Nicholas Institute for Environmental Policy Solutions
Report
NI R 13-05
June 2013

Clean Air and Technology Innovation: Working Concepts for Promoting Clean Technology Innovation Under the Clean Air Act

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Acknowledgements
The authors would like to thank our colleagues Tim Profeta, Jonas Monast, and Jeremy Tarr for their contribution to this paper. We would also like to thank the following students for their invaluable assistance with legal and policy research: Carla Gray, Peter Marshall Hansel, Jesse Johnson, Amy Mersol-Barg, Jake Vestal, Tyler Warner, Gray Wilson.

How to cite this report
Jody Foster, et. al. 2013. *Clean Air and Technology Innovation: Working Concepts for Promoting Clean Technology Innovation Under the Clean Air Act* NI R 13-05 Durham, NC: Duke University.

Duke
NICHOLAS INSTITUTE
FOR ENVIRONMENTAL POLICY SOLUTIONS

THE CLEAN AIR AND TECHNOLOGY INNOVATION PROJECT

The Clean Air and Technology Innovation (CATI) project was created by the Nicholas Institute for Environmental Policy Solutions at Duke University to develop strategies to accelerate deployment of innovative clean energy technology in key stationary source sectors regulated under the Clean Air Act (CAA).

CATI is led by Rob Brenner, who has decades of experience implementing the CAA at the U.S. Environmental Protection Agency, and Jody Foster, an attorney with private sector expertise in CAA stationary source compliance.

CATI focuses on deployment of clean technology innovations in industrial sectors with the most significant emissions. These sectors include power generation, refineries and chemical manufacturing, and cement manufacturing.

Stakeholder roundtable discussions will be held to help identify the most cost-effective technology deployment strategies under the CAA for each industrial sector. Participants will include leading companies in each sector, technology vendors and innovators, federal and state public agencies, environmental and public health advocates, academic and other policy strategists, and the venture capital and investment communities.

EXECUTIVE SUMMARY

In the face of difficult economic conditions, global climate challenges, and the increasing exhaustion of end-of-pipe solutions, the United States is pursuing continued progress on clean air and energy. The stationary source sectors most implicated in emissions of greenhouse gases—in particular, power generation, refining and chemical manufacturing, and cement manufacturing—face both a new imperative to address those emissions and some of the most challenging tasks in complying with forthcoming tightened criteria pollutant and toxics regulations. Absent political intervention, these sectors must begin deploying—quickly and broadly—innovative clean air and energy technologies that are already developed or nearly market ready and that could significantly reduce industrial emissions. They also need to plan for and support development and deployment of technology innovations that can be brought to scale and create potentially game-changing impacts in addressing air, energy, and climate challenges.

Existing and emerging clean air and energy innovations range from advancing technologies for wind and solar generation, combined heat and power, and oxy-combustion to biomass fuels and bio-refining, advanced batteries and other energy storage technologies, microgrids, and smart grids, and carbon capture and use. Many of these innovations offer significant potential to meet the nation's complex, interrelated challenges to simultaneously improve air quality, address climate change, and maintain reliable and affordable energy. Accelerating the speed and extent of their deployment could create new projects and jobs essential to keeping American industry competitive and could reconcile divergent economic interests among industries, geographic regions, and other stakeholders.

The United States has used the Clean Air Act in the past to successfully address environmental challenges that many groups argued were insurmountable (e.g., ozone depletion, smog, acid rain, air toxics, diesel pollution). In those cases, collaborative efforts based on public-private sector initiatives put in place regulations and policies that promoted the development and deployment of radically more effective emissions control technologies such as scrubbers, catalytic converters, diesel particulate filters, and activated carbon injection.

As the executive branch develops a CAA regulatory strategy to jointly address clean air and climate challenges, Duke University's Nicholas Institute for Environmental Policy Solutions is engaging stakeholders in an exploration of CAA implementation strategies to encourage, and not impede, deployment of innovative technologies in key stationary source sectors. Called the Clean Air and Technology Initiative (CATI), this project has undertaken policy and legal research and informal consultations and interviews with relevant Clean Air Act regulators, policy makers, and other stakeholders to develop preliminary concepts about the potential regulatory and non-regulatory tools available to promote innovative technology deployment under the Clean Air Act.

This paper examines tools that could be utilized in CAA implementation policies to help promote deployment of innovative clean air and clean energy technologies to reduce greenhouse gas (GHG) emissions. Specifically, it examines five types of regulatory tools that could cost-effectively promote innovative technology deployment in stationary source sectors without compromising public health protection:

- **Standard-setting tools:** The EPA can provide greater regulatory certainty to industrial sectors for technology investment decisions, while also achieving superior environmental outcomes, by increasing reliance on multi-pollutant and sector-based

standard setting, aligning CAA regulatory obligations and timelines, and ensuring that GHG regulatory standards under Section 111 and other CAA programs can be achieved consistent with existing regulatory programs.

- **Market-based compliance flexibility alternatives:** For some pollutants, the EPA can increase the flexibility and cost-effectiveness of compliance in industrial sectors by increasing use of market-based compliance options, including emissions trading and other crediting mechanisms in federal transport and trading programs, New Source Review and Prevention of Significant Deterioration (NSR/PSD) programs, and State Implementation Plan (SIP) programs; in addition, broader use of innovative control technology waivers for New Source Performance Standards (NSPS) and other emerging concepts could increase operating flexibility for sources to develop or deploy innovative technologies.

- **Permitting tools:** Facility-wide permitting and streamlined permitting processes could be offered for clean air and energy technologies that are projected to help sources meet or exceed CAA regulatory requirements.

- **Enforcement tools:** The EPA can promote innovative technology deployment through strategic use of enforcement-based tools, such as expanded use of supplemental enforcement projects in consent decrees and use of individual and programmatic enforcement discretion.

- **Accountability mechanisms:** Compliance flexibility can cost-effectively promote CAA and other goals when accompanied by adequate accountability mechanisms, such as targeted technology performance safeguards and backstops, innovative monitoring and reporting methodologies, and environmental justice protections for communities.

In addition to these regulatory tools, the EPA and other public and private sector institutions also have many "non-regulatory" tools to support CAA-based efforts to accelerate stationary source deployment of innovative clean air and energy technologies. The regulatory tools are likely to be more effective to the extent that they are implemented in conjunction with complementary non-regulatory strategies such as the following:

- **Programmatic technology initiatives**: The power of the EPA and other agencies to facilitate public-private collaborations to support particular technologies can be systematically applied to promote deployment of innovative clean air and energy technologies. Successful models include EPA's technology innovation partnerships, the E3: Economy-Energy-Environment Initiative (E3), and a federal-state community-based project in California's San Joaquin Valley.

- **Technology demonstrations:** Pilots, showcases, supplemental environmental projects (SEPs), and other technology demonstration efforts can help establish the technical and economic viability of untested technologies, promoting their financing, marketing, and permitting. Collaborative efforts with other agencies are potentially a promising route forward in today's resource-constrained environment.

- **Technology testing and certification**: Establishment of a creditable, reliable, and effective technology certification program, or reinvigoration of EPA's Established Technology Verification (ETV) Program could help innovators obtain financing and commercialization assistance to develop and market a new technology.

- **Coordination of relevant non-CAA regulatory programs:** Overlapping regulatory requirements can adversely affect innovative technology investment in stationary source sectors, such as power generation.

- **Financing and commercialization assistance:** Neither the EPA nor other public agencies are likely to be able to provide direct financing assistance, but they can work with other public and private sector resources to maximize the value of private sector capital and resources in promoting innovative clean air and energy technologies. Tools include, for the private sector, strategic partnerships and multiple revenue streams and, for the public sector, state and federal policy proposals to cost-effectively leverage private investment in clean air and energy innovations.

In short, many potentially effective regulatory and non-regulatory tools are available to the EPA and others to promote and accelerate the development and deployment of innovative and potentially game-changing clean air and energy and climate technologies in the nation's key industrial sectors. The challenge will be to effectively combine these tools industry by industry. Fostering broad and fast deployment of proven innovations in the short term while developing promising technologies over the long term is likely to be an effective general strategy.

Solar technologies illustrate the potential of this approach. Renewable energy solar technologies that initially were cost-prohibitive are much more cost-effective today. Strategies to encourage this type of proven technology in conjunction with deployment of innovative micro-grid developments could provide near-term environmental progress and "buy time" for further development of fossil fuel-related technologies such as carbon capture use and sequestration (CCUS). Although CCUS is not yet scaled, it could be closer to economic feasibility than is commonly perceived when coupled with related marketable production strategies such as enhanced oil recovery. Indeed, some of the greatest potential of emerging technologies comes from combining one or more technology options – for example, combining advanced battery storage or micro-grid technologies or both with intermittent renewable energy sources like wind or solar to ensure reliable energy delivery.

Key stakeholders in each sector could help sort out which combination of public and private sector tools, and regulatory and non-regulatory tools, could most effectively accelerate emerging technologies in the sector. The goal is not to design regulatory policies premised on particular technology innovations, but to create a CAA policy environment that supports efforts to deploy innovative technologies at stationary sources generally. By offering this paper, we hope to begin a conversation with those stakeholders to explore which of the approaches within might unlock innovation.

Contents

BACKGROUND

In the face of difficult economic conditions, global climate challenges, and the increasing exhaustion of end-of-pipe solutions, the United States is pursuing continued progress on clean air and energy. The stationary source sectors most implicated in emissions of greenhouse gases—in particular, power generation, refining and chemical manufacturing, and cement manufacturing—face both a new imperative to address those emissions and some of the most challenging tasks in complying with forthcoming tightened criteria pollutant and toxics regulations. Absent political intervention, these sectors must begin deploying—quickly and broadly—innovative clean air and energy technologies that are already developed or nearly market ready and that could significantly reduce industrial emissions. They also need to plan for and support development and deployment of technology innovations that can be brought to scale and create potentially game-changing impacts in addressing air, energy, and climate challenges.

Existing and emerging clean air and energy innovations range from advancing technologies for wind and solar generation, combined heat and power, and oxy-combustion to biomass fuels and bio-refining, advanced batteries and other energy storage technologies, microgrids and smart grids, and carbon capture and use. Many of these innovations offer significant potential to meet the nation's complex, interrelated challenges to simultaneously improve air quality, address climate change, and maintain reliable and affordable energy. Accelerating the speed and extent of their deployment could create new projects and jobs essential to keeping American industry competitive and could reconcile divergent economic interests among industries, geographic regions, and other stakeholders.

The Nicholas Institute for Environmental Policy Solutions at Duke University has undertaken a project to engage stakeholders in identifying ways to implement the Clean Air Act (CAA) that encourage, and do not impede, deployment of innovative clean air and energy technologies. To stimulate conversation about those possibilities, this paper provides a first take on tools within the CAA and available to the U.S. Environmental Protection Agency (EPA) to promote innovative clean technologies. In particular, it outlines a range of policy options under the Clean Air Act—relating to standard setting, compliance flexibility, permitting, and enforcement—that could be used to accelerate deployment of these technologies in the nation's industrial sectors, particularly in the short term. It also outlines accountability mechanisms to ensure that the new policies achieve superior environmental outcomes. Finally, since CAA-based regulatory strategies are more likely to be successful if they are implemented with complementary non-regulatory programs and resources, the paper also briefly outlines the range of non-regulatory tools that can be applied with these strategies.

Innovative Technologies on the Horizon

In 2011, advanced energy technologies represented a $1.1 trillion global market and $132 billion in revenues in the United States alone.[1] Thus, in addition to promoting air, climate, and energy goals, innovative energy technologies offer domestic and international business opportunities for American industry.[2]

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[1] Pike Research for Advanced Energy Economy, "Economic Impacts of Advanced Energy," (January 2013), http://advancedenergynow.net/index.cfm?objectid=7B983D80-5522-11E2-8D26000C29CA3AF3.
[2] See Environmental Technologies Industries, FY2010 Industry Assessment, available online.

Innovative clean air and energy technologies are on the market or in development in each of the nation's key industrial sectors.[3] Such technologies include:

- **Advancing energy efficiency (EE) and renewable energy (RE) technologies:** energy-efficient technologies for power monitoring and conservation, demand response management, combined heat and power co-generation (CHP), and other efficient production and building processes and renewable energy technologies for solar, wind, nuclear, and geothermal generation

- **Advanced energy storage (AES):** advanced batteries (wet cells, dry cells, reserve batteries), fuel cells, thermal storage, compressed air, flywheels, ultra-capacitors, and hydrogen storage to increase use of renewables, electric vehicles, and other innovations

- **Advanced energy distribution:** smart grids and microgrids, with sensors and measurement, distribution automation, superconductors, high-voltage DC and control devices, and other innovative software to improve control and real-time management of the electric grid for increased reliability, efficiency, and use of cost-optimizing intermittent energy sources

- **Biofuels and biochemical processes for energy capture and conversion:** algal oils, ethanol, cellulosic ethanol, bio-butanol, biodiesel, methanol, drop-in synthetic fuels, biogas, and hydrogen from non-fossil sources

- **Low-carbon technologies:** carbon capture and use or storage (CCUS) technologies, particularly as being developed for coal-fired power generation and other highly combustion-dependent sectors like refineries and cement kilns

- **Waste-to-energy and other waste reuse technologies:** advanced technologies for recovery of waste heat and landfill gas from anaerobic digestion as well as developing technologies for making fuel or other products from industrial production byproducts

In devising strategies to promote innovative technology deployment under the CAA it can be helpful to think of emerging technologies as falling into two broad categories. In the first category are proven but insufficiently deployed technologies. This category includes many technologies with relatively well-developed track records for performance and potential benefit that are deployed on a relatively limited basis due to regulatory or economic hurdles faced by individual sources. In the second category are developing technologies, including some with significant emissions reduction potential. These are technologies in advanced stages of development that appear to have significant pollution control capacity but little or no track records to address market uncertainty about performance estimates. Also in the second category are technologies that if developed to cost-effective scalability could have game changing impact in addressing air, climate, and energy needs.

While it is not possible at this point to predict which of the developing technologies will be successfully scaled "game changers," there is no question that many of the existing and developing innovations in combination can achieve significant emissions reductions and climate benefits. The path forward will almost certainly differ with respect to each industry sector and class of new technologies, but effective

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[3] Attachment A provides details about emerging technologies and examples of their use in the industrial sectors with the most intensive criteria pollutant, toxics, and greenhouse gas emissions—i.e., the power generation sector, the refining and chemical manufacturing sectors, and the cement manufacturing sector.

strategies are likely to be based on encouraging broader and faster deployment of proven innovations in the short term and development and deployment of potential technologies over the long term.

For example, solar technologies that initially were cost-prohibitive are much more cost-effective today. Strategies to promote deployment of these proven technologies could vastly expand solar energy production and "buy time" for the development of fossil fuel-related technologies such as carbon capture use and sequestration. Carbon capture technologies provide another example: although CCUS is not yet scaled, it could be closer to economic feasibility than is commonly perceived when coupled with related marketable production technologies such as enhanced oil recovery. Indeed, some of the greatest potential of emerging technologies—with potential "game changer" impact—is found in the context of combining one or more technology options, such as advanced battery storage technologies or micro-grid technologies (or both) with wind or solar to ensure reliable energy delivery from renewable sources.

The Clean Air Act's Innovation Track Record

Historically the Clean Air Act has promoted cost-effective deployment of innovative emissions control technologies in stationary source sectors.[4] Significant technology developments spurred by the 1970, 1977, and 1990 CAA enactments include:

- Selective catalytic reduction (SCR) and ultra-low burners to reduce NOx
- Scrubbers to remove SO2
- Electrostatic precipitators (ESP) to reduce fine particle emissions
- Activated carbon injection (ACI) to reduce mercury emissions
- Low- or zero-VOC paints, consumer products, and cleaning processes
- New valve seals and leak detection equipment for refineries and chemical plans
- Chlorofluorocarbon (CFC)-free air conditioners, refrigerators, and solvents
- Water- and powder-based coatings to replace petroleum-based formulations
- Retrofit technologies to cut toxics and soot emissions from older diesel engines.

Some of these advances—such as scrubbers for SO_2, SCR for NOx, ESP for particulate matter, and ACI to control mercury—radically improved capacities to reduce air emissions, resulting in pollution reductions on the order of 90% or more. As a result of these and other technologies, the nation has made great progress in cutting smog, air toxics, and acid rain pollution. Efforts to develop and deploy those technologies were beneficial for parts of U.S. industry as well, creating a greater role for American vendors in global markets for control technologies such as selective non-catalytic reduction and flue-gas desulphurization.[5]

Nonetheless, critics have argued that the CAA has been successful at promoting innovation only when it has targeted relatively well-developed technologies and that it has spurred only incremental efficiency and cost improvements in such technologies.[6] Some have argued that the CAA's rigid standards result in

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[4] See P. Amar, "Environmental Regulation and Technology Innovation: Controlling Mercury Emissions from Coal-fired Boilers," Northeast States for Coordinated Air Use Management (September 2000); S. Yeh, E. Rubin, M. Taylor, and D. Hounshell, "Technology Innovations and Experience Curves for Nitrogen Oxides Control Technologies," *Journal of the Air & Waste Management Association* 55, no. 12: 1827–1838.

[5] See, e.g., an assessment following enactment of the 1990 Clean Air Act Amendments by the Office of Technology Assessment, "Industry Technology and the Environment: Competitive Challenges and Business Opportunities" (January 1994), 149.

[6] See D. Popp, "Pollution Control Innovations and the CAA of 1990," *Journal of Policy Analysis and Management* 22: 641–660; D. Popp, N. Johnstone, and I. Hascic, "Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts," *Environmental and Resource Economics* 45, no. 1: 133–145; D. Popp, R. Newell, and A. Jaffee, "Energy the Environment and Technological Change," (NBER Working Paper 14832, April 2009). See also B. Swift, "How Environmental

overly costly implementation and that programs like New Source Performance Standards (NSPS) and New Source Review (NSR) stifle innovative pollution control and reduction technologies.[7] Some studies have found that CAA permitting and compliance policies have discouraged innovation.[8]

Some of the critics focus on the CAA's reliance on performance standards that are technology based. Rather than specify a particular technology, CAA programs in many cases establish emissions limitations on the basis of what available and affordable technology can achieve. For example, the NESHAP program bases standards on maximum achievable control technology (MACT) for hazardous pollutants. Similarly, other programs rely on reasonably available control technology (RACT) for existing sources or best available control technology (BACT) for new sources.[9] These technology-based standards have been criticized for discouraging innovation and the deployment of alternative means of improving the air quality impacts of manufacturing because they do not provide adequate incentives for firms to reduce pollution beyond what is required.[10] Such standards also are argued to inhibit innovation, as regulated entities have short-term incentives to resist adoption of innovative technologies based on concerns that they can lead to tighter emissions control requirements for the sector.[11]

What is clear is that the CAA has most effectively promoted innovative technology deployment when the EPA and the private sector have worked together to develop new technologies and strategies to promote their demonstration and deployment.[12] The development of scrubbers, ESPs, and SCRs benefitted from collaboration between the EPA and industry scientists and engineers. New fuel economy standards for motor vehicles, announced in 2011, demonstrate how the EPA and industry can work together to promote new technologies under the CAA. The auto industry is required to develop new materials and technologies—lighter, more fuel-efficient materials for cars and advanced battery technology for hybrids and electrics—to meet tightened standards. In turn, the auto industry can market these innovations in the United States and globally. Although such technology partnerships have been successful on the mobile source side, collaborative efforts by stationary emissions sources have been less effective.

Collaborative, stakeholder-based efforts to find effective ways to accelerate innovative technology deployment in the nation's key industrial sectors could help redress this imbalance. And beyond the industrial firms themselves, a large network of nongovernmental organizations, ranging from industrial and business-based trade associations to organizations promoting the significant environmental, health, and economic benefits of clean energy innovation, is working to promote clean energy innovation. This

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Laws Work: An Analysis of the Utility Sector's Response to Regulation of Nitrogen Oxides and Sulfur Dioxide under the Clean Air Act," *Tulane Environmental Law Journal* 14: 309.

[7] See, e.g., S. Power, "Why the Clean Air Act May Be Past Its Prime," *Wall Street Journal*, April 17, 2010.

[8] See U.S. EPA, Report and Recommendations of the Technology Innovation and Economics Committee, "Permitting and Compliance Policy: Barriers to U.S. Environmental Technology Innovation," (January 1991).

[9] See 42 USC Sections 7412, 7502, and 7475.

[10] See B. Swift, "How Environmental Laws Work: An Analysis of the Utility Sector's Response to Regulation of Nitrogen Oxides and Sulfur Dioxide under the Clean Air Act," *Tulane Environmental Law Journal* 14, no. 309: 383–385. See also B. Swift, "How Environmental Laws Can Discourage Pollution Prevention: Case Studies of Barriers to Innovation," Progressive Policy Institute (2000). For a detailed discussion of how emission rate-based standards hinder technological innovation, see U.S. EPA, "Permitting and Compliance Policy: Barriers to U.S. Environmental Technology Innovation" (1991).

[11] See L. Stewart, "The Impact of Regulation on Innovation in the United States: A Cross-Industry Literature Review, Information Technology & Innovation Foundation (ITIF), 4. For example, in the context of CAA regulation of coal-fired generation, environmental advocates support demonstration projects for carbon capture technologies, and industry sources tend to resist them, in part because of the perception that a successful demonstration would lead to costly requirements for all sources to adopt the technology in the context of BACT permitting.

[12] See U.S. EPA, Report and Recommendations of the Technology Innovation and Economics Committee, "Permitting and Compliance Policy: Barriers to U.S. Environmental Technology Innovation," (January 1991), 26.

network offers a significant pool of intellectual capital and collaboration opportunities to develop sector-specific strategies to promote technology innovation under the Clean Air Act.[13]

REGULATORY TOOLS UNDER THE CLEAN AIR ACT

On the CAA's 40th anniversary in 2010, then-administrator Lisa Jackson noted that EPA was renewing efforts to promote technology innovation under the act and stated the agency would focus on:

- Common-sense strategies to promote energy efficiency and updated technologies
- Multi-pollutant, sector-based approaches for cost-effectiveness
- Clear, achievable standards with maximum flexibility
- Cost-effective strategies that don't unduly burden small business and other insignificant contributors.[14]

As this list reflects, any efforts to promote innovative technology under the CAA must do so cost-effectively, which will likely require the EPA to allow stationary sources some flexibility in achieving compliance. But market-based and other flexible compliance options can raise concern about whether they will produce equivalent or better environmental results than less flexible options. That concern can be addressed by coupling increased compliance flexibility with increased accountability in source performance and environmental and public health outcomes.

Among the regulatory tools available to the EPA under the CAA to promote innovative technology deployment cost-effectively in stationary source sectors without compromising public health protection are the following:

- **Integrated standard setting:** Multi-pollutant and sector-based standard setting to give emissions sources greater regulatory certainty while achieving superior environmental outcomes, aligning CAA regulatory obligations and timelines to the extent possible, and ensuring that GHG regulatory standards under Section 111 and other CAA programs can be achieved consistent with existing regulatory programs

- **Market-based and other compliance flexibility alternatives:** For appropriate pollutants, additional emissions trading and emissions credit mechanisms in federal transport and trading programs, NSR/PSD programs, and state SIP programs as well as other alternative compliance options such as innovative control technology waivers and emerging insurance-based regulatory concepts

- **Flexible and streamlined permitting:** For innovative clean air and energy technologies with potential to help sources meet or exceed regulatory requirements, facility-wide permitting and streamlined permitting processes

- **Strategic enforcement actions:** Expanded use of supplemental enforcement projects in consent decrees and use of individual and programmatic enforcement discretion to promote innovative technology deployment

[13] Attachment B (forthcoming) provides a brief overview of this innovation stakeholder network and some of the organizations that comprise it.
[14] Administrator Lisa Jackson's remarks at 40th anniversary celebration of the Clean Air Act, Sept. 14, 2010, are available online.

- **Accountability mechanisms:** Targeted technology performance safeguards and backstops, innovative monitoring and reporting methodologies, and environmental justice protections for communities.

Standard-Setting Tools

Because facility owners can be reluctant to invest in new technologies or processes if they are uncertain about how the investment will square with other upcoming regulatory requirements to which they may be subject, many stakeholders and the EPA have concluded that more integrated regulatory standard setting is an important component of regulatory reforms to promote investment in innovative clean air technologies.[15] To promote greater regulatory certainty for industry and other stakeholders, the EPA can develop more multi-pollutant and sector-specific standards, align CAA regulatory timelines, coordinate CAA regulatory programs with non-CAA regulatory programs, and establish new GHG regulatory programs that align with existing programs.

Multi-Pollutant and Sector-Specific Standards

In both domestic and international contexts, sector-specific technology strategies have been recognized as effective because they allow for comparatively efficient identification of shared barriers and opportunities for technology deployment.[16] Although CAA regulatory programs vary, much of the regulation of stationary sources is implemented on a sectoral basis, and the EPA increasingly has pursued regulatory strategies in that manner.

Since at least 2004, when a National Academy of Sciences report on air quality management recommended that the EPA take an "integrated, multi-pollutant approach to controlling emissions of pollutants posing the most significant risks,"[17] the agency has been exploring and developing concepts for aligning the various criteria pollutants, toxics, and other air quality standards for particular industrial sectors such as cement and refining.[18] The agency has concluded there are many benefits to highly integrated multi-pollutant and sector-specific regulatory approaches, including the potential to improve source-wide emissions reduction performance, accelerate deployment of innovative emissions reduction technologies, more effectively integrate energy efficiency strategies into air pollution control investments, and maximize the co-benefits of air pollution investments.[19]

[15] See S. Napolitano et al., "A Multi-Pollutant Strategy," *Public Utilities Fortnightly*, (January 2009): 34–41 (detailing EPA and stakeholder multi-pollutant efforts, including Clean Air Power Initiative, a stakeholder process begun in 1995 to integrate regulation of electric power generation emissions of SO_2, NOx, and mercury).

[16] For example, many industry associations and research organizations have developed sector-specific technology roadmaps to reduce greenhouse gas emissions. See, e.g., technology and sector-specific roadmaps available online for sectors covered in this paper: (a) power generation: The European Commission's "Low Carbon Europe Roadmap 2050," the International Energy Agency (IEA) roadmaps for various power generation technologies, such as nuclear energy, geothermal, and solar, and control technologies such as carbon capture and sequestration; and EPA's GHG Control Measures Paper—Electric Generating Units; (b) refining and chemical manufacturing: CERES Roadmap for Sustainability—Oil and Gas Producers; IEA Biofuels Roadmap; EPA GHG Control Measures-Refineries; and (c) cement manufacturing: European Commission Cement Roadmap 2050; IEA Roadmap for Cement; EPA GHG Control Measures Paper-Cement.

[17] National Academies of Science, National Research Council, "Air Quality Management in the United States," (2005).

[18] See "Moving towards Multi-Air Pollutant Reduction Strategies in Major U.S. Industry Sectors: Report to EPA from the CAAAC Multi-Pollutant, Sector-Based Workgroup," (Nov. 17, 2011); "Moving to Multi-Pollutant Sector-Based Approaches," a draft report by the Office of Air Quality Planning and Standards Sector Policies and Programs Division prepared for the Economic Incentives and Regulatory Innovation Subcommittee of CAAAC (September 2010); U.S. EPA, "The Multi-Pollutant Report: Technical Concepts and Examples" (July 2008).

[19] See "Moving towards Multi-Air Pollutant Reduction Strategies in Major U.S. Industry Sectors: Report to EPA from the CAAAC Multi-Pollutant, Sector-Based Workgroup," (Nov. 17, 2011) generally. The approach to promote innovative technologies is detailed at pp. 25–26.

In 2010, the EPA's Office of Air Quality Planning and Standards (OAQPS) identified the following as important components of a more integrated multi-pollutant approach:

- Review multiple regulatory actions in CAA programs in a coordinated manner
- Combine analyses for multi-pollutant considerations
- Consolidate regulatory requirements
- Improve emissions inventories and data systems
- Coordinate program timelines with the NAAQS eight-year review cycle. [20]

The EPA has taken steps to promulgate fairly broad multi-pollutant and sector-based regulatory programs, but these programs have not always fared well in judicial review. Examples include the 2005 Clean Air Interstate Rule (CAIR) and the 2011 Cross-State Air Pollution Rule (CSAPR) to address NOx and SO_2 from power plants in the eastern half of the United States.[21] CAIR remains in effect, but the D.C. Circuit Court of Appeals found the EPA's efforts legally insufficient in both rulemakings.[22] The EPA has also promulgated more narrowly focused multi-pollutant sector-based regulation, such as combined reconsiderations of new source performance standards (NSPS) and national emissions standards for hazardous air pollutants (NESHAP) in a single rulemaking package for a particular sector. For example, in 2010 the EPA proposed for the cement sector revised NESHAP and NSPS rules that included some coordination of standard-setting and compliance strategies, thereby streamlining some of the monitoring, record-keeping, and reporting requirements of both rules.[23]

For many industrial sectors, environmental compliance investment decisions are constrained not only by uncertainties associated with the complex, multiple unaligned CAA regulatory program requirements, but also by uncertainties relating to other environmental regulations. For example, the utility sector is increasingly focused on forthcoming regulations under Section 111(d) that will control CO_2 emissions from existing power plants. These regulations could have a wide range of economic impacts for utilities and consumers, depending on the regulations' stringency and the extent to which they permit utilities to employ flexible compliance options. Utilities also are concerned about how to reconcile investments not only to comply with CAA regulatory requirements, but also to address coal ash regulations under the Resource Conservation and Recovery Act (RCRA) and cooling water intake structure requirements under the Clean Water Act.[24]

Ideally, sector-specific, multi-pollutant strategies to encourage innovative technology deployment would be designed to align with all current and upcoming GHG, criteria, and toxics rules affecting each sector as well as take into account additional environmental concerns relating to other media such as water, soil, and waste to facilitate cost-effective and environmentally preferable emissions control investment decisions. Clearly, such an integrated approach would take some time to develop and implement in a legally defensible manner. It may be possible in the near term, however, for the EPA to establish pilot efforts with industry and other stakeholder groups, including environmental stakeholders, to develop

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[20] "Moving to Multi-Pollutant Sector-Based Approaches," draft report by OAQPS Sector Policies and Programs Division for the Economic Incentives and Regulatory Innovation Subcommittee of CAAAC, (September 2010), 1.
[21] CAIR Final Rule, 70 *Fed. Reg.* 25162 (May 12, 2005) and CSAPR Final Rule, 76 *Fed. Reg.* 48,208 (Aug. 8, 2011).
[22] *North Carolina v. EPA,* 531 F.3d 896 (D.C. Cir 2008), subsequently modified on rehearing, 550 F.3d 1176 (D.C. Cir. 2008) (flaws found include regional caps with no state-specific determination of significant contribution, but rule held in place until fixed) and *EME Homer City Generation LP v. EPA* (D.C. Cir. Aug. 21, 2012) (2012 WL 3570721) (vacating CSAPR transport rule for requiring states to reduce irrespective of their significant contribution and for setting forth FIP prior to giving states opportunity to implement reductions within their own borders).
[23] See 75 *Fed. Reg.* 54970 (Sept. 9, 2010). The EPA subsequently spent two years reconsidering the rule and issued a final rule amending the Cement MACT Final NESHAP and NSPS Rule on Dec. 20, 2012.
[24] For a detailed summary of environmental regulations affecting the power sector, see Northeast States for Coordinated Air Use Management, "A Primer on Pending Environmental Regulations and Their Potential Impacts on Electric System Reliability" by P. Miller (updated Jan. 9, 2013).

feasible alternative "regulatory compliance programs" wherein a group of companies in a particular sector agree to invest in innovative technologies coupled with clear accountability mechanisms designed to ensure superior environmental results.

Alignment of CAA Regulatory Timelines

Aligning regulatory program timelines with the CAA's mandated eight-year review cycle for the NAAQS is particularly important to give businesses greater certainty about future regulatory requirements and thereby promote their investment in innovative technologies.[25] However, aligning the CAA's major statutory regulatory programs (such as the NSPS, NESHAPs, and the developing GHG programs) with that review cycle is a complex legal and regulatory challenge, as the programs entail multiple sequenced statutory duties for federal and state agencies that were not designed in an integrated fashion.[26] Thus, aligning air pollution control standards for stationary sources most likely has a significantly longer timeline and broader scope than the other tools explored in this paper, and it could require legislative action to ensure legal sufficiency.

In the near term, the EPA can continue to promote targeted and specific provisions to address multi-pollutant considerations, wherever feasible, in new rulemakings, reforms, and pilot programs. For example, the EPA's recently issued guidance to promote energy efficiency and renewable energy deployment through metrics for crediting the emissions benefits of such technologies in SIPs could be extended to develop similar metrics for crediting deployment of other innovative clean energy technologies that provide cost-effective multi-pollutant or multi-media benefits.[27] Such technical assessments from the EPA could help promote increased deployment of these technologies, particularly where environmental tradeoffs among varying pollutants and media impacts are at issue.

Alignment with Non-CAA Regulatory Programs

In many cases, innovative technologies that could benefit stationary-source CAA compliance implicate regulatory considerations not just under the Clean Air Act, but under other environmental statutes and other non-environmental regulatory programs. In promoting innovative technology deployment at stationary source sectors, the EPA and other agencies can coordinate relevant regulatory policies to maximize positive outcomes from deployment efforts and avoid unintended negative consequences. Identifying these types of opportunities will be an important part of the CATI project's upcoming discussions with stakeholders.

Consider this strategy in the context of power generation. In addition to CAA regulation, electric generating units face complex regulatory requirements under other environmental statutes, such as cooling water intake regulations under the Clean Water Act and coal ash regulations under the Resource Conservation and Recovery Act.[28] These units also face complex and varying state regulations from public utility commissions.[29] Thus, the power generation sector faces particularly high levels of regulatory uncertainty as well as regulatory constraints that affect decisions to deploy

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[25] See OAQPS Report, p. 1.

[26] See U.S. EPA CAAAC Report (Nov. 17, 2011), Appendix B, for detailed analysis of varying regulatory program timelines. An innovative proposal for reconciling the NAAQS, NSPS, and NSR timelines is detailed in a subcommittee report by Patrick Traylor, "A Conceptual Framework for a Source-wide Multi-pollutant Strategy," prepared for the Economic Incentives and Regulatory Innovation Subcommittee of the Clean Air Act Advisory Committee (September 2010).

[27] EPA's roadmap for crediting energy efficiency and renewable energy actions in state SIPs is detailed below.

[28] See P. Miller, "A Primer on Pending Environmental Regulations and Their Potential Impacts on Electric System Reliability" (NESCAUM Report updated January 9, 2013) .

[29] J. Monast and S. Adair, "A Triple Bottom Line for Electric Utility Regulation: Aligning State-Level Energy, Environmental, and Consumer Protection Goals," *Columbia Journal of Environmental Law* 38, no. 1.

innovative technologies.[30] Efforts to develop new CAA implementation policies to promote technology innovation in the power sector should be coordinated, to the extent possible, with these other regulatory constraints on the sector and designed, if possible, to increase business certainty regarding future regulatory requirements.

Another opportunity to maximize positive impacts from innovation deployment efforts exists with cross-sector and cross-agency emissions crediting policies. The EPA's guidance to states on crediting emissions reductions from energy efficiency and renewable technology deployments is a good start to improve tools for more market-based regulatory approaches, and EPA can expand on it. For example, the USDA's Office of Environmental Markets (OEM) supports development of emerging markets for carbon sequestration, water quality, wetlands, biodiversity, and other ecosystem services and is intended to help develop systems for quantifying, registering, and verifying the environmental benefits produced by land management activities.[29] The EPA might explore ways to partner with the OEM to promote innovative technology deployment, such as on efforts to include agricultural sources of emissions offsets in trading programs.

Establishment of Greenhouse Gas Standards for Stationary Sources

The EPA is developing performance standards under Section 111 of the Clean Air Act for CO_2 emissions from new and existing stationary sources, starting with the power sector. Agency decisions regarding the standards have the potential to advance clean air technologies and to design the new standards to integrate with existing CAA regulatory programs. In addition, the process of issuing standards for a new CAA pollutant (greenhouse gases) offers the opportunity to reconsider established CAA programs in a new light, along with concepts for better aligning existing regulatory program requirements, particularly as they relate to three GHG-intensive sectors: power generation, refining and chemical manufacturing, and cement and other infrastructure manufacturing.

In its most recent action to regulate GHG emissions, EPA proposed, in April 2012, an NSPS under section 111(b) that limits CO_2 emissions from new fossil fuel-fired power plants to 1,000 lbs/MWh.[30] Modern combined-cycle natural gas turbines can achieve the standard, but even the most efficient coal-fired units cannot comply without using carbon capture technologies. [31] Once the NSPS is finalized, section 111(d) will require performance standards for existing power plants. States will use EPA guidance to establish for "any existing source" performance standards that "reflect" an emissions limit achievable by the best system of emissions reduction. States then submit a section 111(d) implementation plan to the EPA for approval, and the agency can impose a federal implementation plan if it finds the state plan inadequate.

Section 111(d) gives the EPA a unique opportunity to encourage the development and deployment of innovative technologies. The agency has some flexibility in designing Section 111(d) regulations, in part because of the statute's broad language and the limited precedent interpreting the statute. At the same time, these factors contribute to legal uncertainty regarding various policy options.[32] The following policy

[30] See, e.g., S. Adair, D. Hoppock, J. Monast, and D. Echeverri, "The State Role in Technology Innovation," NIEPS Report (January 2013).
[29] See USDA, "The Use of Markets to Increase Private Investment in Environmental Stewardship," (Economic Research Report No. ERR-64, September 2008).
[30] EPA Standards of Performance for Greenhouse Gas Emissions for New Stationary Sources: Electric Utility Generating Units, 77 *Fed. Reg.* 22,392 (proposed April 13, 2012).
[31] See J. M. Tarr, J. Monast, and T. Profeta, "Regulating Carbon Dioxide under Section 111(d) of the Clean Air Act: Options, Limits, and Impacts" (2013), http://nicholasinstitute.duke.edu/sites/default/files/publications/ni_r_13-01.pdf.
[32] Jeremy M. Tarr, Jonas Monast, and Tim Profeta, *supra* at 14–17.

choices may affect the extent to which the existing source regulations spur clean technologies in the power sector:

- The degree to which states can permit use of flexible compliance mechanisms, such as trading, averaging, and end-use energy efficiency, including the degree to which credit can be given for emissions reductions that occur "beyond the fence line"(i.e. as a result of emissions reduction activities undertaken outside the geographic boundaries of the source)
- The stringency of performance standards and whether the EPA can consider flexible compliance mechanisms as part of the "best system of emissions reduction" when setting the emissions limit
- The number of years covered sources will have to comply with regulations and whether to define an emissions limit that increases stringency on a predetermined schedule
- Whether existing state efforts to control CO_2 emissions qualify as a performance standard under the statute and the degree to which regulations recognize emissions reductions already achieved by states
- How modifications of existing power plants will be treated under the New Source Review program

Compliance Flexibility Tools

The CAA contains several provisions that require or encourage the EPA to use emissions trading or other forms of economic instruments to provide compliance flexibility to sources in air pollution programs. The most well-known mechanism is the trading program in the acid rain title of the 1990 CAA amendments, but other sections also expressly provide authority for market-based strategies, such as provisions relating to market incentives in state SIP planning, economic incentive programs for ozone non-attainment areas, and international trading for stratospheric ozone.[33] Notably, some of the most cost-effective and environmentally beneficial applications of market-based environmental regulation have involved air quality programs, such as those relating to acid rain, leaded gasoline, and chlorofluorocarbons.[34]

Significant academic research documents the advantages of regulatory approaches that provide compliance flexibility through market-based incentives compared to conventional performance or technology-based standards.[35] Authors and advocates point out that such approaches are less appropriate for some pollutants (i.e., toxics such as mercury) or problems such as downwind or geographically

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[33] Specifically, significant authority for market-based mechanisms in stationary source regulatory programs is found in Section 110, which addresses state SIP planning for the primary and secondary NAAQS, and specifies in Section 110(a)(2)(A) that measures states may use include "economic incentives such as fees, marketable permits and auctions of emission rights" 42 USC § 7510(a)(2)(A). In addition, the ozone nonattainment provisions of §182(g)(4) require state economic incentive programs for control of mobile and stationary sources of air pollution; 42 USC § 7511a(g)(4), and the stratospheric ozone program relies on an international cap-and-trade scheme for pollutants that degrade the stratospheric ozone layer; §§607, 616; 42 USC §§7671f, §7671o. More implicit authorization is found in provisions that reference the EPA's Section 110 authority (which, as noted above, includes use of economic incentives): Section 115, which authorizes the EPA to require plan revisions under Section 110 to address international transport, and Section 126's interstate pollution provisions, which authorize the EPA to require measures as necessary for a state to avoid violating Section 110's "good neighbor" provision prohibiting significant contribution or interference with attainment in downwind states, see 42 USC §§7410(a)(2)(D).

[34] See R. Stavins, "Experience with Market-Based Environmental Policy Instruments," (Resources for the Future Discussion Paper, November 2001), 20–30.

[35] See L. Stewart, "The Impact of Regulation on Innovation in the United States: A Cross-Industry Literature Review," Information Technology & Innovation Foundation (ITIF); W. Harrington, R. Morgenstern, and T. Sterner, eds., *Choosing Environmental Policy: Comparing Instruments and Outcomes in the United States and Europe,* (Washington, DC: Resources for the Future, 2004); R. Stavins, *Experience with Market-Based Environmental Policy Instruments,* (Washington, DC: Resources for the Future, 2001).

specific pollution, but because pollutant trading options can lower overall control costs by encouraging the largest reductions at facilities that can reduce pollution at the lowest cost, market-based mechanisms have been found to provide greater industry incentive and leeway for compliance and to allow cost-effective and commercially viable solutions to emerge in markets.[36] In addition, some studies find they promote continuing improvement in environmental performance through new and innovative technology developments.[37] Importantly, the existence of market information (allowing pollution emitters and pollution preventers or reducers to find each other) has been found to promote innovation.[38]

In the specific context of CAA programs, market-based policies have been found to promote efficiency and lower the cost of achieving given emissions reduction goals, while also permitting utilization of a broad range of compliance technologies through abatement, pollution avoidance and prevention, pollution transformation, and other choices, particularly in circumstances where abatement costs vary significantly.[39] Title IV's acid rain trading program, in particular, has been found to have promoted technology innovation because of the comparatively great operational flexibility its market-based trading program provides.[40]

Thus, incorporating additional market-based mechanisms and incentives into CAA stationary source regulatory policies could help accelerate broader deployment of innovative clean energy technologies. The potential compliance alternatives for consideration range from the fairly narrow (i.e., crediting sources for emissions reductions associated with specific innovative control technology deployed at their facilities) to much more flexible alternatives that if well-designed with appropriate accountability mechanisms might allow sources to demonstrate (1) emissions reductions resulting from pollution avoidance or prevention (for example, through energy efficiency and use of renewable energy), (2) reductions of non-targeted pollutants, (3) reductions at non–co-located facilities, (4) reductions at non-regulated sources, or (5) reductions aggregated across time or geographical locations.

Reasonable and feasible market-based options for alternative compliance may vary according to the specific sector, pollutants, and programs under consideration. The design of such options should ensure consistency with EPA guidelines on emissions trading to minimize market risks.[41] To gain needed

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[36] L. Stewart, Cross-Industry Literature Review, at 21.
[37] See A.B. Jaffe and R.N. Stavins, "Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion," *Journal of Environmental Economics and Management* 29 (1995): S43–S63; S. Kerr and R. Newell, "Policy-Induced Technology Adoption: Evidence from the U.S. Lead Phasedown," *Journal of Industrial Economics* 51, no. 2 (2003): 317–343. For theoretical analyses of incentives for technological change, see C. Jung, K. Krutilla, and R. Boyd, "Incentives for Advanced Pollution Abatement Technology at the Industry Level: An Evaluation of Policy Alternatives," *Journal of Environmental Economics and Management* 30 (1996): 95–111; J. Montero, "Permits, Standards, and Technology Innovation," *Journal of Environmental Economics and Management* 44 (2002): 23–44. For some caveats to the value of market-based tools in inducing innovation, see R.G. Newell, A.B. Jaffe, and R. Stavins, "The Induced Innovation Hypothesis and Energy-Saving Technological Change," *Quarterly Journal of Economics* 114, no. 3 (1999): 941–975; and W. Pizer, I. Parry, and C. Fischer, "How Important Is Technological Innovation in Protecting the Environment?" (Resources for the Future Discussion Paper, March 2000) (concluding that spurring technological innovation should not be emphasized at the expense of achieving the optimal amount of pollution control.)
[38] L. Stewart, Cross-Industry Literature Review, 21–22. (Stewart also concludes that research supports the view that regulatory uncertainty—with respect to clarity, coherence, and timing of regulatory requirements—is detrimental to innovation.)
[39] R. Newell and R. Stavins, "Cost Heterogeneity and the Potential Savings from Market-Based Policies," *Journal of Regulatory Economics* 23: 43–59 (finding over 50% cost savings in utilizing market-based policy instruments for electric utility NOx emissions compared with relying of the uniform emission rate standard); D. Burtraw, D.A. Evans, A. Krupnick, K. Palmer, and R. Toth, "Economics of Pollution Trading for SO_2 and NOx," *Annual Review of Environment and Resources* 30: 253–289; G. Chan, R. Stavins, R. Stowe, and R. Sweeney, "The SO2 Allowance Trading System and the CAA Amendments of 1990: Reflections on Twenty Years of Policy Innovation," (Resources for the Future, February 2012) (SO_2 trading program found to spark innovation in scrubber technology and also in compliance alternatives).
[40] B. Swift, "How Environmental Laws Work," *Environmental Law Journal* 14, no. 309: 333–335 at 320.
[41] The EPA's policy on emissions trading in 51 FR 43814 (Dec. 4, 1986) identified four principles for SIP control strategies involving market-based strategies: the principles of quantification, enforceability, replicability, and accountability. The EPA's

support, it also should address other environmental impact concerns, such as avoiding any potential for adverse impacts related to a particular pollutant's potential for hot spots, degree of toxicity, and tendency to migrate.[42]

In addition, market-based options are more likely to be supported by a broad range of stakeholders to the extent that they address community concerns by, for example, establishing conditions that must be met before a strategy is adopted and mechanisms for monitoring to ensure conditions are met. Some conditions might be that alternative compliance options result in overall gains in ambient air quality, that no community be disproportionately burdened by alternative compliance options, and that increased costs for monitoring to avoid disproportionate impacts be borne by regulated parties, not communities.

The following sections highlight some key contexts in which greater use of flexible compliance mechanisms, especially market-based ones, in CAA regulatory policies could encourage deployment of innovative technologies in stationary source sectors: (1) emissions trading programs, (2) offset credits in the NSR and PSD programs, (3) state SIP programs, (4) innovative control technology waivers, and (5) emerging insurance-based concepts.

Federal Emissions Trading Programs

As noted above, the CAA provides the EPA and states with specific authority in some cases and discretion generally to develop market-based mechanisms in implementing CAA regulatory programs. The EPA has created criteria pollutant trading programs under Section 110 and is likely to consider a trading program for greenhouse gases under Section 111(d).[43] It may explore the establishment of GHG trading programs under Section 115 to address international pollution.[44] As the EPA has moved toward regulation of greenhouse gases, policy analysts and scholars have also suggested that states have authority to develop GHG trading programs under Section 111(d)'s provisions for state NSPS plans to address existing emissions sources.[45]

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emissions trading policy provides that only trades producing reductions that are surplus, enforceable, permanent, and quantifiable can get credit and be banked or used in an emissions trading program.

[42] See E. Ringquist, "Trading Equity for Efficiency in Environmental Protection? Environmental Justice Effects from the SO_2 Allowance Trading Program," (Indiana University, NSF Award Study, 2011); see also J. Wiener, "Hormesis, Hotspots and Emissions Trading," *Human & Experimental Toxicology* 23 (2004): 289–301 (arguing that risk trading can address hotspot concerns).

[43] See, e.g., J. Tarr, J. Monast, and T. Profeta, "Regulating Carbon Dioxide under Section 111(d) of the Clean Air Act: Options, Limits, and Impacts," (Nicholas Institute for Environmental Policy Solutions, Duke University, 2013); and M. Rhead Enion, "Using Section 111 of the Clean Air Act for Cap-and-Trade of Greenhouse Gas Emissions: Obstacles and Solutions," *UCLA Journal of Environmental Law & Policy* 30, no. 51 (2012).

[44] Legal scholars argue that Section 115's international air pollution provision has potential as a tool for a national GHG trading program and thus could offer an economical, effective, and flexible solution for emissions regulations that could encourage innovative technology deployment. See Hannah Chang, "Cap and Trade under the Clean Air Act? Rethinking Section 115," *Columbia Journal of Environmental Law* 37, no. 1 (2010): 1–2; R. Martella and M. Paulson, "Regulation of Greenhouse Gases under Section 115 of the Clean Air Act," *BNA Daily Environment Report*, Mar. 9, 2009. Because Section 115 lacks specificity regarding enforcement and compliance strategies, it may offer more room for agency regulatory innovation generally than other programs, and it could be developed to more effectively apply lessons learned from previous transport programs in order to encourage technology innovation. However, others question the legality of using short, vague statutory provisions to implement sweeping regulatory programs. See N. Richardson, A. Fraas, and D. Burtraw, "Greenhouse Gas Regulation under the Clean Air Act: Structure, Effects, and Implications of a Knowable Pathway," (Resources for the Future Discussion Paper 10-23, April 2010), 17. Ultimately, the viability of using Section 115 as a tool is uncertain.

[45] An extensive literature explores the options, legality, and effectiveness of cap-and-trade programs to address GHGs under the Clean Air Act. See, e.g., J. Tarr, J. Monast, and T. Profeta, "Regulating Carbon Dioxide under Section 111(d) of the Clean Air Act: Options, Limits and Impacts," (Nicholas Institute for Environmental Policy Solutions, Duke University, 2013); M. Rhead Enion, "Using Section 111 of the Clean Air Act for Cap and Trade of Greenhouse Gas Emissions: Obstacles and Solutions," *UCLA Journal of Environmental Law & Policy* 30, no. 51 (2012); K. Siegel et al., "Strong Law, Timid Implementation: How the EPA Can Apply the Full Force of the Clean Air Act to Address the Climate Crisis," *UCLA Journal of Environmental Law & Policy* 30, no. 185 (2012); N. Riccardi, "Necessarily Hypocritical: The Legal Viability of EPA's Regulation of Stationary Source

Market-based mechanisms could include specific incentives for deploying innovative clean energy technologies. The EPA has already developed a flexible approach to generating credits in the context of energy efficiency and renewable energy-related reductions in state SIP programs, issuing a guidance that identifies four varying "pathways" for states wishing to credit energy efficiency and renewable energy related reductions.[46] The EPA could apply this approach to credit emissions reductions for facilities deploying innovative technologies to achieve compliance with caps or emissions performance standards under federally enacted transport programs like CAIR and BART or their successors. Applying the pathways concepts in the context of performance standards or emissions caps rather than just for air quality purposes would be challenging but could be explored.[47]

However, when the EPA has established trading programs to promote more flexibility and cost-effectiveness in achieving clean air goals, such efforts have faced uphill legal battles and sometimes been remanded or vacated by courts.[48] Thus, any market-based mechanisms for creating emissions credits to promote deployment of innovative technology in federal CAA programs, such as emissions trading programs established in conjunction with interstate transport requirements, must be carefully designed. Market-based policy designs must closely adhere to statutory requirements, be consistent with EPA guidelines, and avoid potential adverse impacts related to trading of a particular pollutant, such as localized hot spots in the case of mercury.

Offset Credits in the NSR/PSD Program

New major sources locating in areas that do not meet current clean air standards, or existing sources in those areas that seek to make major changes that increase emissions, are often required to obtain "offsets" for purposes of non-attainment NSR programs—i.e., they must demonstrate emissions reductions from other sources in the area sufficient to offset their own new emissions.[49] Such offsets are exceedingly scarce and expensive in non-attainment areas such as southern California; as air quality standards tighten, offset costs in other areas of the country may increase. Emissions offsets are also important in attainment areas, where offsets are not required but where new sources must comply with prevention of significant deterioration (PSD) requirements to demonstrate that their proposed operations will cause no significant emissions increases; otherwise, they will be required to install best available control technology.

The EPA could develop broader approaches to defining NSR offsets and determining PSD applicability that allow alternative emissions crediting strategies for facilities seeking to deploy or support innovative technologies—technologies that would allow offsets for less certain controls (new technologies) in

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Greenhouse Gas Emissions under the Clean Air Act," *Boston College Environmental Affairs Law Review* 39, no. 213 (2012); N. Richardson, D. Burtraw, and A. Fraas, "GHG Regulation under the CAA: Structure, Effects, and Implications of a Knowable Pathway," *Environmental Law News & Analysis* 41 (2011): 10098; Pew Center on Global Climate Change, "GHG NSPS for the Power Sector: Options for EPA and the States" (2011); and G. Wannier et al., "Prevailing Academic View on Compliance Flexibility under Section 111 of the Clean Air Act," (Resources for the Future Discussion Paper 11-29, 2011).

[46] See U.S. EPA, "Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs into State and Tribal Implementation Plans" (July 2012).

[47] For example, the baseline or control pathways model might be drawn on in developing compliance strategies under a 111(d) performance standard, although this would require some reconceptualization.

[48] For example, the EPA promulgated several rules under Section 110 and Section 126 requiring upwind states in the eastern half of the United States to address prohibited significant contributions of NOx, SO_2 or both to downwind states' poor air quality. These rules included the Clean Air Interstate Rule, which established a regional cap-and-trade program for SO_2 and NOx emissions (70 *Fed. Reg.* 25162, May 12, 2005). The rule was vacated in July 2008 (*North Carolina v. EPA,* 531 F.3d 896 (D.C. Cir. 2008), but on appeal it was remanded with the rule left in place until the EPA addresses the court's concerns (550 F.3d 1176, D.C. Cir. 2008). In July 2011, the EPA issued the Cross-State Air Pollution Rule (CSAPR), which was intended to replace CAIR (76 *Fed. Reg.* 48208 (Aug. 8, 2011), but in August 2012 the CSAPR was vacated (*EME Homer City Generation v. EPA,* Case No. 11-1302, D.C. Cir., Aug. 21, 2012).

[49] The PSD and NSR program regulations for major sources are found at 40 CFR Parts 51 and 52.

nonattainment areas. Given that innovative technologies can often provide emissions reductions beyond those achievable with traditional approaches, the EPA could help early adopters by giving clear guidance that these additional reductions and pollution prevention could be used as offsets and by specifying acceptable quantification metrics. To address concerns about potential innovative control technology failures, programs should include stringent monitoring, reasonable further progress, and quantification requirements to help protect air quality while encouraging innovative technology deployment.

Under one approach, the EPA would extend its guidance on crediting energy efficiency and renewable energy actions in state SIP programs to crediting offsetting emissions in nonattainment NSR and PSD programs. In nonattainment areas in California, this approach would be particularly effective: it would add another strong economic incentive to the incentives already created by the AB 32 climate initiative and help to increase the number of available offsets in a way that drives deployment of innovative control technologies while ensuring air quality improvements. Of course, the extent of EPA and state authority to credit emissions reductions achieved by regulated sources through actions and reductions occurring at sites other than the regulated source may vary in particular programs and contexts. However, the EPA and states can utilize emissions credit approaches to the extent permitted under the CAA to enable cost-effective achievement of air, energy, and climate goals as well as cost-effective scaling of the innovative technologies that can help achieve these goals.

State SIP Programs

The CAA gives states great flexibility and discretion in developing compliance strategies for state SIP programs, discretion sufficient to include adoption of innovative and alternative compliance options.[50] For example, many policy analysts argue that state authority under Section 111(d) to address GHG emissions from existing sources includes the authority to develop trading programs.[51] Thus, as the EPA and states move forward to implement GHG regulatory programs, and to encourage innovative technologies to meet the goals of such programs, state programs can provide opportunities for exploring more innovative and flexible regulatory approaches.

One example is the EPA's recently issued guidance document (labeled a "Roadmap") on incorporating energy efficiency and renewable energy (EE/RE) policies and programs into state air quality plans.[52] The roadmap identifies four pathways for including EE/RE initiatives in SIPs and provides methods for quantifying the emissions impacts of those initiatives. Because EE/RE benefits often result from numerous energy projects whose impacts can be difficult to assess individually, the roadmap provides metrics for assessing cumulative impacts. Such metrics are particularly useful for projecting baseline emissions under adopted EE/RE policies and programs based on modeling. They are also useful for estimating from modeling the quantifiable, surplus, enforceable, and permanent reductions from future control strategies and from voluntary or emerging measures that can be difficult to model.

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[50] See *Luminant Generation Company v. EPA,* Mar. 26, 2012 (Fifth Circuit, No. 10-60891).

[51] An extensive literature explores the options, legality, and effectiveness of cap-and-trade programs to address GHGs under the Clean Air Act. See, e.g., J. Tarr, J. Monast, and T. Profeta, "Regulating Carbon Dioxide under Section 111(d) of the Clean Air Act: Options, Limits, and Impacts," (Nicholas Institute for Environmental Policy Solutions, Duke University, 2013); M. Rhead Enion, "Using Section 111 of the Clean Air Act for Cap and Trade of Greenhouse Gas Emissions: Obstacles and Solutions," *UCLA Journal of Environmental Law & Policy* 30, no. 51 (2012); K. Siegel et al., "Strong Law, Timid Implementation: How the EPA Can Apply the Full Force of the Clean Air Act to Address the Climate Crisis," *UCLA Journal of Environmental Law & Policy* 30, no. 185 (2012); N. Riccardi, "Necessarily Hypocritical: The Legal Viability of EPA's Regulation of Stationary Source Greenhouse Gas Emissions under the Clean Air Act," *Boston College Environmental Affairs Law Review* 39, no. 213 (2012); N. Richardson, D. Burtraw, and A. Fraas, "GHG Regulation under the CAA: Structure, Effects, and Implications of a Knowable Pathway," *Environmental Law News & Analysis* 41 (2011): 1009; Pew Center on Global Climate Change, "GHG NSPS for the Power Sector: Options for EPA and the States" (2011); and G. Wannier et al., "Prevailing Academic View on Compliance Flexibility under Section 111 of the Clean Air Act," (Resources for the Future Discussion Paper 11-29, 2011).

[52] See U.S. EPA, "Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs into State and Tribal Implementation Plans" (July 2012).

The EPA could build on the EE/RE roadmap by encouraging similar flexible measures to drive innovative technology substitutions for heavily polluting conventional technologies in other contexts. For example, credit could be provided to cement manufacturing on the basis of installation of innovative manufacturing technologies requiring comparatively less energy use or producing comparatively low CO_2 emissions. The EPA could develop guidance to help states promote deployment of such technologies and encourage them to act as laboratories for innovation. Such guidance could, like the EE/RE roadmap, provide a variety of tools and resources to help states develop innovative deployment strategies in their SIPs. Because states must account for a variety of state-specific factors when developing control programs (e.g., upwind emissions, geographic and regional factors, financial and political limitations), they generally benefit from flexibility to adapt EPA guidance to diverse circumstances. Importantly, quantification and documentation requirements would need to be tailored to minimize burdens for states while ensuring equivalent or superior environmental outcomes, particularly in the case of less certain innovative technologies.[53]

The EPA could also establish incentives to encourage programs and policies that promote technology innovation. For example, it could allow states to allow less stringent controls on smaller sources or require different monitoring obligations in exchange for innovative control methods for larger sources. Implementing innovative clean energy control measures or production technologies at large sources would allow technology companies to showcase these technologies, which could attract technology companies and investment to the state. To be feasible, however, such state flexibility must be accompanied by accountability mechanisms to confirm that innovative technology projects are performing effectively and to require backup provisions if they are not. As in the case of offset credits in NSR/PSD programs, the extent to which EPA and states can credit emissions reductions achieved through actions and reductions occurring at sites other than regulated sources may vary in particular contexts.

Section 111(j) Innovative Control Technology Waivers

One provision of the CAA expressly intended to provide compliance flexibility for sources seeking to deploy innovative technologies has been little used: Section 111(j), which provides additional time for sources using new technologies to complete installation and work out problems associated with a "first-of-its-kind" technology. Specifically, Section 111(j) allows the EPA to delay the application of new source performance standards (NSPS) for a particular emissions source "to encourage the use of an innovative technological system or systems of continuous emissions reduction."[54] A source has up to seven years after the waiver is granted or up to four years after it starts operating, whichever is earlier, to demonstrate the viability of the technology. If the technology fails to reach viability, the EPA may grant the source up to three years to comply with the regular NSPS.[55]

Although the ICT waiver only applies to NSPS according to the statutory language, the EPA used its regulatory authority to make the waiver applicable to the PSD–BACT process.[56] The PSD-BACT regulations generally track the Section 111(j) provisions, defining an "innovative control technology" as

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[53] J. Tarr et al., "Energy Efficiency and Clean Air Act Section 111(d): Learning from EPA Precedent," Nicholas Institute for Environmental Policy Solutions, Duke University (publication forthcoming).

[54] CAA § 111(j)(1)(A), 42 U.S.C. § 7411(j)(1)(A). The EPA may grant the waiver to a source if it makes three findings: (1) The technology the source proposes to employ has not been "adequately demonstrated." In other words, the technology is not sufficiently developed to serve as the basis for a universally applicable NSPS. (2) There is a "substantial likelihood" that the proposed technology will either achieve greater emission reductions than the NSPS would require or that it will achieve equivalent emission reductions at lower cost. (3) The proposed technology will not "cause or contribute to an unreasonable risk to public health, welfare, or safety."

[55] Id. at § 111/7411(j)(2).

[56] "Requirements for Preparation, Adoption, and Submittal of Implementation Plans; Approval and Promulgation of Implementation Plans," 45 *Fed. Reg.* 52,676, 52,727 (Aug. 7, 1980).

any system of air pollution control that has not been adequately demonstrated in practice but that would have a substantial likelihood of achieving greater continuous emissions reduction than any control system in current practice or of achieving at least a comparable reduction at lower cost in terms of energy, economics, or non-air quality environmental impacts.[57]

One reason Section 111(j) has been little used is that it limits the EPA's discretion as to the number of waivers "necessary to ascertain whether" a technology will meet requirements.[58] Consequently, the waiver is thought to apply only to pilot projects, a perception reinforced by a 1991 EPA memorandum (known as the Kamine memo) indicating that the agency would only grant an ITC waiver for multiple applications of a particular control technology in very limited circumstances, namely, where one owner controlled all facilities using the technology, one state agency would permit these facilities, and all the facilities would be constructed simultaneously.[59] The Kamine memo severely limited the utility of the ICT waiver as a tool to bring a technology to commercial scale.

In 2010, the Climate Change Workgroup (CCW) of the CAA Advisory Committee analyzed how the ICT waiver could be used more effectively to promote technology development and application. It identified three general problems with the current ICT waiver approach: the limited availability of the waiver under the Kamine memo, the timeframe within which the BACT limit must be met, and the applicant's risk should the technology fail and a different technology be required.[60] The CCW recommended that the EPA disavow the Kamine memo, provide guidance on the availability of the waiver and the circumstances under which a technology would no longer be considered innovative, and allow a range of emissions limits for BACT for ICT waiver applications.[61] Subsequently, the EPA indicated that it "will consider approving more than one waiver" for a particular technology where the statutory criteria are met.[62]

The statutory intent of Section 111(j) is to encourage deployment of innovative control technologies. When combined with other tools, such as greater use of innovative and more effective monitoring and verification technologies, Section 111(j) waivers could promote investments and business risk taking while ensuring environmental protection. Moreover, because the ICT extends to the PSD program, and states have great flexibility to craft SIP compliance trading programs, states could, arguably, develop SIP and PSD compliance options by allowing ICT waivers, i.e., additional time to comply, for sources deploying innovative control technologies.

Other Emerging Concepts

Some policy analysts are promoting innovative options to create compliance flexibility for new emissions sources that are based on the concept of insuring against noncompliance. These options combine conventional performance-based standards with flexibility mechanisms such as exceedance insurance programs or additional payments for exceedances. For example, one proposal would allow alternative compliance payments (surcharges) for emissions in excess of a standard and would use surcharge revenue to fund retrofits at the source or at other sources. Preliminary analytical results suggest that increasing flexibility leads to earlier introduction of new technologies, lower aggregate emissions, and higher

[57] 40 C.F.R. § 51.166(b)(19) (defining "innovative control technology" for purposes of preparation, adoption, and submittal of SIPs); see also 40 C.F.R. § 52.21(b)(19) (defining "innovative control technology" in identical language for purposes of approval and promulgation of SIPs).
[58] Id. at § 111/7411(j)(1)(C).
[59] See "In re Kamine Development Corporation's (KDC) Request for a Prevention of Significant Deterioration (PSD) Innovative Control Technology Waiver," memorandum from Ed Lillis, EPA Region 7 Chief of Permits Program, to Kenneth Eng, Chief of Air Compliance Branch, Aug. 20, 1991.
[60] See Clean Air Act Advisory Committee, Permits, New Source Review and Toxics Subcommittee, Climate Change Work Group, Phase II Report (Aug. 5, 2010), 18.
[61] Id. at pp. 18–22.
[62] See "PSD and Title V Permitting Guidance for Greenhouse Gases," (Mar. 2011), 28.

profits.[63] Other proposals would apply market mechanisms offered by the insurance industry to manage compliance risks associated with pollution. Environmental insurance mechanisms such as general environmental liability insurance for hazardous material transport or site-specific pollution liability such as landfill closure coverage could be extended in various ways. For example, "group risk plans" could aggregate payments across many parties, with payments made to regulatory agencies in the case of exceedances; insurance companies would provide incentives for best pollution control technology by offering group premium deductions such as those available to nonsmokers in group health insurance policies.[64]

Whether such alternative compliance options can be developed under the existing Clean Air Act or would require legislative action is uncertain, but the principles are worth exploring in the context of initiatives to promote deployment of innovative clean air and energy technologies at stationary sources, particularly in the relatively uncharted waters of regulating GHG emissions or in the context of new CAA implementation approaches to existing CAA regulatory programs, such as new approaches to ICT waivers.

Permitting Tools

Industry has had long-standing concerns about regulatory permitting policies that burden technology investment decisions, and the EPA has struggled to find ways to avoid the barriers associated with permitting policies that may inhibit efforts to deploy innovative technologies. Agency efforts to make these policies more supportive of source flexibility have sometimes been met with resistance from regulators and environmental advocates concerned about potential increases in toxics and GHG emissions.[65] Some similar efforts, such as proposed revisions to "streamline and simplify" the NSR program, have also not fared well.[66] The agency's efforts to increase flexibility have been struck down by the courts for exceeding statutory authority.[67]

Recent developments in CAA implementation should help allay such concerns. Implementation of the current NESHAP program is greatly reducing emissions of toxics from stationary sources, and the EPA is establishing regulations for controlling GHG emissions directly rather than relying on the New Source Review program for other pollutants to provide ancillary benefits.[68] These developments may make it appropriate to revisit the need for some of the policies that appear to have discouraged technology innovation in the past.

The EPA and states have several permitting tools to provide greater flexibility to stationary sources, and thereby promote innovative technology deployment. These include facility-wide permitting and streamlined permitting procedures for sources seeking to rely on innovative technologies for Clean Air Act compliance.

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[63] See, e.g., D. Echeverri, D. Burtraw, and K. Palmer, "Flexible Mandates for Investment in New Technology," *Journal of Regulatory Economics* (January 2013).
[64] See A. Telesetsky, "Mandatory Index Insurance: An Unexplored Market Mechanism for Regulatory Compliance," paper presented at EPA Next Generation Environmental Compliance Workshop, December 2012.
[65] One example is EPA's proposal to include a "green group" mini-NSR PAL provision in the Flexible Air Permits Final Rule, which was rejected in the final rule due to concerns about environmental impacts raised by regulators and environmental advocates. See 74 *Fed. Reg.* 51418 (Oct. 6, 2009) at 51433–34.
[66] EPA, New Source Review: Fact Sheet, http://www.epa.gov/NSR/fs20070226.html.
[67] *N.Y. v. E.P.A.,* 413 F.3d 3, 40, 41 (D.C. Cir. 2005) (vacating the Clean Unit and Pollution Control Project exemptions for NSR).
[68] The EPA estimates that when fully implemented, the 96 air toxics regulations affecting some 174 major industrial emission sources will reduce annual air toxics emissions by about 1.7 million tons. See http://www.epa.gov/ttn/atw/nata2005/airtoxred.html.

Facility-wide Permitting

The EPA has developed several permitting policies that give emissions sources additional flexibility, such as plant-wide applicability limits (PALs) and flexible permits (FPs). PALs are an NSR permitting option that allow plant operators to make changes in operations that affect particular emissions points so long as the total emissions of the facility remain under the PAL. FPs allow sources to include alternative operating scenarios and methodologies in their permits to avoid future permit revision procedures.[69] To promote innovative technology deployment, the EPA could apply the policies and criteria developed in the context of PALs and flexible permitting to develop appropriate facility-wide permitting approaches for a broad range of CAA regulatory programs.

Promising concepts have been developed for such approaches to encourage greater innovative technology deployment in other major CAA programs, such as the NSPS and NESHAP programs. One of these concepts has been developed in conjunction with the EPA's exploration of sector-specific, multi-pollutant regulatory initiatives. The concept is to provide a source-wide regulatory approach for major NSPS and NESHAP sources that combines conventional technology-based performance standards with a plant-wide reductions strategy.[70] This concept could be developed with a strong enforceability component, at least on a pilot basis, to promote innovative technology deployment in facility- or sector-specific contexts. Such an approach could help facilities better manage the multiple standards applicable to them under NSPS and other programs and could reduce the facilities' reluctance to implement new technologies or processes for fear of opening the door to unpredictable permitting reviews and delays, even when innovations have superior environmental impacts.

The EPA could evaluate proposed innovative technology opportunities that are good candidates for facility-wide permitting through pilot programs or through development of guidance for flexible, source-wide permitting specifically targeted to innovative clean air and energy technology deployment. Any facility-wide permitting flexibility strategies to promote technology innovation must ensure accountability, replicability, and enforceability, and include effective monitoring and verification requirements.

HOV Lanes, Ride Sharing and Other Streamlining Mechanisms

The EPA could establish specific permitting paths and resources for stationary sources seeking to deploy promising innovative technologies that are modeled on concepts used in the mobile source sector to reward choices to invest in more efficient, less polluting activities. For example, in the stationary source sector, an analog to motor vehicle "HOV" lanes on highways would be access to faster "lanes" for permitting of innovative technologies, such as an expedited permitting process with priority for timely decisions—and, if necessary, resolution of issues—among the EPA, states, and facilities. An analog to ridesharing would be provision of such HOV permitting lanes or other regulatory benefits to groups of sources seeking to invest jointly in innovative technology.

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[69] For detailed information about the FAP program, see the EPA's 2009 Final Flexible Air Permitting Rule, 74 *Fed. Reg.* 51418 (Oct. 6, 2009); U.S. EPA, "Evaluation of the Implementation Experience with Innovative Air Permits (OAQPS, Nov. 18, 2002); and Guidance Document White Paper No. 3, 64 *Fed. Reg.* 49803 (Aug. 15, 2000). For detailed information about the NSR PAL program, see 40 CFR 52.21 (aa); NSR Improvement Final Rule, 67 *Fed. Reg.* 80186 (Dec. 31, 2002); U.S. EPA, "Establishing a Plantwide Applicability Limitation for Sources of GHGs," (April 19, 2011); and the GHG Tailoring Rule 77 *Fed. Reg.* 41051 (July 12, 2012).

[70] See the proposal mentioned above for reconciling the NAAQS, NSPS, and NSR timelines detailed in a CAAAC subcommittee report by P. Traylor, "A Conceptual Framework for a Source-wide Multi-Pollutant Strategy," prepared for the Economic Incentives and Regulatory Innovation Subcommittee of the Clean Air Act Advisory Committee (September 2010).

The EPA has been exploring such concepts in the context of GHG regulation, and the CAA Advisory Committee released a report evaluating options for streamlining GHG permitting.[71] Recommended options included permitting groups of sources rather than issuing individual permits, simplifying the establishment of control technology standards, improving the permitting process, and reducing barriers to wider use of PALs.[72] Some of the concepts addressed in the CAAAC report can be helpful for designing mechanisms to expedite and streamline permitting in the context of deploying innovative technologies. For example, the report addresses how to establish PAL emissions baselines and monitoring requirements for new facilities or new technologies lacking actual performance data, concepts that could be used in issuing a PAL or facility-wide permit to sources seeking to deploy a clean air or energy technology without a demonstrated emissions record.[73]

Enforcement Tools

Innovative Technology SEPS

EPA has encouraged innovative technology deployment by negotiating pilot projects, supplemental environmental projects (SEPs), and other innovative compliance provisions in consent decrees, which has sometimes resulted in sources committing to invest in new technologies in lieu of paying additional financial penalties. This strategy could be applied (and in some cases has already successfully been used) in stationary source sectors to promote innovative technology deployment. For example, the EPA's national effort to reduce air pollution from flares at refinery, petrochemical, and chemical plants led to development and installation of advanced control and monitoring and other technologies.[74] Similar sector-based enforcement strategies that focus on deployment of specific innovative technologies through consent decree could be a lever for promoting deployment of innovations under the CAA.

Enforcement Discretion in Individual Cases

Waivers or deferrals of compliance deadlines in enforcement proceedings are probably the most direct means of employing enforcement discretion to facilitate innovative technology deployment. This mechanism has been used to provide additional compliance time for sources where needed despite good faith efforts to implement advanced technology solutions. The EPA could exercise enforcement discretion to provide well-defined alternative enforcement scenarios for particular projects wherein a costly innovative technology has uncertain performance outcomes but is of potentially great value to achieving air quality goals in many sectors. Such waivers could include "over compliance" margins to help mitigate air quality risks and specific limits to the ability of regulated parties to rely on enforcement discretion.[75] In addition, the EPA could require timely public notice relating to the performance failure of any project with alternative enforcement compliance strategies.[76]

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[71] In the Tailoring Rule, the EPA sought comment on mechanisms for more efficient GHG permitting such as general permits, permits-by-rule, defining PTE for source categories, establishing presumptive BACT for source categories, electronic permitting, and leaner permitting processes. See ANPR, 75 *Fed. Reg.* at 31526 (Mar. 8, 2012).

[72] EPA CAAAC, Air Permitting Streamlining Techniques and Approaches for Greenhouse Gases Final Report (Sept. 14, 2012).

[73] See CAAAC Air Permitting Streamlining Techniques Report, 35–36.

[74] In 2012, an innovative agreement with Marathon Petroleum Company (MPC) resulted in installation of state-of-the-art controls on flares and a cap on the volume of gas sent to flares that achieved both significant VOC and benzene reductions and cost savings for the company. Together, Marathon and the EPA developed a protocol and first-ever test of emissions from an operating, industrial flare using an innovative measurement technology. See http://www.epa.gov/compliance/resources/cases/civil/caa/marathonrefining.html.

[75] For example, the EPA and the source could agree to a specified period during which enforcement discretion could be relied on and to pre-established compensatory damages for violations of conditions of the waiver.

[76] For example, permits could require additional notifications to the EPA and to the public of any malfunctions or emission standard exceedances associated with a project within 14 days of occurrence.

Such approaches carry some risk of legal challenge, but if the particular application was developed to promote innovative technology with support and input from relevant stakeholders, and was designed with reasonable performance safeguards and limited periods of deferral, such a challenge would be less likely to be successful. In general, courts have found that agency discretionary decisions regarding enforcement represent a complicated balancing of priorities and resources that agencies are best suited to decide.[77]

Programmatic Enforcement Discretion

In some CAA rulemakings, the EPA has utilized enforcement discretion as a programmatic tool to address compliance issues associated with the state of technology or other administrative issues. For example, in the Mercury Air Toxics Rule (MATS), the EPA provided an extended compliance "pathway" to address concerns that installation of the required control technology under the rule in the statutory three-year compliance period might compromise electric reliability in some cases. Thus, the EPA provided the standard three years for compliance but also encouraged permitting authorities to make a fourth year broadly available for technology installations. If still more time were needed to avoid compromising localized electric reliability in the case of any specific source, the EPA provided a well-defined pathway for enforcement discretion to allow an additional year to complete installation of controls (making a total of five years available in appropriate circumstances).[78] The agency specifically addressed—and carefully bounded—the proposed "programmatic" use of its enforcement discretion in a separate memorandum from the Office of Enforcement and Compliance.[79]

Discretion granted to programmatic applications of enforcement discretion may be more bounded than use of such discretion in individual cases, but the general trend of case law is that agency use of discretion to provide alternative enforcement options is upheld where the enforcement alternatives support fundamental purposes of the act in question. Deference is more likely when enforcement discretion only defers the date of compliance or would achieve better results than would be possible under more conventional enforcement. [80]

Accountability Tools

To the extent that the EPA provides greater operational flexibility to regulated sources in permitting, compliance, and enforcement policies, it will want to ensure that the resulting emissions reduction and other environmental outcomes are equivalent or superior to those achieved in the absence of such flexibility. The EPA can do so by incorporating into any new policies or programs specific accountability mechanisms relating to monitoring and evaluating local and broader impacts of newly deployed innovative technologies. These mechanisms include (1) ensuring that policies or actions to promote innovative technology deployment at stationary sources include provisions for default backstops with clear triggers for action, (2) requiring fence-line and other innovative monitoring and communication

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[77] This concept was originally established in *Heckler v. Chaney,* 470 US 821, 830-31 (1985). Chaney indicated that a limit exists "where the substantive statute has provided guidelines for the agency to follow in exercising its enforcement powers." Id. at 833. However, in *Town of Castle Rock v. Gonzales,* 545 US 748 (2005), and *Mass. v. EPA,* 127 S.Ct. 1438, 1459 (2007) the court affirmed deference to agency discretion not to bring enforcement actions.

[78] See "National Emission Standards for Hazardous Air Pollutants from Coal- and Oil-Fired Electric Utility Steam-Generating Units and Standards of Performance for Fossil-Fuel-Fired Electric Utility, Industrial-Commercial-Institutional, and Small Industrial-Commercial-Institutional Steam Generating Units," EPA Final Rule, 77 *Fed. Reg.* 9304 (Feb. 16, 2012), 9406 ("Compliance Date and Reliability Issues").

[79] See 77 *Fed. Reg.* at 9411, and Dec. 16, 2011 Memorandum from Cynthia Giles to Regional Administrators.

[80] See *Association of Irritated Residents v. E.P.A,* 494 F.3d 1027, 1032 (DC Cir. 2007) (finding consent agreements under the CAA, CERCLA, and EPRCA between EPA and more than 10,000 animal feeding operations were not judicially reviewable). In this case, consent agreements permitted AFOs to remain in environmental compliance by paying a fee to be used to develop measurement techniques to more effectively monitor emissions. The court noted that the consent agreements did not cease enforcement but only delayed it and that the data collection would lead to "quicker industry-wide compliance" than traditional enforcement.

technologies in conjunction with deployment of innovative technologies, and (3) ensuring that best practices are used to evaluate and address environmental justice concerns.

Default Backstops with Clear Triggers

Upfront agreements on remedial steps to be undertaken if a new technology does not provide superior environmental results are an important component of any regulatory policies or projects to foster innovative technology. Actions to accelerate innovative technology deployment can include mid-stream evaluation measures to assure on-track performance and appropriate mechanisms such as well-defined triggers and pathways for off and on ramps. Design for the evaluation measures will depend on context, but best practices would require that they be well articulated and designed in a stakeholder process with input from the regulated industry, the public and state agencies, vendors, policy experts, and environmental and environmental justice and other advocates.

Triggers for backstops could include achievement shortfalls such as failure to comply with emissions forecasts by a source or an area; or health risk triggers based on ambient and localized monitoring, depending on the program, the pollutants at issue, and so on. Backstop measures can include both off ramps from the innovative technology program when monitoring and other evaluation processes (such as designated period program reviews and individual facility audits) raise concerns about program or facility performance; and on-again ramps when a performance shortfall or failure is remedied. In appropriate cases, deadline extensions to achieve a goal might be appropriate if progress is shown.

Innovative Monitoring and Reporting Technologies

As advanced emissions control and clean energy technologies are emerging, so too are advanced emissions monitoring and verification technologies. CAA regulation continues to rely primarily on continuous emissions monitoring systems for stacks coupled with leak detection and repair for fugitive emissions, but new monitoring methods that include micro-sensing instruments and passive collection through hand-held photoionization detectors with real-time sensitivity are in development. These detectors can register particular VOC concentrations to 1 ppb and process equipment leaks tens of feet away. In addition, and of particular interest to nearby communities, fence-line or open-path monitoring sensors can identify contaminants by projecting a beam of ultraviolet or infrared light over distances as far as a kilometer, allowing accurate measurement of the highest concentrations of emissions outside a facility at the property boundary near the ground level. New technologies have also improved direct transfer of measurement capabilities from the lab to the field.

The EPA could give sources greater operating flexibility to risk deploying innovative production and control technologies if correspondingly innovative monitoring and verification technologies were providing support. Regulatory strategies to accelerate the deployment of innovative production and control technologies should include strategies to accelerate deployment of promising monitoring innovations as well. These innovations, particularly fence-line monitoring, can be deployed to ensure that facilities receiving regulatory benefits provide nearby communities with superior environmental results. Although there is some risk of shortfall in the environmental performance of new technologies, that concern can be mitigated by enhanced capability to detect and correct underperformance or other implementation failures.

The EPA has begun to evaluate the cost and other market-based challenges for accelerating fence-line and other monitoring technologies.[81] In moving forward to rely on more innovative monitoring technologies,

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[81] See U.S. EPA, "Case Study Primer for Participant Discussion: Fence-Line Air Quality Monitoring" (Technology Market Summit, May 14, 2012).

the agency will need to evaluate strategies for reporting and communicating data to the public in timely and appropriate formats as well. Strategies that rely on innovative monitoring and verification technologies should also include mechanisms to provide for the public-informed, expert evaluation of the growing emissions information available and to manage responsible social media strategies for that information.

Environmental Justice Best Practices

Minority and lower-income populations frequently bear disproportionate environmental burdens. With regard to air emissions, specifically, these populations have concerns that include "urban" asthma, air toxics hotspots, siting and permitting of major sources, and monitoring and notifications of adverse air quality and high local concentrations (particularly due to exceptional events). Energy production, in particular, can be a significant source of environmental discrimination. Industrial operations with high emissions and other adverse environmental impacts are more likely to be located near minority and lower-income communities in both the urban context (heavily industrialized refining and chemical operations) and the rural context (mining and other energy extraction activities). Fortunately, many of the most promising clean air and energy technologies, such as solar, wind, biomass, natural gas, and clean coal technologies, can help reduce the disproportionate burden borne by such communities.

For reasons of equity and political acceptance, regulatory strategies to promote innovative technology deployment at stationary sources should achieve specific improvements for overburdened communities and should expose these communities to no new environmental risks. The EPA's "Plan EJ 2014" includes an appendix detailing strategies to better integrate environmental justice considerations into permits issued under the Clean Water Act, the Clean Air Act, and other environmental laws.[82] Furthermore, a recent analysis from the National Advisory Council for Environmental Policy and Technology (NACEPT) provides very specific and helpful recommendations for ways the EPA can better promote use of innovative technologies to promote EJ goals.[83] NACEPT recommends that the EPA improve community participation in research design and conduct.[84] It also recommends that the agency work with its regional offices to develop pilot test beds for effective detection, monitoring, and assessment technologies and that it work with other federal agencies to mobilize a federal initiative to develop and deploy technology solutions.[85]

Environmental justice strategies may provide an important tool for the EPA to promote environmental justice and innovative technology deployment goals in tandem. In particular, expanding the use of innovative pollution detection, monitoring, and assessment technologies (from portable sensors that can be used by members of a locally affected community to complex systems operated by trained personnel) could be particularly beneficial. These technologies could dramatically increase capacity to assess the multiple impacts that communities face and significantly improve environmental justice outcomes in conjunction with accelerating innovative technology deployment under the CAA. For example, they could help enhance local air quality management relating to emissions inventories and air quality monitoring (such as micro-scale monitoring), compliance reviews, outreach and education to facilitate local

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[82] Environmental justice issues in permitting are particularly addressed in Appendix 2 to the Plan EJ 2014 Report, "Considering Environmental Justice in Permitting."

[83] "Technologies for Environmental Justice Communities and Other Vulnerable Populations," Feb. 15, 2012, letter from NACEPT to Lisa Jackson. In particular, NACEPT details at p. 7 the need for assessment technologies such as risk assessment, life-cycle assessment, environmental footprint assessment, resilience analysis, integrated assessment models, and sustainability impact assessment.

[84] NACEPT cites OSWER's Community Engagement Initiative as a model and recommends that EJ stakeholders be involved in the Regionally Applied Research Effort program. See NACEPT Letter, 15.

[85] See NACEPT Letter, 16. NACEPT also notes that the EPA needs to develop technical information, an inventory of innovative technologies that could be deployed now to meet the needs of environmental justice communities and regulatory agencies, and any legal, financial, or other barriers to the deployment of these technologies.

empowerment, community training on air quality and data gathering, public information dissemination, and communication channels between local governments and communities.

One way to ensure that environmental justice improves in conjunction with innovative technology deployment would be to identify best practices for addressing environmental justice concerns related to innovative technology projects, so that any such projects are thoroughly vetted and evaluated by local community members. Agency guidance on such practices could detail community safeguards for situations in which sources seek to operate with particular innovative technology-based flexibilities such as streamlined permitting or ICT waivers. The guidance could cover practices related to environmental justice concerns that arise under co-located USDA, DOE, or DOD area projects. Development of a set of best practices for early, constructive engagement by innovative technology developers with nearby communities and adoption of these practices should be a pre-requisite for the use of regulatory and operational flexibilities in conjunction with innovative technology deployment.

NON-REGULATORY TOOLS

In addition to promulgating and enforcing regulations under the Clean Air Act, the EPA has discretion to undertake "non-regulatory" activities to promote and support particular goals or outcomes that advance CAA objectives. With regard to promoting the deployment of innovative technologies, the non-regulatory tools available to the EPA—and to others working with the EPA or separately—range from promoting R&D to promoting access to capital and helping to bring technologies to scale in the marketplace.[86] Such efforts can be more successful when pursued in conjunction with both private sector partners and other public sector agencies. To promote innovative technologies of particular importance to achieving stationary source compliance goals under the CAA, the EPA could work with the Department of Energy (DOE), the Department of Defense (DOD), the U.S. Department of Agriculture (USDA), and the Department of the Interior (DOI).

The EPA and other agencies have several types of non-regulatory tools they can use to promote deployment of innovative clean air and energy technologies in key industrial source sectors:

- **Programmatic initiatives:** The agencies can facilitate public-private sector collaborations to promote and support particular technologies. They can systematically facilitate such collaborations to promote deployment of innovative clean air and energy technologies. Successful models include EPA's technology innovation partnerships and E3 initiatives and a federal-state community-based project in California's San Joaquin Valley.

- **Technology demonstrations:** The agencies can use pilots, showcases, supplemental environmental project, and other such technology demonstration efforts to help establish the technical and economic viability of untested technologies and thus promote their financing, marketing, and permitting. Collaborative efforts with other agencies are potentially a promising route forward in today's resource-constrained environments.

- **Technology testing and certification:** The agencies can establish a creditable, reliable, and effective technology certification program, or EPA can reinvigorate its established technology verification program, to help innovators obtain financing and commercialization assistance to develop and market new technologies.

[86] See EPA, "Roadmap for Technology Innovation for Environmental and Economic Progress," (April 2012). The EPA also published a longer version in October 2011, a draft from the Science and Technology Policy Council that outlines agency and inter-agency strategies and that discusses, in Appendix 3, 8–10, statutory authorities for action.

- **Financing and commercialization assistance:** Neither the EPA nor other public agencies are likely to be able to provide direct financing assistance in current economic and fiscal circumstances, but they can work with other public sector and private sector resources to maximize the value of private sector capital and commercialization resources in promoting innovative clean air and clean energy technologies. Tools include, for the private sector, strategic partnerships and multiple revenue streams and, for the public sector, state and federal policy proposals to cost-effectively leverage private investment in clean air and energy innovations.

The EPA and other agencies are utilizing many of these tools already, but the tools' effectiveness could be significantly increased if applied in a concerted strategy to accelerate technological innovation in particular stationary source sectors under the Clean Air Act.

Programmatic Initiatives

The EPA, alone or in conjunction with other agencies, has developed public-private voluntary partnerships to promote deployment of particular technologies. For example, the EPA's Combined Heat and Power Partnership works with the CHP industry, state and local governments, and other clean energy stakeholders to develop new CHP projects and promote their environmental and economic benefits.[87] Other initiatives the EPA has undertaken in recent years to promote innovative technology could be expanded and could operate more effectively when developed in conjunction with a regulatory tool strategy. These initiatives include EPA's Technology Innovation Partnership, the E3 Initiative, and a federal-state community-based project to address air quality concerns in California's San Joaquin Valley.

EPA's Technology Innovation Partnership

In 2012, the EPA published a roadmap addressing how it can better promote and accelerate the production and adoption of innovative technology.[88] The roadmap focuses on three agency action areas: research and development, engaging with the private sector, and reviewing regulatory processes. In conjunction with the initiative, the agency is conducting three case studies for environmental technologies: (1) automotive supply chain innovations in materials and technologies; (2) air quality monitoring innovations, particularly real-time fence-line monitoring; and (3) biodigesters and biogas from waste resources. In April 2012, EPA held an innovative technology summit to present work on the three case studies and subsequently entered into a partnership with industries and stakeholders in the affected sectors to lower regulatory and production costs, identify problem areas, lower market barriers, promote innovation, and examine life cycles.[89] The partnership is designed to facilitate information exchange about research, development and deployment needs, joint goals, and roadmaps and to evaluate approaches to addressing institutional, policy, and financial barriers that inhibit innovation, development, deployment, commercialization, and export of environment-friendly technologies.[90]

This initiative is a good example of the kind of programmatic initiative that can help support specific projects to deploy innovative clean air and energy technologies at stationary sources. In addition, the research and the stakeholder resources developed in conjunction with the initiative are likely to be useful to similar projects.

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[87] Some incentives are aimed directly at installing CHP systems to reduce load on the grid or to reward efficient generation, whereas others provide funding specifically for biomass CHP systems. For a more detailed overview of federal incentives for CHP, visit the Federal Incentives projects page at http://www.epa.gov/chp/incentives/index.html.

[88] See "Roadmap: Technology Innovation for Environmental and Economic Progress," http://www.epa.gov/envirofinance/EPATechRoadmap.pdf.

[89] Information on the summit and background papers is available at http://www.epa.gov/osa/summit2012.htm.

[90] Partnership Agreement, per copy in possession of Rob Brenner. The Nicholas Institute at Duke University was a co-sponsor of the Summit and is now a member of the Partnership.

The E3 Initiative

The EPA also has developed the interagency Economy, Energy and Environment Initiative. Sister agencies include the Department of Commerce, the DOE, the DOL, the Small Business Administration, and the USDA. E3 provides resources to small and medium-sized businesses to help them become more sustainable, efficient, and competitive by completing assessments and audits to identify opportunities to reduce costs and waste, improve productivity and efficiency, and measure GHG emissions.[91] The EPA provides tools and expertise on pollution prevention, toxic chemical use reduction, and GHG measurement, while DOE, through its Save Energy Now Program, provides assessments and deployment assistance.[92]

San Joaquin Collaborative Project

Initiatives for innovative technology deployment can involve federal-state partnerships, such as a collaborative project in which the EPA and other federal agencies (DOE Advanced Research Projects Agency-Energy, DOT, National Renewable Energy Laboratory, General Services Administration, and USDA) are working with the California Air Resources Board, the San Joaquin Valley Air Pollution Control District, and the South Coast Air Quality Management District (SCAQMD) to expedite technology development and commercialization of clean technologies to meet clean air standards in the area. Under a July 9, 2008, MOU, these organizations and others are collaborating to accelerate advanced clean technologies to improve air quality in California's South Coast and San Joaquin Valley air basins (focusing in particular on the communities of San Bernardino and Bakersfield). The project's goals include evaluating emissions reduction technologies and choosing which ones to develop, commercialize, and deploy on a fast track to meet clean air objectives; showcasing an integrated approach to addressing air toxics and GHG and non-GHG emissions in affected communities; modeling the approach for other areas facing nonattainment and environmental justice challenges; and fostering opportunities for green jobs, sustainable businesses, and local participation in clean air policy making.

Technology Testing and Certification

Technology certification programs (also called technology verification programs) evaluate the performance of technologies under specific protocols and testing conditions to provide greater regulatory certainty to agencies, the public, and financiers about the environmental benefits of the technology and reasonable performance parameters.[93] Typically, such programs develop information relating to the technology's performance; the basis for emissions claims; intended market applications; unique monitoring and operating constraints; potential health, safety, or environmental impacts; and experience with testing and in-use operation.[94]

Such programs could be run with a nonprofit institute, as is the EPA's Environmental Technology Verification (ETV) program, founded in 1995 but now operating at much reduced levels due to funding constraints.[95] Alternatively, such programs can be managed independently by a third-party nonprofit

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[91] U.S. Economy, Energy, and Environment Initiative, "About E3," accessed November 8, www.e3.gov/index.html.
[92] Information about the E3 program is available at http://www.e3.gov/index.html.
[93] The EPA's Office of Research and Development (ORD) conducts such technology evaluations on an ad hoc basis in conjunction with the Superfund Innovative Technology Evaluation (SITE) program. EPA's SmartWay program evaluates technologies with the potential to reduce GHG emissions from freight transport.
[94] An innovative technology verification program may need to distinguish between "commercially ready" technologies and "emerging" technologies, as is the case in the national clean diesel campaign (NCDC), because the kind of data and the level of business and regulatory uncertainty is markedly different for the two categories. Such a distinction could help marshal resources more efficiently to encourage both greater deployment of commercially ready technologies and greater demonstration of non-commercially ready technologies.
[95] See "U.S. EPA Environmental Technology Verification Program, Purpose of Verifications and Use of Program Name and Logo," on the ETVP website.

organization funded by regulated entities, such as is the LEED program. If modeled on the ETV program, the programs would be voluntary and would not determine regulatory compliance, rank technologies or their performance, certify acceptability of technologies, or identify best available technology. The ETV avoided picking winners and losers and focused instead on providing objective performance data for commercially ready technologies to aid in decision making by purchasers, permitting authorities, vendors, and the public.

Technology Demonstrations

The EPA can broaden deployment of innovative technologies by helping enable technology demonstrations in pilot projects and showcases. As noted above, the EPA has negotiated deployment of innovative technology as supplemental environmental projects (SEPs) in consent decrees in the enforcement context. It has also promoted them in voluntary programmatic initiatives such as the federal-state joint effort in San Joaquin. The EPA can also work with other agencies (such as the DOE, DOD, and USDA) to expand the scope and success of such efforts. For example, the USDA has developed specific programs, such as the Agricultural Technology Innovation Partnership, a technology transfer program run by the USDA's Agricultural Research Services (ARS) office, to promote deployment of ARS-developed technologies such as bioenergy from biomass in private sector and public sector contexts such as the Air Force and the Navy.[96] Similarly, the EPA could facilitate clean air technology demonstration and deployment projects with other agencies.

Given its high energy use and need to protect energy reliability and security, the DOD has been involved in providing test beds for demonstrating innovations.[97] For example, it partnered with the DOE to research and accelerate deployment of clean energy technologies.[98] The DOD uses its Environmental Security Technology Certification Program to demonstrate and help scale up emerging energy technologies such as smart microgrids, advanced energy storage, and EE/RE technologies on military installations.[99] The DOD's technology demonstration activities serve as a model for how agencies can work together and with public-private partnerships to spur deployment of innovative technologies.

While this list is exploratory and admittedly preliminary, the following examples illustrate the kinds of clean air and clean energy technology demonstration partnerships that EPA could develop with other federal agencies:

- **Department of Energy:** The DOE's Advanced Manufacturing Office could work with the DOD to test cements that capture CO_2 while they cure; natural gas converted to hydrogen for fuel cells could be sited at DOE labs as a replacement for existing boilers.

- **Department of Defense:** Combined microgrids/renewables systems could be established at DOD facilities with electric power off the grid as the backup.

- **Department of the Interior:** Cement ash could be produced from coal ash at one of the coal-fired plants on DOI lands; a floating solar reservoir could be demonstrated at one of the Indian reservations. More broadly, a program for clean-energy leasing on public lands, such as extensive holdings in the western half of the United States, could also be

[96] Information about ATIP is available at http://www.ars.usda.gov/pandp/docs.htm?docid=763&page=3.
[97] "Energy Innovation at the Department of Defense: Assessing the Opportunities," by the Consortium for Science, Policy, and Outcomes at Arizona State University and the Clean Air Task Force (Bipartisan Policy Commission, 2011).
[98] DOE, "Memorandum of Understanding between the U.S. Department of Energy and the U.S. Department of Defense," (July 22, 2010), http://energy.gov/sites/prod/files/edg/media/Enhance-Energy-Security-MOU.pdf.
[99] For more information on the ESTCP Installation Energy Test Bed and its demonstration projects, see http://www.serdp-estcp.org/Featured-Initiatives/Installation-Energy.

developed, along with transmission lines to link new wind, solar, and geothermal generation projects to the grid.

- **Department of Agriculture:** Underground coal gasification could be demonstrated on Forest Service lands; algal oil or cellulosic-based fuel projects could be developed with partial USDA funding and could be located at USDA research facilities.

Financing and Commercialization Assistance

The technologies most needed at stationary sources to meet clean air goals are capital intensive. Efforts to promote these technologies will be more successful to the extent that they help address the challenges of financing.[100] These challenges arise at every stage, from getting a project built, through achieving broad distribution through the market and weathering early business cycle challenges.[101] Financing innovative technologies can be particularly difficult in the energy sector because large-scale infrastructure commitments and many levels of regulation complicate technology choices. In addition, public sector and private sector investment in energy innovation have declined due to many factors, including adverse economic conditions, constrained public budgets, expiring federal subsidies for clean energy, and low natural gas prices that are decreasing incentives to invest in alternative fuels.[102]

Despite these constraints, however, private sector providers of non-equity capital (i.e., banks, venture capital firms, corporations, and individuals) are demonstrating interest in making investments in clean energy technologies.[103] For example, Goldman Sachs has made public commitments to maintain annual investment levels in clean energy technology and has hosted a summit on clean energy investment.[104] Citibank is working with the Environmental Defense Fund to develop innovative financing instruments for aggregation, standardization, and participation by institutional investors in renewable energy projects such as photovoltaic power plants.[105]

In the current climate, financing efforts for innovative energy technologies have tended to focus on maximizing the value and impact of the private sector resources available. Advocated strategies include, for the private sector, forming strategic industry partnerships and developing multiple profitable revenue

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[100] Clean energy financing challenges have been documented by a number of organizations, including The Brookings Institution (*Boom to Bust*), the Bipartisan Policy Center (Energy Report), the Clean Energy Group and Bloomberg New Energy Finance ("Crossing the Valley of Death: Solutions to the Next Generation Clean Energy Project Financing Gap," June 2010), the Coalition for Green Capital (CGC), and the Center for American Progress.

[101] See R. Day, "Lessons from the Past Ten Years, Part IV: Gaps," https://financere.nrel.gov/finance/content/lessons-past-ten-years-cleantech-investing-capital-gaps-part-4-4 (summarizing financial "gaps" for clean tech innovators and solutions).

[102] See Environment and Energy Publishing, "Clean-tech sector sees drop in venture capital investment," Jan. 7, 2013, http://www.eenews.net/Greenwire/2013/01/07/archive/15?terms=clean+energy+investment; see also MoneyTree™ Report by PricewaterhouseCoopers and the National Venture Capital Association based on data from Thomson Reuters or the PwC/NVCA MoneyTree™ report based on data from Thomson Reuters. "Annual venture investment dollars decline for first time in three years, according to the MoneyTree report," Jan. 18, 2013, http://www.pwc.com/us/en/press-releases/2013/annual-venture-investment-dollars.jhtml.

[103] For informative discussions of clean energy investment strategies, see R. Day, "Clean Tech Investing Summit I Would Like to See," id.; A. James, "The Angels and Demons of Clean Tech Investment," prepared for Climate Progress (March 2013), http://oilprice.com/Alternative-Energy/Renewable-Energy/The-Angels-and-Demons-Of-Clean-Tech-Investment.html (quoting David Miller, angel investor with Clean Energy Venture Group).

[104] See "Key Trends in the Clean Energy Industry," summarizing Clean Energy Ecosystem Summit, Menlo Park, CA, Oct. 11–12, 2012, http://www.goldmansachs.com/our-thinking/our-conferences/clean-energy-summit/goldman-sachs-clean-energy-ecosystem-summit.pdf.

[105] EDF collaborated with Citibank on a July 2011 paper called "Show Me The Money: Energy Efficiency Financing Barriers and Opportunities." Citibank and EDF's relationship on energy efficiency began in 2008 when the two groups worked together with other banks, NGOs, and utilities on guidelines for banks financing coal-fired power in the United States that included diligence to assess efficiency opportunities. In early 2013, EDF Renewable Energy announced financing that included Citibank, GE Energy Financial Services, and others for a 143-MW photovoltaic plant in the Mojave Desert.

streams in conjunction with technology projects, and for the public sector, proposals for state and federal policies that do not directly fund investment but instead help facilitate access to private sector capital.

Strategic Partnerships and Multiple Revenue Streams

Because energy innovations tend to need longer and more capital-intensive investment than some other kinds of technology innovation, innovators need to be aware they are more likely to attract private capital to the extent they can demonstrably reduce project risk through strategies such as developing strategic partnerships (sometimes called "matchmaking") and visible, multiple paths to cash flow.[106] Partnerships require less capital from each participant while providing additional markets, revenue streams, and opportunities for synergistic production processes. Two examples: Conoco Philips, GE, and NRG in 2011 formed Energy Technology Ventures, a joint venture for investing $300 million in "next-generation energy technology."[107] Exelon, GE, and the Louisiana-based Shaw Group in 2012 partnered with NET Power to build a power plant with NET Power's technology for clean combustion of fossil fuels and cost-effective capture of CO_2.[108]

Strategies for identifying potential partners include identifying mutually profitable revenue streams that can be developed in conjunction with innovative clean energy technologies, such as incorporating sales of higher-margin products like renewable chemicals or fertilizer in an energy production project. Another strategy is to find companies with complementary existing technologies or for which the proposed technology is disruptive to a competitor's technology base.[109] Partnering with relevant regulatory agencies can also help promote development and commercialization of a technology, as evidenced in Solazyme's partnership with the DOD to develop commercial-scale production of algae-derived biofuel for the Navy.

State Financing Strategies to Leverage Private Sector Investment

States programs to help innovators fund development and commercialization of clean energy technologies are well known and well documented. They include programs for funding energy efficient and renewable energy technologies.[110] They also include projects to provide intellectual capital and informational resources to help innovators locate private funding, such as innovation clusters and incubators.[111]

Recently, some states have been exploring the concept of using public funds to leverage greater private sector clean energy investment. One promising approach is Connecticut's Clean Energy Finance

[106] See, e.g., Goldman Sachs, "Key Trends in the Clean Energy Industry"; R. Day, "Clean Tech Investing Summit I Would Like to See," id.; A. James, "The Angels and Demons of Clean Tech Investment," id.

[107] E. Gossens, "GE, Conoco, NRG commit $300 million in venture to support clean energy," *Bloomberg,* Jan. 27, 2011, http://www.bloomberg.com/news/2011-01-27/ge-conoco-nrg-to-form-energy-projects-joint-venture-wsj-says.html.

[108] In the interest of disclosure, Net Power is a technology developed by 8 Rivers Capital, a Durham-based firm whose Advisory Board is chaired by Tim Profeta, Director of the Nicholas Institute. Duke University School of Law also has an ownership interest in Net Power through shares donated to the law school by the founders of 8 Rivers Capital. See http://law.duke.edu/news/5737/.

[109] See summary of remarks of R. Hawkins, vice president of business development for GE Energy, at Goldman Sachs Clean Energy Ecosystem Summit, October 2012, http://www.goldmansachs.com/. our-thinking/our-conferences/clean-energy-summit/goldman-sachs-clean-energy-ecosystem-summit.pdf.

[110] See, e.g., Database for State Incentives for Renewables and Efficiency (DSIRE), "Renewable Portfolio Standard Policies," http://www.dsireusa.org/documents/summarymaps/RPS_map.pdf; Database of State Incentives for Renewables and Efficiency, "Property Assessed Clean Energy (PACE)," http://www.dsireusa.org/documents/summarymaps/PACE_Financing_Map.pdf; L. Milford, M. Muro, J. Morey, D. Saha, and M. Sinclair, "Leveraging State Clean Energy Funds for Economic Development," (Brookings Institute, January 2012), http://www.brookings.edu/~/media/research/files/papers/2012/1/11%20states%20energy%20funds/0111_states_energy_funds.

[111] See L. Milford et al., "Leveraging State Clean Energy Funds." See also M. Muro and K. Fikri, "Job Creation on a Budget: How Regional Industry-Clusters Can Add Jobs, Bolster Entrepreneurship and Spark Innovation," (Brookings Institute, January 2011), http://www.brookings.edu/~/media/research/files/papers/2011/1/19%20clusters%20muro/0119_clusters_muro.pdf.

Authority, or "Green Bank." CEFIA is a quasi-public bank that uses public sector capital to leverage greater private sector investment in energy efficiency, renewable energy, and other clean energy technologies. Funded primarily by an electricity bill surcharge, CEFIA runs several programs, including the Clean Energy Fund that invests $20 million annually in a wide range of renewable energies and clean technology.[112] Another promising approach is the Massachusetts Clean Energy Center (MassCEC), which provides capital to growing companies and makes venture capital investments in early-stage companies. It has awarded $8 million in equity investments, loans, and grants and has leveraged nearly $285 million in additional funds.[113]

States can develop such programs by transforming existing public financing programs to allow private investment and clean energy investments, transforming existing grant authorities into lenders that can leverage private funds with partnership agreements, attach clean energy finance banks to an existing infrastructure bank, or both.[114]

Proposals that go beyond state efforts have focused on regionally or nationally coordinated efforts to leverage private investment. For example, a joint policy proposal by the Clean Energy Group (CEG) and the Council of Development Finance Agencies (CDFA) would establish a federal program housed at the Treasury Department to oversee state-operated financing programs emphasizing bond finance.[115] It would also establish a regional program proposed by MIT's Professor Richard Lester that would have states put an innovation surcharge on retail electricity and then allocate the funds to regional venture investment banks for investments to leverage private capital for carbon-mitigating projects.[116]

Federal Taxation Strategies to Leverage Private Sector Investment

Tax policy—such as the wind production tax credit, for example—has in the past and can continue to play a key role in promoting innovative clean air and energy technologies. Achieving enactment of federal legislative solutions is always uncertain, but there appears to be significant bipartisan interest in promoting investment in clean energy innovations at the federal level through tax policies that could help open access to private sector capital for innovative technology investment. Proposals include:

- **Clean energy REITs and MLPs:** Financing mechanisms established for other industries, such as real estate investment trusts (REITs) and master limited partnerships (MLPs), could be extended to innovative energy projects.[117] Although REITs are traded publicly like stocks, they tap broader pools of capital to lower the cost of financing. MLPs have the fund-raising advantages of a corporation in that ownership interests are publicly traded, and they have the liquidity, limited liability and dividends of classic corporations, so MLP investment vehicles could substantially reduce the cost of financing renewables if such investments were permitted. The IRS would need to clarify the eligibility of innovative energy technologies for REITs and MLPs.[118]

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[112] Database of State Incentives for Renewables and Efficiency, "Connecticut Clean Energy Fund (CCEF)," accessed Nov. 8, 2012, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CT03R&re=1&ee=1.
[113] L. Milford et al., "Leveraging State Clean Energy Funds."
[114] K. Berlin et al., "State Clean Energy Finance Banks."
[115] See CEG and CDFA, "CE+BFI State Clean Energy Finance Initiative Proposal," February 2013.
[116] See R. Lester, "Look to the States," *Boston Globe,* Jan. 27, 2013, op ed.
[117] See "How to Make Renewable Energy Competitive," by F. Mormann and D. Reicher of Stanford's Steyer-Taylor Center for Energy Policy and Finance, *New York Times*, June 1, 2012, op ed, http://www.nytimes.com/2012/06/02/opinion/how-to-make-renewable-energy-competitive.html?pagewanted=all#h[BclWst,6].
[118] The tax code currently bars master limited partnerships from investing in "inexhaustible" natural resources like solar and wind while allowing investments in exhaustible resources like coal and natural gas. Congress did amend the tax code in 2008 to enable master limited partnerships to invest in alternative transportation fuels like ethanol.

- **Repatriation of off-shore funds:** Proposals to channel stranded off-shore capital into domestic clean tech investment through tax reforms are appealing to some even though "tax-holiday" proposals general meet with some resistance.[119] U.S. businesses have an estimated $1 trillion in bank accounts outside of the United States, and current tax policy, which levies a 35% repatriation fee, discourages re-investing the funds in the United States. The New England Clean Energy Council has advocated reducing the repatriation tax to 1% and requiring that the funds be directly invested into clean energy scale-up, generation, manufacturing, and deployment projects.

- **CCS tax credit:** The Center for Climate and Energy Solutions (C2ES) has proposed that an existing tax credit for the sequestration of CO_2 in enhanced oil recovery (EOR) operations be improved and expanded, arguing that over time the proposed incentive would generate net federal revenue through oil royalties and tax payments and would also improve the economic viability of carbon capture and storage technologies as well as reduce emissions.[120]

In short, as the clean energy investment sector undergoes transformation, new ways to invest in clean energy are being developed because there are and will continue to be good returns, ranging from economic profits to economic and environmental benefits. An important goal is identifying how to link evolving clean technology financing strategies with the EPA's evolving clean air and climate programs. Regulatory policies that provide credit for development and deployment of clean energy technologies, and for the environmental benefits associated with them, can help create demand for new technologies and, if implemented, can provide latitude for experimentation and foster both competition and innovation. The emerging markets for clean air emissions overseas and domestically (such as trading programs in Australia, the northeast Regional Greenhouse Gas Initiative and California's AB 32 programs) and the developing federal GHG regulatory program ensure continued demand for new, cleaner energy technologies.

CONCLUSION

This paper identifies a number of potential regulatory tools under the Clean Air Act, along with accompanying non-regulatory tools, which could accelerate the development and deployment of potentially game-changing clean air, clean energy, and climate technologies in the nation's key industrial sectors. The challenge is how to effectively utilize and combine subsets of these tools. The answer will almost certainly be different with respect to each industry sector and class of new technologies. The working hypothesis of the Nicholas Institute is that bringing together key stakeholders—sector by sector—could help sort out which combination of public and private sector tools could most effectively accelerate deployment of emerging technologies in each sector. Over the course of 2013, the Nicholas Institute will test this hypothesis by convening sectoral roundtables to explore the working concepts presented in this paper and whether and how they could be of use in promoting needed innovative clean air and clean energy technologies in sectors with energy and emissions intensive activities. The roundtables will be comprised of leading regulated companies with demonstrated environmental performance track records from each sector and other stakeholders such as regulators, environmental advocates, energy and economic policy analysts, financial investment experts, and others with interest in promoting innovative technology deployment to achieve clean air and clean energy goals.

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[119] See R. Hunt and T. Mann, "Rebuild American Infrastructure? Companies' Offshore Profits Can Help," *Washington Post,* June 16, 2011, editorial.
[120] See C2ES, "Recommended Modifications to the 45Q Tax Credit for Carbon Dioxide Sequestration," (February 2012).

APPENDIX: INNOVATIVE TECHNOLOGIES IN KEY INDUSTRIAL SECTORS

This Appendix briefly describes some promising types of innovative clean air and clean energy technologies in three key industrial sectors, and provides a few representative examples. For each sector, innovations are identified that include proven but under-deployed technologies as well as developing technologies and potential game changers. Industry efforts to develop and deploy innovations such as those outlined here could be supported through more innovative ways of implementing CAA stationary source regulatory programs.

Power Generation

Developing successful CAA strategies for the utility sector is important because the scale of the sector's conventional pollutant, toxic, and greenhouse gas emissions is huge: for example, electric power generation accounts for about 34% of the nation's total GHG emissions, compared with about 20% for the industrial sector generally.[121] A complex web of CAA and other environmental requirements, including clean air transport program requirements, utility MACT and NSPS standards, GHG requirements, NAAQS revisions, and other environmental regulations relating to cooling water intakes, effluent guidelines, and coal ash combustion make the need for innovative air and energy technologies particularly pressing.[122] Equally important, many such technologies—especially advanced renewable energy (RE) and energy efficiency (EE) technologies—could be broadly deployed in the near term in the power sector, making reductions cheaper in that sector than in other sectors. Addressing technology deployment barriers relating to cost, grid access, and competition and regulation in the public utility sector could accelerate this effort.[123]

Proven Technologies Needing Broader Deployment

Energy efficiency technologies are widely recognized to provide significant near-term opportunity to achieve air emission reductions. Relatively low-cost EE opportunities in the context of power generation and power use include

- **Power plant operations:** increasing the efficiency of combustion technologies, fuel sources, and cooling processes;

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121 See EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010," EPA 430-R-12-001 (April 15, 2012). The 20% associated with the industrial sector does not include emissions due to the sector's electricity use. In a 2008 draft EPA report that expressly attributed to each sector responsibility for the GHG emissions associated with electricity consumption, EPA found that the industrial sector was responsible for about 30% of total 2002 GHG emissions, factoring in purchased electricity. See EPA, "Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States," (working draft, May 2008), 1–1, available online.

122 In recent years, the Edison Electric Institute (EEI), National Economic Research Association (NERC), and others have published timelines and papers detailing a "train wreck" of environmental regulations facing the industry and related concerns about impacts on the economics of electric generation, fuel choice, and energy reliability. As a CRS evaluation concluded, most of the regulatory impacts were based on projections made before the EPA released the regulations (or courts reviewed them), and actual control requirements have been less than projected. See J. McCarthy and C. Copeland, "EPA's Regulation of Coal-Fired Power: Is a Train Wreck Coming?" prepared for the Congressional Research Service (July 11, 2011). Factors other than environmental regulation have been seen to have greater impact in the short term, such as increasing supplies of natural gas and renewables, for example.

123 See J. Monast and S. Adair, "A Triple Bottom Line for Electric Utility Regulation: Aligning State-Level Energy, Environmental, and Consumer Protection Goals," *Col. J. of Env. Law* 38, no.1 (2013).

- **Energy distribution:** implementing demand-response management, monitoring and measuring tools, and power conservation mechanisms;
- **Greener building:** improving automation, lighting, HVAC systems, and refrigeration;
- **Greener products:** deploying advances in energy-efficient electronics, appliances, and semiconductors.

Many innovative RE technologies, including in solar, wind, hydropower, geothermal, biomass, nuclear, and hydrogen and fuel technologies, similarly are available today. If broadly deployed in conjunction with EE efforts, they could help the United States make great strides toward a cleaner energy economy.

Combined heat and power (CHP), also known as cogeneration, is an efficient process that combines electricity and heat production from a single fuel input, and offers potentially significant climate and clean air benefits. Currently less than one-tenth of the nation's electric generation is produced with CHP, meaning that the majority of heat generated by electricity production is wasted.[124] Because CHP is most efficient when heat is used on or close to the power generation site, the most common applications are in heating systems for institutions such as hospitals, prisons, oil refineries, paper mills, wastewater treatment plants, and industrial plants with large heating needs.

Developing Technologies and Potential Game Changers

Promising technologies and game-changing technologies abound in the power sector, but their emissions impacts and timelines for development and deployment can vary widely and are uncertain.

Pollution abatement technologies for coal-powered plants continue to advance. They include

- software to optimize plant emissions control, efficiency, costs, and reliability;
- improved circulating fluidized-bed (CFB) technology, including supercritical and ultra-supercritical combustion;
- oxy-combustion for collecting CO_2-rich flue gas;
- combustion of biomass as a fuel;
- gasification to convert coal into substitute natural gas (SNG); and
- coal-to-liquids projects.

NET Power, a venture of Exelon, Toshiba, and the Shaw Group, promotes an innovative oxyfuel gas-fired power generation technology to cost-effectively produce electricity and pipeline-ready CO_2 for sequestration or enhanced oil recovery (EOR). A 25MW natural gas plant is expected to begin operating in mid-2014; construction of the first 250MW plant is scheduled to begin in late 2014 or early 2015.[125]

124 U.S. Dept. of Energy, "Combined Heat and Power: A Clean Energy Solution," (August 2012): 3.

125 As noted above, Net Power is a technology developed by 8 Rivers Capital, a Durham-based firm whose Advisory Board is chaired by Tim Profeta, Director of the Nicholas Institute, and Duke University School of Law also has an ownership interest in Net Power through shares donated to the law school by the founders of 8 Rivers Capital.

Advancing EE and RE technologies are important because broader deployment of EE and RE technologies is one of the more cost-effective and feasible ways to promote short-term progress on clean air, climate, and energy goals. Potential solar improvements, alone, include concentrated solar plants, thin film, more efficient solar panels (glass panels, roof shingles, micro and nano solar), and flexible solar cells that can coat any item. Other RE technologies (wind, biomass, nuclear, hydropower, geothermal) are similarly advancing.

Solaris Synergy is piloting concentrated photo-voltaic technology that floats on water surfaces. The idea is to avoid the barriers to solar deployment associated with land use planning permits and other land-based ecological resource issues. Because the technology reduces evaporation, it could be ideal for reservoirs.

Advancing energy storage technology also is key to optimizing many aspects of the energy delivery system, from generation to transmission and distribution. Advanced energy storage**,** particularly when combined with smart and microgrid technologies, could have game-changing impacts by allowing broader and more reliable use of renewables, electric vehicles, and other power generation innovations and by helping to address transmission constraints on the grid. Energy storage technologies can be based on electrochemical, mechanical, or thermal methods and have differing costs, efficiencies, and life cycles that affect their applications. Advancing storage technologies include

- batteries with larger capacity for long-term storage of electricity;
- super capacitors and superconducting magnetic storage;
- fly wheels and other frequency regulators that store kinetic energy;
- pumped hydro, hydrogen storage, and thermal storage; and
- compressed air energy storage (CAES).

Ambri is developing utility-scale energy storage based on liquid metal battery technologies to address solar and wind intermittency generation. The idea is to provide a way for utilities to store energy when demand is low and release it during peak demand periods. The project received early funding from MIT, a $6.95 million grant from ARPA-E in 2009, and private sector investment from Khosla Ventures and Bill Gates.

Smart-grid technology refers to devices that use computer-based remote control and automation to improve control and real-time management of the electric grid to increase energy reliability, efficiency, and the use of cost-optimizing intermittent energy sources. Advancing smart-grid technologies include advanced sensors and measurement devices, distribution automation, superconductors, high voltage DC and control devices, and software advances in the areas of transmission, distribution, energy storage, power electronics, and real-time measures.

Microgrid technology refers to discrete energy systems that have multiple distributed energy sources for their load, such as renewables, conventional sources, and storage units, and that can operate in conjunction with, or independently from, the main grid. Microgrids may be utility or customer owned but tied to the grid, or they may be entirely remote, as in the case of mobile military microgrids. In the United States, most microgrids are operated by public institutions such as the military and universities,

but advancing technologies are making other applications viable. Microgrids can achieve specific localized goals such as reliability, energy diversification, and CO_2 reduction by facilitating use and integration of renewable energy sources in communities or institutions, while increasing reliability, freeing peak capacities, improving cyber-security, and promoting energy technology innovation. Microgrid-enabling technologies include distributed generation (RE, fuel cells), advanced energy storage, and internal forms of automated demand response (ADR).

Spirae in Colorado and **Energinet** in Denmark are developing scalable smart-grid technologies to optimize grid management and control distributed generation from renewable energy sources such as wind and solar, fuel cells, and CHP.

Carbon capture storage (CCS) and use or storage (CCUS) technologies could have game-changing impacts not only for the coal and power sector but also for other highly combustion-dependent sectors like refineries and cement kilns. CCUS technologies in development include mineral carbonation technologies (using CO_2 emissions to create products), chemical looping (combustion with iron oxide rather than oxygen to produce power, gas, or hydrogen in addition to high purity CO_2), and gas-separation technologies followed by CO_2 compression and capture. The most common use for captured CO_2 is enhanced oil recovery applications.

Skyonic has a technology that removes CO_2 from industrial waste and transforms it into solid carbonate or bicarbonate materials that can be marketed or stored long term in mines or as landfill, making CO_2 storage possible in areas where geological storage is not feasible. The process also removes SOx and NO_2 from flue gas and heavy metals such as mercury, eliminating the need for scrubbers. Skyonic projects that the technology will offset about 15% of CO_2 emissions from a commercial-scale carbon-capture plant that it is building.

Innovative technology combinations in the power sector also offer great potential for game-changing impacts in the short term. For example, cost-effective energy storage advancements combined with strategic, cost-effective microgrids could permit renewable generation (and other clean energy technologies such as electric vehicles) to be much more broadly deployed and could dramatically improve the outlook for meeting climate, air, and energy goals.

Atlantic Hydrogen Inc. has a plasma-based process to remove some of the carbon from natural gas pre-combustion to produce a stream of hydrogen-enriched natural gas (HENG); the process also produces pure hydrogen that can be used to generate electricity in fuel cells. Thus, if scalable, it could enable much greater use of fuel cells at industrial sites.

Refining and Chemical Manufacturing

Refining and chemical manufacturing sector processes often are located near each other in heavily industrialized areas and are often interlinked. Chemical plants use oil and gas products as feedstock and also consume natural gas and electricity to power production. As a result, innovative technology and regulatory solutions for these sectors should be jointly evaluated.

Due to the energy-intensive nature of their operations, the refining and chemical sectors combined are equivalent to power generation with regard to scale of CO_2 emissions.[126] Refining is expected to become even more energy intensive as the sector increasingly processes heavier and dirtier crude oils and processes them to higher levels. The sector uses synthetic fuels as blending components for diesel fuel, undertakes coal-to-liquid (CTL) and gas-to-liquid (GTL) processing, and increasingly refines fuels to meet regulatory standards, such as ethanol to meet biofuel standards and diesel fuels to meet low sulfur standards.

Thus, emissions reductions in the refining and chemical manufacturing sectors could have a significant environmental impact, as could efficiency opportunities within the sectors' interconnected production processes. Regulatory strategies to promote deployment of innovative technologies in these sectors also could provide insights for developing synergistic solutions in other sectors with beneficial interactions, such as the waste disposal and reuse sector in combination with certain manufacturing sectors.

Proven Technologies Needing Broader Deployment

Energy efficiency and process improvements can reduce energy loss during energy-intensive refining and chemical manufacturing processes such as distillation, hydro-treating, alkylation, and reforming processes. Catalysis, for example, lowers the heat input necessary to convert feed into products. Energy efficiency opportunities in the refining and chemical manufacturing sectors include improved energy management and control, energy recovery, steam generation and distribution, heat exchangers and process integration, process heaters, distillation, hydrogen management and recovery, motors, pumps, compressors, fans, and lighting.[127]

Significant unused CHP implementation capacity also exists in these sectors, particularly in chemical manufacturing contexts, even though both refining and chemical manufacturing are relatively more highly invested in **CHP** than other sectors and together represent about half of CHP capacity in the United States.[128]

Developing Technologies and Potential Game Changers

Biochemical advancements in pollution abatement technologies are being developed by many chemical companies. Bioremediation of oil spills with genetically engineered microbes is probably the best known innovation, but biochemical technologies associated with emissions reductions are also being developed. For example, microbe-based technologies to convert heavy oil at its source to lighter grades of oil or to convert sour gas to sweet gas have great potential value to decrease the carbon footprint of refining operations.[129]

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[126] Factoring in electricity consumption, the EPA estimated that the oil and gas sector was responsible for 24% of total 2002 GHG emissions and the chemical industry for 18%. See EPA, "Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States," (working draft, May 2008).
[127] The EPA identifies such technologies in a March 2007 report on energy trends in selected manufacturing sectors.
[128] EPA, "Combined Heat and Power: A Clean Energy Solution," (August 2012), 11 and 13.
[129] Society of Petroleum Engineers, "In-Situ Molecular Manipulation," (white paper, August 23, 2011), available online.

Ciris Energy plans to more cost-effectively convert underground coal to natural gas. The company's in-situ bioconversion (ISBC) technology that activates indigenous microbes in coal seams is being implemented in the Powder River Basin to recover gas from the previously depleted Big George coal seam.

Biogas & Electric has a NOx and SOx reduction add-on technology for biogas engines that reduces emissions during anaerobic digestion by putting the biogas engine exhaust in contact with the liquid waste stream. The bench-scale prototype reduced NOx and SOx each by more than 95% each.

The emerging bio-refining or biofuel manufacturing industry is developing a range of technologies for fuels from non-fossil sources, including algal oils, ethanol, cellulosic ethanol, biodiesel, methanol, drop-in synthetic fuels, and biogas. These technologies are in various stages of development and deployment and are expected to be game changers.

Envergent Technologies, a division of Honeywell, has developed a process to convert cellulosic biomass feedstock into pyrolysis oil, a clean-burning liquid that can replace petroleum-based fuel oil for process heat, power generation, and, with further refining, transportation fuels. In 2011, Honeywell began construction in Hawaii of an integrated demonstration project, supported by a $25 million award from DOE.

Mercurius Biofuels is developing cellulosic fuel technology to make diesel fuel and to produce a gasoline range blending component and various green chemicals in a process that could be more economically viable than other biofuels processes.

Cool Planet Biofuels has produced 3,000 gallons of biofuel per acre from giant miscanthus. The company, whose investors include Google and GE, expects its first mass producible plant, nearing completion in 2013, to produce 400,000 gallons per year in sub-scale systems.

Technologies for transforming CO_2 or other GHGs such as methane into materials that can be used in making fuels or other products are also being developed and are potential game-changers. For example, university laboratories are modifying biological organisms to use carbon as a food to make isobutanol and are pursuing electrochemical production of methanol or butanol from CO_2. Any technologies that can transform CO_2 into useful products or fuels not only could help address climate concerns but also could provide cost-offset opportunities through product sales.

Lanzatech has developed biotechnology to take a high CO_2 waste stream, such as from a steel mill, and produce ethanol and other hydrocarbons for use in gasoline or as a chemical feedstock.

FlexEnergy has a pilot in Orange County, California, with eight power stations that use low-quality landfill methane gases that typically are flared to generate electricity.

Skyonic's carbon capture process, detailed above, produces minerals that if not stored can be used in manufacturing other products, such as glass, paper, and a base to grow algae as a feed for aquaculture.

Innovative technology combinations in the refining and chemical manufacturing sectors also exist. For example, the methane produced by anaerobic digestion can be used for electricity generation—either on site or distributed through a grid—or could produce natural gas distributed through a pipeline. If developed to scalability and broadly deployed, these technology combinations could provide significant emissions and climate gains as well as help address other environmental concerns associated with large waste-generating operations, such as waste lagoons at concentrated animal feeding operations (CAFOs) or at landfills.

Cement Manufacturing

After power generation and refining and chemicals, the next most energy- and emissions-intensive manufacturing industries are cement, iron and steel, and paper and pulp, each of which accounts for about 5 to 7% of total national emissions.[130] Of these, the cement industry is particularly promising for achieving significant emissions reductions through innovative technology deployment because it has relatively inefficient production processes and faces tightened criteria and toxics standards that will require the industry to develop new production processes.

Cement manufacturing has a single emissions source, the cement kiln. Conventional production processes involve the production of clinker (lumps of fused residue) by heating limestone and clay to very high temperatures. The clinker is then ground with the addition of gypsum to become cement. The industry is developing clinker substitutions and other ways of producing lower-carbon cements as well as carbon capture technologies for cement kilns.[131] However, these new technologies are unlikely to be broadly deployed without supportive economic and regulatory policies.

CAA strategies to accelerate the technologies must recognize some sector-specific challenges. The availability of alternative raw materials, fuels, and clinker substitutes differs widely across the country, necessitating regulatory options that allow emissions and efficiency goals to be tailored to local circumstances. CAA strategies must also take into account that deployment of cement manufacturing technology is constrained by nonenvironmental regulatory policies, such as cement product standards, building codes, and waste management practices.

[130] EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010," (April 2012), 2–16.
[131] See EPA, "Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Portland Cement Industry" (October 2010), available online.

Proven Technologies Needing Broader Deployment

Much can be done to modernize cement manufacture operations and facilities. The process for transforming raw materials such as limestone and clay into clinker, known as pyroprocessing, is highly inefficient, particularly at older wet-process kilns.

Energy efficiency and renewable energy improvements that forward-thinking companies are undertaking include

- more efficient dry and semi-dry processes;
- better energy management, preheaters, and precalciners;
- more efficient fluidized bed systems; and
- site-specific electricity generation through waste heat recovery and wind power.

Broader deployment of alternative fuels has significant emissions reduction potential in the cement manufacturing sector because fuel-related emissions account for about 40% of the sector's GHG emissions.[132] Alternative fuels don't have to be incinerated or landfilled as waste and, when burned in a controlled environment, *can* have better emissions outcomes than fossil fuel burning. But waste management regulation significantly affects the availability and cost of alternative fuels, which include discarded tires, pre-treated industrial and municipal solid wastes, waste oil and solvents, plastics, textiles and paper mill, and biomass (animal meal, logs, wood chips, agricultural residues, sewage sludge, and biomass crops).

Developing Technologies and Potential Game Changers

Advances in oxyfuel and end-of-pipe controls that do not require fundamental changes in the clinker-burning process are viewed as most economical for retrofits in the cement industry. Technologies being explored include:

- oxyfuel technologies that use oxygen rather than air in cement kilns to produce comparatively pure CO_2 streams;
- membrane technologies, where suitable materials and cleaning techniques can be developed;
- chemical absorption of CO_2 using amines, potassium; and other chemicals that have been successful in other industries; and
- adsorption processes known as carbonate looping that produce calcium carbonate by putting CO_2 combustion gas in contact with calcium oxide.

Use of clinker substitutes could significantly reduce energy use and related emissions in the cement sector because the production of clinker, which is the main component in most cement, is energy intensive and the most CO_2-emitting step of the cement-manufacture process. Potential substitutes include:

- furnace slag from iron or steel production,
- fly ash from coal-fired power plants,
- natural pozzolanas (volcanic ash), and
- less well-known artificial pozzolanas such as calcined clay.

[132] See DOE, Industrial Technologies Program, "Energy and Emission Reduction Opportunities for the Cement Industry," (2003), 24; see also International Energy Association, "CO_2 Abatement in the Cement Industry," (July 2011), 1.

Lafarge has developed a cement product called Aether, which reportedly has 25% to 30% lower CO_2 emissions than typical cement. It is made from the same raw materials but in a process that requires less energy.

Schwenk KG, a German building materials manufacturer, and the Karlsruhe Institute of Technology are developing a new form of cement based on a hydraulic binding agent called Celitement. Production is slated to begin in 2017 and is projected to emit half the CO_2 of ordinary Portland cement production.

Advances in geopolymer cement manufacture, in which companies make cement from industrial waste, are also being developed. The geopolymer process was first developed in the 1950s and is supported by the Geopolymer Institute. Because geopolymer cement is made from aluminum and silicon, instead of calcium and silicon, it does not require an energy-intensive calcination process and avoids releasing vast quantities of CO_2 during manufacture. Performance varies according to the chemical composition of the source materials, and geopolymer cement has been commercialized only in small-scale facilities to date. Waste materials that can be used in the production process include

- wet-form waste from the paper, mining, and petroleum industries that is usually deposited on open land;
- fly ash from coal-fired power plants;
- blast furnace slag from iron and steel plants; and
- red mud from the aluminum industry.

Zeobond, an Australian company, markets a geopolymer cement but limits its use to flooring, ground, and wall applications. According to the company, a life cycle analysis shows the product the CO2 footprint of the product is only 20% that of traditional Portland cement.

Less carbon-intensive production processes and carbon capture processes are also being developed for cement manufacturing, although most technologies are in early stages of being demonstrated and performance varies. Similarly, recognized opportunities for game-changing technology combinations in the cement manufacturing sector are relatively few, but sector-based stakeholder groups could help identify promising combinations for exploration.

Novacem, a UK-based company, makes a cement from magnesium oxides in a process that results in more CO_2 being absorbed from the atmosphere while the cement is hardening than is released during manufacture. The company is operating a laboratory pilot and projects construction of its first commercial-scale plants in 2018.

Calix, an Australian company, is developing a process to capture the CO_2 released in cement manufacturing through rapid calcination of dolomitic rock in a superheated steam and CO_2 emissions capture in a separate scrubbing stream. The CO_2 capture technology can also be used in other industries.

In short, the nature and range of innovative clean air and energy technologies available for broader deployment in the nation's key industrial sectors, as well as those nearly market ready and in advanced stages of development, are promising. CAA implementation strategies and related supportive public policies could accelerate the rate at which these technologies are finalized, adopted, and broadly deployed, achieving significant air, energy, and climate goals for the nation. Such policies can also be designed to promote investment in less-developed technologies with game-changing potential.