Air Quality

History of the Clean Air Act

The Clean Air Act (CAA) was the first major federal environmental law in the U.S. that required the development and enforcement of regulations to protect the general public from air pollutants known to harm human health. The CAA was passed in 1963, but the first law to resemble air quality rules as we know them today was the Clean Air Act Amendments of 1970. These Amendments provided the framework for air quality regulation in the United States that remains in effect today. Importantly, these Amendments differentiated areas of the country with relatively good air quality (those meeting established ambient standards, known as "attainment" areas) from those with relatively poor air quality (known as "nonattainment" areas) and created different rules to regulate air pollution based on these different areas. Congress again passed significant amendments to the CAA in 1977, which established increasingly stringent requirements on new and existing air emission sources. Even with the more stringent requirements included in the 1977 Amendments, many areas of the country continued to have trouble meeting the National Ambient Air Quality Standards (NAAQS). Despite this fact, Congress stalled the development of new air quality legislation at the federal level for many years, until it passed the Clean Air Act Amendments of 1990.

Among other issues, the Amendments of 1990 addressed what Congress saw as four significant threats to the health and welfare of Americans, all of which have affected power plants and other sources of air pollution:

- Acid rain and regional haze (Title IV of the CAA) – For the first time, required cuts in sulfur dioxide (SO2) and nitrogen oxides (NOx) emissions from fossil fuel-fired power plants to prevent acidic deposition and improve visibility. Title IV of the 1990 CAA Amendments established the first "cap and trade" program for SO2 emissions designed to use market forces and pollutant trading to drive pollution control.

- Toxic or hazardous air pollution (Title III of the CAA) – Identified 189 Hazardous Air Pollutants (HAPs) and, for the first time, established control technology-based standards for various types of sources, most requiring at least 95% reduction in HAP emissions.

- Urban air pollution (Title I of the CAA) – In addition to the new toxics provisions, greatly expanded the number and types of pollutants and sources subject to regulation to address persistent "ozone smog" pollution in most metropolitan areas.

- Stratospheric ozone depletion (Title VI of the CAA) – Identified and regulated, for the first time, ozone-depleting substances (ODS) and provided a framework for U.S. participation in the "1987 Montreal Protocol on Substances that Deplete the Ozone Layer."

History of International Climate Change Initiatives

A global effort on climate change initiatives has been pursued for decades. The 1992 United Nations Framework Convention on Climate Change (UNFCCC or the Convention) provides the foundation for multilateral action to combat climate change and its impacts on humanity and ecosystems. The objective of the UNFCCC is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The 1997 Kyoto Protocol and the 2015 Paris Agreement were negotiated under the UNFCCC and built on the Convention.

The Kyoto Protocol was agreed upon in December 1997 in Kyoto, Japan. It includes an obligation and individual legally binding emission reduction targets for developed countries. The Protocol had two commitment periods: the first ran from 2008–2012, and the second ran from 2013–2020.

In December 2015, governments adopted the Paris Agreement, which commits nearly all countries to:

- Limit global temperature rise to well below 2 degrees Celsius (°C), and preferably to 1.5°C, above pre-industrial levels.
- Submit and periodically update Nationally Determined Contributions national climate action plans (NDCs).
- Enhance adaptation, resilience, and finance flows to developing nations.

Greenhouse Gas Policies

Evidence of a rising average global temperature has driven global efforts to reduce human impact on Earth's climate. Human activities, such as fossil fuel combustion for electricity generation and transportation, industrial processes, and changes in land use, including deforestation, contribute significant amounts of CO_2 and other greenhouse gases (GHGs) to the atmosphere. At the turn of the 21st century, record-high levels of atmospheric concentrations of GHGs sparked national debate about the responsibility to reduce human contribution to global climate change.

Some of the potential impacts associated with increased GHG levels in the atmosphere are global temperature increases, sea-level rise that may gradually inundate coastal areas and increase shoreline erosion, flooding from coastal storms, changes in precipitation patterns, increased risk of severe weather events and droughts, threats to biodiversity, and challenges for public health and wellness.

The electricity sector is particularly vulnerable to the effects of sea level rise and extreme weather events. If global temperatures continue to trend upward, sea levels will continue to rise and extreme weather events are likely to occur more frequently. Thermal generating units often require large quantities of cooling water, which has resulted in the siting of these facilities

adjacent to large water bodies, often in tidal waters. Therefore, investments in renewable energy stations sited in areas not affected by sea level rise and investments that modernize our transmission grids are necessary to make our electric systems more resilient and reliable.

As published in Chapter 1 of "A Sustainable Chesapeake,"[1] historical tide-gauge records indicate that Maryland's coastal waters have increased by one foot in the past 100 years and are projected to continue to rise by approximately one meter by 2100 relative to 2005 levels,[2] which is expected to convert 260,000-926,000 acres of land in the Chesapeake Bay region to tidal marshes.[3] As sea levels continue to rise, coastal floods reach higher lands, threatening the reliability of power plants in the affected regions and increasing the number of electric facilities put at risk. "Maryland and the Surging Sea" reports that seven generating stations in Maryland are sited less than nine feet above local high tide, and three facilities are sited less than five feet above high tide.[4] Maryland has 3,190 miles of shoreline, making it highly vulnerable to the effects of sea-level rise associated with climate change.[5]

Another effect of climate change is more frequent heat waves. In Maryland, the mean annual temperature increased from 1977 to 1999 by 2°F according to the "Comprehensive Assessment of Climate Change Impacts in Maryland."[6] The study also indicated that in the late 1990s, there was an average of 30 days per year with maximum daily temperatures greater than 90°F. The number of days with a daily temperature greater than 90°F is expected to double by the end of the century. These trends suggest that extended heat waves in Maryland are likely to occur more frequently and last longer. Extreme heat creates periods of high energy demand due to increased use of air conditioning and cooling equipment, while at the same time, warmer ambient temperatures in surface water bodies can reduce efficiency at power plants that rely on cooling water.

Regional Greenhouse Gas Initiative (RGGI)

State Participation

Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont currently participate in RGGI. In 2020, the governor of

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[1] The Conservation Fund (n.d.). "A Sustainable Chesapeake: Better Models for Conservation."
[2] Boesch, D. F., Baecher, G. B. & Boicourt, W. C. et al. (2023) *Sea-level Rise Projections for Maryland 2023.* University of Maryland Center for Environmental Science.
[3] Carr, C. A., Ganju, N, K., Kirwan, M, L. & Molino, G, D. (2022) *Variability in marsh migration potential determined by topographic rather than anthropogenic constraints in the Chesapeake Bay region*. Association for the Sciences of Limnology and Oceanography. https://aslopubs.onlinelibrary.wiley.com/doi/10.1002/lol2.10262
[4] Strauss, B., Tebaldi, C. & Kulp, S. et al. (2014). *Maryland and the Surging Sea: A vulnerability assessment with projections for sea level rise and coastal flood risk*. Climate Central Research Report. https://www.umces.edu/wp-content/uploads/2026/06/Maryland-Sea-Level-Rise-Projections-2023-report.pdf sealevel.climatecentral.org/uploads/ssrf/MD-Report.pdf.
[5] Maryland Department of Natural Resources, Watershed & Climate Services. https://dnr.maryland.gov/ccs/pages/coastal-planning.aspx
[6] Scientific and Technical Working Group of the Maryland Commission on Climate Change (2008). *Comprehensive Assessment of Climate Change Impacts in Maryland*, Chapter 2. mde.maryland.gov/programs/air/climatechange/documents/final-chapt%202%20impacts_web.pdf.

Pennsylvania initiated a process for the commonwealth to join RGGI.[7] Once the commonwealth's CO_2 Budget Trading Program (i.e. their regulation pursuant to RGGI) was finalized in 2022, it was met with litigation. The matter has ultimately made its way to the Pennsylvania Supreme Court, but before the Court was able to reach a decision, the Pennsylvania CO_2 Budget Trading Program was repealed through a budget bill signed on November 12, 2025.[8] The Supreme Court of Pennsylvania has decided to dismiss all remaining cases on this matter, deeming them moot. [9,10]

Virginia enacted legislation to join RGGI in 2020 and subsequently joined RGGI in January 2021. In 2022, former Governor Glenn Youngkin issued an executive order to begin a regulatory process for withdrawing the commonwealth from RGGI.[11] The Virginia State Air Pollution Control Board voted to withdraw from RGGI in June 2023.[12] Virginia officially withdrew from RGGI in 2024 and will rejoin in 2026, following the passage of HB 397.

RGGI Background and Emissions Cap

Initially, CO_2 emissions were capped from 2009 through 2014 at 188 million allowances (or short tons). This cap level was determined in 2005 and was based on the goal of maintaining expected 2009 emissions, which at the time were projected to increase by about 4 percent from average emissions observed between 2000 and 2002.[13] A phased approach was used to provide regulatory certainty for electricity generators to begin planning for, and investing in, lower-carbon alternatives without creating dramatic electricity price impacts. The annual allowances were reduced to 165 million tons following New Jersey's exit from the RGGI program at the end of 2011. RGGI states agreed that they would continue to recognize allowances that were in circulation and had been sold by New Jersey for generator compliance.[14] The departure or joining of a state does not impact the CO_2 budgets of other RGGI states.

Then, following the 2012 program review, the CO_2 emissions cap was reduced by 45 percent to 91 million tons in 2014. The ultimate decision to reduce the cap was to better align the cap with observed emissions levels, which had decreased significantly since the start of the program largely due to low natural gas prices causing a shift toward natural gas and away from coal, and

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[7] Executive Order of the Commonwealth of Pennsylvania Governor's Office (2020). https://www.pa.gov/content/dam/copapwp-pagov/en/oa/documents/policies/eo/2019-07.pdf

[8] Routh, R. (2025). "Unprecedented: Pennsylvania's RGGI Repeal." NRDC. nrdc.org/bio/robert-routh/unprecedented-pennsylvanias-rggi-repeal#courts

[9] Hall, P. (2026). "Pa. Supreme Court dismisses appeals to revive RGGI carbon credit program." Pennsylvania Capital-Star. penncapital-star.com/briefs/pa-supreme-court-dismisses-appeals-to-revive-rggi-carbon-credit-program/.

[10] Huangpu, K. &Meyer, K. (2023). "Gov. Josh Shapiro appeals decisions that struck down key climate program to Pa.'s highest court." Spotlight PA. spotlightpa.org/news/2023/11/pennsylvania-josh-shapiro-climate-change-appeal-regional-greenhouse-gas-initiative-court-case/#:~:text=HARRISBURG%20%E2%80%94%20Gov.,emissions%20and%20fight%20climate%20change.

[11] Commonwealth of Virginia, Office of the Governor (2022). Executive Order Number 9, "Protecting Ratepayers from the Rising Cost of Living Due to the Regional Greenhouse Gas Initiative."

[12] Staley, M. (2023). "Virginia's Air Pollution Control Board votes to withdraw from RGGI agreement."whsv.com/2023/06/12/virginias-air-pollution-control-board-votes-withdraw-rggi-agreement/

[13] Congressional Research Service (Updated 2017). "The Regional Greenhouse Gas Initiative: Lessons Learned and Issues for Congress." congress.gov/crs_external_products/R/PDF/R41836/R41836.14.pdf.

[14] The Regional Greenhouse Gas Initiative. New Jersey Participation. rggi.org/program-overview-and-design/design-archive/nj-participation

due to energy efficiency improvements.[15,16] RGGI states arrived at a cap of 91 million tons as a result of a process of modeling the impacts of different cap scenarios on items such as carbon emissions, fuel use mix, costs to ratepayers and more.[17] In 2020, the allowance cap increased 16 million tons to 96.4 million tons because of New Jersey's return to RGGI. Emission allowances were reduced by 2.5 percent per year from 2015 through 2020, for a total reduction of 10 percent as established in the 2012 program review.[18]

Following a second program review that again consisted of a stakeholder process and modeling the impacts of different cap scenarios, RGGI states agreed that in 2021, the cap would be lowered to 75.1 million tons and would then decline by 2.275 percent annually.[19] The cap was also adjusted in 2021 for the addition of Virginia to RGGI, and again in 2024 for its departure.[20]

Compliance Outcomes

During the program's first compliance period from 2009 to 2011, 206 of the 211 power plants subject to RGGI (over 97 percent) met the program's compliance obligations. For the second compliance period from 2012 to 2014, 161 of the 167 power plants subject to RGGI requirements met their compliance obligations. During the third control period from 2015 to 2017, 161 of the 163 power plants subject to RGGI requirements met their compliance obligations. For the fourth control period (2018-2020), 198 of the 203 power plants subject to RGGI requirements, or 97.5 percent, met their compliance obligations and 99.1 percent of covered power sector emissions were compliant.[21]

It should be noted that of the 13 states, and the District of Columbia, that are included in whole or in part in the PJM footprint, only Maryland, Delaware and New Jersey participated in RGGI as of the 2024-2026 control period. To some degree, therefore, "emissions leakage" may occur (i.e., reductions in emissions from plants subject to RGGI are offset by emissions from power plants not subject to RGGI). The energy generation in PJM states not participating in RGGI is not subject to the emissions cap and, therefore, may offset reduction in PJM states participating in RGGI. The extent of emissions leakage depends upon numerous factors, including energy consumption levels, power plant running-cost differentials, the price of RGGI emission allowances, the level of the emissions caps, and transmission congestion. Connecticut, Massachusetts, New Hampshire, Rhode Island, Vermont, and the majority of Maine make up the Independent System Operator of New England (ISO-NE) and are all also part of RGGI. ISO-NE relies on imports from outside the ISO for 7 percent of its total usage based on 2025 data, leaving

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[15] U.S. Energy Information Administration (2014). Today in Energy. "Lower emissions cap for Regional Greenhouse Gas Initiative takes effect in 2014." eia.gov/todayinenergy/detail.php?id=14851

[16] Congressional Research Service (Updated 2017). "The Regional Greenhouse Gas Initiative: Lessons Learned and Issues for Congress." congress.gov/crs_external_products/R/PDF/R41836/R41836.14.pdf

[17] Memorandum from Members of the Modeling Analysis Subgroup, as Led by Representatives from New York (2004). "Update on Subgroup Activities and Next Steps." rggi.org/sites/default/files/Uploads/Design-Archive/Staff-Working-Group/modelingbriefing.pdf

[18] The Regional Greenhouse Gas Initiative. Elements of RGGI. rggi.org/program-overview-and-design/elements.

[19] The Regional Greenhouse Gas Initiative (2017). Summary of RGGI Model Rule Updates. rggi.org/sites/default/files/Uploads/Program-Review/12-19-2017/Summary_Model_Rule_Updates.pdf

[20] The Regional Greenhouse Gas Initiative. Elements of RGGI. rggi.org/program-overview-and-design/elements

[21] RGGI, Inc. (2021). "RGGI States Release Fourth Control Period Compliance Report." rggi.org/sites/default/files/Uploads/Press-Releases/2021_04_02_FoCP_Compliance.pdf.

it also vulnerable to emissions leakage risks. ISO-NE's level of imports, however, has declined every year from 2021 to 2025.[22]

RGGI Auction Details and Outcomes

RGGI bids are submitted and allowances are sold in lots of 1,000. Each lot of 1,000 that is sold in the auction is comprised of the equivalent percentage that each state offered in the auction. For example, if Maryland offered 15 percent of the allowances offered in the auction, each lot of 1,000 would be made up of 150 Maryland-stamped allowances.[23]

The 2012 Program Review established the Cost Containment Reserve (CCR), which took effect in 2014. Intended to help provide price stability, the CCR allows the sale of a fixed number of allowances beyond the amount that is offered by states in an auction. These additional

allowances become available when demand bids provided in a quarterly auction would result in a clearing price that exceeds the CCR trigger price (i.e. prices are deemed too high.)[24] Within the confines of the annual CCR allowance limit, if the price-setting bid in a quarterly auction exceeds the CCR trigger price, RGGI will clear bids beyond that point until the trigger price is met.[25] Established through the third program review, RGGI will update the CCR to contain two tiers beginning in 2027. The CCR Tier 1 trigger price will be set at $19.50 in 2027 and will increase by 7 percent annually. As is the current practice, RGGI will clear extra bids in response to the price-setting bid being below the CCR Tier 1 trigger price. However, if RGGI clears all available CCR allowances and the price has not even reached the CCR Tier 2 price, which will begin at $29.25 in 2027 and increase 7 percent annually, then RGGI will begin to clear CCR Tier 2 allowances.[26]

Beginning in 2021, the emissions containment reserve (ECR), a new mechanism designed to provide market stability, commenced operation. Like the CCR, this mechanism is designed to help provide market stability. The ECR is implemented in seven states: Connecticut, Delaware, Maryland, Massachusetts, New York, Rhode Island and Vermont. Under the ECR, if prices fall below the ECR trigger price, RGGI will work backwards, denying bids until the total ECR withholding limit is reached (10 percent of all participating states' annual allowance budgets) or until the ECR trigger price is hit. The ECR trigger price started at $6 per ton and has increased 7 percent annually through 2026.[27] Under the ECR, states may then choose to impose further reductions if prices are lower than expected. The auction price floor in 2023 was $22.20 per ton,

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[22] ISO-New England. 2026 New England Power Grid Regional Profile. https://www.iso-ne.com/about/public-affairs/new-england-regional-profile.
[23] The Regional Greenhouse Gas Initiative. (2026). "CO2 Allowance Auctions FAQ." rggi.org/sites/default/files/Uploads/Auction-Materials/71/FAQs_Jan_13_2026.pdf#page=21.
[24] Potomac Economics (2025). *Annual Report on the Market for RGGI CO2 Allowances: 2024*. RGGI Inc. rggi.org/sites/default/files/Uploads/Market-Monitor/Annual-Reports/MM_2024_Annual_Report.pdf#page=12.
[25] The Regional Greenhouse Gas Initiative. (2025). "Auction Notice for CO2 Allowance Auction 70 on December 3, 2025." rggi.org/sites/default/files/Uploads/Auction-Materials/70/Auction_Notice_Oct_7_2025.pdf#page=23.
[26] The Regional Greenhouse Gas Initiative. Program Review. rggi.org/program-overview-and-design/program-review
[27] RGGI, Inc. (Revised 2018). 2017 Model Rule, Table 2.

which increased by 5 percent plus inflation as measured by the Consumer Price Index (CPI).[28] As of Auction 70, the ECR has not yet been triggered.

Table 1, Table 2, and Table 3 show the results of RGGI allowance auctions since 2018,revenue to Maryland from allowances sold, and volume-weighted average prices per year and per control period.

Table 1 RGGI Allowance Auctions, 2018–2025

Auction Date	Total RGGI Allowances Sold	Clearing Price Per Ton	Maryland Allowances Sold	Maryland Revenues (million USD)
Mar-18	13,553,767	$3.79	2,539,908	$9.63
Jun-18	13,771,025	$4.02	2,576,249	$10.36
Sep-18	13,590,107	$4.50	2,576,249	$11.59
Dec-18	13,360,649	$5.35	2,576,249	$13.78
Mar-19	12,883,436	$5.27	2,387,512	$12.58
Jun-19	13,221,453	$5.62	2,389,718	$13.43
Sep-19	13,116,447	$5.20	2,620,524	$13.63
Dec-19	13,116,444	$5.61	2,620,525	$14.70
Mar-20	16,208,347	$5.65	2,330,353	$13.17
Jun-20	16,336,298	$5.75	2,314,790	$13.31
Sep-20	16,192,785	$6.82	2.314,790	$15.79
Dec-20	16,237,495	$7.41	2,359,501	$17.48
Mar-21	23,467,262	$7.60	2,870,129	$21.81
Jun-21	22,987,719	$7.97	2,851,783	$22.73
Sep-21	22,911,423	$9.30	2,851,783	$26.52
Dec-21	27,041,000	$13.00	3,401,257	$44.22
Mar-22	21,761,269	$13.50	2,477,283	$33.44
Jun-22	22,280,473	$13.90	2,821,238	$39.22
Sep-22	22,404,023	$13.45	2,821,238	$37.95
Dec-22	22,233,203	$12.99	2,821,238	$36.65
Mar-23	21,522,877	$12.50	2,596,685	$32.46

[28] International Carbon Action Partnership (2023). *Emissions Trading Worldwide, Status Report 2023*, p. 119. ICAP reports that, as of the March 2023 released date, the ECR trigger price was suspended, and therefore the ECR provision was not operational. icapcarbonaction.com/en/publications/emissions-trading-worldwide-2023-icap-status-report.

Auction Date	Total RGGI Allowances Sold	Clearing Price Per Ton	Maryland Allowances Sold	Maryland Revenues (million USD)
Jun-23	22,026,639	$12.73	2,616,709	$33.31
Sep-23	21,948,358	$13.85	2,616,709	$36.24
Dec-23	27,656,000	$14.88	3,397,263	$50.55
Mar-24	24,272,157	$16.00	4,303,526	$68.86
Jun-24	16,053,188	$21.03	2,782,327	$58.51
Sep-24	15,943,608	$25.75	2,782,327	$71.64
Dec-24	15,943,608	$20.05	2,782,327	$55.79
Mar-25	23,527,000	$19.76	4,344,582	$85.85
Jun-25	15,244,479	$19.63	2,761,452	$54.21
Sep-25	15,177,783	$22.25	2,761,452	$61.44
Dec-25	15,230,235	$26.73	2,761,453	$73.81
Total	**536,945,009**		**76,445,684**	**$1,059**

Source: https://www.rggi.org/auctions/auction-results.

Table 2 RGGI Volume-Weighted Annual Average Prices

Auction Date	Volume-Weighted Average Price
2018 Auctions	$4.42
2019 Auctions	$5.42
2020 Auctions	$8.53
2021 Auctions	$9.63
2022 Auctions	$13.46
2023 Auctions	$13.58
2024 Auctions	$20.17
2025 Auctions	$21.81

Sources: https://www.rggi.org/auctions/auction-results and https://www.rggi.org/auctions/market-monitor-reports.

Table 3 RGGI Volume-Weighted Control Period Average Prices

Auction Date	Volume-Weighted Control Period Price
2018-2020 Control Period	$5.84
2021-2023 Control Period	$12.16
2024-2026 Control Period	Control Period Ongoing

Source: https://www.rggi.org/auctions/auction-results.

RGGI Offsets

The RGGI program allows covered entities to use qualifying offset projects to reduce the total number of allowances they are required to secure. Offset projects or emission credit retirements are awarded one CO_2 offset allowance for every ton of CO_2 reduced or sequestered. At this time, the RGGI Model Rule limits the award of offset allowances to five project categories, each of which is designed to reduce or sequester emissions of carbon dioxide or methane within the region. Although the CO_2 Budget Trading Programs in Massachusetts, New Hampshire, and Rhode Island do not grant CO_2 offset allowances, regulated power plants in those states may use CO_2 offset allowances awarded by another RGGI state. A source may cover up to 3.3 percent of its CO_2 emissions with offset project allowances. A total of 53,506 offsets were awarded to the one current offset project in Maryland, the New Beulah Landfill Gas Reconstruction Project.[29]

The RGGI Model Rule issued in December 2017 did not include three categories that previously qualified for offsets: Afforestation, Sulfur Hexafluoride Reduction, and End-Use Efficiency.

The three remaining categories of offset projects that qualify under the RGGI program are:

1. Landfill Methane Capture and Destruction – applicable to municipal solid waste landfills that are not subject to New Source Performance Standards (NSPS).
2. Sequestration of Carbon Due to Reforestation, improved forest management or avoided conversion – sequestering carbon through the conversion of land that has been in a non-forested state.
3. Avoided Methane Emissions from Agricultural Manure Management Operations – destroying methane generated by anaerobic digesters and uncontrolled storage of manure or organic food.

As of 2020, Delaware, Maine, Maryland, New Jersey, New York, and Vermont only allow the following two offsets: Landfill Methane Capture and Destruction and Avoided Methane Emissions from Agricultural Manure Management Operations.

[29] RGGI CO2 Allowance Tracking System, RGGI CO2 Budget Trading Programs, rggicoats.org/eats/rggi/index.cfm?fuseaction=search.project_offset&clearfuseattribs=true

Maryland Offset Projects

In Maryland, two additional offset project categories are being pursued, specifically terrestrial sequestration through urban forestry and the restoration of salt marshes. Maryland is promoting the development of programs within urban communities to plant and grow trees, which reduces GHG emissions in two ways. First, CO_2 is removed from the atmosphere by growing trees as their biomass increases. Second, GHG emissions are avoided through energy conservation, as the trees can provide shade with a natural cooling effect for residences and other buildings in the community. Several state agencies and community groups are interested in pursuing urban forestry projects as an alternative or supplement to other more traditional afforestation projects.

Salt marshes are prevalent in Maryland and are of critical importance for estuarine ecosystems, such as those associated with the Chesapeake Bay, by serving as habitats for wildlife and buffers to large storms. In addition, salt marsh soils have the capacity to sequester large amounts of CO_2 by accreting carbon-containing sediments and organic matter. Marsh decline, however, is occurring throughout the region as sea level increases and land areas subside. Raising the elevation of the marsh beds by supplementing natural sediment (e.g., depositing clean dredged material) can restore the tidal fluctuations required to support the marsh systems and promote carbon storage. Over the last several years, PPRP has assisted with an effort by Restore America's Estuaries to develop a formal offset protocol for salt marsh systems (see sidebar below).

Forestry Carbon Sequestration

Biological processes can capture and sequester carbon, providing an offset to carbon emissions from fossil fuel power generating facilities. Restoring or planting forests is one approach to enhancing these carbon sequestration services. One method suggested to protect or expand the natural sequestration services provided by such ecosystems is to create trading markets that place a value on carbon in a way that results in economic incentives and payments for removing carbon from the atmosphere and storing it in biomass.

To understand the requirements and potential of applying such an approach in Maryland, PPRP has been evaluating previously restored forest sites. Data have been collected at the Old Dominion Electric Cooperative (ODEC) Patapsco and Seneca Creek restoration sites to measure the carbon content of soils and vegetation, and estimate changes over time. These studies helped develop carbon measurement methodologies and establish baseline values for determining the rate of carbon storage by such systems.

A second initiative has been developing models that can use the field data to project the amount of carbon that will be sequestered over the lifetime of the project (which may be several decades). PPRP has adapted the Graz-Oak Ridge Carbon Accounting Model (GORCAM) for use in terrestrial and wetlands carbon sequestration projects in Maryland. The GORCAM model has been used to characterize the sequestration benefits of different management regimes in Maryland's state-owned forests and to estimate the range of results expected using different mixes of species in the DNR's carbon sequestration demonstration project.

At present, these investigations show that the low carbon prices in the experimental trading markets will not stimulate forestry offset projects in Maryland. However, sustainable forestry that selectively harvests high-quality timber that can be converted into wood products with long lifetimes can be effective in increasing the amount of carbon removed from the atmosphere by biological processes and subsequently sequestered in stable forms for long periods.

Maryland has considerable potential for reducing GHG emissions through sequestering carbon in restored wetlands and marshlands around the Chesapeake Bay. Maryland's Department of Natural Resources (DNR) has identified three focus areas to promote wetland carbon sequestration with the potential to reduce the state's net emissions by an estimated 0.5 to 0.65 million metric tons of CO_2 equivalent (CO_2e):

Blackwater Tidal Marsh Sequestration Project – PPRP, the U.S. Department of Energy (DOE) and several other partners collaborated with the University of Maryland to restore up to 20,000 acres of tidal marshes using clean dredged material. The project investigated carbon storage rates and the effects of management practices on carbon sequestration, while also developing a sampling protocol to validate CO_2 storage in restored marshes. These efforts were intended to support the development of projects that could generate carbon offsets. The restoration project was estimated to store approximately 24,550 metric tons of carbon each year, a rate above the national average. In addition, the restored marsh provided habitat for native and migratory birds, terrestrial animals and aquatic life.

Dorchester County Wetlands Study – PPRP conducted a study of wetlands in Dorchester County to demonstrate the potential carbon sequestration opportunities that may result from protecting and restoring wetlands. Areas for potential restoration were identified within Dorchester County's extensive coastal marshes. Satellite-derived net primary productivity of the wetlands was used to estimate gross sequestration, and net accumulation was estimated based on the current understanding of carbon dynamics in coastal wetlands.

"Coastal Blue Carbon" Wetlands Restoration and Conservation Offsets

Research focusing on "Blue Carbon" in coastal wetland ecosystems suggests that some coastal wetlands can sequester carbon at rates three to five times greater than temperate forests, making them particularly valuable as carbon sinks that can offset carbon emissions by human activities. Unfortunately, current estimates indicate that 50 percent of U. S. coastal wetlands have been lost since the 1800s, and that coastal wetlands are being lost globally at a rate of 0.7 to 2 percent per year. Efforts to preserve and restore coastal wetlands can now be financed by payments for the additional carbon that the wetlands sequester.

Restore America's Estuaries, with support from PPRP, developed a GHG offset category for measuring and crediting climate benefits from a broad range of wetlands, including freshwater tidal coastal wetlands, salt marshes, seagrasses, floodplains, peatlands and other wetland types. The Wetlands Restoration and Conservation category, which received approval under the Verified Carbon Standard (VCS) in October 2012, allows increased private investment in wetland restoration and conservation projects through the issuance of internationally recognized carbon credits. VCS is the majority holder in the voluntary carbon market with a 58 percent global and U.S. share and is widely considered the leading certification available globally.

In late 2015, VCS approved the specific methodology for implementing tidal wetland and seagrass restoration projects in the Wetlands Restoration and Conservation offset category. The methodology, which is applicable throughout the world, details the procedures required to calculate, report and verify the GHG reductions from these projects and thereby obtain "carbon credits" that can be traded in the VCS or other carbon markets.

Sea Level Affecting Marshes Model – DNR utilized this model to identify areas known as wetland transition zones, or areas projected to convert into wetlands. These identified areas will become targets for wetland restoration and land conservation efforts to help maintain coastal wetlands into the future.

Geological Storage of CO_2

Geological sequestration involves injecting CO_2 into underground formations for permanent storage. Subsurface sequestration can be achieved through either structural mechanisms (i.e., physical trapping) or adsorption storage (i.e., chemical reaction). The ultimate goal of long-term, permanent storage of CO_2 is more likely achieved through reactions involving the chemical adsorption of CO_2 due to the potential for CO_2 leakage associated with structural storage. Chemical reactions involving injected CO_2 include capillary attraction in small fractures, physical adsorption of CO_2 known to occur on the surface of rock containing organic material, and chemical adsorption of CO_2 known to occur on the surface of some rocks and with some brines. Unfortunately, the first two reactions are not reliable in the long term since they are reversible when subject to pressure swings such as may occur in seismic events. Thus, the only ultimately secure CO_2 storage is that achieved with chemical adsorption. Within a candidate geologic formation, the most promising strategy appears to be the use of capillary attraction and physical adsorption to saturate the formation with CO_2 and thus foster chemical adsorption, which is expected to occur over a longer period.

The primary types of target geological reservoirs are depleted oil and gas fields, unmineable coal seams and deep saline formations. Potential utilization of CO_2 occurs with geological sequestration in oil and gas fields when pressurized CO_2 can be used to displace residual oil and gas, allowing greater extraction volume. A similar technique utilizes CO2 injection into unmineable coal seams to displace and recover coal bed methane. Another potential sequestration option involves injecting CO_2 into (otherwise unused) deep saline reservoirs. Deep saline reservoir injection has two important advantages—potential storage capacity in the U.S. is very large and many reservoirs are close to major point sources of CO_2.

Certain geological formations in Maryland, including unconventional natural gas deposits, deep saline aquifers, and Triassic-age sedimentary basins, may offer potential opportunities for carbon utilization and geologic CO_2 storage. The suitability and feasibility of these formations for such applications would depend on site-specific conditions and further evaluation.