the prospects and challenges of an emerging climate policy response, 7 J. ENVTL. STUD. & SCI. 527, 529 (2017).

¹²⁷ U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 62, n.13 and accompanying text.

¹²⁸ *Id.* at 62. See also Kriegler et al., *supra* note 64, at 55 (projecting BECCS deployment limited to a removal of 14–15 GtCO₂ per year).

¹²⁹ EASAC, *supra* note 93, at 4.

¹³⁰ McGlashan et al., *supra* note 114, at 504.

¹³¹ Matthias Honegger & David Reiner, *The Political Economy of Negative Emissions Technologies: Consequences for International Policy Design*, 18 CLIMATE POL'Y 306, 308–09 (2017).

¹³² NRC, *supra* note 39, at 54.

¹³³ *Id.*

¹³⁴ *Id.* The NRC presents calculations for BECCS at 200 million hectares of land; this author has extrapolated those impacts linearly to 500 million hectares of land.

¹³⁵ *Id.*; Kriegler et al., *supra* note 64, at 55. As BECCS nears its upper environmental limit of approximately 12 GtCO₂ per year, the limitations on biomass production increase the costs of BECCS abruptly, likely making other NETs more cost competitive. NRC, *supra* note 39, at 54.

¹³⁶ Fuss et al., *supra* note 54, at 3.

¹³⁷ Yuki Ishimoto et al., *Putting Costs of Direct Air Capture in Context* 4 (Inst. of Applied Energy, Working Paper No. 002, June 30, 2017).

stream of CO₂, which then is available for manufacturing processes or sequestration.¹³⁸ Businesses can use CO₂ to make synthetic gas, liquid fuels, and other chemicals to stimulate the growth of plants in greenhouses.¹³⁹

The sequestration process is similar to that used with power plants. Since CO₂ is 100 to 300 times more concentrated in natural gas or coal-fired power plants, direct air capture (“DAC”) systems require two to ten times more energy to capture CO₂ than do power plants using carbon capture and sequestration (“CCS”).¹⁴⁰ Consequently, renewable energy sources need to power DAC systems to ensure that they produce truly net negative emissions.¹⁴¹ This may limit the siting of DAC systems to locations with access to sufficient wind, solar, geothermal, or hydro-power.¹⁴² They also require geographic formations which support sequestration of carbon.¹⁴³ Conversely, since they pull CO₂ directly out of the air, DAC systems have few other constraints on their siting.¹⁴⁴ Indeed, when compared to BECCS, they impose smaller burdens on productive lands and likely will have lower impacts on ecosystems.¹⁴⁵ Because of DACCS’s ability to capture and sequester large amounts of CO₂ with few siting or land use concerns, some scientists have concluded that limiting warming to 1.5°C is possible only with DACCS.¹⁴⁶

Although DACCS technology is well established, questions remain concerning its scalability and its cost.¹⁴⁷ Cost remains its greatest barrier.¹⁴⁸ Current projections range from \$400 per tCO₂ captured to as high as \$1,000 per tCO₂.¹⁴⁹ By contrast, the cost of BECCS should not exceed \$100 per tCO₂.¹⁵⁰ Concerning scalability, fewer than twenty large-scale projects

¹³⁸ NRC, *supra* note 39, at 67.

¹³⁹ Katherine Bourzac, *We Have the Technology*, NATURE, Oct. 12, 2017, at S66, S68.

¹⁴⁰ NRC, *supra* note 39, at 68.

¹⁴¹ U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 63–64.

¹⁴² Psarras et al., *supra* note 60, at 8. On the other hand, reliance upon renewable energy sources, particularly wind and solar photovoltaics, will diminish one of DACCS’s advantages over other NETs, which is its relatively minor land footprint. Smith, *supra* note 74, at 46.

¹⁴³ Psarras et al., *supra* note 60, at 8; Smith, *supra* note 74, at 46.

¹⁴⁴ Psarras et al., *supra* note 60, at 9.

¹⁴⁵ Parson, *supra* note 45, at 2.

¹⁴⁶ Marcucci, Kypreos & Panos, *supra* note 69, at 181.

¹⁴⁷ Ishimoto et al., *supra* note 137.

¹⁴⁸ U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 64.

¹⁴⁹ NRC, *supra* note 39, at 69–72. New technologies may be able to reduce these costs sharply. A recent analysis suggests that a DACCS model may be able to sequester CO₂ at a cost between \$94 and \$232 per tCO₂. *NET Gains*, 3 NATURE ENERGY, July 10, 2018, at 531.

¹⁵⁰ Honegger & Reiner, *supra* note 131, at 308.

currently operate.¹⁵¹ While they capture 40 million tCO₂, this represents only a fraction of the billions of tons that will need to be sequestered.¹⁵²

Ocean alkalinity enhancement—these methods facilitate the storage of carbon in the ocean by altering the equilibrium between atmospheric CO₂ and inorganic oceanic carbon.¹⁵³ This term encompasses three different approaches to enhance ocean alkalinity: weathering of silicate and carbonate materials on land to introduce calcium and magnesium into the ocean; adding calcium oxide or calcium hydroxide (often called ocean liming); and electrolysis of sea water.¹⁵⁴ The ocean contains forty-five times more carbon than the atmosphere, and the ocean and weathering would eventually return atmospheric carbon to pre-industrial levels over 100,000 to 200,000 years.¹⁵⁵ These methods simply accelerate these natural processes. Ocean alkalinity enhancement methods are scalable,¹⁵⁶ with limitations arising mainly from the ability to scale up mining of minerals and construction of ships for transportation.¹⁵⁷ Costs range from \$30 to \$60 per tCO₂.¹⁵⁸ If operated at the appropriate scale, this method could sequester sufficient carbon to return the atmosphere to its pre-industrial state.¹⁵⁹

Ocean fertilization—this method adds nutrients to the ocean to stimulate phytoplankton growth, which consumes CO₂, which is then buried with the organisms at the bottom of the ocean after they die.¹⁶⁰ The fertilization process utilizes iron, phosphate, or nitrogen.¹⁶¹ Scientists project that ocean fertilization can remove up to 3.7 GtCO₂ per year.¹⁶² While early cost estimates were relatively low, \$50 per tCO₂ or lower,¹⁶³

¹⁵¹ *Id.* at 313.

¹⁵² Bourzac, *supra* note 139, at S66.

¹⁵³ U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 64. One unique benefit of this method is that it helps to reverse ocean acidification. *Id.*

¹⁵⁴ *Id.*

¹⁵⁵ Phil Renforth & Gideon Henderson, *Assessing Ocean Alkalinity for Carbon Sequestration*, 55 *REVIEWS OF GEOPHYSICS* 636, 637 (2017).

¹⁵⁶ McLaren, *supra* note 66, at 18.

¹⁵⁷ Renforth & Henderson, *supra* note 155, at 660–61. For instance, extraction and processing of minerals would need to increase at a rate of growth of 12 percent per year over the next 45 to 60 years. *Id.* at 660.

¹⁵⁸ McLaren, *supra* note 66, at 18.

¹⁵⁹ T. Kruger, *Increasing the Alkalinity of the Ocean to Enhance its Capacity to Act as a Carbon Sink and to Counteract the Effect of Ocean Acidification*, in *GeoConvention 4* (2010), https://www.geoconvention.com/archives/2010/1067_GC2010_Increasing_the_Alkalinity_of_the_Ocean.pdf [<https://perma.cc/E2D4-R6TP>].

¹⁶⁰ Fuss et al., *supra* note 54, at 3.

¹⁶¹ McLaren, *supra* note 66, at 19.

¹⁶² NRC, *supra* note 39, at 61.

¹⁶³ *Id.*; McLaren, *supra* note 66, at 19.

recent estimates have risen. Concluding that the process might be less efficient than previously anticipated and that some leakage may occur of CO₂ back to the surface, a recent study projects the cost of fertilization to be near \$450 per tCO₂.¹⁶⁴

Several concerns complicate use of this method. First, the extensive ocean environment will render problematic the analysis of the relatively minor changes produced by fertilization.¹⁶⁵ Second, continuous fertilization might impair the food web and fisheries.¹⁶⁶ Finally, in response to a recent experiment concerning ocean fertilization, in 2014 the parties to the London Convention amended the London Protocol to prohibit all ocean fertilization activities except for scientific research.¹⁶⁷ This suggests that efforts to proceed with ocean fertilization may be vigorously opposed.¹⁶⁸

II. NETS ARE NOT SUFFICIENTLY DEVELOPED

Despite the importance of NETs to addressing climate change, these technologies remain significantly underdeveloped. Many critical uncertainties remain regarding all CDR technologies. These unknowns include the time required to develop their technologies, development of accounting and legal standards, NETs' ability to operate at the scale required, their environmental impacts, and their actual effectiveness.

Many NETs involve technologies that are still nascent,¹⁶⁹ remaining at the level of concepts, prototypes, or pilot projects.¹⁷⁰ Even the most developed CDR technologies have not progressed beyond the early prototyping stages, and these technologies have limited potential capacities.¹⁷¹ Where technologies are more developed, their deployment—or even their planned deployment—still falls substantially short of the level necessary.¹⁷² For instance, although BECCS is the most advanced of the NETs, only fifteen pilot plants and one commercial plant currently operate.¹⁷³ Similarly,

¹⁶⁴ *Id.*

¹⁶⁵ NRC, *supra* note 39, at 60.

¹⁶⁶ *Id.* at 61.

¹⁶⁷ Tim Dixon et al., *Update on the London Protocol—Developments on Transboundary CCS and on Geoengineering*, 63 ENERGY PROCEDIA 6623, 6627 (2014).

¹⁶⁸ McLaren, *supra* note 66, at 19.

¹⁶⁹ Field & Mach, *supra* note 42, at 706.

¹⁷⁰ Oliver Geden et al., *Integrating Carbon Dioxide Removal into EU Climate Policy: Prospects for a Paradigm Shift*, WIRES CLIMATE CHANGE 1 (2018).

¹⁷¹ *Id.*

¹⁷² Fuss et al., *supra* note 54, at 4.

¹⁷³ Burns & Nicholson, *supra* note 126, at 3. Based upon the build rate of CCS projects required to meet the 2°C goal, the current build rate is nearly 100 times too slow. R. Stuart

implementing biochar at scale would require an increase of over sixty-three times the current charcoal production capacity.¹⁷⁴ Regarding DAC, emissions scenarios anticipate that several thousand will be operating by 2030; planned construction, however, only numbers in the tens.¹⁷⁵ Moreover, parties to the Paris Agreement—an agreement which contemplates deployment of NETs to achieve its targets¹⁷⁶—display little commitment to developing CDR technologies. The parties' INDCs fail to mention NETs, and only three even recognize carbon capture and sequestration as a priority.¹⁷⁷

The lack of current commitment to developing NETs is of particular concern because many of the technologies will require significant time to develop. Despite the significant role they play in many analytical models, most of the technologies are still immature.¹⁷⁸ Fundamental uncertainties remain concerning their effectiveness. For example, when operated at scale, carbon sequestration's geological viability and permanence of storage are uncertain.¹⁷⁹ Thus, advancing NETs to maturity and widespread deployment will require “many decades.”¹⁸⁰ Nevertheless, progressive deployment would be superior because it would spread the cost over time, minimize future risks, and accelerate technological innovation.¹⁸¹ As the 2015 report of the United States National Research Council states of NETs, “it is critical now to embark on a research program to lower the technical barriers to efficacy and affordability.”¹⁸²

Additional, non-technological concerns support imminent commitment to NETs research and deployment. For instance, a number of legal issues concerning development and deployment of NETs, as well as accounting issues regarding recording and crediting the value of their

Haszeldine et al., *Negative Emissions Technologies and Carbon Capture and Storage to Achieve the Paris Agreement Commitments*, 376 PHIL. TRANS. R. SOC. A1, 1 (Oct. 28, 2018).

¹⁷⁴ Niall R. McGlashan et al., *Negative Emissions Technologies*, 8 Grantham Institute for Climate Change Briefing Paper (October 2012), at 15.

¹⁷⁵ Glen P. Peters et al., *Key Indicators to Track Current Progress and Future Ambition of the Paris Agreement*, 121 NATURE CLIMATE CHANGE 1, 4 (2017). The first commercial DACCS plant commenced operations in 2017. EASAC, *supra* note 93, at 9.

¹⁷⁶ Peters & Geden, *supra* note 34, at 619.

¹⁷⁷ Fuss et al., *supra* note 54, at 7.

¹⁷⁸ Keller et al., *supra* note 41, at 1334.

¹⁷⁹ Kriegler et al., *supra* note 64, at 55. Global storage capacity estimates vary widely, and even regional level differences are sufficient to necessitate individual assessments. Naomi E. Vaughan et al., *Evaluating the use of biomass energy with carbon capture and storage in low emission scenarios*, 13 ENVTL. RES. LETTERS 4, 6 (2018).

¹⁸⁰ Lomax et al., *supra* note 2, at 499.

¹⁸¹ Allen et al., *supra* note 75, at 3.

¹⁸² NRC, *supra* note 39, at 111.

operations, have yet to be confronted. A number of liability issues, especially concerning NETs that mechanically sequester carbon, arise with these technologies. Liability issues for CCS fall into two categories: operational and post-injection.¹⁸³ Operational liability concerns the environmental, health, and safety risks resulting from CO₂ capture, transport, and injection.¹⁸⁴ Post-injection liability pertains to injuries to human health, the environment, and property.¹⁸⁵ A specific concern regards possible contamination of water used for drinking or agricultural purposes.¹⁸⁶ Another concern stems from the long-term nature of the sequestration involved.¹⁸⁷ Because liability for the injection site may have been transferred (or the original operators may no longer exist), governments which have already confronted this situation have enacted legislation transferring liability to their governments.¹⁸⁸ Uncertainty concerning liability issues impairs rapid deployment of NETs systems, especially those involving sequestration.¹⁸⁹

Even land management and reforestation methods will require uniform policies. For instance, uniform standards will be necessary to measure carbon, to ensure sequestration, and to verify that these measurements are consistent across natural and technological approaches.¹⁹⁰ Ocean fertilization and ocean alkalinization fall within 2013 amendments to the

¹⁸³ Mark de Figueiredo, *The Liability of Carbon Dioxide Storage* (Jan. 12, 2007), https://sequestration.mit.edu/pdf/Mark_de_Figueiredo_PhD_Dissertation.pdf [<https://perma.cc/C6EN-YM7Q>].

¹⁸⁴ *Id.* at 1.

¹⁸⁵ *Id.*

¹⁸⁶ Ian Havercroft & Richard Macrory, *Legal Liability and Carbon Capture and Storage: A Comparative Perspective* 11 (Global Carbon Capture and Storage Institute/UCL Laws 2014), <http://hub.globalccsinstitute.com/sites/default/files/publications/179798/legal-liability-carbon-capture-storage-comparative-perspective.pdf> [<https://perma.cc/NH74-H3XB>].

¹⁸⁷ *Id.* at 36.

¹⁸⁸ *Id.* at 37. See also Wendy B. Jacobs & Debra Stump, *Proposed Liability Framework for Geological Sequestration of Carbon Dioxide* 12 (Emmitt Env'tl. L. & Pol'y Clinic, Working Paper, 2010).

¹⁸⁹ *Id.* at i.

¹⁹⁰ CTR. FOR CARBON REMOVAL, CARBON REMOVAL POLICY: OPPORTUNITIES FOR FEDERAL ACTION 8 (2017), <https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/5b9427cd8a922dd0d7451136/1536436200923/Carbon%2BRemoval%2BPolicy%2BOpportunities%2Bfor%2BAction+%281%29.pdf> [<https://perma.cc/92YX-UQYN>]. For instance, a possible supply chain for a BECCS system could span several countries and require detailed accounting over a period of decades with provisions for independent measurement, reporting, and verification. Peters & Geden, *supra* note 34, at 620–21. In fact, a recognized knowledge gap for all NETs concerns consistent accounting rules. Fuss et al., *supra* note 54, at 7. BECCS and several other NETs will require the adoption of uniform international accounting and accreditation systems. Early development and agreement of these measurements will facilitate timely development of NETs. Lomax et al., *supra* note 2, at 500.

London Protocol, which regulate marine geoengineering activities (though the amendments have not yet been ratified by a sufficient number of parties to enter into force).¹⁹¹ Besides liability and measurement issues, legal regimes can also provide incentives, or remove barriers, to adopt carbon removal farming practices.¹⁹² Similarly, incentives are needed to support favorable forest management.¹⁹³ Finally, carbon dioxide removal efforts could also be facilitated by policies that provide financial encouragement for these practices, such as a carbon tax,¹⁹⁴ carbon trading,¹⁹⁵ tax credits, or other means.¹⁹⁶

NETs also need to be developed soon because uncertainty remains over the ability of many of these technologies to be utilized at the scale necessary.¹⁹⁷ None of the NETs currently operate at scale, and, in fact, none of them have been developed as a commercial product. Since they do not yet function at this level, uncertainties remain regarding their feasibility, potential, and risks.¹⁹⁸ The ability of biochar, for example, to stabilize carbon is poorly understood.¹⁹⁹ Most NETs may also run into limitations when implemented at scale.²⁰⁰ For instance, factors such as low CO₂ uptake during some stages of tree growth and constraints on the availability of land suitable for trees will limit sequestration through afforestation and reforestation.²⁰¹ Similarly, methods that rely upon reactions with minerals, such as weatherization and ocean liming, will face limitations resulting from the amount of minerals needed to be extracted, processed, and transported.²⁰² Also, the availability of bio-feedstocks and the land on which to grow them may restrict the implementation of BECCS.²⁰³

¹⁹¹ Renforth & Henderson, *supra* note 155, at 665.

¹⁹² CTR. FOR CARBON REMOVAL, *supra* note 190, at 17.

¹⁹³ *Id.* at 22–23.

¹⁹⁴ A carbon tax imposes a fee upon sources for the carbon they emit into the atmosphere. Robinson Meyer, *Republicans Blow Their Chance to Pass a Carbon Tax*, THE ATLANTIC (Dec. 20, 2017), <https://www.theatlantic.com/science/archive/2017/12/republicans-blow-their-chance-to-pass-a-carbon-tax/548891/> [<https://perma.cc/GKV5-3NTG>].

¹⁹⁵ Havercroft & Macrory, *supra* note 186, at 34. Carbon trading involves the purchasing and selling of permits to emit carbon dioxide. *What is carbon trading?*, FERN, <http://old.fern.org/campaign/carbon-trading/what-carbon-trading> [<https://perma.cc/2Z48-YEEF>] (last visited Nov. 17, 2018).

¹⁹⁶ CTR. FOR CARBON REMOVAL, *supra* note 190, at 10–11.

¹⁹⁷ NRC, *supra* note 39, at 110.

¹⁹⁸ Keller et al., *supra* note 41, at 1338.

¹⁹⁹ McGlashan et al., *supra* note 174, at 23.

²⁰⁰ Fuss et al., *supra* note 54, at 3.

²⁰¹ de Lannoy et al., *supra* note 78, at 243–44.

²⁰² *Id.* at 243.

²⁰³ McLaren, *supra* note 66, at 17. Similar issues may limit the ability to produce biochar at scale. Workman et al., *supra* note 67, at 2881.

Another unknown about NETs is their environmental impact. Different methods raise different concerns. Ocean fertilization may disrupt the ecology of the oceans.²⁰⁴ Ocean alkalinity enhancement may have localized effects and detrimental impacts on ocean ecosystems.²⁰⁵ Carbon injection may increase seismicity.²⁰⁶ Afforestation and reforestation may disrupt hydrological cycles, ecosystems, and biodiversity.²⁰⁷ Implementation of BECCS at scale may require land needed for food production, consume scarce water resources, and endanger biodiversity.²⁰⁸ Because of these consequences, even a combination of NETs with different impacts would still impose significant impacts on either land, water, nutrients, or planetary albedo.²⁰⁹

Other benefits will accrue from an early commitment to NETs. First, some more mature technologies—such as BECCS, biochar, and weatherization—could begin providing CO₂ reductions.²¹⁰ Second, until policies are adopted that support the development of NETs, significant investment of resources into them will likely be deferred.²¹¹

III. RPS CAN STIMULATE THE DEVELOPMENT OF NETS

RPSs²¹² require that electricity providers generate or receive a set amount of their electricity from a predetermined type of source.²¹³ RPSs incorporate a number of specific requirements, which allow for tailoring to accommodate jurisdictional priorities. These policies have stimulated the development of renewable energy in the United States and a number of other countries in Europe and Asia. RPS policy structures can similarly

²⁰⁴ NRC, *supra* note 39, at 61.

²⁰⁵ Renforth & Henderson, *supra* note 155, at 666. Not all effects may be negative; it may also reduce ocean acidification. *Id.*

²⁰⁶ NRC, *supra* note 39, at 111.

²⁰⁷ Keller et al., *supra* note 41, at 1337.

²⁰⁸ Burns & Nicholson, *supra* note 126, at 3.

²⁰⁹ Smith, *supra* note 74, at 49.

²¹⁰ Lomax et al., *supra* note 2, at 500.

²¹¹ *Id.*

²¹² Jurisdictions and scholars use a range of labels to refer to this concept, including quotas, obligations, targets, and mandates. Felix Mormann, *Constitutional Challenges and Regulatory Opportunities for State Climate Policy Innovation*, 41 HARV. ENVTL. L. REV. 189, 198 (2017). Other interchangeable names include renewable energy standards and tradable green certificate programs. Ryan Wiser et al., *Supporting Solar Power in Renewables Portfolio Standards: Experience from the United States*, 39 ENERGY POL'Y 3894, 3894 (2011).

²¹³ *Id.*

establish markets for NETs, thereby stimulating their innovation and reducing their costs.

A. *RPSs Successfully Promoted Development of Renewable Energy*

RPSs obligate electricity providers to source a set percentage of electricity from particular types of generation.²¹⁴ Usually, they require that a specified percentage of electricity generated or procured be produced from particular types of energy sources, but some RPSs may identify a certain amount of megawatts that must be produced.²¹⁵ RPSs are typically neutral among energy sources, though they can include policies to support specific technologies.²¹⁶ RPSs usually require that electricity that satisfies the mandate be generated from renewable energy sources, but some states allow nonrenewable sources to satisfy their mandates.²¹⁷ RPS requirements may be either mandatory or voluntary.²¹⁸

RPSs typically provide six criteria with which electricity suppliers must comply. First, they set a minimum percent or amount of electricity required to satisfy the mandate and a timeline for compliance.²¹⁹ Often these requirements increase gradually over time.²²⁰ Typically, they start modestly, increasing over a period ranging from ten to twenty years, and then remaining at that level indefinitely.²²¹ Second, RPSs specify the electricity sources that will satisfy the mandate.²²² Third, they identify

²¹⁴ *Id.*

²¹⁵ Corey N. Allen, *Untapped Renewable Energy Potential: Lessons for Reforming Virginia's Renewable Energy Portfolio Standard from Texas and California*, 35 VA. ENVTL. L.J. 117, 120 (2016).

²¹⁶ Mormann, *supra* note 212, at 198.

²¹⁷ See, e.g., *Clean Energy Portfolio Standard: Indiana*, DSIRE, <http://programs.dsireusa.org/system/program/detail/4832> [<https://perma.cc/PA3F-MATL>] (last updated June 18, 2018) (identifying as eligible technologies coal bed methane and clean coal); *Clean Energy Portfolio Standard: Colorado*, DSIRE, <http://programs.dsireusa.org/system/program/detail/133> [<https://perma.cc/3RCX-Z7EW>] (last updated June 14, 2018) (allowing coal mine methane to satisfy its RPS); *Clean Energy Portfolio Standard: Delaware*, DSIRE, <http://programs.dsireusa.org/system/program/detail/1231> [<https://perma.cc/4JWN-RBQ6>] (last updated July 3, 2018) (recognizing as eligible technologies fuel cells that use non-renewable fuels to produce hydrogen); *Clean Energy Portfolio Standard: Maine*, DSIRE, <http://programs.dsireusa.org/system/program/detail/452> [<https://perma.cc/VBQ8-QDZZ>] (last updated July 12, 2018) (recognizing the same fuel cells as Delaware).

²¹⁸ Allen, *supra* note 215, at 120.

²¹⁹ *Id.*

²²⁰ See U.S. ENVTL. PROT. AGENCY (EPA), ENERGY AND ENVIRONMENT GUIDE TO ACTION 5-10 (2015).

²²¹ *Id.*

²²² Allen, *supra* note 215, at 120.

the parties required to comply with the obligation.²²³ Fourth, they indicate whether a party can satisfy its obligation through the purchase of renewable energy credits (“RECs”).²²⁴ Fifth, they identify an administrator—usually a government agency—for the program.²²⁵ Lastly, RPSs specify their enforcement mechanisms.²²⁶

Renewable portfolio standards have lengthy and widespread track records. Iowa became the first state to enact an RPS in 1983.²²⁷ Currently, twenty-nine states plus the District of Columbia utilize RPSs, and these policies directly cover 56 percent of retail electricity sales in the United States.²²⁸ Another eight states have adopted voluntary, non-binding renewable energy goals.²²⁹ Nations which have enacted a form of RPS include Australia, Belgium, Canada, China, parts of India, Italy, Japan, Poland, Romania, Sweden, Thailand, and the United Kingdom.²³⁰

Because of the range of characteristics encompassed by RPSs and the unique aspects of each state, as many different RPS designs exist as do jurisdictions that have enacted these policies.²³¹ States have tailored their RPS policies to fit each state’s objectives, energy resources potential, and electricity market characteristics.²³² Besides the six criteria described above, RPSs may also differ regarding specifics of qualifying electricity resources and technologies (vintage, location, and deliverability), mechanisms used to favor particular resources, and specifics of RECs systems.²³³ Some of these characteristics—and the manner in which states have tailored them to their particular circumstances—will be reviewed below.

²²³ *Id.*

²²⁴ *Id.*

²²⁵ *Id.*

²²⁶ *Id.*

²²⁷ Magali Delmas & Maria J. Montes-Sancho, *US state policies for renewable energy: context and effectiveness*, 39 ENERGY POL’Y 2273, 2275 (2011).

²²⁸ GALEN BARBOSE, U.S. RENEWABLES PORTFOLIO STANDARDS: 2017 ANNUAL STATUS REPORT 6 (2017).

²²⁹ *State Renewable Portfolio Standards and Goals*, NAT’L CONFERENCE OF STATE LEGISLATURES, <http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx> [<https://perma.cc/6RG3-RYUY>] (last updated July 20, 2018).

²³⁰ Wisner et al., *supra* note 212, at 3894; Greg Buckman, *The Effectiveness of Renewable Portfolio Standard Banding and Carve-Outs in Supporting High-Cost Types of Renewable Electricity*, 39 ENERGY POL’Y 4105, 4106 (2011).

²³¹ *See* GOVERNORS’ WIND ENERGY COALITION, RENEWABLE ELECTRICITY STANDARDS: STATE SUCCESS STORIES 9 (2013).

²³² EPA, *supra* note 220, at 5-2.

²³³ BARBOSE, *supra* note 228, at 7.

One key decision that crafters of RPS requirements must address involves their policies concerning RECs. RECs are tradable rights representing attributes related to the generation of electricity from renewable energy sources.²³⁴ Power generators receive one REC for every megawatt of electricity that they produce.²³⁵ For tracking purposes, RECs contain information about the electricity generator, including its energy source, location, and operation date.²³⁶ At the end of each compliance period, a generator must possess the appropriate number of RECs, whether acquired through generation or purchase.²³⁷ The attributes represented by RECs may include, among others, credit for the renewable energy generated.²³⁸

RPS provisions may allow RECs to be unbundled—traded separately from their electricity generation.²³⁹ Unbundled RECs can benefit both the purchaser and the seller.²⁴⁰ The seller benefits because its electricity generation produces a second salable product in addition to the actual electricity.²⁴¹ This incentivizes renewable power production.²⁴² Purchasers benefit because the credit enables them to satisfy renewable energy source requirements of RPSs without actually needing to receive the generated electricity (and thereby avoiding the need for physical delivery to the purchaser, thus broadening the geographic market).²⁴³

Unbundling thus can incentivize additional renewable energy generation in two ways. It encourages overproduction, since generators can sell excess credits.²⁴⁴ This can incentivize renewable energy investment even in the absence of an RPS mandate.²⁴⁵ This may be especially

²³⁴ Felix Mormann, Dan Reicher & Victor Hanna, *A Tale of Three Markets: Comparing the Renewable Energy Experiences of California, Texas and Germany*, 35 STAN. ENVTL. L.J. 55, 78 (2016).

²³⁵ *Id.*

²³⁶ EPA, *supra* note 220, at 5-2.

²³⁷ Allen, *supra* note 215, at 124.

²³⁸ EPA, *supra* note 220, at 5-2.

²³⁹ Allen, *supra* note 215, at 125.

²⁴⁰ *Id.*

²⁴¹ *Id.*

²⁴² *Id.*

²⁴³ EPA, *supra* note 220, at 5-2. RECs not only can allow shifting of procedures and purchasers geographically, they can also shift them temporally. *Id.* Some states allow RECs to be bankable which enables purchasers to acquire them in one year, but to apply them in another year. A benefit of this system is it smooths fluctuations in REC prices and electricity production. Allen, *supra* note 215, at 126.

²⁴⁴ See Miriam Fischlein & Timothy M. Smith, *Revisiting Renewable Portfolio Standard Effectiveness: Policy Design and Outcome Specification Matter*, 46 POL'Y SCI. 277, 288 (2013).

²⁴⁵ Allen, *supra* note 215, at 125.

important with new technologies, where the costs of production may not be competitive with other methods and market prices do not fully cover costs.²⁴⁶ Not surprisingly, all but three RPS states permit the unbundling of RECs.²⁴⁷

RPSs also require states to develop an accounting infrastructure.²⁴⁸ Indeed, the primary role of RECs is to track electricity generation from renewable sources and to guarantee that generators claim each credit only once.²⁴⁹ RECs also ensure that credited electricity complies with other restrictions, such as approved energy source or geographic location of the generator.²⁵⁰ Because of the integral nature of RECs to RPS compliance, nine regional tracking systems have arisen to support them.²⁵¹ States require utilities to demonstrate compliance with RPS requirements by filing annual reports.²⁵² These reports document utilities' ownership and retirement of RECs, which they received by the state for generation or acquired through the regional markets.²⁵³

RPS designers need to address a number of additional issues. One involves the temporal eligibility of sources. This concerns whether pre-existing facilities (generating electricity from qualifying sources before implementation of the RPS) will receive credit for complying with the subsequent RPS mandate. Even if they do, the designers may choose to tier the credits for compliance, so that facilities of different vintages receive different levels of compliance credit.²⁵⁴ A second issue concerns the geographic eligibility of sources. Some states recognize only in-state generation as compliant, some impose no restrictions, while still others allow the electricity to be sourced outside the state's boundaries as long as the generator actually feeds it into the regional grid.²⁵⁵ Third, RPSs must specify the entities which must comply with its mandate.²⁵⁶ For

²⁴⁶ Buckman, *supra* note 230, at 4107.

²⁴⁷ Fischlein & Smith, *supra* note 244, at 288.

²⁴⁸ Chip Gaul & Sanya Carley, *Solar Set Asides and Renewable Electricity Certificates: Early Lessons From North Carolina's Experience with its Renewable Portfolio Standard*, 48 ENERGY POL'Y 460, 462 (2012).

²⁴⁹ *Id.*

²⁵⁰ Fischlein & Smith, *supra* note 244, at 289.

²⁵¹ *Id.*

²⁵² EPA, *supra* note 220, at 5-11.

²⁵³ *Id.*

²⁵⁴ Allen, *supra* note 215, at 122.

²⁵⁵ Fischlein & Smith, *supra* note 244, at 291. Often geographic origin requirements serve purposes other than renewable energy promotion, such as assuring receipt of environmental, employment, and financial benefits. *Id.*

²⁵⁶ Allen, *supra* note 215, at 123.

instance, RPSs uniformly impose obligations on investor-owned utilities, but they apply mandates to publicly owned utilities and retail sellers less often.²⁵⁷ Finally, RPSs also include enforcement mechanisms to ensure compliance. Typically, these consist of financial penalties.²⁵⁸ More severe penalties may consist of temporary suspension or permanent revocation of generators' licenses.²⁵⁹

While the failure to establish a national RPS has impeded renewable energy development, many benefits have resulted from their state-level development.²⁶⁰ As the Supreme Court has noted, states can serve "as laboratories for experimentation to devise various solutions where the best solution is far from clear."²⁶¹ Indeed, in the federalism system of the United States, states function as "innovation centers."²⁶² Not only do they experiment with policies, they also "compete" with other states to "develop the most effective and efficient regulatory program."²⁶³ Indeed, the popularity of RPSs suggests to some that this decentralized policymaking engendered a race to the top.²⁶⁴ Another advantage of state-level experimentation is that it limits risks to the rest of the country.²⁶⁵ Also, because of their smaller size, state governments better understand local resources, can respond to developments more nimbly, and best reflect local economic and political interests.²⁶⁶ Experimentation also provides the many parties involved in the electricity system experience with issues that arise with increased reliance upon renewable sources,²⁶⁷ such as development

²⁵⁷ See Uma Outka, *Prospects for Public Power and Distributed Renewable Energy*, 45 ENVTL. L. REP. NEWS & ANALYSIS 10537, 10539 (2015); see also *Programs*, DSIRE, [http://programs.dsireusa.org/system/program?type=38& \[https://perma.cc/4JEP-2TVZ\]](http://programs.dsireusa.org/system/program?type=38& [https://perma.cc/4JEP-2TVZ]) (last visited Nov. 17, 2018) (linking summaries of each state's RPS program).

²⁵⁸ *Id.*

²⁵⁹ Allen, *supra* note 215, at 127.

²⁶⁰ Francesca F. Bochner, *Water, Wind, and Fire: A Call for a Federal Renewable Portfolio Standard*, 25 DUKE ENVTL. L. & POL'Y F. 201, 221–22 (2014).

²⁶¹ *United States v. Lopez*, 514 U.S. 549, 581 (1995) (Kennedy, J., concurring).

²⁶² Allison C.C. Hoppe, *State-Level Regulation as the Ideal Foundation for Action on Climate Change: A Localized Beginning to the Solution of a Global Problem*, 101 CORNELL L. REV. 1627, 1650 (2016).

²⁶³ *Id.* at 1650–51.

²⁶⁴ Thomas P. Lyon & Haitao Yin, *Why Do States Adopt Renewable Portfolio Standards?: An Empirical Investigation*, 31 THE ENERGY J. 133, 153 (2010); see *infra* notes 284–89 and accompanying text (most states have raised their quotas, with several states now requiring from 50 percent to as much as 100 percent of electricity from renewable energy).

²⁶⁵ Lyon & Yin, *supra* note 264, at 1650, n.126.

²⁶⁶ Hoppe, *supra* note 262, at 1646.

²⁶⁷ LEON, *supra* note 4, at 6.

of new technologies,²⁶⁸ interconnection to the grid,²⁶⁹ the “duck curve,”²⁷⁰ and the financing of projects,²⁷¹ among others. Finally, local experimentation rarely risks the environmental consequences that might arise when new technologies are implemented at a global scale.²⁷²

Because RPSs have “dozens of design elements,”²⁷³ they are very flexible policy tools.²⁷⁴ Since RPSs are state policies and numerous permutations are possible with the many criteria that each RPS must include, the resulting RPSs are highly tailored to the circumstances and needs of each particular state.²⁷⁵ This flexibility has allowed states with diverse renewable energy potentials to adopt successful RPSs.²⁷⁶ Indeed, states have crafted RPS programs that are distinct over the range of criteria incorporated in RPSs.²⁷⁷ Not surprisingly, no two states have identical RPSs.²⁷⁸

The inherent flexibility of RPSs facilitates another of their defining experiences: continual revision and strengthening.²⁷⁹ For instance, from 2015 to 2017, the legislatures in the twenty-nine states with RPSs passed more than 200 RPS-related bills.²⁸⁰ RPS flexibility has enabled

²⁶⁸ *Renewable Portfolio Standard (RPS)*, HYDROPOWER REFORM COALITION, <http://www.hydroreform.org/policy/rps> [<https://perma.cc/R4TE-6NXW>] (last visited Nov. 17, 2018) (noting that the goal of most RPSs is to encourage the development of new energy sources).

²⁶⁹ See Debrup Das et al., Note, *Reducing Transmission Investment to Meet Renewable Portfolio Standards Using Smart Wires* 6 (2010), https://www.smartwires.com/wp-content/uploads/2015/01/Smart_Wire_4.pdf [<https://perma.cc/4FYR-VNHA>] (concluding that the adoption of RPSs will necessitate consideration of Smart Grid technologies).

²⁷⁰ See OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY, *Confronting the Duck Curve: How to Address Over-Generation of Solar Energy* (2017), <https://energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy> [<https://perma.cc/HS3C-ZHPW>] (explaining that the “duck curve” (named for its resemblance to a duck) illustrates the complications that arise when an intermittent energy source, such as solar energy, provides a significant portion of a system’s electricity, but its resource diminishes (because of the setting sun) at the time when demand peaks in the early evening).

²⁷¹ Wisner et al., *supra* note 212, at 3904.

²⁷² See Matteo Muratori et al., *Global Economic Consequences of Deploying Bioenergy with Carbon Capture and Storage (BECCS)*, 11 ENVTL. RES. LETTERS 2 (2016).

²⁷³ GOVERNORS’ WIND ENERGY COALITION, *supra* note 231, at 9.

²⁷⁴ Luke J.L. Eastin, *An Assessment of the Effectiveness of Renewable Portfolio Standards in the United States*, 27 THE ELECTRICITY J. 127 (2014).

²⁷⁵ LEON, *supra* note 4, at 6.

²⁷⁶ Vicki Arroyo et al., *State Innovation on Climate Change: Reducing Emissions from Key Sectors While Preparing for a “New Normal,”* 10 HARV. L. & POL’Y REV. 385, 398 (2016).

²⁷⁷ Allyson Browne, *RPS Evolving: States Take on U.S. Climate Goals*, 31 NAT. RES. & ENV’T 50, 50 (2017).

²⁷⁸ *Id.*

²⁷⁹ *Id.* at 51.

²⁸⁰ *Id.*

states to learn from experience and modify their policies accordingly.²⁸¹ They have tweaked RPS timetables, percentages, technologies, incentives, durations, and other provisions.²⁸² These modifications have responded to the achievement of program goals, approaching target dates, changing market conditions, and other considerations.²⁸³

Importantly, these modifications were not enacted to weaken too-demanding standards; quite the contrary, they made the RPSs more ambitious.²⁸⁴ Two states, California and Texas, provide examples. In 2006, California accelerated its initial deadline for compliance from 2017 to 2010.²⁸⁵ Next, the state increased its renewable energy targets from 20 percent to 33 percent and subsequently to 50 percent.²⁸⁶ Similarly, Texas has regularly extended its deadlines and raised its renewable energy requirements. From its original target of 2009, it added new targets for 2015 and then for 2025.²⁸⁷ Overall, the average RPS obligation rose from 7.6 percent of total electricity to 17.5 percent.²⁸⁸ Since 2013, several states have adopted even more substantial increases in their target mandates. As of July 2017, four jurisdictions (California, New York, Oregon, and the District of Columbia) now have renewable energy targets of 50 percent by 2040 or sooner; Vermont has a mandate of 75 percent by 2032; and Hawaii's is now 100 percent by 2045.²⁸⁹

RPSs inherently incentivize utilization of the least-cost technology. RPSs are market-oriented policies that establish general targets, but they allow market actors—such as utilities, other electricity suppliers, project developers, and other private sector participants—to determine their methods of compliance.²⁹⁰ These actors typically satisfy RPS requirements by choosing lower-cost and lower-risk technologies.²⁹¹ This market pressure

²⁸¹ *Id.*

²⁸² LEON, *supra* note 4, at 10. Implicit in these constant refinements and strengthening of RPS policies is the need to evaluate RPS progress routinely. EPA, *supra* note 220, at 5-17.

²⁸³ Browne, *supra* note 277, at 51.

²⁸⁴ BARBOSE, *supra* note 228, at 9 (noting that more than half of RPS states have raised their overall targets or those of their carve outs).

²⁸⁵ Allen, *supra* note 215, at 137-38.

²⁸⁶ *Id.*

²⁸⁷ *Id.* at 148. In each instance, the state surpassed its goal early, by four, seven, and then ten years, respectively, while increasing installed wind power capacity from 900 MW to 10,000 MW. *Id.*

²⁸⁸ Fischlein & Smith, *supra* note 244, at 280.

²⁸⁹ BARBOSE, *supra* note 228, at 6.

²⁹⁰ LEON, *supra* note 4, at 8.

²⁹¹ Wisser et al., *supra* note 212, at 3896. The incentive to provide electricity at the lowest

to utilize lower-cost methods of production drives innovation.²⁹² It “concentrates the mind and alters the behavior” of these parties to develop means to comply with the RPS requirements.²⁹³ Thus, RPSs encourage development and adoption of low-cost methods.²⁹⁴ Then, industrial dynamics, such as “economies of scale” and efficiencies gained through experience, further drive down costs as markets expand.²⁹⁵ Numerous examples exist of the interrelation of economies of scale, lowering costs, and expanding markets.²⁹⁶

While RPSs are traditionally viewed as a means to increase renewable energy in general, states can and do tailor their RPSs to promote specific technologies that are not yet competitive.²⁹⁷ Sometimes, states specifically design aspects of their RPSs to diversify renewable energy resources.²⁹⁸ For instance, the RPSs of thirteen states and of the District of Columbia allow electricity generated from at least fifteen sources to satisfy their mandates.²⁹⁹ RPS designers also incorporate policy mechanisms to subsidize more costly technologies.³⁰⁰ States utilize these devices

cost also incentivizes improving technologies to become more cost competitive. EPA, *supra* note 220, at 5-3.

²⁹² See LEON, *supra* note 4, at 6.

²⁹³ *Id.*

²⁹⁴ Some commentators suggest that a weakness of RPSs is that they are so market-driven that they do not sufficiently encourage investment in less mature technologies. Buckman, *supra* note 230, at 4106–07. As discussed in the next Section, RPSs can utilize carve outs or multipliers to stimulate development of such resources. *Id.* at 4107.

²⁹⁵ John A. Mathews & Hao Tan, *Manufacture Renewables to Build Energy Security*, 513 NATURE 166, 167 (Sept. 11, 2014).

²⁹⁶ *Id.* An historic example comes from the auto industry. From 1909 to 1916, the cost of the Ford Model T dropped 62 percent while sales doubled annually, skyrocketing from 6000 in 1908 to 800,000 in 1917. *Id.* More recently, the prices of solar panels and wind turbines have dropped as mass production of each has increased. Anna Hirtenstein, *China’s Hunger for Solar Boosts Clean Energy Funding Near Record*, BLOOMBERG BNA ENV’T & ENERGY REP. (Jan. 16, 2018). For instance, the price of solar installations has decreased 60 percent since 2008. Sara Matasci, *How solar panel cost and efficiency have changed over time*, ENERGY SAGE (Mar. 16, 2017), <https://news.energysage.com/solar-panel-efficiency-cost-over-time/> [<https://perma.cc/WT97-SPN9>]. From 2008 to 2016, domestic solar photovoltaic installations have increased from 298 MW to 14,762 MW. *Solar Market Insight Report 2016 Year in Review*, SOLAR ENERGY INDST. ASS’N (SEIA), <https://www.seia.org/research-resources/solar-market-insight-report-2016-year-review> [<https://perma.cc/PV3G-CY3Y>] (last visited Nov. 17, 2018).

²⁹⁷ Fischlein & Smith, *supra* note 244, at 286.

²⁹⁸ Wiser et al., *supra* note 212, at 3895.

²⁹⁹ DSIRE, *supra* note 257. States allowing at least fifteen sources are Arizona, Connecticut, Hawaii, Maryland, Massachusetts, Nevada, New Hampshire, North Carolina, Oregon, Pennsylvania, Utah, Vermont, and Wisconsin. *Id.*

³⁰⁰ Joshua Novacheck & Jeremiah X. Johnson, *The environmental and cost implications*

to encourage investment in particular technologies whose development is a policy objective of the state.³⁰¹ States turn to these methods because the technologies are not currently competitive with other energy sources because of their higher cost, still-developing technology, or other market barriers.³⁰² Two RPS devices are particularly effective at promoting new technologies.³⁰³ The first are technology carve outs; the second are credit multipliers.³⁰⁴

Carve outs (or set asides)³⁰⁵ identify particular levels of electricity to be produced from a particular type of source. These targets are “carved out” of the overall renewable energy percentage for the state’s electricity.³⁰⁶ Essentially, the set aside establishes a submarket reserved for the particular technology.³⁰⁷ Some states, however, establish these set asides as electricity to be produced in addition to the overall RPS obligation.³⁰⁸ One of the most commonly used carve outs is for solar generation.³⁰⁹ In fact, solar carve outs have become popular in a manner that was unforeseen when RPSs were first being developed.³¹⁰ As of 2015, half of the states with RPSs—fifteen—used a solar set aside.³¹¹ Thirteen of the states use a percentage requirement, ranging from a high of 4.1 percent in New Jersey by 2027 to a low of 0.2 percent in North Carolina by 2018.³¹² Two other states utilize a requirement stated in megawatts (“MW”).³¹³ Not surprisingly, so many states have chosen to use this device because it has proven

of solar energy preferences in Renewable Portfolio Standards, 86 ENERGY POL'Y 250, 251 (2015).

³⁰¹ EPA, *supra* note 220, at 5-10.

³⁰² *Id.*

³⁰³ Wisner et al., *supra* note 212, at 3897.

³⁰⁴ *Id.*

³⁰⁵ *Id.* Several labels apply to this policy tool. *Id.* They include carve outs, set asides, bands, and tiers. *Id.*

³⁰⁶ EPA, *supra* note 220, at 5-10.

³⁰⁷ Buckman, *supra* note 230, at 4105.

³⁰⁸ EPA, *supra* note 220, at 5-10.

³⁰⁹ LEON, *supra* note 4, at 10.

³¹⁰ *Id.*

³¹¹ EPA, *supra* note 220, at 5-4, 5-5.

³¹² *Id.*

³¹³ *Id.* In addition, another four states require that set percentages of electricity be provided by distributed generation sources. *Id.* These set asides likely will be met by solar energy. Gaul & Carley, *supra* note 248, at 460. While the percentage of electricity provided from solar is a small percent of total state electricity, often these percentages constitute substantial portions of the RPS obligation. For instance, although New Mexico requires only 4 percent of its electricity to be sourced from solar, this constitutes 20 percent of its renewable energy requirement. Novacheck & Johnson, *supra* note 300, at 251.

results. Analysis has found that the use of set asides in RPSs has “heavily influenced” the deployment of solar energy in those states.³¹⁴ For instance, a solar carve out in Massachusetts has been quite successful.³¹⁵ The state met its first goal (450 MW by 2017) three years early, and it surpassed its next goal (nearly quadrupling solar energy to 1600 MW by 2020) more than two years early.³¹⁶

Multipliers, on the other hand, provide that the generation of electricity by particular energy sources will earn multiples of RECs.³¹⁷ For instance, seven states use multipliers for solar, with multipliers of credits ranging from two to three times the standard one credit for each megawatt of generation.³¹⁸ Multipliers are credited with successfully supporting high-cost offshore wind development in the United Kingdom.³¹⁹

One advantage that both carve outs and multipliers share is that states can apply these devices to multiple technologies at once, thereby supporting several undeveloped methods at the same time.³²⁰ Delaware, for instance, has instituted multipliers for fuel cells, solar, and offshore wind.³²¹ New Mexico, on the other hand, carves out minimum percentages of its RPS goals that must be satisfied by solar, wind, and “other renewables.”³²²

Despite some similarities, carve outs and multipliers have had disparate track records.³²³ As mentioned above, carve outs have been more popular in the United States, with twice as many states utilizing set asides as providing multipliers.³²⁴ European countries, on the other hand, have preferred multipliers.³²⁵ An early comparison of solar set asides and multipliers concluded that carve outs provided greater certainty that

³¹⁴ Andrea Sarzynski et al., *The Impact of State Financial Incentives on Market Deployment of Solar Technology*, 46 ENERGY POL’Y 550, 551 (2012). The authors also note that another successful approach involved states offering cash incentives, such as rebates and grants. *Id.* Combining carve outs with subsidies has been particularly effective in incentivizing solar power. Fischlein & Smith, *supra* note 244, at 286.

³¹⁵ See Samantha Donalds, *Solar Insights from the 2016 RPS Summit*, RENEWABLE ENERGY WORLD (Jan. 2, 2017), <https://www.renewableenergyworld.com/ugc/articles/2017/01/03/solar-insights-from-the-2016-rps-summit.html> [<https://perma.cc/CBQ9-8FZ3>].

³¹⁶ *Id.*

³¹⁷ Buckman, *supra* note 230, at 4105. Multipliers are also identified as banding. *Id.*

³¹⁸ EPA, *supra* note 220, at 5-4, 5-5.

³¹⁹ Buckman, *supra* note 230, at 4114.

³²⁰ Fischlein & Smith, *supra* note 244, at 290.

³²¹ *Id.*

³²² *Id.* at 287.

³²³ Compare EPA, *supra* note 220, at 5-4, 5-5, with Buckman, *supra* note 230, at 4107.

³²⁴ EPA, *supra* note 220, at 5-4, 5-5.

³²⁵ Buckman, *supra* note 230, at 4107.

the targeted energy would be produced.³²⁶ Indeed, set asides successfully initiated solar generation in a number of states, while multipliers did not demonstrate comparable success.³²⁷ Another comparison of set asides and multipliers comes from Novacheck and Johnson, who analyzed the relative costs and benefits of applying carve outs and multipliers as part of a future extension of Michigan's RPS.³²⁸ They concluded that carve outs could raise costs by requiring the installation of technologies that are not the least cost source.³²⁹

Carve outs and multipliers do have downsides. As noted previously, RPSs incentivize utilization of the lowest-cost technologies.³³⁰ Since carve outs require utilities to provide electricity generated from sources which would otherwise not be used or used in lower quantities (since they are not the lowest-cost source), carve outs require utilities to replace electricity from lowest-cost sources with electricity from sources which have higher costs.³³¹ Thus, carve outs will raise energy costs. Conversely, while multipliers demonstrate strong deployment of new technologies, overall they typically yield less of the desired product—electricity generated from renewables.³³² This occurs because the state awards credits in excess of the amount of electricity actually generated from renewable sources.³³³ Thus, multipliers incentivize particular resources, but they do so at the expense of the overall amount of renewable energy generation.

Besides set asides and multipliers, states have combined RPSs with other tools to increase renewable energy generation.³³⁴ For instance, some states provide direct monetary subsidies.³³⁵ One quarter of RPS states provide subsidies for solar, and researchers have found these subsidies to provide important support for the technology.³³⁶ Another policy that five states have incorporated into their RPSs are feed-in tariffs ("FITs").³³⁷ A FIT requires utilities to purchase electricity from independent producers

³²⁶ Wisner et al., *supra* note 212, at 3904.

³²⁷ *Id.*

³²⁸ Novacheck & Johnson, *supra* note 300, at 251.

³²⁹ *Id.* at 256.

³³⁰ Wisner et al., *supra* note 212, at 3896.

³³¹ *Id.*

³³² Novacheck & Johnson, *supra* note 300, at 254.

³³³ *Id.* at 251.

³³⁴ See Fischlein & Smith, *supra* note 244, at 286.

³³⁵ *Id.*

³³⁶ *Id.*

³³⁷ *Summary Tables: Feed-In Tariff*, DSIRE, [http://programs.dsireusa.org/system/program?type=92&\[https://perma.cc/T7KZ-WWX3\]](http://programs.dsireusa.org/system/program?type=92&[https://perma.cc/T7KZ-WWX3]) (last visited Nov. 17, 2018). These states are California, Hawaii, Michigan, Vermont, and Washington. *Id.*

at fixed amounts, usually above-market rates, and for set periods of time.³³⁸ California, for instance, has instituted its Renewable Market Adjusting Tariff, which is a FIT program for small renewable generators who produce no more than 3 MW of electricity.³³⁹ The program requires utilities to enter into fixed-price ten-, fifteen- or twenty-year standard contracts with these generators.³⁴⁰ The state divides eligible generators into three categories based upon their energy resource: Baseload (bioenergy and geothermal), As-Available Peaking (solar), and As-Available Non-Peaking (wind and hydro).³⁴¹

This inherent flexibility of RPSs is important because of the discretion that it allows policymakers. Studies have concluded that, in general, policies enabling discretion promote innovation and increase productivity.³⁴² Flexible policies stimulate innovation because they do not limit producers to “best-available technolog[ies]”, thus encouraging competition to develop more efficient means to comply with the mandates.³⁴³ In the specific context of RPSs, their market-based approach pushes producers to utilize lower-cost methods of production, which drives innovation.³⁴⁴ Furthermore, government policies are most effective when they provide long-term certainty to market actors.³⁴⁵ Many RPSs achieve this objective by instituting mandates that extend ten to twenty years into the future.³⁴⁶ In

³³⁸ Mormann, *supra* note 212, at 199.

³³⁹ *Renewable Feed-In Tariff (FIT) Program*, CAL. PUB. UTIL'S COMM'N, <http://www.cpuc.ca.gov/feedintariff/> [<https://perma.cc/VT2G-QQCS>] (last visited Nov. 17, 2018).

³⁴⁰ *Id.*

³⁴¹ *Renewable Market Adjusting Tariff (ReMAT)*, DSIRE, <http://programs.dsireusa.org/system/program/detail/5665> [<https://perma.cc/479Y-AX6Q>] (last visited Nov. 17, 2018).

³⁴² Fischlein & Smith, *supra* note 244, at 297.

³⁴³ *Id.* The authors cite one study finding that the most successful policies set clear and ambitious goals and then allow producers sufficient time and flexibility to achieve them. *Id.* This opportunity to determine the means for compliance fosters innovation. *Id.*

³⁴⁴ Nathaniel Horner et al., *Effects of Government Incentives on Wind Innovation in the United States*, 8 ENVTL. RES. LETTERS 1, 6 (2013).

³⁴⁵ LEON, *supra* note 4, at 9.

³⁴⁶ Paul Dvorak & Nathaniel Horner, *RPS policies are driving wind turbine innovation*, WINDPOWER (Feb. 28, 2014), <http://www.windpowerengineering.com/design/rps-policies-driving-wind-turbine-innovation/> [<https://perma.cc/2TK9-RZHP>]. These long-term signals provided by RPSs contrast with federal energy policies, which Congress has instituted primarily through the tax code. LEON, *supra* note 4, at 9. For instance, a primary support for wind power, the production tax credit (“PTC”), has experienced a rather irregular pattern. Since its initial establishment in the Energy Policy Act of 1992, Congress has allowed the PTC to expire on six occasions, and it has renewed the credit six times. *Production Tax Credit for Renewable Energy*, UNION OF CONCERNED SCIENTISTS, https://www.ucsusa.org/clean-energy/increase-renewable-energy/production-tax-credit#.W-zr_2NReUk [<https://>

this way, RPSs' fostering of innovation to lower costs helps "move technologies to maturity."³⁴⁷

States with RPSs have experienced significant increases in renewable energy generation during the past two decades.³⁴⁸ The Lawrence Berkeley National Laboratory concluded that RPSs are "key driver[s]" for renewable energy generation.³⁴⁹ Approximately half of the growth in renewable energy in the United States since 2000 is attributable to satisfying RPS requirements.³⁵⁰ In several regions—notably the West, Mid-Atlantic, and Northeast—RPSs currently account for 70 to 90 percent of renewable energy capacity additions.³⁵¹ Consistent with these numbers, all but four states have met their RPS quotas; of those four, two still achieved at least 90 percent of their target.³⁵²

Contrasting the differences between renewable energy installations in RPS states and non-RPS states further demonstrates RPSs' impact. One analysis considered the change in renewable energy production from 1997 (or the date of adoption for RPS states if later) to 2011.³⁵³ In non-RPS states, renewable energy production increased by 128.5 percent.³⁵⁴ In RPS states, it increased by 666.6 percent.³⁵⁵

While half of renewable energy additions were attributable to RPSs since 2000, this broad statistic masks a meaningful underlying trend. Up to 2012, the amount of total renewable energy additions that occurred in RPS states was 67 percent.³⁵⁶ By 2016, however, this percentage fell to

perma.cc/G7PQ-EJKM] (last visited Nov. 17, 2018). The PTC first expired in 1999. Since then, Congress has typically extended it for a one- or two-year period. *Tax Policy*, AM. WIND ENERGY ASS'N, <https://www.awea.org/policy-and-issues/tax-policy> [<https://perma.cc/97BP-Z7MC>] (last visited Nov. 17, 2018). As a result, investment has followed a boom-and-bust pattern driven by the short-term cycles of expiration and renewal of credit. Figure 2, *infra*, illustrates this pattern, as investors rushed to install wind capacity in 2001, 2003, and 2012, prior to expirations (and subsequent extensions) in 2002, 2004, and 2013. A similar rush to install wind power occurred in 2009; Congress extended the PTC in 2010 prior to its expiration. UNION OF CONCERNED SCIENTISTS, *supra*.

³⁴⁷ GOVERNORS' WIND ENERGY COALITION, *supra* note 231, at 4.

³⁴⁸ Arroyo et al., *supra* note 276, at 398–99.

³⁴⁹ *Id.*

³⁵⁰ BARBOSE, *supra* note 228, at 3.

³⁵¹ *Id.*

³⁵² *Id.* at 28. Similarly, twelve of sixteen states with solar carve outs satisfied them, and a thirteenth exceeded more than 90 percent of its quota. *Id.*

³⁵³ Eastin, *supra* note 274, at 132.

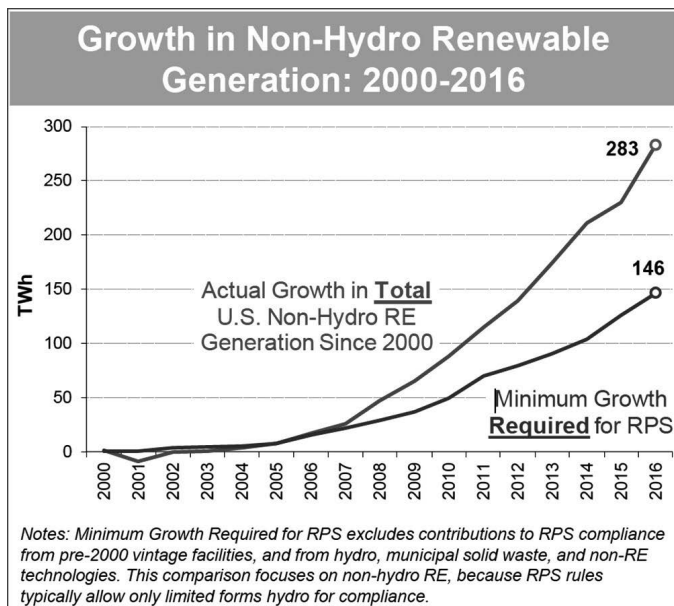
³⁵⁴ *Id.*

³⁵⁵ *Id.*

³⁵⁶ LEON, *supra* note 4, at 4.

only 44 percent.³⁵⁷ The fact that an increasing percentage of renewable energy additions is occurring in non-RPS states reflects another benefit of RPSs. Consistent with their ability to incentivize innovation, over time RPSs drive increased efficiencies, thereby lowering costs. Initially, utilities build renewable energy additions to satisfy RPS targets. Yet, as electricity generation costs decline, they become competitive against other sources, and utilities install renewable energy even though not required to do so by RPS quotas. Figure 1 demonstrates this pattern.

Figure 1³⁵⁸



As Figure 1 illustrates, until 2007, utilities made nearly all renewable energy additions to satisfy RPS quotas.³⁵⁹ However, since that time, investments in renewables increasingly were not tied to RPS mandates—investments occurred in RPS states in excess of RPS mandates or in states without RPS quotas.³⁶⁰

³⁵⁷ BARBOSE, *supra* note 228, at 3.

³⁵⁸ BARBOSE, *supra* note 228, at 12.

³⁵⁹ *Id.*

³⁶⁰ *Id.*

Despite these laudable statistics, analyses of the effects of RPSs on renewable energy installation have failed to reach a consensus.³⁶¹ Indeed, one author noted that studies of RPSs have found “all possible impacts ranging from negative to none to positive.”³⁶² On the other hand, another analyst concluded that attempts to generalize the effects of RPSs may be misplaced.³⁶³ Impacts of RPSs also vary across states.³⁶⁴ Not surprisingly, the very flexibility inherent in RPSs complicates analysis of them. Furthermore, the effectiveness of RPSs depends upon the characteristics of the RPS and the state’s electricity market.³⁶⁵

A number of factors cloud comparisons of RPS systems. One consideration is the policies of surrounding states. Approximately three quarters of all electricity in the United States is traded before reaching customers, and it often crosses state lines.³⁶⁶ Initially, the presence of RPS policies in neighboring states positively impacts in-state renewable energy generation. However, as policies allow interstate trading and the trading zone increases, in-state generation tends to decrease, and generation concentrates in a few states—those that are most cost-effective.³⁶⁷ This effect of deployment increasing in other states occurs even when those states do not utilize RPSs.³⁶⁸ Renewable energy additions in thirteen states without RPSs were actually made to comply with RPSs of other states. These installations accounted for 10 percent of renewable energy additions.³⁶⁹ Magnifying this tendency, most RPSs do not require that renewable energy be generated in-state to receive credit.³⁷⁰ This may not be surprising since parties have filed several challenges to RPSs’ in-state generation requirements on Commerce Clause grounds.³⁷¹

³⁶¹ Karen Maguire & Abdul Munasib, *The Disparate Influence of State Renewable Portfolio Standards on Renewable Electricity Generation Capacity*, 92 LAND ECON. 486, 486 (Aug. 2016).

³⁶² GIREESH SHRIMALI ET AL., HAVE STATE RENEWABLE PORTFOLIO STANDARDS REALLY WORKED? 33 (2012).

³⁶³ Maguire & Munasib, *supra* note 361, at 487.

³⁶⁴ *Id.* at 468.

³⁶⁵ *Id.* at 487.

³⁶⁶ Fischlein & Smith, *supra* note 244, at 279.

³⁶⁷ SHRIMALI ET AL., *supra* note 362, at 34.

³⁶⁸ BARBOSE, *supra* note 228, at 16.

³⁶⁹ *Id.*

³⁷⁰ Fischlein & Smith, *supra* note 244, at 279.

³⁷¹ Mormann, *supra* note 212, at 203–09. The Tenth Circuit upheld a finding that Colorado’s RPS did not violate the Dormant Commerce Clause. *Id.* at 205. The Eighth Circuit, conversely, upheld a ruling that a “negative” sourcing mandate (requiring that “no person”

Other considerations also impact the perceived success of RPSs. Some states allow pre-existing renewable electricity production to count to the state quota, which has the obvious effect of minimizing investment into new renewables.³⁷² Another factor which can depress renewable energy investment is the inclusion of energy efficiency as a means of compliance.³⁷³ Typically, these states credit investment in energy efficiency to satisfy RPS mandates for one of two reasons. In some instances, they seek to reduce greenhouse gas emissions, and are less concerned about stimulating renewable energy generation.³⁷⁴ In others, states include energy efficiency as a means to minimize the amount of investment in renewable energy sources, thereby reducing the costs of compliance while also lowering the nominal renewable goal.³⁷⁵

Another factor that often plays a significant role in states achieving their RPS targets is the enforcement mechanism of their RPSs. States are less likely to achieve their RPS targets when their RPSs fail to penalize noncompliance or enable utilities to circumvent their mandates.³⁷⁶ Although most RPSs include some form of enforcement mechanism, states have notoriously failed to enforce them, in many instances waiving or excusing penalties.³⁷⁷ In fact, only two states, Texas and Connecticut, have assessed penalties for shortfalls in compliance.³⁷⁸ In addition to insufficient penalties and enforcement, the success of RPSs can also be impacted by their reporting and verification procedures.³⁷⁹ Analyses have suggested that current enforcement is sufficiently weak that RPS targets could actually be “much lower” if loopholes were closed.³⁸⁰

In light of these considerations, the seeming “contradictory” findings of analysts trying to determine the impact of RPSs is hardly surprising.³⁸¹

shall import power that would contribute to the state’s CO₂ emissions) constitutes impermissible extraterritorial regulation in violation of the Dormant Commerce Clause. *Id.* at 206. Massachusetts settled a challenge to the in-state generation requirement of its RPS by repealing that provision. *Id.* at 204.

³⁷² Fischlein & Smith, *supra* note 244, at 282.

³⁷³ *Id.* at 285.

³⁷⁴ U.S. ENVTL. PROT. AGENCY, CUTTING POWER SECTOR CARBON POLLUTION: STATE PROGRAMS AND POLICIES 25 (2016).

³⁷⁵ Fischlein & Smith, *supra* note 244, at 285.

³⁷⁶ *Id.* at 281.

³⁷⁷ Ivan Gold & Nick Thaker, *A Survey of State Renewable Portfolio Standards: Square Pegs for Round Climate-Change Holes?*, 35 WM. & MARY ENVTL. L. & POL’Y REV. 183, 195 (2010).

³⁷⁸ *Id.* at 250, n.467.

³⁷⁹ Horner et al., *supra* note 344, at 7.

³⁸⁰ Gold & Thaker, *supra* note 377, at 205.

³⁸¹ SHRIMALI ET AL., *supra* note 362, at 33.

Attempts to determine an average effect for RPSs fail to take into account the unique factors of the states, their RPS policies, and those of surrounding states.³⁸² Once analysts factor in these differences, correlations between RPS enactment and renewable energy generation emerge.³⁸³ More recent analysis finds significant correlations between RPS enactment and renewable electricity generation.³⁸⁴ Analysts have also found factors that strengthen the connection between RPSs and renewable energy generation. For instance, the stringency³⁸⁵ of RPSs has a positive and significant impact on renewable energy deployment.³⁸⁶ Similarly, REC unbundling also increases renewable energy generation.³⁸⁷

The bottom line: consistent with their market-based approach to incentivize innovation, RPSs tend to be more effective than other domestic policies at driving innovation.³⁸⁸

B. Two Prominent RPS Successes—Wind and Solar

Another means to evaluate the effectiveness of RPSs considers their impact upon specific renewable energy technologies. Two obvious examples arise: wind and solar. As discussed below, throughout the past two decades, RPS policies have uniquely supported these two sources. Both technologies were only minimally deployed domestically before the adoption of RPSs.³⁸⁹ Installations of each have increased substantially since the enactment of these policies.³⁹⁰

Several indicators demonstrate that RPSs have significantly and positively impacted wind energy. Indeed, because of RPSs' low-cost focus,³⁹¹

³⁸² Maguire & Munasib, *supra* note 361, at 468.

³⁸³ Fischlein & Smith, *supra* note 244, at 304.

³⁸⁴ MATTHEW J. DENNEY, STATE-LEVEL RENEWABLE PORTFOLIO STANDARDS: EVALUATING THEIR EFFECTIVENESS IN INCREASING RENEWABLE ELECTRICITY GENERATION AND REDUCING CARBON EMISSIONS 29 (2015).

³⁸⁵ For these purposes “stringency” focuses on the incremental, as opposed to the nominal, requirement of the RPS policy. Haitao Yin & Nicholas Powers, *Do State Renewable Portfolio Standards Promote In-State Renewable Generation?*, 38 ENERGY POL'Y 1140, 1147 (2010).

³⁸⁶ SHRIMALI ET AL., *supra* note 362, at 33.

³⁸⁷ *Id.* at 34.

³⁸⁸ Horner et al., *supra* note 344, at 7. They further suggest that the best combination of policies to encourage innovation would be a combination of an RPS with aggressive targets and meaningful penalties. *Id.*

³⁸⁹ *Id.* at 1.

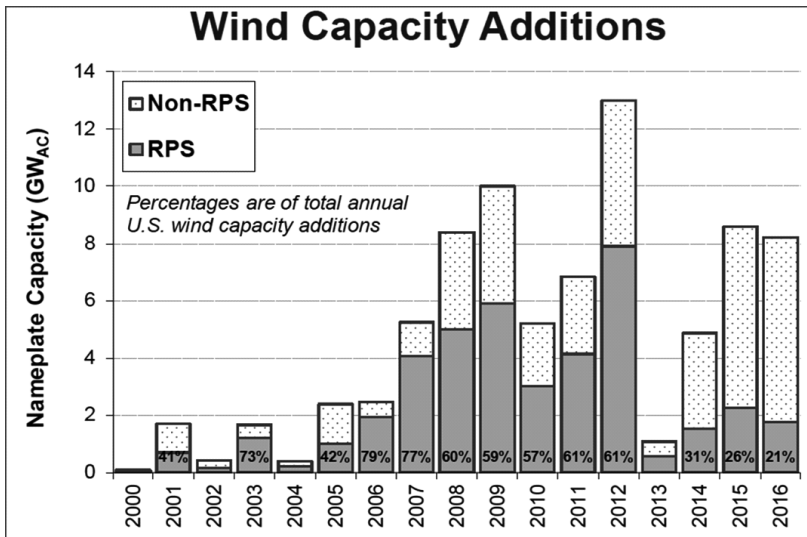
³⁹⁰ *Id.*

³⁹¹ Wisner et al., *supra* note 212, at 3896.

wind power especially benefitted from RPS policies.³⁹² Of non-hydro renewable resources, wind was the most developed and widely available at the time that states enacted their RPSs.³⁹³ As a result, utilities typically turned to wind power to satisfy RPS mandates. Indeed, the Department of Energy estimates that between 1998 and 2011 utilities used wind to satisfy 89 percent of RPS obligations.³⁹⁴

Wind development illustrates another result of RPS policies. RPSs stimulated renewable energy investment in covered states. As this investment incentivized innovation and lowered costs, utilities in other states invested in this now competitive technology. Thus, over time, new investments in these technologies shifted disproportionately to non-RPS states, as illustrated by Figure 2 below.

Figure 2³⁹⁵



³⁹² GOVERNORS' WIND ENERGY COALITION, *supra* note 231, at 13.

³⁹³ See *History of Europe's Wind Industry*, WIND EUROPE, <https://windeurope.org/about-wind/history> [<https://perma.cc/N974-PTYV>] (last visited Nov. 17, 2018) (for a history of European policies and subsequent milestones of its wind industry in the 1980s and 1990s).

³⁹⁴ GOVERNORS' WIND ENERGY COALITION, *supra* note 231, at 13.

³⁹⁵ BARBOSE, *supra* note 228, at 18.

By 2016, only 21 percent of annual new wind capacity was added to meet RPS requirements.³⁹⁶ In other words, 79 percent of wind power additions either were in RPS states but exceeded RPS mandates or were installed in non-RPS states.³⁹⁷

In addition to impacting wind power deployment, RPSs have positively impacted the domestic wind industry, too. During the five years from 2006 to 2011, the domestically sourced content of wind projects nearly doubled, jumping from 35 percent to 67 percent.³⁹⁸ Furthermore, the largest wind turbine producers, with the exception of GE, were based in other countries,³⁹⁹ but they began manufacturing components domestically. In 2004, only one of the top ten manufacturers had factories in the United States.⁴⁰⁰ By 2016, this had increased to eight in ten.⁴⁰¹ RPSs have also positively impacted domestic wind power innovation.⁴⁰² Notably, the period of RPS enactments coincided with a significant increase in wind turbine patenting.⁴⁰³ As noted previously, this results because RPSs are inherently technology forcing. By requiring compliance within a market system, RPSs force suppliers to reduce production costs, thereby stimulating innovation.⁴⁰⁴

RPSs have also been instrumental in the development of solar power. Solar, however, started from a very different position from that of wind. Prior to the adoption of most RPSs, wind technology was already established and available for commercial use.⁴⁰⁵ Solar technology, on the other hand, was relatively undeveloped.⁴⁰⁶ Nevertheless, RPSs successfully

³⁹⁶ RYAN WISER & MARK BOLINGER, 2016 WIND TECHNOLOGIES MARKET REPORT 67 (2016).

³⁹⁷ *Id.*

³⁹⁸ *Id.*

³⁹⁹ Veronika Henze & Katrin Thomas, *Vestas reclaims top spot in annual rankings of wind turbine makers*, BLOOMBERG NEW ENERGY FINANCE (Feb. 22, 2017), <https://about.bnef.com/blog/vestas-reclaims-top-spot-annual-ranking-wind-turbine-makers/> [<https://perma.cc/W369-YDT9>].

⁴⁰⁰ *Id.*

⁴⁰¹ *Id.*

⁴⁰² Horner et al., *supra* note 344, at 1.

⁴⁰³ Dvorak & Horner, *supra* note 346.

⁴⁰⁴ Horner et al., *supra* note 344, at 6.

⁴⁰⁵ Mitchell Schmidt, *Iowa's status as a renewable energy leader: How we got here and what's next*, THE GAZETTE (July 9, 2017), <http://www.thegazette.com/iowaideas/stories/energy-environment/iowas-status-as-a-renewable-energy-leader-how-we-got-here-and-whats-next-20170709> [<https://perma.cc/S9XC-UUQP>].

⁴⁰⁶ For instance, global solar photovoltaic installations were negligible in 2000. By 2017, installations reached 402,500 MW. INT'L ENERGY AGENCY, 2018 SNAPSHOT OF GLOBAL PHOTOVOLTAIC MARKETS 6 (2018).

drove development and deployment of solar technology.⁴⁰⁷ As mentioned previously, half of RPS states utilize solar carve-outs.⁴⁰⁸ In addition, six states provide multipliers for solar, and a seventh allows a multiplier for distributed generation,⁴⁰⁹ fulfillment of which typically involves solar power.⁴¹⁰ Initial growth of solar was concentrated in these states. Specifically, between 2005 to 2009, 65 percent to 81 percent of solar installations outside of California occurred in states with solar carve-outs.⁴¹¹

Comparisons of new installations of wind and solar reveal another RPS pattern—RPSs help drive technologies to maturity, at which point their deployment becomes widespread. For instance, as discussed previously, through 2011 wind power provided 89 percent of the installed capacity required to satisfy RPS mandates.⁴¹² Through 2016, wind still constituted 61 percent of all RPS installations.⁴¹³ In 2016, however, solar accounted for 79 percent of all new builds.⁴¹⁴ Just as wind was used primarily to meet RPS requirements and subsequently came to be installed as additional capacity in RPS states or as new capacity in non-RPS states,⁴¹⁵ solar is beginning to follow a similar trajectory. Figure 3 illustrates this transition.

⁴⁰⁷ Wisner et al., *supra* note 212, at 3894.

⁴⁰⁸ EPA, *supra* note 220, at 5-4, 5-5.

⁴⁰⁹ *Id.* Distributed generation refers to the generation of electricity near the point of consumption rather than by a centralized source such as a power plant. *Renewable Energy: Distributed Generation Policies and Programs*, U.S. DEPT OF ENERGY, <https://energy.gov/eere/slsc/renewable-energy-distributed-generation-policies-and-programs> [https://perma.cc/923E-6YJ4] (last visited Nov. 17, 2018).

⁴¹⁰ Gaul & Carley, *supra* note 248, at 463.

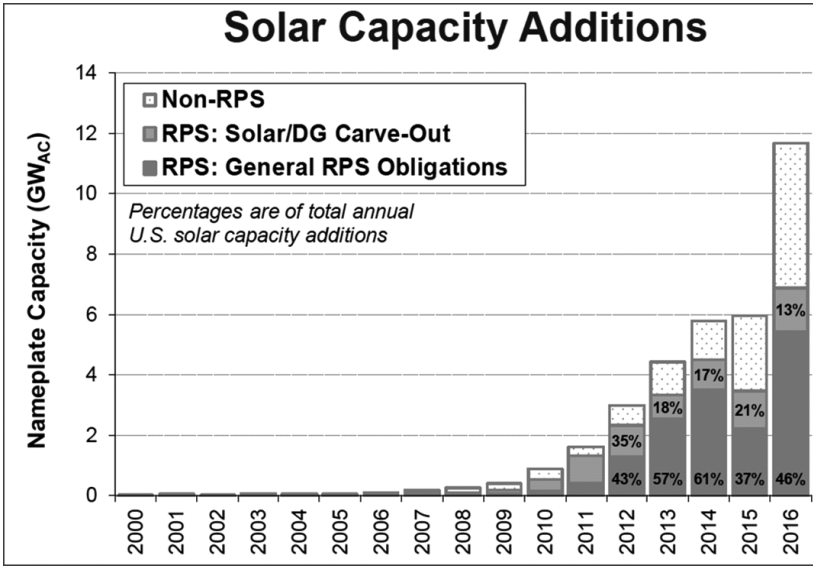
⁴¹¹ Wisner et al., *supra* note 212, at 3900.

⁴¹² GOVERNORS' WIND ENERGY COALITION, *supra* note 231, at 13.

⁴¹³ BARBOSE, *supra* note 228, at 17.

⁴¹⁴ *Id.*

⁴¹⁵ *Id.*

Figure 3⁴¹⁶

Through 2014, nearly 80 percent of solar installations occurred to satisfy RPS mandates; in both 2015 and 2016, however, more than 40 percent of new solar was installed outside RPS requirements.⁴¹⁷ Thus, as RPSs have helped drive innovation in solar and reduce its costs,⁴¹⁸ it has become increasingly popular as a resource even in states without any mandates for its adoption. Both the actual number of solar installations and the proportion of installations not required by RPS mandates have increased substantially.⁴¹⁹

Thus, with two different technologies in very different circumstances, RPSs have promoted the improvement, adoption and growth of each. Especially instructive is the example of solar energy. RPS policies established markets for a technology that previously was expensive and

⁴¹⁶ BARBOSE, *supra* note 228, at 17.

⁴¹⁷ *Id.* at 18.

⁴¹⁸ Since 2008, the price of solar panel installation has declined 60 percent. Solar panel efficiency also has improved approximately 60 percent during this period. Matasci, *supra* note 296. During this period, total United States installations increased nearly fifty-fold. SEIA, *supra* note 296.

⁴¹⁹ Matasci, *supra* note 296.

rarely utilized. These policies led to technological innovations that fostered investment. As prices fell in RPS markets, these prices attracted investment in solar not required by RPS mandates.

C. *RPSs Can Facilitate the Development of NETs*

RPS-type systems, or RPSs themselves, could successfully incentivize NETs' investment and eventual deployment. A number of considerations suggest that RPSs should also be successful in fostering the development of NETs. RPSs can establish markets for multiple technologies, enabling the development of several NETs at once. Through their markets, RPSs have a track record of attracting financing that helps to stimulate innovation and drive down costs.⁴²⁰ RPSs also allow for local tailoring to address regional differences. In addition, RPSs have developed accounting systems, which will be essential for NETs.⁴²¹

States could expand current RPSs to incorporate NETs as a means to satisfy their requirements. As discussed previously, RPSs could incorporate carve outs or multipliers to target NETs as means for compliance. To the extent that the states adopted their RPSs to limit atmospheric CO₂ (through the reduction of carbon emissions),⁴²² the inclusion of NETs will further this goal. Alternatively, states could establish a separate program, an RPS, solely dedicated to the development of NETs.

One reason why RPSs can help to develop NETs is because these policies can promote multiple technologies at once. States using RPSs often set a goal of diversifying their renewable energy sources.⁴²³ To this end, states typically identify a broad range of technologies eligible to satisfy their RPS requirements. For instance, Wisconsin's RPS identifies twenty-six eligible technologies.⁴²⁴ Furthermore, RPSs are sufficiently flexible to enable states to revise their RPSs to add new technologies as they are developed.⁴²⁵ As discussed previously, RPSs also often include carve outs or multipliers to target specific resources for development.⁴²⁶

⁴²⁰ LEON, *supra* note 4.

⁴²¹ *Id.*

⁴²² OTTMAR EDENHOFER ET AL., SPECIAL REPORT ON RENEWABLE ENERGY SOURCES AND CLIMATE CHANGE MITIGATION 18 (2012).

⁴²³ Wisner et al., *supra* note 212, at 3895.

⁴²⁴ *Renewable Portfolio Standard Program Overview: Wisconsin*, DSIRE, <http://programs.dsireusa.org/system/program/detail/190> [<https://perma.cc/7C9T-NFG3>] (last updated May 31, 2018).

⁴²⁵ LEON, *supra* note 4, at 10.

⁴²⁶ *Supra* note 304, and accompanying text.

This ability of RPSs to encompass multiple technologies will be critical when applied to NETs. Of the eight identified categories of NETs, the potential of each is limited when implemented at scale.⁴²⁷ These limits range from costs,⁴²⁸ to land availability,⁴²⁹ to food security,⁴³⁰ to biodiversity risks,⁴³¹ among others. Because of these limitations, we can anticipate that society will need to rely upon a portfolio of different NETs.⁴³² Furthermore, scientists project that the suite of anticipated NETs will not be able to remove the required amount of CO₂ from the atmosphere.⁴³³ Even if society were to commence implementing NETs immediately, they would fall short of sequestering the carbon necessary to avoid planetary warming of 2°C.⁴³⁴ Not only will we likely utilize most of the currently known NETs, we will almost certainly need to identify and implement additional technologies. Thus, the ability of RPSs to include a range of technologies and to incorporate new technologies as they are developed will be critical.

By establishing markets for NETs, RPSs will provide a critical service to their development. As noted previously, RPSs create markets for new technologies.⁴³⁵ Such markets will be essential for the development of NETs. Specialized, niche markets are especially important to foster innovation.⁴³⁶ Development of new technologies requires opportunities for the technologies to be tested and improved while being supported by actual markets.⁴³⁷ Financing of NETs at the scale required will also be critical. Attracting this level of financing will require strong and certain policy and price signals.⁴³⁸ By creating markets for these technologies,

⁴²⁷ Fuss et al., *supra* note 54, at 3.

⁴²⁸ Cost is the most significant barrier to the implementation of DACCS. U.N. ENVIRONMENTAL PROGRAMME, *supra* note 92, at 64.

⁴²⁹ Afforestation and reforestation are available only to the extent of suitable land. McLaren, *supra* note 66, at 20.

⁴³⁰ Ocean fertilization may also impair ocean food resources. NRC, *supra* note 39, at 61. Land required to grow BECCS feedstocks may also be needed for food production. McLaren, *supra* note 66, at 17.

⁴³¹ *Id.*

⁴³² Jan C. Minx et al., *Fast Growing Research on Negative Emissions*, 12 ENVTL. RES. LETTERS 2 (2017).

⁴³³ See Psarras et al., *supra* note 60, at 16.

⁴³⁴ *Id.* Specifically, scientists project that NETs could remove up to 1000 GtCO₂ by mid-century. However to avoid a 2°C rise in global mean temperature, we would need to sequester 1800 GtCO₂ by 2050. *Id.*

⁴³⁵ LEON, *supra* note 4, at 8.

⁴³⁶ Ishimoto et al., *supra* note 137, at 12.

⁴³⁷ *Id.*

⁴³⁸ MacDowell et al., *supra* note 13, at 244.

RPSs provide long-term visibility for cash flows and routes to market.⁴³⁹ Both of these encourage investors and entrepreneurs to engage in these technologies.⁴⁴⁰ For at least one technology, DACCS, the establishment of markets will be crucial. Because of the high-risk, high-return nature of DACCS, business startups are especially involved in developing this method.⁴⁴¹ The establishment of markets for this important technology will help to encourage additional investment.

Cost considerations also support RPSs as appropriate mechanisms for NETs. Partly because of the nascent status of NETs, the range of estimates of their costs remains quite broad. For instance, the NRC divided the costs of NETs into their two components operations: carbon capture and its sequestration.⁴⁴² The NRC projected the costs of carbon capture as ranging from \$50 to more than \$1,000 per tCO₂.⁴⁴³ The costs of sequestration, it estimated, would range from \$6 to hundreds of dollars per tCO₂.⁴⁴⁴ Estimated costs of specific technologies cover similarly broad ranges. For example, projections of the costs of DACCS range from below \$100 to more than \$1,000 per tCO₂.⁴⁴⁵ Similarly, the range of projections for mineral carbonation are wide ranging. Part of this results from the different circumstances in which weathering may occur—in the ocean or on land.⁴⁴⁶ As a result, its costs range from \$100 per tCO₂ to as much as \$1,000 per tCO₂ for terrestrial operations.⁴⁴⁷ While land management methods will be substantially less expensive, even their costs are difficult to predict.⁴⁴⁸ Currently, experts project their costs to range from \$20 to \$100 per tCO₂.⁴⁴⁹

These wide cost ranges suggest two considerations, both of which support utilization of RPSs. First, in view of the wide possible range of costs of NETs overall and seemingly of each technology in particular,

⁴³⁹ McGlashan et al., *supra* note 174, at 17.

⁴⁴⁰ *Id.*

⁴⁴¹ *Id.* at 13.

⁴⁴² NRC, *supra* note 39, at 106.

⁴⁴³ *Id.* Part of this range derives from the method of carbon capture. Capture from an emissions source is dramatically less expensive than from the ambient air. Accordingly, the latter may cost up to ten times more than capture directly from an emissions source. Psarras et al., *supra* note 60, at 4.

⁴⁴⁴ NRC, *supra* note 39, at 106.

⁴⁴⁵ Lomax et al., *supra* note 2, at 498.

⁴⁴⁶ See Psarras et al., *supra* note 60, at 16.

⁴⁴⁷ *Id.*

⁴⁴⁸ *Id.*

⁴⁴⁹ *Id.*

utilizing mechanisms that will drive innovation and lower costs will be critical. With their market-driven approaches, RPSs excel at these objectives.⁴⁵⁰ Second, because of the magnitude of the carbon which will need to be captured and sequestered, reducing the overall costs of NETs will be essential. The scale of NETs will be substantial. The overall system to capture and bury carbon will likely need to be as extensive as that which extracted it.⁴⁵¹ Thus, the ability to deploy NETs at scale at as low a cost as possible will be critical. Using RPSs to develop these technologies will help to minimize their costs.⁴⁵²

Geographical considerations also favor using RPSs to facilitate NETs' development. Some NETs technologies are geographically constrained as to where they can be effectively implemented.⁴⁵³ BECCS is an example of a technology that is regionally dependent.⁴⁵⁴ Conversely, one of the primary advantages of DACCS is that DACCS facilities may be placed "virtually anywhere."⁴⁵⁵ Because of the RECs system used by RPSs, RECs can facilitate taking advantage of the geographic diversity of NETs. RECs can allow RPS programs to award credits, for instance, to BECCS installations which cannot be located within the RPSs' jurisdictions, as the vast majority of RPSs already allow for renewable energy generation outside the jurisdiction.⁴⁵⁶ Conversely, DACCS facilities, which can be sited nearly anywhere, need not be restricted to the territorial boundaries of the jurisdictions awarding credits.⁴⁵⁷ This may free them up to be sited in locations with cheaper land, better access to roads, abundant renewable energy sources, or other favorable conditions.

⁴⁵⁰ EPA, *supra* note 220, at 5-3.

⁴⁵¹ NRC, *supra* note 39, at 105.

⁴⁵² FITs are another policy mechanism used successfully to incentivize renewable energy. *Feed-in Tariff: A policy tool encouraging deployment of renewable electricity technologies*, U.S. ENERGY INFORMATION ADMINISTRATION (May 30, 2013), <https://www.eia.gov/todayinenergy/detail.php?id=11471> [<https://perma.cc/7MAC-L6UP>]. Lincoln L. Davies & Kirsten Allen, *Feed-in Tariffs in Turmoil*, 116 W. VA. L. REV. 937, 938 (2014). While a comparison of these two policies is beyond the scope of this Article, it is worth noting that Germany, Spain, and South Korea recently abandoned their FITs because of the high electricity costs resulting from their FITs contracts. *Id.* at 1000.

⁴⁵³ Psarras et al., *supra* note 60, at 5.

⁴⁵⁴ *Id.*

⁴⁵⁵ *Id.* at 9. Nevertheless, constraints may arise concerning the sufficiency of particular sinks for long-term sequestration, their capacities, and commercial availability. See Haszeldine et al., *supra* note 173, at 14.

⁴⁵⁶ Fischlein & Smith, *supra* note 244, at 279.

⁴⁵⁷ See *Direct Air Capture (2018)*, CARBON ENG., <http://carbonengineering.com/about-dac/> [<https://perma.cc/UY9L-498A>] (last visited Nov. 17, 2018).

Another aspect of RPSs that will fit well with NETs is their established accounting systems.⁴⁵⁸ The removal of CO₂ by NETs will present significant issues of tracking and accounting.⁴⁵⁹ These issues will arise from the unique nature of NETs operations as well as the breadth of their markets. Capturing and sequestering greenhouse gases is more complicated than other forms of environmental accounting, such as tracking emissions.⁴⁶⁰ Furthermore, consistent accounting rules have not been established for NETs processes.⁴⁶¹ Complicating this record-keeping will be the novel ecosystems, soils, and biomass involved with NETs.⁴⁶² Finally, NETs likely will involve multi-jurisdictional transactions necessitating independent measurement, reporting, and verification of activities.⁴⁶³

While these will be novel issues for RPSs to address, they benefit by having already-established tracking systems for RECs transactions.⁴⁶⁴ RPS states typically require annual reports of RECs transactions demonstrating compliance with RPS obligations.⁴⁶⁵ To facilitate the development of robust RECs markets, many states participate in regional tracking systems.⁴⁶⁶ These regional systems are sufficiently compatible to enable future interconnection and expansion.⁴⁶⁷

If a favorable environment is provided for NETs, experts anticipate that they can achieve significant growth.⁴⁶⁸ BECCS, for instance, has the technological potential to contribute significantly to carbon removal as soon as 2030.⁴⁶⁹ DACCS, for its part, has been projected to have the potential to develop into a major industry.⁴⁷⁰ This would require, however, a maturing of the technology and a dropping in prices.⁴⁷¹ For example, analysts expect that increasing the number of CCS plants will create

⁴⁵⁸ Lomax et al., *supra* note 2, at 499.

⁴⁵⁹ *Id.*

⁴⁶⁰ *Id.* Among other complications, carbon dioxide removal can vary by time and external factors, emissions may result from direct and indirect land use changes, and since carbon is not completely separated from the natural carbon cycle (it is buried in some manner), the permanence of sequestration is uncertain. *Id.* at 499–500.

⁴⁶¹ Fuss et al., *supra* note 54, at 7.

⁴⁶² Lomax et al., *supra* note 2, at 499.

⁴⁶³ Peters & Geden, *supra* note 34, at 622.

⁴⁶⁴ Arroyo et al., *supra* note 276, at 399.

⁴⁶⁵ EPA, *supra* note 220, at 5-11.

⁴⁶⁶ LEON, *supra* note 4, at 6.

⁴⁶⁷ *Id.*

⁴⁶⁸ McGlashan et al., *supra* note 114, at 508.

⁴⁶⁹ *Id.*

⁴⁷⁰ Field & Mach, *supra* note 42, at 707.

⁴⁷¹ *Id.*

a virtuous cycle. Construction of new plants will lower their costs, which will facilitate building of more facilities.⁴⁷² Similarly, projections for DACCS technologies anticipate that their costs will fall to \$200 per ton of CO₂; that cost may be further cut in half in a medium-term timeframe.⁴⁷³ Other technologies will likely require at least two decades before they can increase to scale.⁴⁷⁴ RPSs, of course, have established track records of fostering both increased investment and reduced costs over multiple decades.⁴⁷⁵

This will be critical because of a significant difference between renewable energy and NETs. Renewable energy not only produces a valuable product, electricity, it also provides a number of additional benefits. Besides electricity generation, renewable energy reduces the amount of greenhouse gases in the atmosphere,⁴⁷⁶ stabilizes and reduces energy costs,⁴⁷⁷ improves the resiliency of the energy grid,⁴⁷⁸ fosters energy independence,⁴⁷⁹ creates jobs,⁴⁸⁰ and improves health by reducing pollution.⁴⁸¹

Conversely, few NETs produce valuable services in addition to carbon sequestration. BECCS generates electricity.⁴⁸² Conceivably, CCS systems produce a salable product—the captured CO₂. Carbon capture and utilization (“CCU”) systems apply the captured CO₂ to a number of processes, including enhanced oil recovery, mineral carbonation, food and beverage carbonation, polymer processing, microalgae production, and

⁴⁷² Bourzac, *supra* note 139, at S67.

⁴⁷³ *Id.* at S68.

⁴⁷⁴ McGlashan et al., *supra* note 114, at 508.

⁴⁷⁵ *Supra* note 227, and accompanying text.

⁴⁷⁶ EDENHOFER ET AL., *supra* note 422, at 18.

⁴⁷⁷ See LAZARD, LAZARD'S LEVELIZED COST OF ENERGY ANALYSIS—VERSION 11.0 5 (2017), <https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-11.0.pdf> [<https://perma.cc/LT38-HBFP>] (illustrating that several renewable energy sources provide cheaper electricity in a narrower price range than do conventional energy sources).

⁴⁷⁸ See David J. Unger, *Are renewables stormproof? Hurricane Sandy tests solar, wind*, THE CHRISTIAN SCIENCE MONITOR (Nov. 19, 2012), <https://www.csmonitor.com/Environment/Energy-Voices/2012/1119/Are-renewables-stormproof-Hurricane-Sandy-tests-solar-wind> [<https://perma.cc/22TH-F5CX>].

⁴⁷⁹ Rebecca Harrington, *There's only one way for the US to reach energy independence*, BUSINESS INSIDER (July 15, 2017), <http://www.businessinsider.com/how-can-america-be-energy-independent-adopt-renewables-2017-7> [<https://perma.cc/S4ZD-3A4A>].

⁴⁸⁰ UNION OF CONCERNED SCIENTISTS, FACT SHEET: CLEAN POWER GREEN JOBS 1 (2009), https://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_energy/Clean-Power-Green-Jobs-25-RES.pdf [<https://perma.cc/5REU-TEXN>] (finding that renewable energy creates three times as many jobs as producing an equivalent amount of energy from fossil fuels).

⁴⁸¹ EDENHOFER ET AL., *supra* note 422, at 20.

⁴⁸² McGlashan et al., *supra* note 114, at 504.

enhanced coal bed methane recovery.⁴⁸³ Nevertheless, at least one analysis concludes that CCU is unlikely to make CCS commercially profitable.⁴⁸⁴ Biochar can generate energy or enrich agricultural lands.⁴⁸⁵ Finally, ocean liming could use spent lime sorbent from solid looping CCS processes, thereby using material from a process that generates a primary product (power and possibly heat), and thus possibly facilitating liming's early deployment.⁴⁸⁶

Since few NETs confer any additional benefits besides CO₂ removal, encouraging their adoption may be more difficult than promoting renewable energy was. To overcome this obstacle, adoption of NETs will need to be incentivized, and utilization of an approach such as an RPS becomes more critical. Incorporating NETs into RPSs, however, will require states to address several considerations. First, states will need to identify the parties required to consider or comply with a NETs requirement. Initially, states could simply add NETs to the technologies available to utilities for RPS compliance. A helpful starting point would be to establish carve outs for BECCS, which will assure some development and installation of that technology. While the other NETs do not produce electricity, to the extent the RPS seeks to mitigate carbon emissions, NETs provide comparable substitutes for renewable energy.⁴⁸⁷ Furthermore, RPSs already apply to utilities,⁴⁸⁸ so limiting application to them may minimize resistance.

Next, states will need to phase-in the NETs requirement. A phase-in will be both necessary and helpful. It will be necessary because, as discussed previously, most NETs currently are not ready for implementation.⁴⁸⁹ Extended implementation will also allow jurisdictions to modify their accounting systems to measure and track the capturing and burying of CO₂. Jurisdictions will need to develop methods to measure the carbon captured, the amount successfully sequestered, and the permanence of sequestration, all of which will need to produce comparable values of carbon capture and sequestration across different environments and technologies.⁴⁹⁰

⁴⁸³ Jennifer Wilcox et al., *Assessment of Reasonable Opportunities for Direct Air Capture*, 12 ENVTL. RES. LETTERS 2 (2017).

⁴⁸⁴ MacDowell et al., *supra* note 13, at 247.

⁴⁸⁵ Workman et al., *supra* note 67, at 2881.

⁴⁸⁶ *Id.*

⁴⁸⁷ Honegger & Reiner, *supra* note 131, at 308.

⁴⁸⁸ DSIRE, *supra* note 424.

⁴⁸⁹ Keller et al., *supra* note 41, at 1335.

⁴⁹⁰ CTR. FOR CARBON REMOVAL, *supra* note 190, at 8. *See also* Fiefie Shen, *China's Prep for Carbon-Market Trading May Take Up to Two Years*, BLOOMBERG BNA ENV'T & ENERGY

Phasing in implementation will also enable states to expand coverage of RPSs to sectors beyond energy. Currently, RPS mandates apply only to parties involved in the provision of electricity—utilities and retail suppliers.⁴⁹¹ For NETs to yield truly negative emissions, however, they must also compensate for the emissions from additional sectors. For instance, current estimates project that, even though emissions in the U.S. electricity sector will decline over the next decade, emissions will continue to rise in the industrial and agricultural sectors.⁴⁹²

Despite the significance of emissions from other sectors, current efforts to reduce emissions do little to address them. For instance, California has one of the most extensive regulatory systems to address climate change. Nevertheless, its RPS covers only investor-owned utilities and municipal utilities.⁴⁹³ The Golden State also has the fourth largest cap-and-trade program in the world.⁴⁹⁴ Nevertheless, it covers only large electric power plants, large industrial plants, and fuel distributors.⁴⁹⁵

Thus, states need to extend their RPSs' coverage to include non-electricity sectors. The inclusion of these new sectors will require a phased-in transition. China currently is planning to institute a broad-reaching program.⁴⁹⁶ In 2018, China is initiating an emissions trading system, which will utilize a phase-in process. After developing rules for the system and testing it through simulated trading, China will then require compliance by its electricity sector.⁴⁹⁷ In a final phase targeted to begin by 2020, China will extend its trading program to non-ferrous metal and cement sectors.⁴⁹⁸

REP. (Dec. 21, 2017) (noting that China may spend up to two years preparing data reporting and other systems before starting trading in its new carbon market). China's program is discussed *infra*.

⁴⁹¹ DSIRE, *supra* note 424.

⁴⁹² KATE LARSEN ET AL., TAKING STOCK 2017: ADJUSTING EXPECTATIONS FOR US GREENHOUSE GAS EMISSIONS 4–5 (2017), <https://rhg.com/research/taking-stock-2017-us-greenhouse-gas-emissions/> [<https://perma.cc/EZ4U-3AB6>].

⁴⁹³ *Renewable Portfolio Standard Program Overview: California*, DSIRE, <http://programs.dsireusa.org/system/program/detail/840> [<https://perma.cc/52LQ-BBAS>] (last updated Sept. 24, 2018).

⁴⁹⁴ *Id.*

⁴⁹⁵ *California Cap and Trade*, CTR. FOR CLIMATE CHANGE AND ENERGY SOLUTIONS, <https://www.c2es.org/content/california-cap-and-trade/> [<https://perma.cc/VMR5-TFNT>] (last visited Nov. 17, 2018).

⁴⁹⁶ *Id.*

⁴⁹⁷ *See id.*

⁴⁹⁸ *See* Dean Scott, *China's Trimmed Carbon Trading Will Still Boost Worldwide Action*, BLOOMBERG BNA ENV'T & ENERGY REP. (Dec. 21, 2017), <https://news.bloombergenvironment.com/environment-and-energy/chinas-trimmed-carbon-trading-will-still-boost-world>

States should not only include NETs in their RPSs, they should similarly phase-in implementation and broaden the scope to include non-power sectors. A phased-in implementation can serve several purposes. First, as with China's cap-and-trade program, it can provide needed time to develop and test procedures and measurements for the inclusion of new technologies.⁴⁹⁹ Second, it will allow previously uncovered industries time to adjust to the new regulations. Finally, by rolling NETs into current RPSs, the initial investments will come from the power sector, which is already well experienced with RPS mandates. Then, as NETs become more abundant and their costs drop,⁵⁰⁰ they may provide a preferable alternative to emissions mitigation in difficult to control sectors.⁵⁰¹

CONCLUSION

Negative emissions technologies will become essential to avoid the worst consequences of climate change. Unfortunately, these technologies are not sufficiently developed to serve this role. Renewable portfolio standards, which were instrumental in incentivizing the development and installation of renewable energy in the United States, can do the same for NETs.

wide-action [<https://perma.cc/ZMJ9-UY77>] (noting that China's carbon trading system will initially cover power generators but will subsequently expand to encompass metals, chemicals, and building materials).

⁴⁹⁹ *Id.*

⁵⁰⁰ See *supra* notes 295–96 and accompanying text.

⁵⁰¹ Honegger & Reiner, *supra* note 131, at 314.