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TECHNICAL SUMMARY

Utilizing East Coast Natural Gas Infrastructure

System-Level Pathways for Emerging Fuels, Infrastructure Modernization, and Regional Flexibility

Table of Contents

Glossary

Term	Definition
Autothermal Reforming (ATR)	A hydrogen production method that involves natural gas reacting with steam and air to produce a gas mix that contains hydrogen, carbon monoxide, and carbon dioxide. The carbon monoxide in the gas mix is then converted to produce more hydrogen and carbon dioxide. The hydrogen is purified for use.
Business as Usual (BAU)	OL-NEMS scenarios that represent a baseline for emerging fuels adoption, assuming no significant changes in current policies, technologies, or behaviors. These include: 1) Reference case, 2) Low Oil & Gas Supply case, 3) High Economic Growth and High-Zero-Carbon Technology. See "Description of Business-as-Usual (BAU) Scenarios" section for scenario descriptions.
Capacity	Annual facility production rate.
Capacity Factor (CF)	Percent of the year facility produces fuel.
Carbon Intensity (CI)	A quantification of the GHG emissions impact of particular fuel pathway; from production to end-use delivery. CI scores are often reported on a kg CO2eq/ energy content fuel produced.
Carbon Capture, Utilization, & Storage (CCS)	Recovery of CO_2 from industrial or natural sources, and storage into geological or synthetic storage
Carbon Capture, Utilization, & Storage (CCUS)	Recovery of CO_2 from industrial or natural sources, utilization for the production of fuels, and storage into geological or synthetic storage

Emerging Fuels	Low-carbon fuels that have the potential to replace conventional natural gas. For this case study, the emerging fuels considered are H_2, RNG, and SNG.
Greenhouse Gas (GHG)	Greenhouse gases trap heat in the atmosphere. These gases include carbon dioxide, methane, nitrous oxide, and fluorinated gases).
Hydrogen (H_2)	Low density fuel, able to be produced from several renewable sources and blendable into NG systems
Landfill Gas (LFG)	Byproduct of the decomposition of organic materials in landfills. It typically consists of about 50% methane, approximately 50% carbon dioxide, and trace amounts of non-methane organic compounds.
Levelized Cost	Total lifetime cost of building and operating a plant divided by its total lifetime energy production
Lifecycle Analysis (LCA)	Estimation of fuel specific GHG emissions impact
Municipal solid waste (MSW); source separated	Discarded waste originating from mixed sources (i.e., households, commercial businesses) including organics such as yard trimmings, food and non-organics such as plastics, waste electronics
Natural Gas Combined Cycle (NGCC)	A gas turbine generates electricity, and its waste heat is used to produce steam, which drives a steam turbine to generate additional electricity.
Renewable Natural Gas (RNG)	Biomass-derived methane produced via micro-organisms or thermal processes, compositionally similar to NG and blendable into NG systems.
Steam Methane Reforming (SMR)	A hydrogen production method that involves reacting natural gas with high-temperature steam and a catalyst to produce hydrogen, carbon monoxide, and carbon dioxide; the carbon monoxide then reacts with steam to yield more hydrogen and carbon dioxide, after which impurities including

	carbon dioxide are separated to purify the hydrogen. This hydrogen production method is currently the most common.
Synthetic Natural Gas (SNG)	In this study, the term refers to methane produced using electrolytic hydrogen and via methanation process. Its composition is similar to natural gas and can be blended into natural gas systems.
Technoeconomic analysis (TEA)	Cost analysis of fuel pathway

Preface

This report provides a synopsis of the analysis methodologies and findings of the main report: **Utilizing East Coast Natural Gas Infrastructure for Emerging Fuels**, developed by the **Reliable Affordable Infrastructure for Secure Energy (RAISE) collaborative.**

For more information, please visit the RAISE website:

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Introduction

In the midst of evolving energy infrastructure and emphasis on reliable and secure domestic energy, sustainable emerging fuels such as hydrogen (H_2) and renewable natural gas (RNG) stand out as promising solutions to further diversify the nation's energy portfolio, enhance energy security, and provide opportunities to increase low-carbon energy supply, all while capitalizing on the pre-established network of US natural gas infrastructure. This case study evaluates the adoption potential of these emerging fuels in the East Coast region, as defined by the Petroleum Administration for Defense Districts (PADD). East Coast region, defined as PADD 1, comprises of 17 states: Connecticut, Delaware, Florida, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, and West Virginia (**Figure 1**).

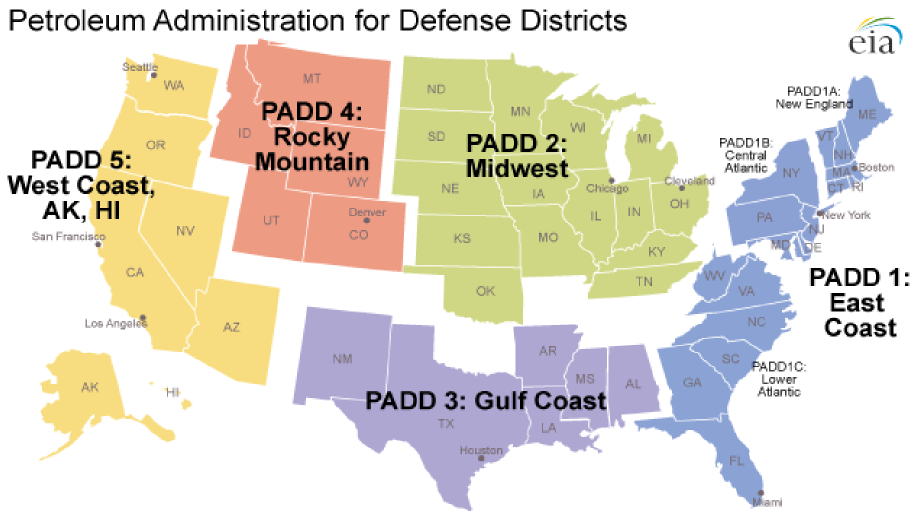

Figure 1. Five U.S. regions, as defined by the Petroleum Administration for Defense Districts. (Source: EIA)

The East Coast case study explores the integration of emerging fuels at both conservative and optimistic adoption rates using average overall blending targets of 5, 10, and 20% by volume, since it is anticipated that some end-uses can accept higher blends in the East Coast region. Based on the analyses' results and the region's regulatory landscape, this report also outlines opportunities, such as policy incentives and technological advancements that could support the adoption of emerging fuels in the East Coast region.

This executive summary contains key insights for each East Coast state from the case study analysis. Further details about the analytical approach and methodology are provided in the body of this executive summary.

Emerging Fuel Pathways Considered

This section provides brief summaries of the various emerging fuel pathways considered, including the case identifiers of the pathways that will be used throughout the text and visual summaries. Eight pathways are associated with H_2 production, three are associated with RNG production, and four are associated with SNG production (**Table 1**).

Table 1. Fuel pathways considered in this case study

H_2 Cases	**SMR**		**ATR**		**Plasma Pyrolysis**	**Electrolysis**
	with CCS	*without CCS*	*with CCS*	*without CCS*		
Identifier	H2-1, H2-5	H2-3	H2-2, H2-6	H2-4	H2-7	H2-8

RNG Cases	**MSW**	**Biomass**		**LFG**
		Forest	**Agriculture**	
Identifier	RNG-1	RNG-2	RNG-3	RNG-4

SNG Cases	**NGCC Power Plant**	**Cement Plant**	**Steel Plant**	**Ethanol Plant**
Identifier	SNG-1	SNG-2	SNG-3	SNG-4

Hydrogen Pathways

- H2-1 & H2-2: Natural gas reforming (steam methane and autothermal) with carbon capture and storage (CCS), achieving 94-96% capture rates
- H2-3 & H2-4: Similar reforming processes using RNG from landfill gas, without CCS
- H2-5 & H2-6: RNG reforming with CCS at the same high capture rates
- H2-7: Plasma pyrolysis of natural gas producing H_2 and solid carbon with minimal CO_2 emissions
- H2-8: Electrolysis using six different low-carbon electricity sources (solar, wind, nuclear, hydro, biomass, and combined solar/wind with battery storage)

Renewable Natural Gas Pathways (RNG-1 through RNG-3)

- RNG-1: Municipal solid waste digestion
- RNG-2: Woody biomass digestion (trees, shrubs, leaves)
- RNG-3: Agricultural residues digestion
- RNG-4: Upgrading landfill gas through anaerobic digestion

Synthetic Natural Gas Pathways (SNG-1 through SNG-4)

All pathways combine captured CO_2 with electrolytic H_2 to produce synthetic natural gas:

- SNG-1: CO_2 from natural gas power plants
- SNG-2: CO_2 from cement plants
- SNG-3: CO_2 from steel plants (limited regional availability)
- SNG-4: High-purity CO_2 from ethanol fermentation

Case Study Approach

The intent of this case study is to identify H_2, SNG, and RNG opportunities, and regional polices and investments that can support emerging fuels adoption in the Gulf Coast. To accomplish this goal, the study integrates three core analyses: Technoeconomic Analysis (TEA), Lifecycle Analysis (LCA), and Regional Fuel Pathway Optimization Analysis. **Figure 2** illustrates the comprehensive analytical approach undertaken in this study.

1) Technoeconomic Analysis (TEA)

The TEA assesses the comparative economic viability of the H_2, RNG, and SNG pathways.

2) Lifecycle Analysis (LCA)

The LCA quantifies the environmental impacts across the entire life cycle of the energy systems, considering raw material extraction, manufacturing, operation, and disposal, as inputs to estimate greenhouse gas emissions.

3) Regional Fuel Pathway Optimization Analysis

The optimization analysis assesses the broader system-level interactions and trade-offs under various scenarios, including business as usual (BAU) scenarios, integrating TEA results and policy and market assumptions to determine optimal technology deployment strategies, energy supply mixes, and associated costs.

These analyses collectively inform the cost-benefit analysis (CBA), which evaluates the total costs against the total benefits of the various pathways, providing a holistic perspective for decision-making.

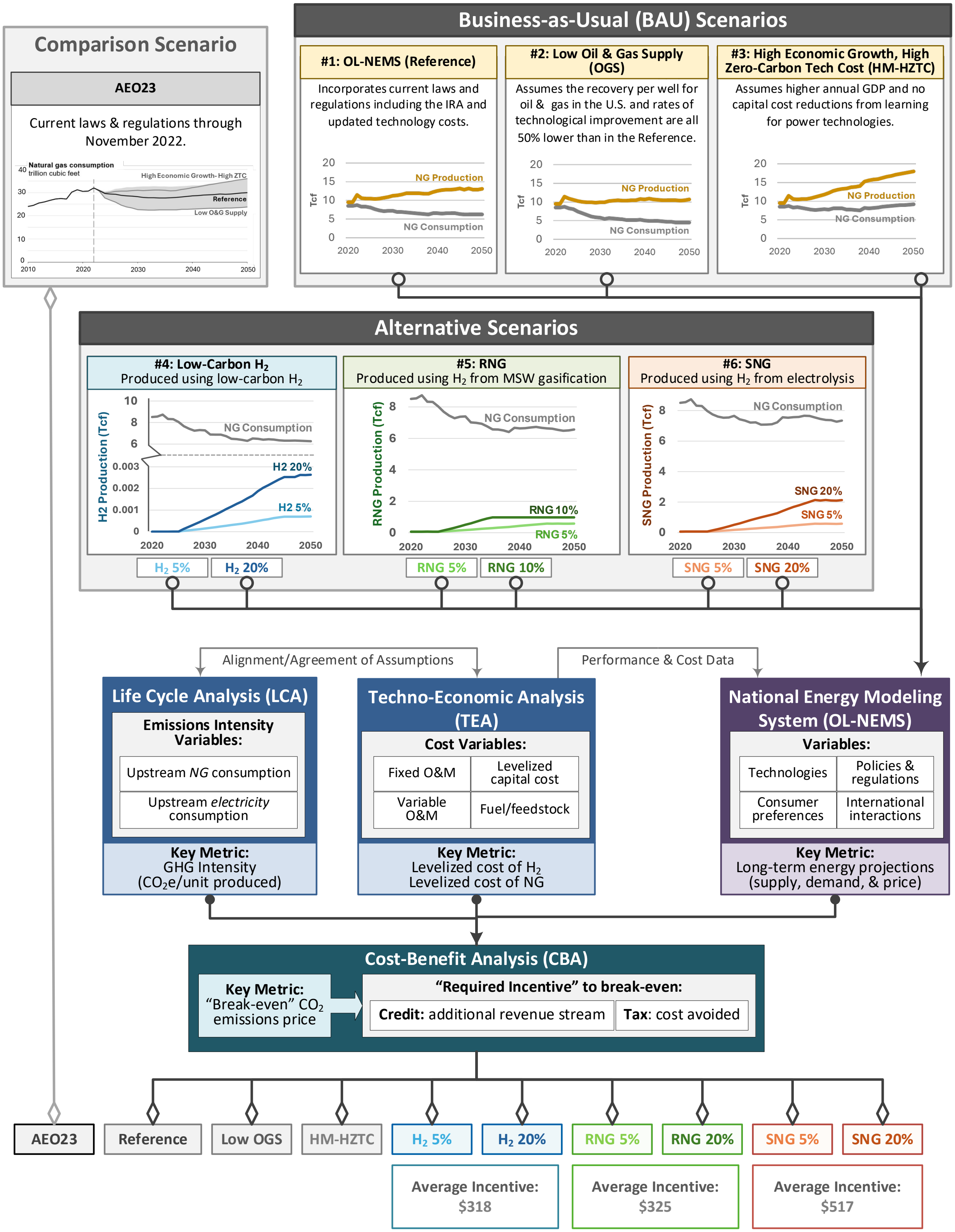

Figure 2. Integrated analysis of cost, emissions, and deployment strategies for H_2, RNG, and SNG pathways

Optimization Model

The National Energy Modeling System (NEMS), developed by the Energy Information Administration (EIA), simulates various U.S. energy market scenarios through 2050. Its outputs inform the Annual Energy Outlook (AEO), which projects energy trends. This case study used the 2023 AEO and OnLocation's customized NEMS version (OL-NEMS) to explore various energy demand scenarios in the Gulf Coast, comparing proactive, policy-driven approaches with more constrained market conditions. The results provide insights into how emerging fuels can be scaled under various market conditions in the Gulf Coast region.

Description of Business-as-Usual (BAU) Scenarios

To consider various economic market conditions, four BAU scenarios are evaluated with OL-NEMS. The **AEO23 Reference Case** provides a baseline assessment of U.S. energy markets through 2050 under November 2022 laws and evolutionary technology assumptions. The **OL-NEMS 2024 Reference Case** builds on AEO23 but incorporates updated EPA standards, state policies, comprehensive IRA provisions (including clean fuel and H_2 tax credits), lower renewable technology costs, and higher electricity demand from data centers, resulting in faster fossil fuel phase-out. The **Low Oil & Gas Supply** assumes 50% lower recovery rates for tight oil/gas, reduced undiscovered resources, and slower technological improvement, making emerging fuels more competitive. The **High Economic Growth-High Zero-Carbon Technology Cost** combines higher GDP growth (2.3% annually) with stagnant zero-carbon technology costs, creating challenging conditions for emerging fuel adoption. **Table 2** summarizes the four BAU scenarios used to model the economic impacts of emerging fuels use on the energy economy and the anticipated impacts on the adoption of emerging fuels.

Table 2. Summary of BAU Scenarios

BAU Scenario	Description	Anticipated Impact
#1: AEO23 Reference Case	Current laws and regulations impact (2022) on energy market growth through 2050	**Neutral**
#2: OL-NEMS 2024 Reference Case	Includes technology cost updates and IRA and other policies implemented	**Supportive**

	since AEO23 was released	
#3: Low Oil/ Gas Supply	Assumes high success of renewables-based technologies adoption	**Supportive**
#4: High Economic Growth-High Zero-Carbon Technology	Assumes higher natural gas use but with a restricted ability to reduce carbon emissions	**Unsupportive**

The basis for the selection of the BAU scenarios was to review economic conditions which generate a neutral, supportive, and unsupportive outlook for the adoption of emerging fuels.

Blending Range Assumptions

To explore conservative and optimistic low-carbon fuels adoption scenarios, this study assesses the integration of H_2 and RNG/SNG blends into the East Coast natural gas systems at 5, 10, and 20 vol% (by volume). It is important to note that some end uses (e.g., residential) may be able to accept higher H_2 blends, while other end uses (e.g., LNG facilities, CNG stations) may be unable to accept H_2 in their gas supplies. Additionally, material compatibility constraints may prevent H_2 blending percentages greater than 20 vol%. Therefore, the target blending rates represent average system-wide targets rather than end-use-specific limits.

Although RNG and SNG do not have the same end-use and material compatibility challenges, 10 and 20 vol% blending targets, respectively, are also assumed to align with goals announced by leading natural gas operators. Due to limited feedstock availability in the East Coast, the optimistic RNG scenario is capped at 10 vol%.

To avoid abrupt shocks to the energy system, the blending rates are assumed to be gradually achieved over a period of 20 years, starting in 2026 and reaching the maximum value by 2045. The rates of increase were 0.25 vol%, 0.5 vol%, and 1 vol% per year for the 5 vol%, 10 vol%, and 20 vol% blending cases, respectively. Blending is assumed to occur through policy mandates and is not evaluated for economic feasibility.

Pathways Evaluation Inputs and Assumptions

Fuel-specific costs, emissions, and regional feedstock availability are captured through TEA, LCA, and resource availability analyses. Figure 3 summarizes the variables used in these assessments and the modeling inputs that inform the cost-benefit analysis.

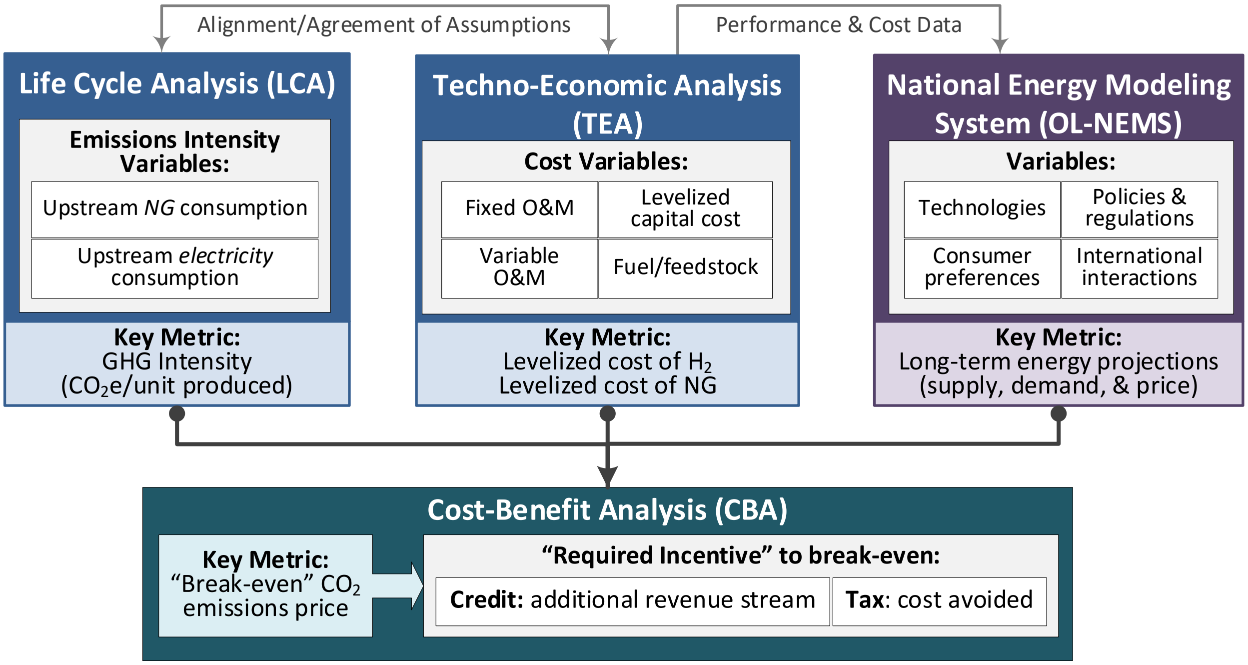

Figure 3. Summary of key TEA, LCA, and resource availability inputs used to inform the cost-benefit analysis.

Techno-Economic Analysis (TEA)

The TEA largely follows the National Energy Technology Laboratory (NETL)'s Quality Guidelines for Energy System Studies (QGESS) method to calculate the fuel-specific levelized cost, which considers the revenue required per unit of product produced during the plant's operational life to meet all capital and operational costs (i.e., \$/kg H_2, \$/MMBTU RNG, \$/MMBTU SNG). Levelized costs are estimated as a summation of capital, operational, and facility maintenance costs; each of which is calculated based on reported facility-specific reference capacities, capacity factors, referenced fixed costs, and time normalized accordingly. Default QGESS assumptions were used with modifications for H_2-specific financial parameters and CO_2 transport and storage costs integrated into variable operations and maintenance (O&M) costs.

Life Cycle Assessment (LCA)

The LCA estimates the cradle to gate carbon intensity for hydrogen production using the DOE's Hydrogen Shot methodology and the Open Hydrogen Initiative (OHI) toolkit. While the toolkit provides default parameters, adjustments were made for low-carbon hydrogen cases involving RNG and plasma pyrolysis. Custom unit-process models were made and assessed using OpenLCA for SNG and RNG production pathways to capture their unique characteristics. Regional variations in upstream GHG emissions from natural gas and electricity were based on NETL and FERC data, adjusted to PADD regions using state-level consumption data. These variations primarily influence GHG intensity, while system-level parameters like CCS efficiency and methane leakage remain constant across locations.

Cost Benefit Analysis (CBA)

The CBA synthesizes the results from the OL-NEMS model, TEA, and LCA to identify the most viable technology pathway to meet the energy demand and manage emissions. The CBA adds the key metric of a "Required Incentive" calculation for each fuel pathway technology, which can be interpreted either as a cost avoided in the case of a tax, or an additional revenue stream in the case of a credit such as 45Q and 45V (U.S. Congress, n.d.). These incentives represent the "break even" CO_2 emissions price required for the given fuel to reach cost-parity with natural gas. The incentives were calculated using the following equation:

$$\text{Required Incentive} = \frac{\text{LC}_{\text{Renew}} - \text{LC}_{\text{NG}}}{\text{CI}_{\text{NG}} - \text{CI}_{\text{Renew}}}$$

where LC is the levelized cost of the renewable fuel or natural gas respectively, in \$/MMBtu, and CI is the carbon intensity of the fuel in tons of CO_2/MMBtu.

TEA and LCA Findings Overview

The analysis reveals notable regional variability in estimated production costs across the different fuel pathways, with particularly pronounced differences for Plasma Pyrolysis (H2-7), SMR without CCS (H2-3), and Electrolysis (H2-8). In certain states, hydrogen produced via natural gas plasma pyrolysis achieves levelized costs below \$35/MMBTU, placing it within the cost range observed for SMR with CCS and ATR with CCS across several East Coast states. Among the ATR and SMR pathways evaluated, the integration of CCS consistently delivers greater emissions reductions and lower costs compared to substituting NG with RNG as the process fuel. NG SMR w/ CCS and NG ATR w/CCS are found to achieve levelized costs from \$14-35/MMBTU H_2 across East Coast states.

There is also wide cost variability across East Coast states for RNG produced via upgraded LFG, as well as the relatively similar cost ranges observed for SNG pathways utilizing different CO_2 capture sources. RNG produced through agricultural and forest residue gasification also exhibits comparable cost profiles. Specifically, RNG derived from upgraded LFG demonstrates levelized costs ranging from $33 to $58/MMBTU, underscoring the influence of feedstock and regional factors on economic performance.

In general, the SNG fuel cases considered are found to require higher incentives due to less competitive emission reductions compared to the RNG cases. However, some RNG production pathways, namely RNG via Ag residue and Forest residue digestion, are found to have especially higher levelized costs ($65 to $2500/MMBTU), depending on the specific state.

Required Incentives Overview

The TEA and LCA required incentive calculation findings show generally reduced incentives when excluding carbon intensities. Across East Coast states, it is the general trend that Hydro electrolysis, RNG ATR w/ CCS, and RNG SMR w/ CCS demonstrate lower LCA required incentives compared to calculated TEA incentives. The most significant differences between LCA and TEA required incentives are for RNG ATR w/ CCS, yielding required incentive reductions from $63-200/$CO_2$ Abated when CI is structured into the required incentive.

As for the RNG and SNG pathways, the LCA incentives for MSW digestion are lower than the TEA incentives by $138-1261/ton CO_2 Abated, depending on the state. Thus, the following section presents both the LCA and TEA incentive findings at the state level.

Summary of East Coast Findings

The state-level findings incorporate consideration of available resources, state-specific costs for electricity, natural gas, CO_2 T&S, and labor rates. The incentives described in this section represent the economic offset required for the given fuel to reach cost parity with natural gas. These incentives illustrate the range of economic stimuli necessary to promote the adoption of some of the technologies being explored by this study. These quantified incentives represent a “break-even” CO_2 emissions price, which can be interpreted either as a cost avoided in the case of a tax, or an additional revenue stream in the case of a credit. The state summaries note the fuel pathways with the lowest estimated incentives required.

State-Level Findings

The state-level findings incorporate consideration of available resources, state-specific costs for electricity, natural gas, CO_2 T&S, and labor rates. The incentives described in this section represent the economic offset required for the given fuel to reach cost parity with natural gas. These incentives illustrate the range of economic stimuli necessary to promote the adoption of some of the technologies being explored by this study. These quantified incentives represent a “break-even” CO_2 emissions price, which can be interpreted either as a cost avoided in the case of a tax, or an additional revenue stream in the case of a credit. The state summaries note the fuel pathways with the lowest estimated incentives required.

PADD 1a: New England

Maine, Vermont, New Hampshire, Connecticut, Rhode Island, Massachusetts

Case Study Analysis: New England State Price Inputs

Figure 4 below summarizes New England state level costs for natural gas, electricity, transportation and storage of CO_2, and average labor rates, each of which contribute to the fuel case technoeconomic findings.

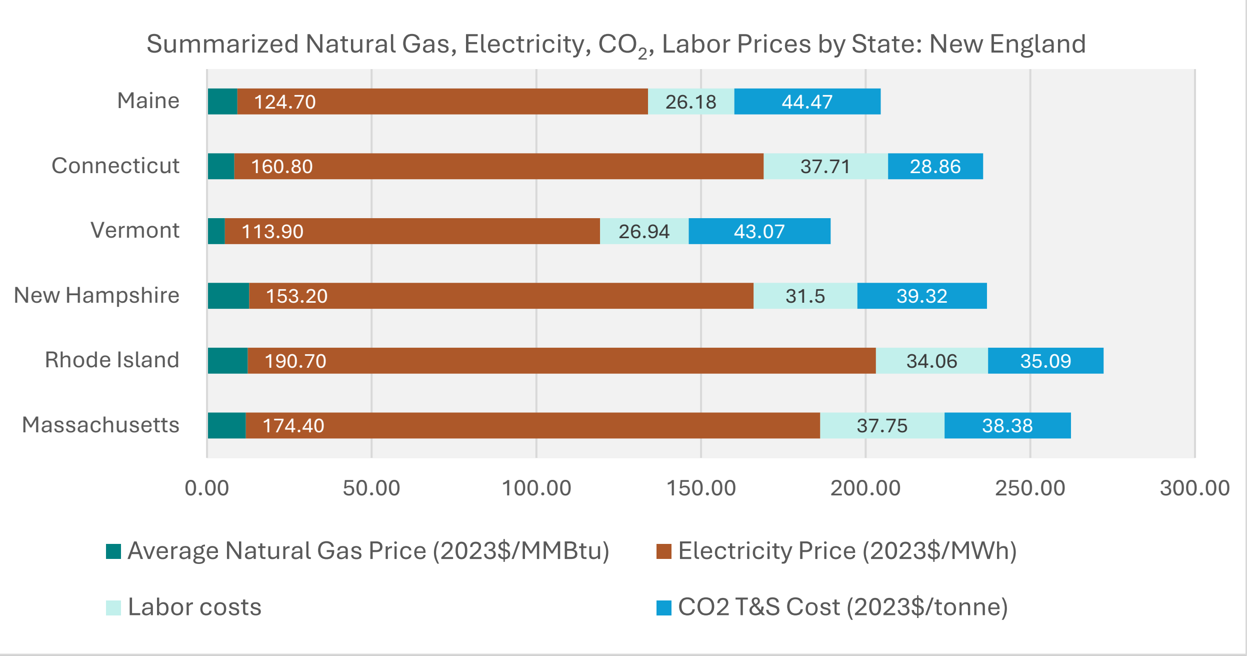

Figure 4. Summarized input prices utilized in New England state-level fuel case analysis

Electricity costs have the greatest influence on overall fuel pathway economics across New England. States such as Rhode Island and Massachusetts experience the highest fuel production costs, driven primarily by elevated electricity prices in these regions. Conversely, natural gas-based pathways are most cost-effective in Vermont, which benefits from having the lowest natural gas prices among all New England states.

PADD 1a: New England Resource Potential v. Cost

Maine

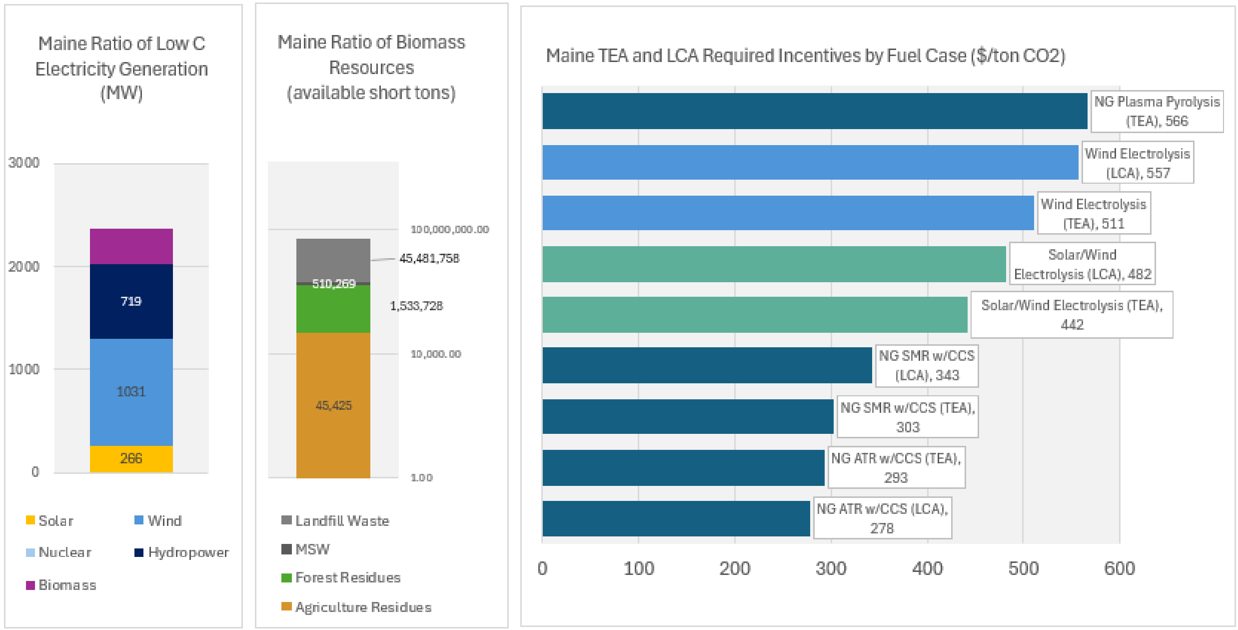

Figure 5. Maine findings summary

Near-Term Fuel Pathways

With the exception of NG SMR and NG ATR w/ CCS, estimated levelized costs and required incentives for H_2 and RNG cases are more similar for Maine compared to other East Coast states.

H_2 produced via NG SMR w/ CCS or ATR w/ CCS are the most economical cases considered. However, when focusing on fuel pathways that do not rely on CO_2 transport and storage infrastructure, electrolytic H_2 presents lower estimated levelized costs and required incentives compared to other H_2 fuel cases, including NG Plasma Pyrolysis (~40/MMBTU H_2, \$566/ton CO_2).

Low C electrolytic H_2 with wind/solar mix is found to require lower incentives, but current wind generation significantly exceeds in-state solar power generation.

Future Opportunities

Maine’s abundant agricultural and forest residues represent a significant resource for expanding RNG and H_2 production. As technology advances and cost reductions are realized, these biomass-based pathways could play a critical role in diversifying Maine’s low-carbon fuel portfolio and enhancing energy resilience.

Vermont

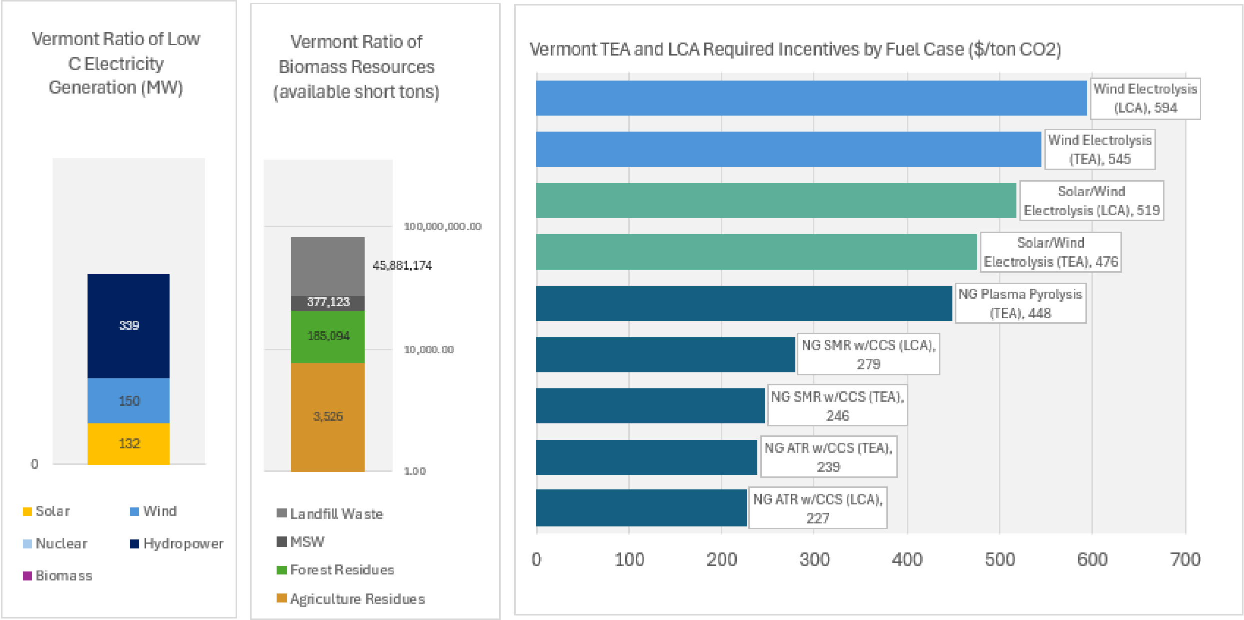

Figure 6. Vermont findings summary

Near-Term Fuel Pathways

H_2 produced via NG SMR w/ CCS or ATR w/ CCS are the most economical cases considered. However, when focusing on fuel pathways that do not rely on CO_2 transport and storage infrastructure, NG plasma pyrolysis is the next most economical pathway. This is largely due to Vermont’s advantage of having the lowest average natural gas price among New England states. This is followed by electrolytic H_2 pathways.

For electrolytic H_2, a mix of wind and solar generation requires comparatively lower incentives to achieve cost parity. However, hydropower is the dominant renewable electricity source in Vermont.

Future Opportunities

Increasing solar and wind generation can reduce the cost of electrolytic H_2, improving its long-term viability. Leveraging agricultural and forest residues and landfill waste can also enhance RNG production.

Massachusetts

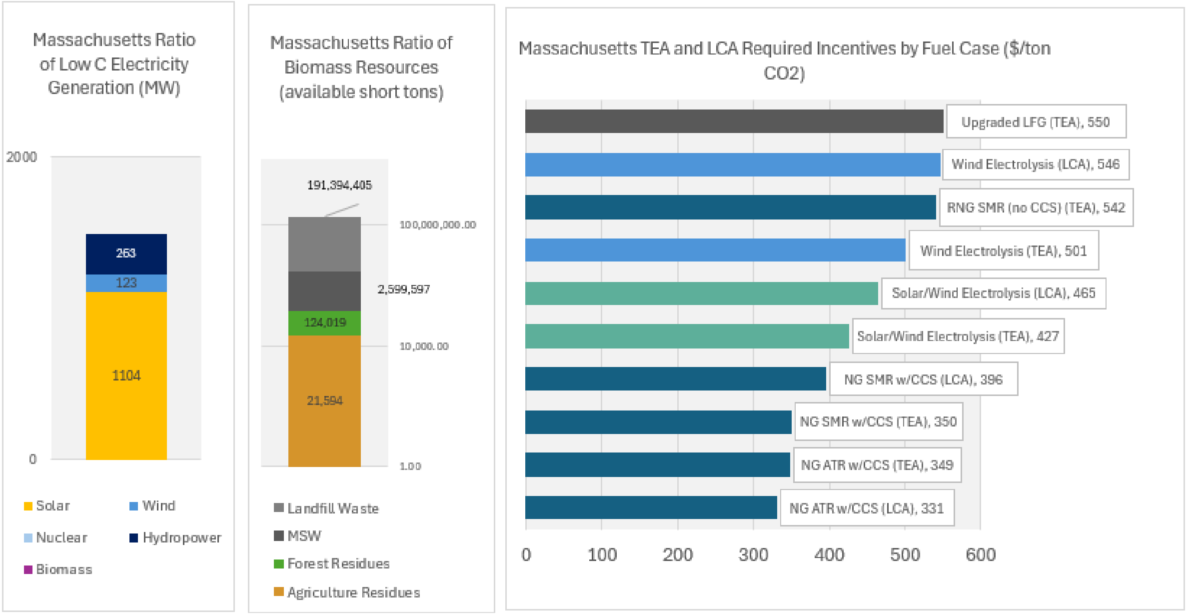

Figure 7. Massachusetts state findings

Near-Term Fuel Pathways

With no in-state natural gas reserves, Massachusetts relies on natural gas sourced from the Marcellus shale, as well as Canada.

H_2 produced via NG SMR w/ CCS or ATR w/ CCS are the most economical cases considered. While Massachusetts does not possess underground storage, the closest estimated CO_2 storage potential is found in the neighboring state of New York in the form of depleted oil and gas reservoirs.

For fuel pathways that avoid reliance on CO_2 transport and storage infrastructure, electrolytic H_2 produced using renewable electricity (primarily solar and wind) emerges as the next most economical alternative. Within this category, a hybrid mix of wind and solar generation generally requires lower financial incentives to achieve cost parity with fossil-based H_2 compared to single-source renewable strategies. However, hydropower is the dominant renewable electricity source in Massachusetts.

Future Opportunities

Increasing solar and wind generation can reduce the cost of electrolytic H_2, improving its long-term viability. Leveraging more agricultural residues and landfill waste, can significantly enhance RNG production, providing a complementary pathway for reducing emissions in sectors where H_2 adoption may be slower.

New Hampshire

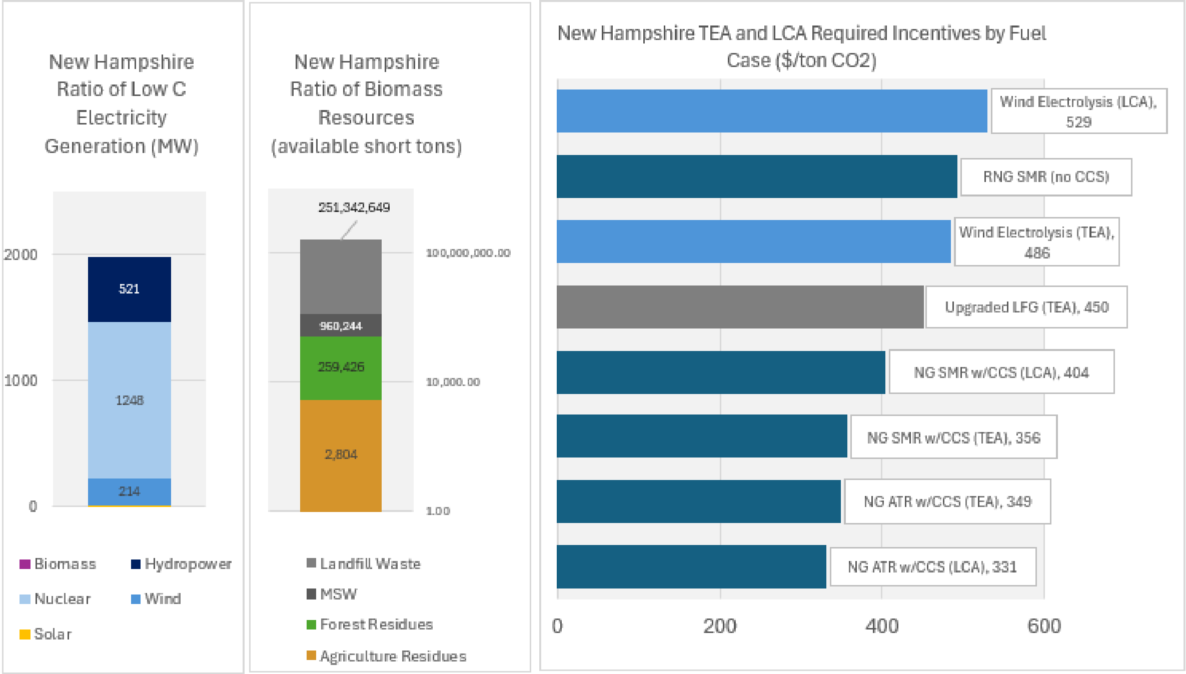

Figure 8. New Hampshire state findings

Near-Term Fuel Pathways

New Hampshire has no existing natural gas production and relies on natural gas sourced from the Marcellus Shale and Canada. H_2 produced via NG SMR w/ CCS or ATR w/ CCS are the most economical cases considered. However, the closest estimated CO_2 storage is depleted oil and gas reservoirs located in New York. For fuel pathways that avoid reliance on CO_2 transport and storage infrastructure, RNG derived from LFG upgrading emerges as the next most economical alternative ($450/MMMBTU). Following RNG, electrolytic H_2 produced using wind power offers a promising solution ($486/MMBTU). New Hampshire is well-positioned to capitalize on electrolytic H_2, given its substantial wind and hydropower generation capacity.

Future Opportunities

Expanding wind and hydroelectric generation will further reduce the cost of electrolytic H_2, enhancing its competitiveness and long-term viability. In parallel, increasing the utilization of agricultural residues, forest biomass, and landfill waste can significantly boost RNG production.

Connecticut

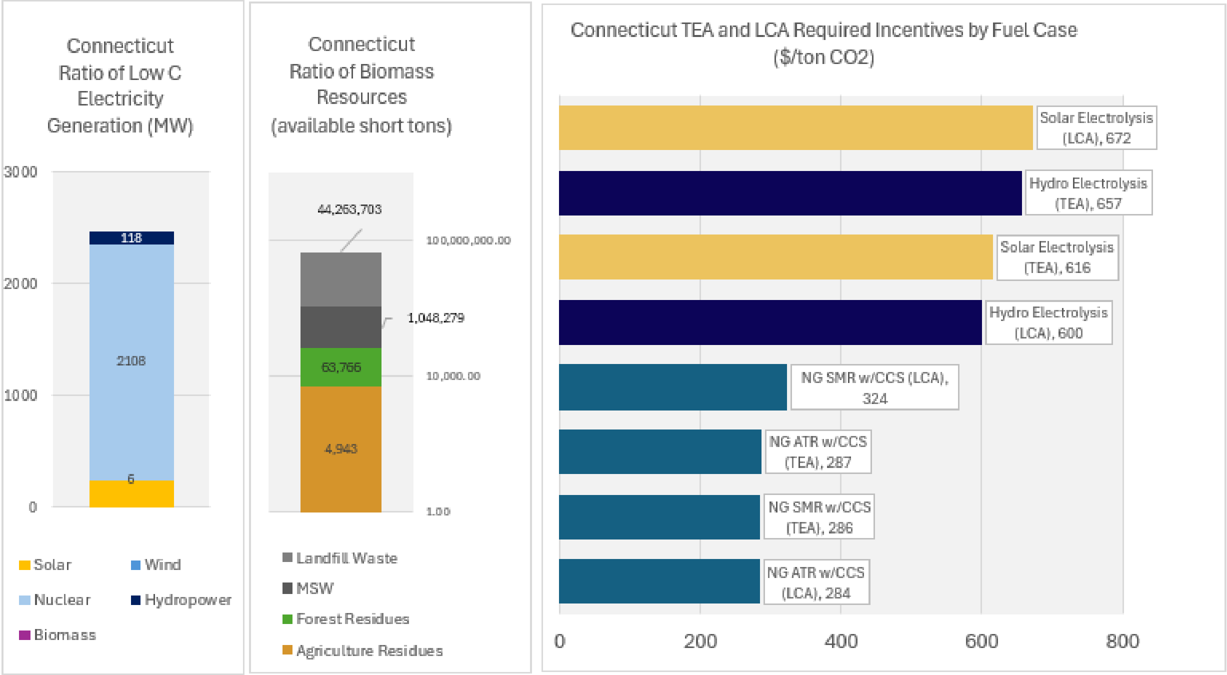

Figure 9. Connecticut state findings

Near-Term Fuel Pathways

Having no existing natural gas production, Connecticut largely receives natural gas through New York transmission pipelines, sourcing from the Marcellus Shale (West Virginia, Pennsylvania), Gulf Coast states, and Canada.

H_2 produced via NG SMR or ATR w/ CCS are the most economical cases considered. However, electrolytic H_2 is the most economical fuel pathway to avoid reliance on CO_2 transport and storage infrastructure. However, estimated CO_2 storage potential in Connecticut is limited, with the closest storage potential being associated with depleted oil and gas reservoirs in New York.

While H_2 from solar-powered electrolysis is projected to require fewer incentives than electrolysis using nuclear electricity, nuclear power is the most abundant source of low-carbon electricity in Connecticut.

Future Opportunities

Agricultural and forest residues offer significant potential for expanding RNG and H_2 production, contingent on achieving cost reductions and technology improvements.

Rhode Island

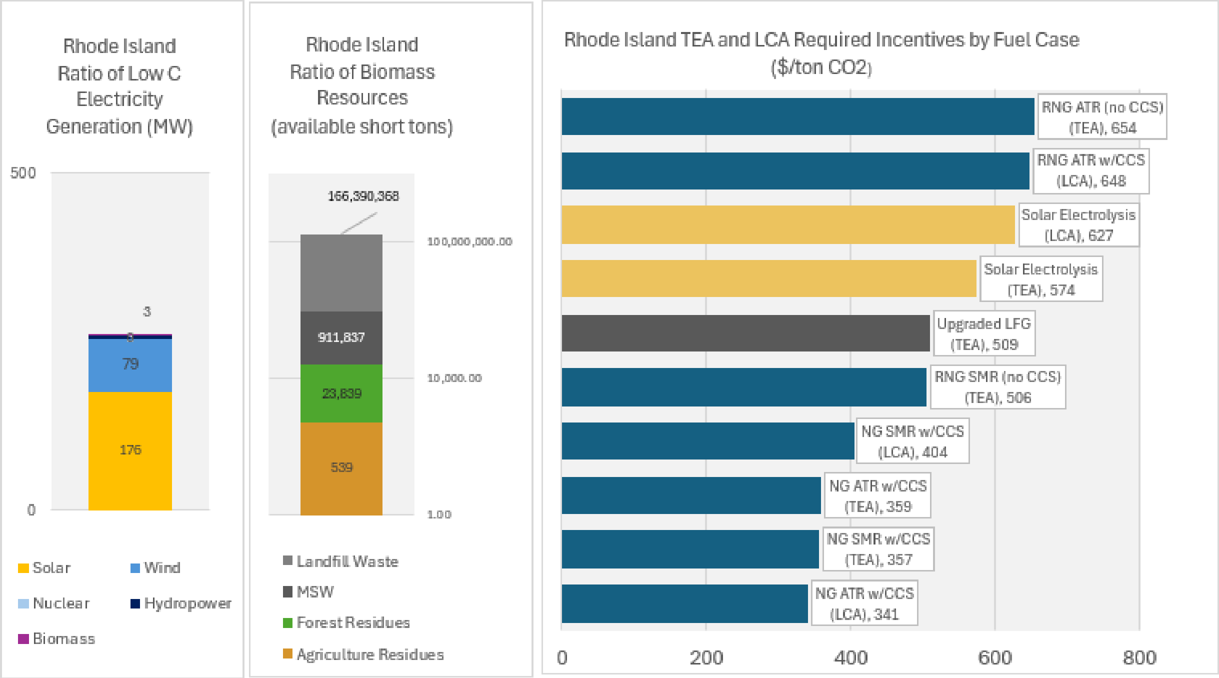

Figure 10. Rhode Island state findings

Near-Term Fuel Pathways

Rhode Island has no existing natural gas production and relies on natural gas sourced from the Marcellus Shale and New York. Estimated required incentives for H_2 production in Rhode Island are similarly higher across different H_2 fuel cases. Due to geographical limitations, RNG produced via upgraded landfill gas and electrolytic H_2 produced powered by existing solar facilities may be stronger opportunities ($509-574/MMBTU).

Future Opportunities

Scaling up landfill gas upgrading can increase RNG production. By prioritizing RNG and electrolytic H_2, Rhode Island can avoid heavy reliance on carbon capture and CO_2 transport infrastructure.

PADD 1b: Central Atlantic

New York, Pennsylvania, New Jersey, Delaware, Maryland

Case Study Analysis: Central Atlantic State Price Inputs

Figure 11 below summarizes Central Atlantic state level costs for natural gas, electricity, transportation and storage of CO_2, and average labor rates, each of which contribute to the fuel case technoeconomic findings.

Among the Central Atlantic states, New York and Pennsylvania exhibit the lowest electricity prices, which helps reduce total fuel production costs. In contrast, New Jersey stands out for having the lowest natural gas prices across the region, offering a competitive advantage for fuel production scenarios that rely on natural gas.

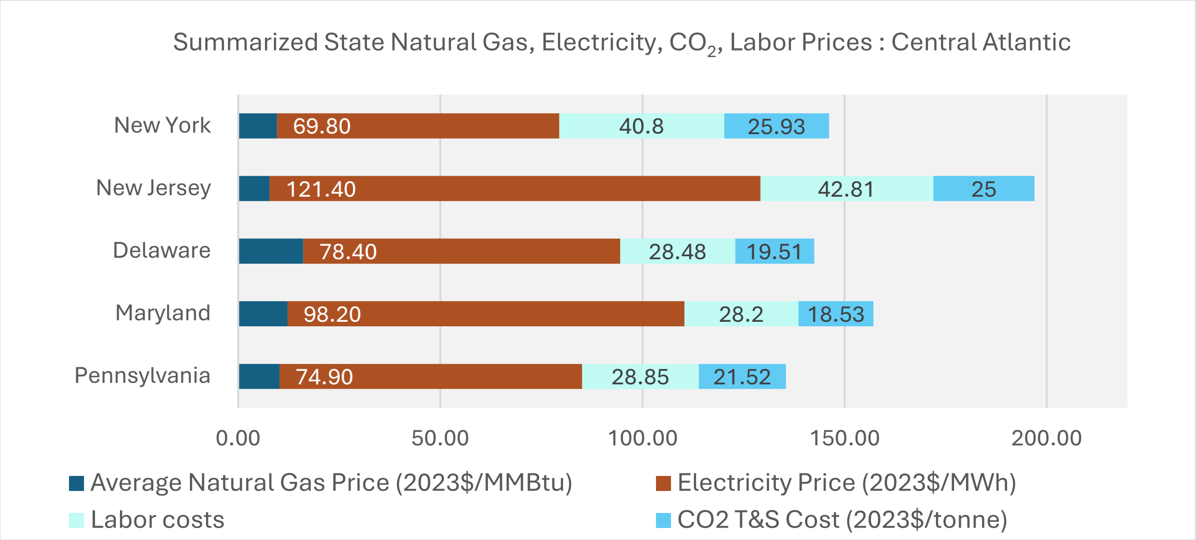

Figure 11. Summarized input prices utilized in Central Atlantic state-level fuel case analysis

When considering the combined effect of all cost drivers (natural gas, electricity, labor, and CO_2 T&S), Pennsylvania emerges as the most cost-advantaged state. This is due to its relatively low prices in all major categories, including natural gas and electricity, as well as lower labor rates and CO_2 transportation and storage costs. These favorable conditions position Pennsylvania as a leading candidate for cost-effective fuel pathway deployment within the Central Atlantic.

PADD 1b: Central Atlantic Resource Potential v. Cost

New York

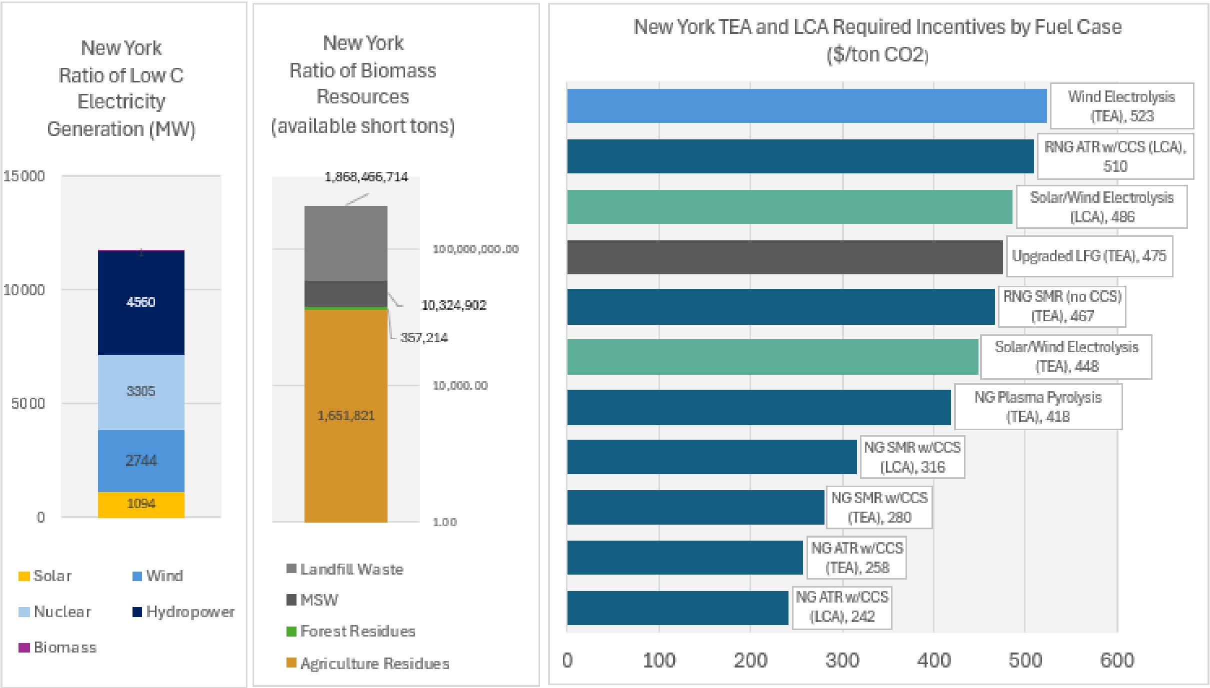

Figure 12. New York state findings

Near-Term Fuel Pathways

Due to New York existing over a portion of the larger Marcellus Shale formation, the state heavily relies on affordable natural gas sourced from other bordering states such as Pennsylvania and also from Canada. Low-carbon H_2 via natural gas-based SMR with CCS and ATR with CCS are identified as the lowest-cost H_2 production options and may leverage existing in-state natural gas reserves and storage fields. Given affordable natural gas prices in New York, these pathways achieve levelized costs of $20-22/MMBTU with incentives of $258-$280 per ton of CO_2 abated. Without CCS, SMR levelized costs increase, aligning with natural gas plasma pyrolysis at $30-33/MMBTU.

When considering RNG-fed SMR or ATR cases, electrolytic H_2 and RNG produced via landfill gas are found to be similarly competitive. For instance, electrolytic H_2 powered by solar or wind is more economical ($448/ton CO_2 abated) than RNG-fed ATR with CCS and comparable to RNG-fed ATR without CCS. RNG from upgraded landfill gas in

New York is estimated to have levelized costs of $34/MMBTU, requiring incentives of $475 per ton of CO_2 abated.

Future Opportunities

New York offers diverse biomass resources and significant untapped low-carbon electricity potential. Developing centralized co-production facilities could enhance cost efficiency for RNG derived from agricultural and forest residues while mitigating land-use challenges. Per New York State's 2025 Energy Plan, the state prefers waste-based feedstocks for alternative fuel production.[1] The state also plans to focus on developing wind, solar, energy storage, advanced nuclear power generation, and revitalizing older combustion power plants to meet future energy demand needs.

Pennsylvania

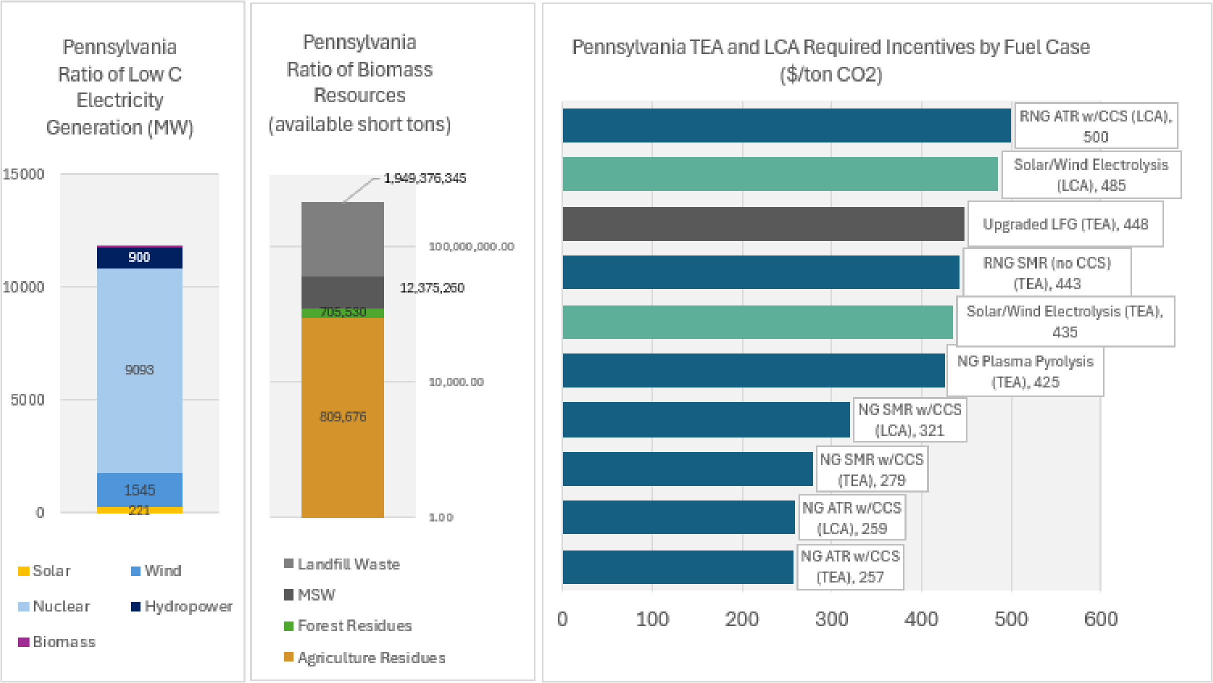

Figure 13. Pennsylvania state findings

Near-Term Fuel Pathways

Affordable natural gas prices, abundant reserves, and ample storage give Pennsylvania a regional edge in producing H_2 via natural gas ATR with CCS and SMR with CCS, at estimated costs of $21-$22/MMBTU and $257-$278 per ton of CO_2 abated. Estimated in-state potential CO_2 storage is in the form of saline aquifers and depleted oil and natural gas reservoirs. As of 2022, the Pennsylvania Department of Environment

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[1] 2025 Energy Plan - New York State New Energy Plan

expressed an interest in applying for Class VI well supremacy with the EPA.[2] Once granted, Class VI well supremacy would encourage further adoption of CCS-dependent H_2 production pathways.

For H_2 production cases excluding CCS in Pennsylvania, natural gas plasma pyrolysis offers the lowest estimated levelized cost ($31/MMBTU) and incentive requirement ($425 per ton CO_2 abated).

RNG from upgraded landfill gas is slightly more expensive ($32/MMBTU) and requires marginally higher incentives ($448 vs. $425 per ton CO_2 abated).

While electrolytic H_2 from solar and wind appears more economical, Pennsylvania's existing low-carbon electricity is predominantly nuclear. Due to higher variable O&M costs, nuclear-based electrolysis results in higher levelized costs ($51/MMBTU) within the state.

Future Opportunities

Currently, Pennsylvania's limited solar and wind generation constrains the near-term potential for electrolytic H_2 production. Increasing solar and wind capacity could significantly enhance the competitiveness of electrolytic H_2 by leveraging lower-cost renewable electricity. This shift would not only reduce production costs but also align with broader decarbonization goals, creating opportunities for H_2 to play a larger role in Pennsylvania's clean energy strategy. Strategic investments in renewable infrastructure and grid integration will be critical to unlocking this potential.

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[2] General Assembly of the Commonwealth of Pennsylvania 2022 Act

New Jersey

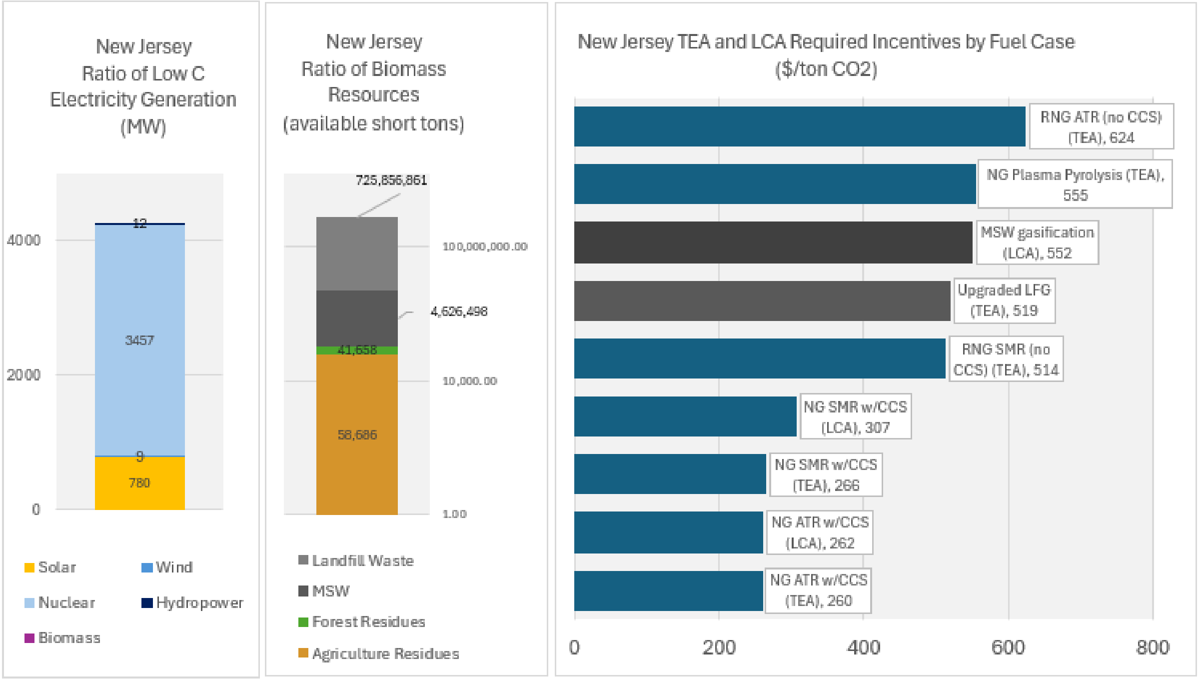

Figure 14. New Jersey state findings

Near-Term Fuel Pathways

Having no existing natural gas reserves, New Jersey largely sources natural gas from the Marcellus Shale, as well as Canada. H_2 produced via natural gas fed SMR w/ CCS and ATR w/CCS demonstrate similarly low levelized costs at approximately $20/MMBTU, with required incentives in the range of $260-$266 per ton of CO_2 abated. Estimated in-state CO_2 storage potential for New Jersey is negligible. However, there is CO_2 storage potential in the form of saline aquifers and depleted oil and gas reservoirs in the neighboring state Pennsylvania.

For fuel pathways excluding CCS, RNG produced from upgraded LFG shows slightly lower levelized costs and required incentives ($36/MMBTU, $519/ton CO_2 abated) compared to NG plasma pyrolysis ($38/MMBTU, $554/ton CO_2 abated). Among H_2 pathways without CCS, RNG-fed SMR offers the lowest levelized cost and incentive requirement ($36/MMBTU, $514/ton CO_2 abated).

Future Opportunities

Current nuclear power generation in New Jersey exceeds solar output by more than three orders of magnitude. However, the estimated levelized cost of electrolytic H_2 from nuclear power ($51/MMBTU) is significantly higher than from solar ($42/MMBTU) or wind ($35/MMBTU), primarily due to higher projected variable O&M costs. Looking ahead, prioritizing wind generation in New Jersey could improve the economics of H_2 production via electrolysis powered by wind.

Maryland

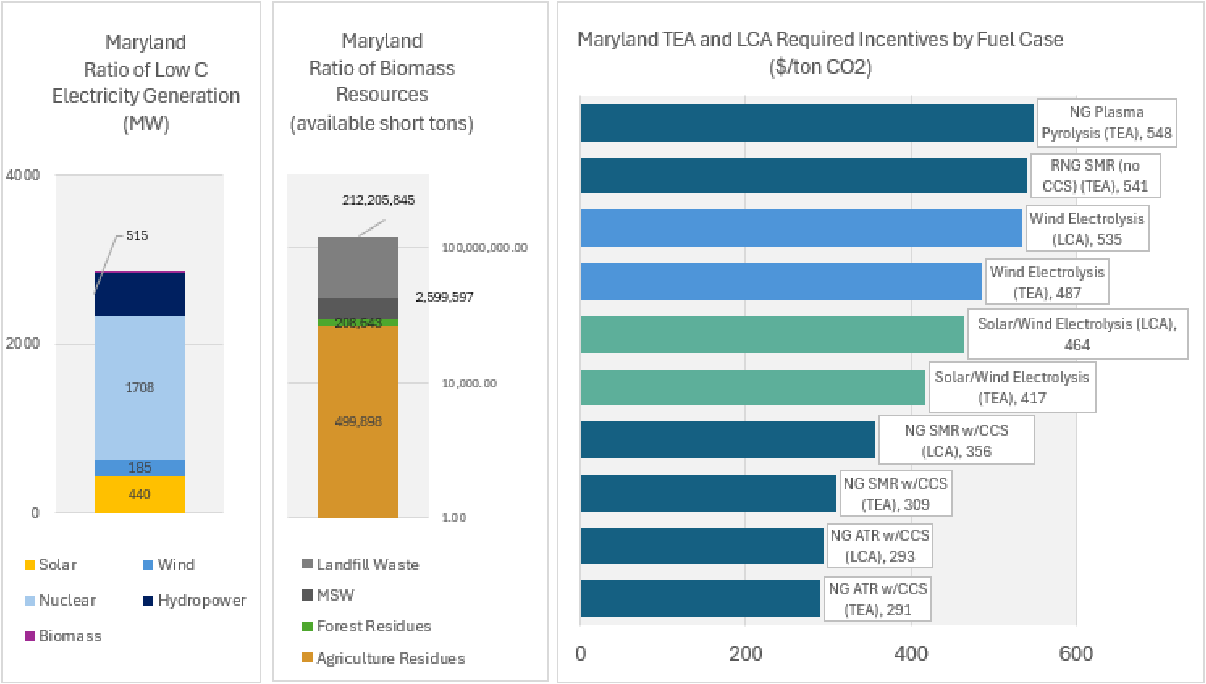

Figure 15. Maryland state findings

Near-Term Fuel Pathways

Maryland has no existing natural gas production and relies on natural gas originating from the Marcellus Share (West Virginia, Pennsylvania) and Canada.

In Maryland, the lowest fuel levelized costs and required incentives are associated with H_2 produced via NG SMR with CCS ($24/MMBTU, $291/ton CO_2 abated) and NG ATR with CCS ($25/MMBTU, $309/ton CO_2 abated). However, estimated CO_2 storage potential is limited to minimal saline aquifers. For cases excluding CCS, electrolytic H_2 from wind shows the lowest levelized cost ($36/MMBTU), followed by NG SMR and NG plasma pyrolysis, both at approximately $40/MMBTU. Notably, NG plasma pyrolysis yields a lower calculated CI score compared to NG SMR without CCS.

Although wind-based electrolysis offers the most cost-effective non-CCS option, current wind generation in Maryland is minimal relative to low-carbon electricity sources such as nuclear and solar.

Future Opportunities

Expanding wind and solar generation can further reduce electrolytic H_2 costs and avoid dependence on carbon capture and storage infrastructure. Additionally, investing in pyrolysis technologies can enhance reliability by supporting intermittent renewable generation.

Delaware

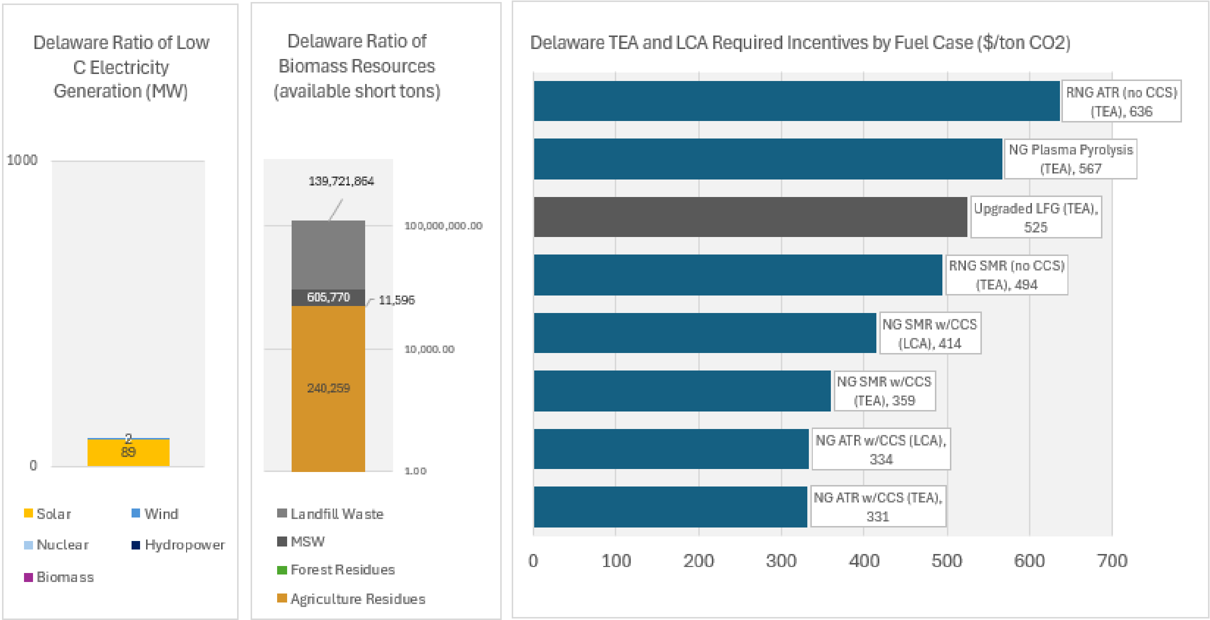

Figure 16. Delaware state findings

Near-Term Fuel Pathways

Delaware relies on natural gas originating from the Marcellus Shale (Pennsylvania) and Canada. H_2 produced via NG SMR w/CCS and NG w/ATR demonstrated the lowest fuel levelized costs ($29-31/MMBTU) and required incentives ($331-359/ton CO_2 abated). However, estimated CO_2 storage potential in Delaware is limited. For fuel pathways excluding CCS, similar levelized costs are observed for RNG SMR without CCS ($39/MMBTU), NG plasma pyrolysis ($43/MMBTU), and RNG from LFG ($41/MMBTU). Among these, RNG-fed SMR without CCS requires the smallest incentives to achieve cost parity with natural gas in Delaware.

The limited availability of low-carbon electricity generation in Delaware constrains the scalability of electrolytic H_2 production.

Future Opportunities

Upgrading LFG offers additional decarbonization potential without relying on carbon capture or CO_2 transport infrastructure. In addition, leveraging agricultural residues can increase RNG production.

PADD 1c: Lower Atlantic

West Virginia, Virginia, North Carolina, South Carolina, Georgia, Florida

Case Study Analysis: Lower Atlantic State Price Inputs

Figure 17 summarizes state-level costs in the Lower Atlantic region for natural gas, electricity, CO_2 transportation and storage, and average labor rates, which are key drivers of the fuel case technoeconomic results.

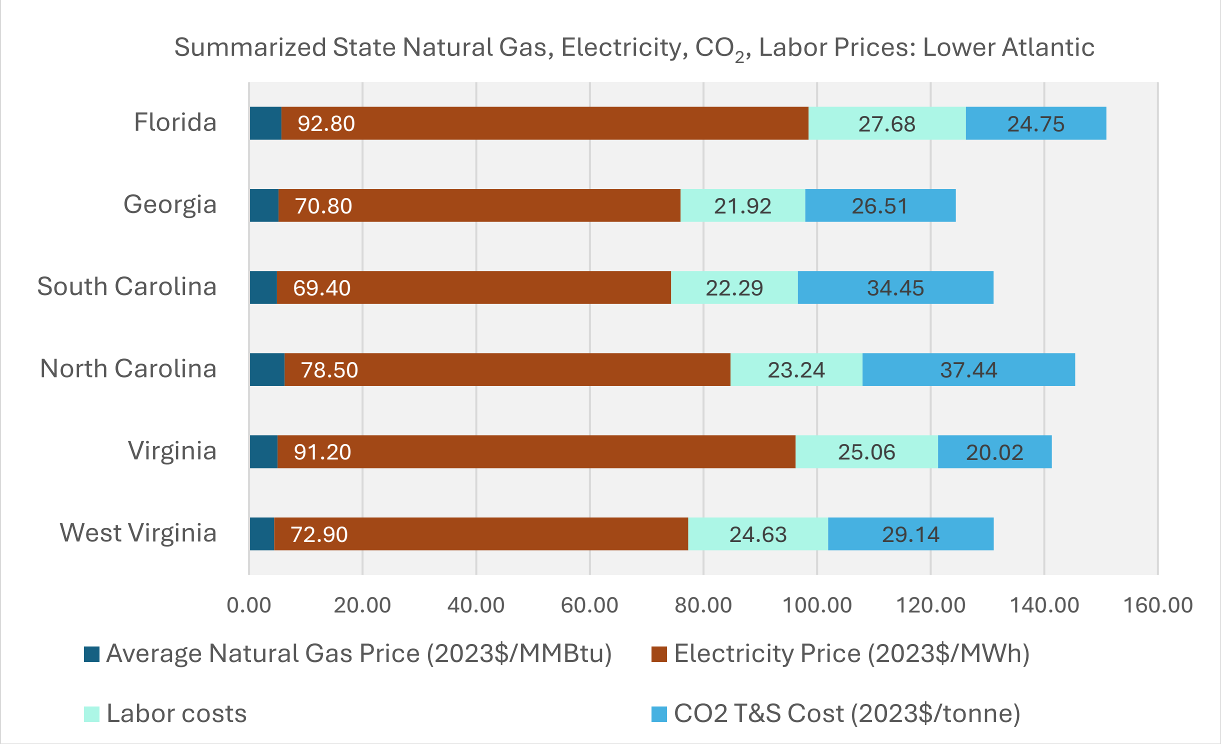

Figure 17. Summarized input prices utilized in Lower Atlantic state-level fuel case analysis

Among these states, South Carolina and Georgia offer the lowest electricity prices, helping to reduce overall fuel production costs. Conversely, West Virginia stands out with the lowest natural gas prices, providing a competitive edge for fuel pathways that rely on natural gas. When considering the combined impact of all cost factors, Georgia emerges as the most cost-advantaged state for emerging fuels deployment within the Central Atlantic region.

PADD 1c: Lower Atlantic Resource Potential v. Cost

West Virginia

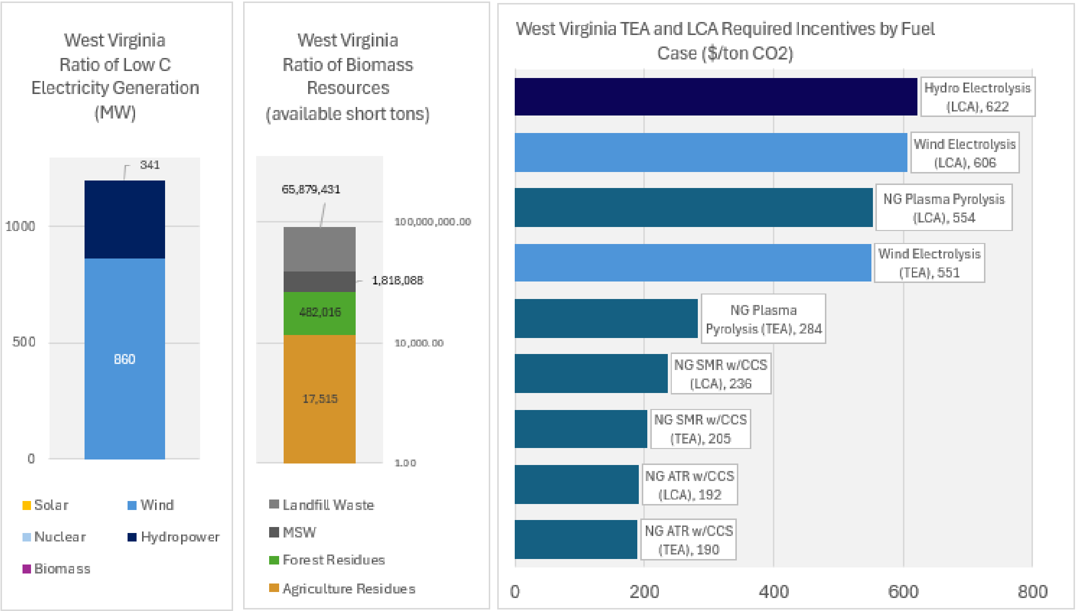

Figure 18. West Virginia state findings

Near-Term Fuel Pathways

West Virginia benefits from regionally abundant natural gas reserves, competitive gas prices, and existing wind power generation, positioning the state favorably for H_2 production through multiple pathways. The lowest fuel levelized costs and required incentives in West Virginia are associated with H_2 via NG ATR w/ CCS ($14/MMBTU, $190/ton CO_2 Abated) and NG SMR w/ CCS ($15/MMBTU, $205/ton CO_2 Abated).

When considering fuel cases excluding CCS in West Virginia, NG Plasma Pyrolysis demonstrates the lowest levelized costs ($20/MMBTU) and required incentives ($284/ton CO_2 Abated).

Prospects for electrolytic H_2 in West Virginia are expected to be associated with wind power due to existing wind power generation and lowest estimated levelized costs for electrolytic H_2 supplied by wind power ($36/MMMBTU). Electrolytic H_2 via hydropower in West Virginia demonstrates higher levelized costs ($43/MMBTU) to electrolysis via wind power.

Future Opportunities

Expanding wind generation can further reduce electrolytic H_2 costs. Additionally, investing in pyrolysis technologies can enhance reliability by supporting intermittent renewable generation.

Virginia

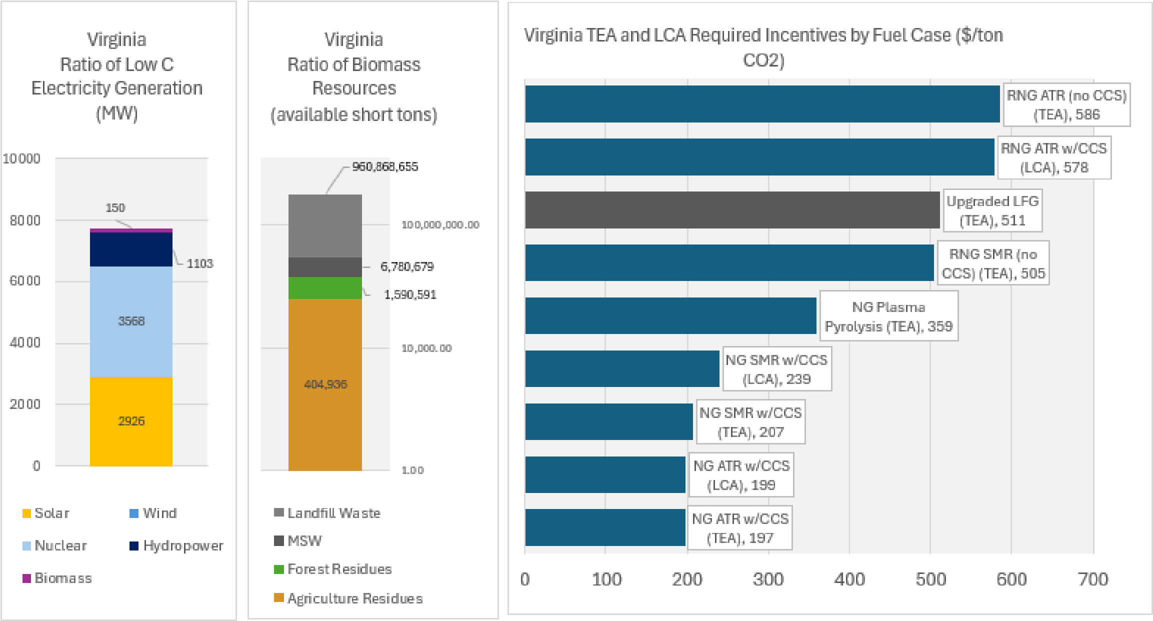

Figure 19. Virginia state findings

Near-Term Fuel Pathways

Virginia relies on in-state natural gas production as well as natural gas sourced from the Marcellus Shale (Pennsylvania, West Virginia), Gulf Coast states (Texas, Louisiana), and Oklahoma.

H_2 produced via NG SMR w/CCS and ATR w/ CCS are found to offer the lowest required incentives ($197-239/MMBTU). Virginia's estimated CO_2 storage potential is limited, with only minimal depleted oil and gas reservoirs. However, neighboring West Virginia offers additional storage potential with saline aquifers and depleted oil and gas reservoirs.

Among pathways that do not require CCS, methane pyrolysis offers the lowest cost, at approximately $25/MMBTU and $359 per ton of CO_2. Additionally, H_2 production via RNG-based SMR without CCS is more economically competitive than electrolytic H_2 in Virginia.

Future Opportunities

With the expansion of solar generation, alternative land use strategies, and available incentives, electrolytic H_2 from solar power could become a cost-effective option in Virginia over time. The Virginia Department of Energy has announced three planning awards to advance clean H_2 production, storage, and use in Southwest Virginia.[3] It is anticipated that these efforts will identify H_2 opportunities for the region. In addition, with incentives, RNG production via LFG upgrades can be a cost-effective alternative to the H_2 pathways.

North Carolina

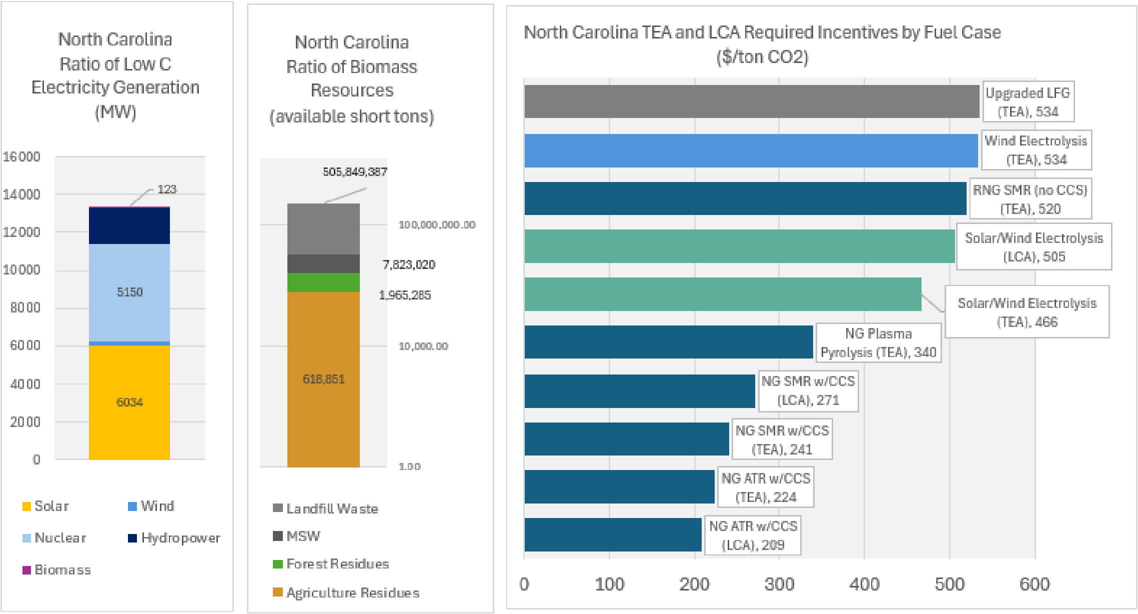

Figure 20. North Carolina state findings

Near-Term Fuel Pathways

North Carolina depends on natural gas sourced from the Marcellus Shale (Pennsylvania, West Virginia, Ohio), Gulf Coast states (Louisiana, Texas), and Canada.

NG SMR with CCS and NG ATR with CCS are identified as the lowest-cost H_2 production pathways in North Carolina, with levelized costs of approximately $17-$18/ MMBTU. These pathways also correspond to the lowest estimated incentives required to achieve cost parity with natural gas in the state, ranging from $224-$240/MMBTU. However, estimated CO_2 storage potential in North Carolina is limited. For pathways that do not incorporate CCS, natural gas plasma pyrolysis offers the most competitive economics,

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[3] https://www.energy.virginia.gov/public/documents/newsroom/2025/Virginia

with levelized costs near \$24/MMBTU and associated incentives of about \$340 per ton of CO_2.

Future Opportunities

Expanding solar and wind generation can further reduce electrolytic H_2 costs. Additionally, investing in pyrolysis technologies can enhance reliability by supporting intermittent renewable generation.

South Carolina

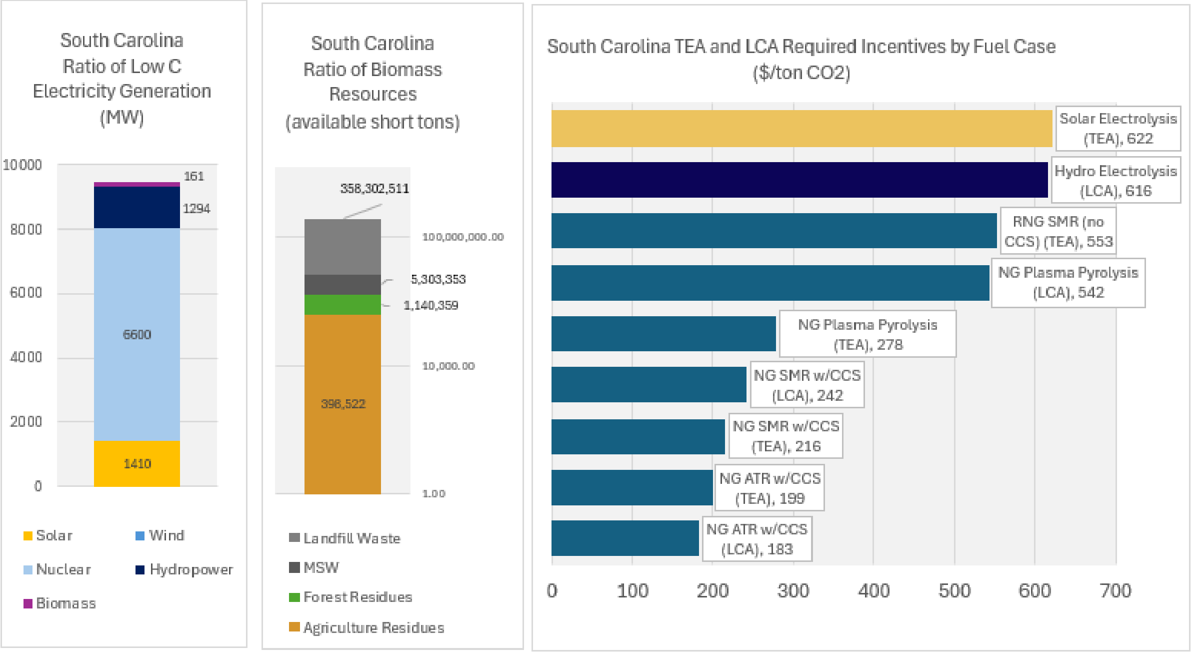

Figure 21. South Carolina state findings

Near-Term Fuel Pathways

With no in-state natural gas production, South Carolina sources natural gas from Gulf Coast states (Louisiana, Mississippi, Alabama), which is delivered via transmission lines crossing through Georgia. Unlike other East Coast states, South Carolina does not heavily rely on the Marcellus Shale. Additionally, estimated in-state CO_2 storage potential is limited to saline aquifers.

Compared to other states in the region, South Carolina generally has the lowest levelized costs across fuel cases, with overall costs of about \$15/MMBtu for reforming and about \$19/MMBtu for plasma pyrolysis. However, when focusing on fuel pathways that do not rely on CO_2 transport and storage infrastructure, NG plasma pyrolysis is the most economical emerging fuel pathway with the lowest required incentive (\$278/ton CO_2).

Future Opportunities

Current H_2 demand in South Carolina is low, at approximately 0.11 petajoules. Introducing targeted incentives to encourage adoption could reduce emissions, especially given the state's lowest H_2 production costs compared to other East Coast states.

Georgia

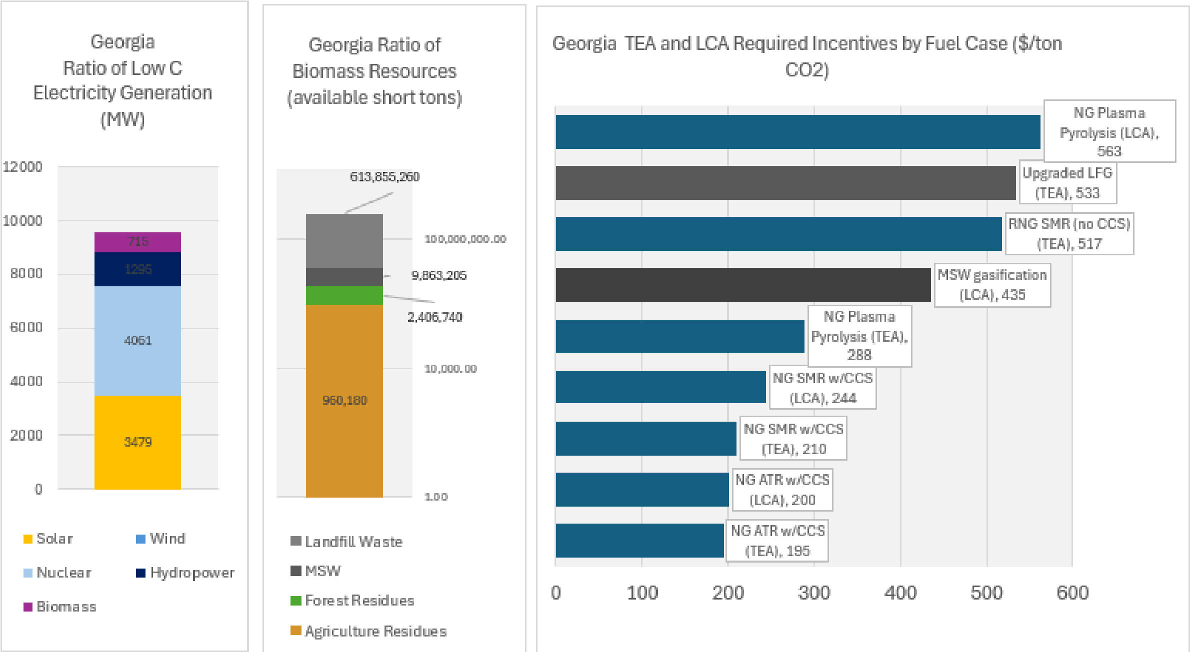

Figure 22. Georgia state findings

Near-Term Fuel Pathways

Natural gas production in Georgia plays a vital role in supplying affordable fuel to various end use sectors. Georgia also sources natural gas from several states in the East Coast (Pennsylvania, West Virginia) as well as from Gulf Coast states (Alabama, Texas, Louisiana).

As a result of competitive natural gas prices, natural gas SMR and ATR with CCS represent the most cost-effective pathways for H_2 production. In-state potential for CO_2 storage is estimated in the form of saline and fossil underground storage sites in the southern portion of the state. Plasma pyrolysis emerges as a promising alternative pathway which does not require CCS, offering potential advantages in terms of lower emissions and scalability, though it is less cost-competitive compared to SMR and ATR with CCS.

For RNG, anaerobic digestion of MSW and LFG are two cost-effective options. Both options capitalize on Georgia's substantial MSW resource base, creating synergies between waste management and renewable fuel production.

Future Opportunities

While Georgia currently lacks significant wind generation capacity, the state possesses strong technical potential for wind power development. Unlocking this resource could significantly enhance the feasibility of electrolytic H_2 production in the long term, particularly when paired with grid decarbonization efforts and renewable integration strategies.

Georgia also possesses considerable agricultural biomass resources. While near-term costs for RNG derived from agricultural residue digestion remain relatively high compared to other feedstocks, technological advancements, economies of scale, and policy incentives could reduce these barriers over time. Developing robust supply chains for biomass and exploring co-location opportunities with existing agricultural operations may further improve cost competitiveness.

Florida

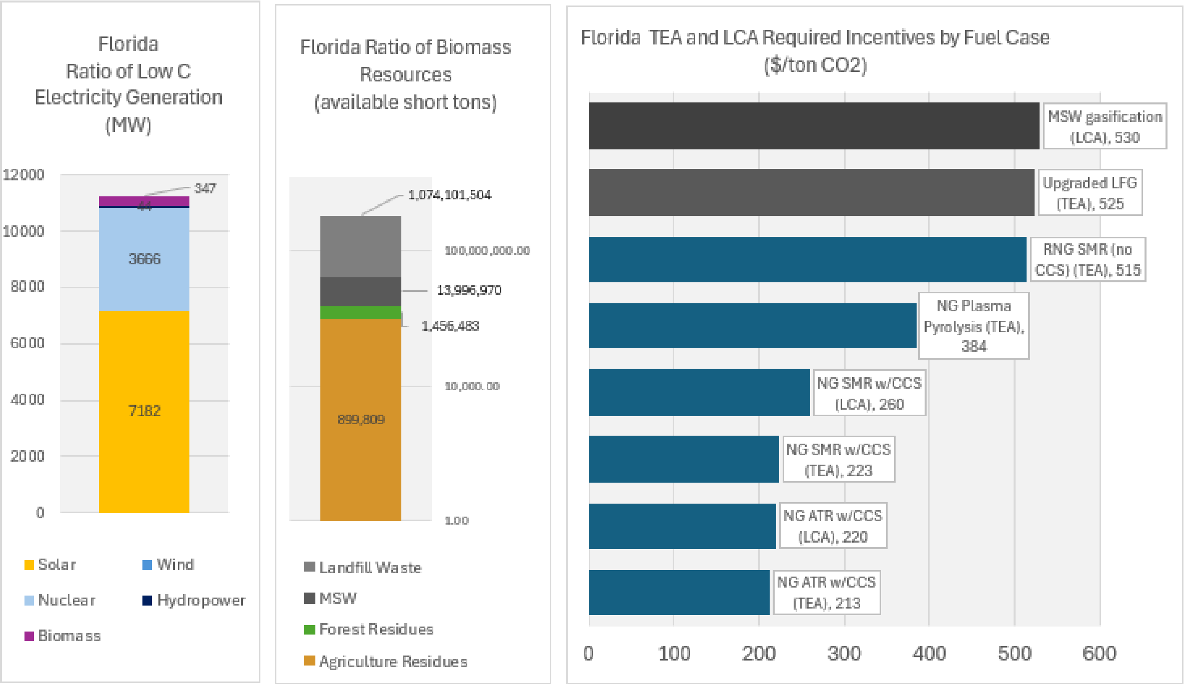

Figure 23. Florida State Findings

Near-Term Fuel Pathways
Natural Gas SMR and ATR with CCS represent the most cost-effective pathways for H_2 production. Estimated in-state CO_2 storage potential is identified in the form of saline underground storage and extends throughout the state.

Plasma pyrolysis emerges as a promising alternative pathway, though it is less cost-competitive compared to SMR and ATR with CCS. For RNG, upgrading of LFG could be a cost-effective option by leveraging the state’s substantial waste generation.

Future Opportunities
Florida’s strong solar resource, which exceeds that of many other East Coast states, positions the state favorably for electrolytic H_2 production as renewable penetration grows. Expanding solar and wind generation capacity will enhance the economics of electrolysis by lowering renewable electricity costs and improving grid flexibility. Over the long term, this could enable Florida to become a competitive hub for electrolytic H_2, complementing natural gas-based pathways and supporting decarbonization across multiple sectors.

Cost Comparison of New and Retrofitted Pipelines

Current estimates show that new H_2 pipelines cost about 2-5% more than natural gas pipelines. However, because H_2 has a lower energy density than natural gas, the cost increase could be as much as 16% more for the same amount of energy delivered (EPRI, 2024). These estimates do not account for capital and operating costs for compressor stations, which can be significant given that H_2 requires approximately three times the compression power as natural gas. A new natural gas pipeline in the East Coast region can cost $5-18 million per mile. Applying the upper end of the EPRI estimate to this range, a new H_2 pipeline in the East Coast could potentially cost between $5.1 and 18.9 million per mile.

One key benefit of repurposing existing pipelines is the potential for substantial cost savings. It is estimated that the cost to repurpose natural gas pipelines for H_2 service is 10 to 35% of the cost of new pipeline construction (ACER 2021). The actual costs will depend on factors such as pipeline diameter, location, material type, and condition of the pipeline. Using the upper end of this estimate, repurposing a pipeline on the East Coast could range from approximately $510,000 to $6.7 million per mile.

When comparing new construction and retrofit options, the financial case for repurposing existing infrastructure is evident. Repurposing infrastructure provides the opportunity to avoid right-of-way acquisition logistics, reduce construction emissions, and fast-track project timelines.

If RNG becomes the primary decarbonization pathway for the East Coast region, no significant design modifications will be needed as it is chemically indistinguishable from conventional natural gas. However, operators will need to ensure that the RNG meets gas quality requirements prior to injection into the gas system as contaminants (e.g., siloxanes, VOCs, hydrogen sulfide) can lead to pipeline integrity and end-use equipment issues.

Conclusions and Opportunities

The East Coast region presents a unique and complex landscape for integrating emerging fuels into existing natural gas infrastructure. This case study demonstrates that leveraging H_2 and RNG can reduce GHG emissions while supporting energy reliability and resilience. However, the feasibility of these pathways depends on multiple factors, including resource availability, infrastructure readiness, regulatory clarity, and cost competitiveness.

Key findings indicate that:

Infrastructure repurposing offers a cost-effective strategy for scaling emerging fuels, particularly RNG, which are chemically similar to natural gas. H_2 integration requires more extensive assessments and upgrades due to material compatibility and operational constraints. The SNG pathways assessed do not provide emissions reduction benefits.

Resource distribution varies widely across states, necessitating a tailored approach to fuel production and blending strategies. States with abundant biomass and LFG are well-positioned for RNG development, while states with strong renewable electricity potential and natural gas reserves can support low-carbon H_2 production. Strategic siting of production facilities near feedstock sources and end-use markets will be critical to minimize costs and optimize logistics.

Economic viability remains a challenge, as the emerging fuel pathways currently exceed the cost of conventional natural gas. Incentives, such as tax credits and low-carbon fuel standards, will be critical to bridge this gap and accelerate adoption.

Policy alignment is essential to enable cross-state projects, harmonize safety standards, and reduce permitting timelines. Coordinated frameworks for H_2 blending, CO_2 transport, and RNG integration will help mitigate uncertainty and attract investment.

Workforce development and infrastructure modernization must advance in parallel with technology deployment. Scaling emerging fuels will require a skilled workforce capable of supporting new technologies and maintaining system integrity. Investments in training programs, credentialing systems, and modernization of aging pipeline networks will ensure safe operations and long-term resilience.

In summary, the East Coast has the potential and resource diversity to become a leader in low-carbon fuels adoption. Achieving this vision will require a strategic mix of infrastructure upgrades, supportive policies, targeted incentives, and collaborative planning across states. By leveraging existing assets, aligning investments with regional strengths, and fostering innovation in both technology and workforce development, stakeholders can accelerate the transition toward a cleaner, more resilient, and economically competitive energy future.

For more information on the case study's background, analysis, and findings, please refer to the full report and appendices available on the RAISE website (raise.gti.energy).

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