Analysis of API's Climate Framework:

API22-NEMS Results for the Combined Policy Case

Prepared for API

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CLIENT CONFIDENTIAL

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Project Overview

- API developed a climate framework and enlisted OnLocation to perform an assessment of the framework's emissions and cost impacts primarily through quantitative modeling supplemented with insights and analysis based on published literature where appropriate.
- The API framework includes an economy-wide CO_2 price starting at \$35-50/tCO_2, revenue recycling split between households and technology R&D, and other provisions that will be analyzed either quantitatively or qualitatively.
- OnLocation created the API22-NEMS[1] model for use in analyzing scenarios and sensitivities in four tracks: reference case, economy-wide CO_2 pricing, federal carbon reduction standards (FCRS) for transportation fuels, and a combined CO_2 pricing/FCRS scenario.
- This slide deck focuses primarily on results of the **API22-NEMS Combined Policy scenario** which includes CO_2 Pricing, FCRS policy, and assumptions for technology improvement expected from the use of 50% of CO_2 revenues for technology R&D.
- Results highlight API's four main areas of interest: emissions, energy system, household expenditures, and technology improvement.

[1] *API22-NEMS is a modified version of the U.S. Energy Information Administration's National Energy Modeling System (NEMS) developed by OnLocation for use in this analysis. API22-NEMS is based on the Annual Energy Outlook (AEO) 2022 and includes the same market and technology assumptions unless otherwise noted. For more information, visit https://www.eia.gov/outlooks/aeo/.*

Summary of Key Findings

- **CO_2 emissions** reductions in the CO_2 Price and Combined Policy scenarios come close to but do not achieve the Biden Administration's goals of creating a CO_2 emissions-free power sector by 2035 and economy-wide net-zero greenhouse gas emissions by 2050.
- The CO_2 price and the FCRS policies both lead to emission reductions, but the CO_2 price has the larger impact. As an intensity standard, the impact of the FCRS is smaller when combined with the CO_2 price because the latter policy causes overall lower liquid fuels demand and thus lower deployment of biofuels is needed to meet the FCRS required intensity reduction. There is little interaction of the two policies outside the transportation sector.
- CO_2 emissions from the power sector decline rapidly in the CO_2 Price and Combined Policy scenarios, while reductions from other energy sectors are relatively small due to fewer cost-effective options for reducing emissions. The transportation sector, specifically on-road vehicles, also contribute CO_2 reductions primarily due to greater adoption of lower-cost electric light-duty vehicles and the shift to more biofuels due to the FCRS policy.
- When a CO_2 price is applied, the **energy system** shifts away from conventional carbon-intensive fuels such as coal and petroleum-based fuels to low- or carbon-free sources such as renewable power, biofuels, and electrification. Declining technology costs for these sources reduce the cost of this system transformation.
- The share of electricity generation from CO_2 emissions-free sources including renewables, nuclear power, and natural gas with carbon capture increases significantly in the CO_2 price case, and conventional fossil-fueled generation decreases as the majority of these power plants retire.
- Annual **household energy expenditures** per household increase by $660 (2021$)* or 8% by 2050 in the Combined Policy scenario relative to Reference case values mainly due to higher energy prices that include the impact of the CO_2 price. The CO_2 revenue returned to households (50% revenue recycling) more than offsets this increase.
- Investing the remaining 50% of CO_2 revenues in **technology R&D** is expected to increase emission reductions achieved and result in cost savings to energy producers and consumers.

** Note, all monetary values in this analysis are expressed in real 2021$ unless otherwise indicated.*

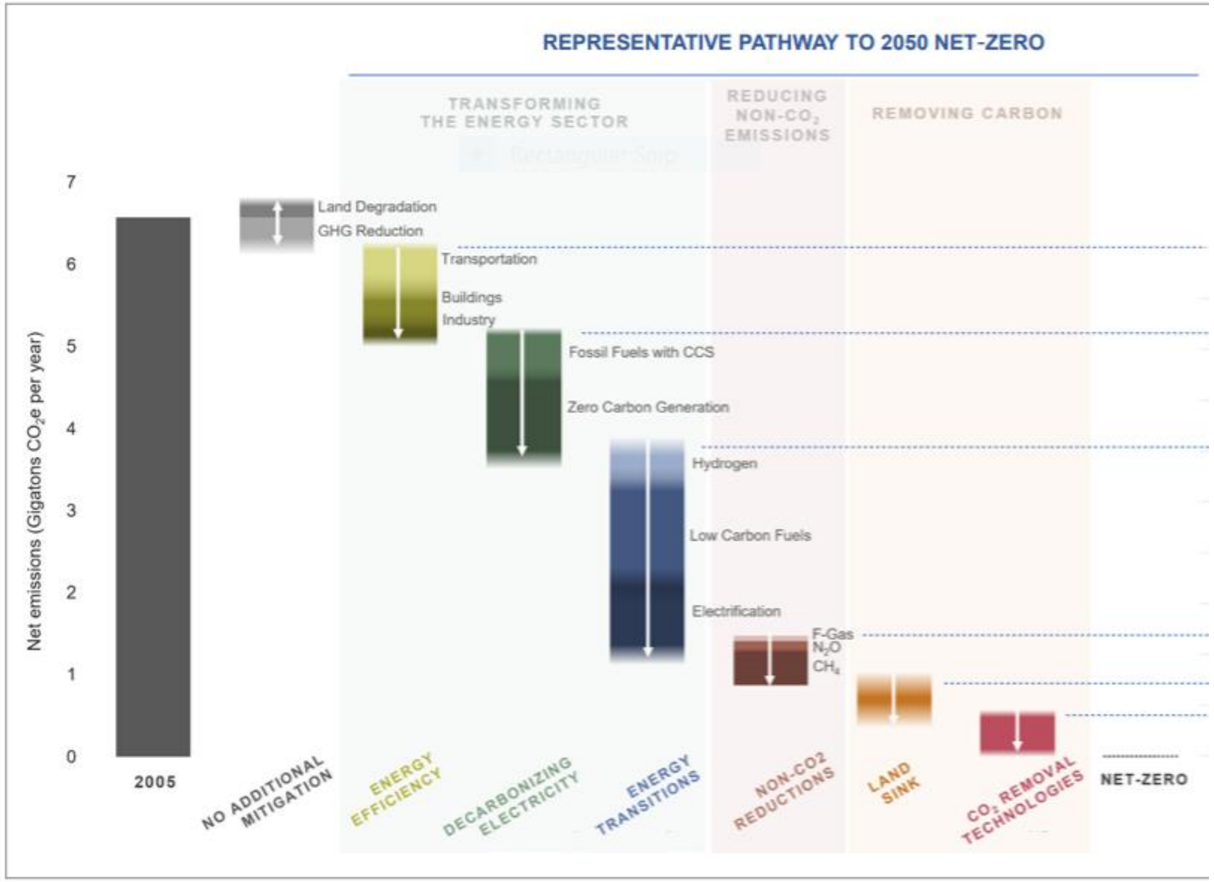
Modeling Results and Observations

Scenario Descriptions

- The following API22-NEMS scenarios are used to analyze the impact of the API proposed policy framework:
  - The ***API22 Reference* case** is a customized reference case created for API that includes policy updates that have occurred since the EIA's Annual Energy Outlook (AEO) 2022 was published, including: power and CO_2 capture provisions of Infrastructure Investment and Jobs Act (IIJA); updated NHTSA CAFE standards through 2026; and updated state level Zero Emission Vehicle policies (including 100% sales by 2050 for CA). This case does not include any provisions from the recently enacted Inflation Reduction Act.
  - The ***API22 CO_2 Price scenario*** includes an economy-wide CO_2 price of $50 per metric tonne (2021$) starting in 2023 and rising at 5 percent per year above inflation; and modified technology assumptions in the power and transportation sectors to reflect improvements expected in low CO_2-emitting technologies from the use of 50% of CO_2 revenues for research and development. All other assumptions are the same as the API22 Reference case.
  - The ***API22 FCRS scenario*** is built from the API22 reference case and includes a Federal Carbon Reduction Standard for non-petroleum transportation fuels similar to the California Low Carbon Fuel Standard (LCFS) that requires a 15% decrease in carbon intensity on a life-cycle basis of gasoline and diesel over 15 years.
  - The ***API22 Combined Policy scenario*** combines all assumptions from the CO_2 Price case and FCRS case to create a scenario reflecting a comprehensive approach to reducing greenhouse gas emissions.
- For comparison purposes, an additional case is used for select results:
  - The ***AEO22 Reference* case** assumes AEO 2022 technology and policy assumptions with no updates beyond those needed for purposes of consistency with the API policy cases. This case was run by OnLocation and its results approximate, but are not identical to, the published EIA AEO 2022.
- For more information about the modeling assumptions for these cases, see Appendices A, B, and C.

Biden Administration Climate Goals

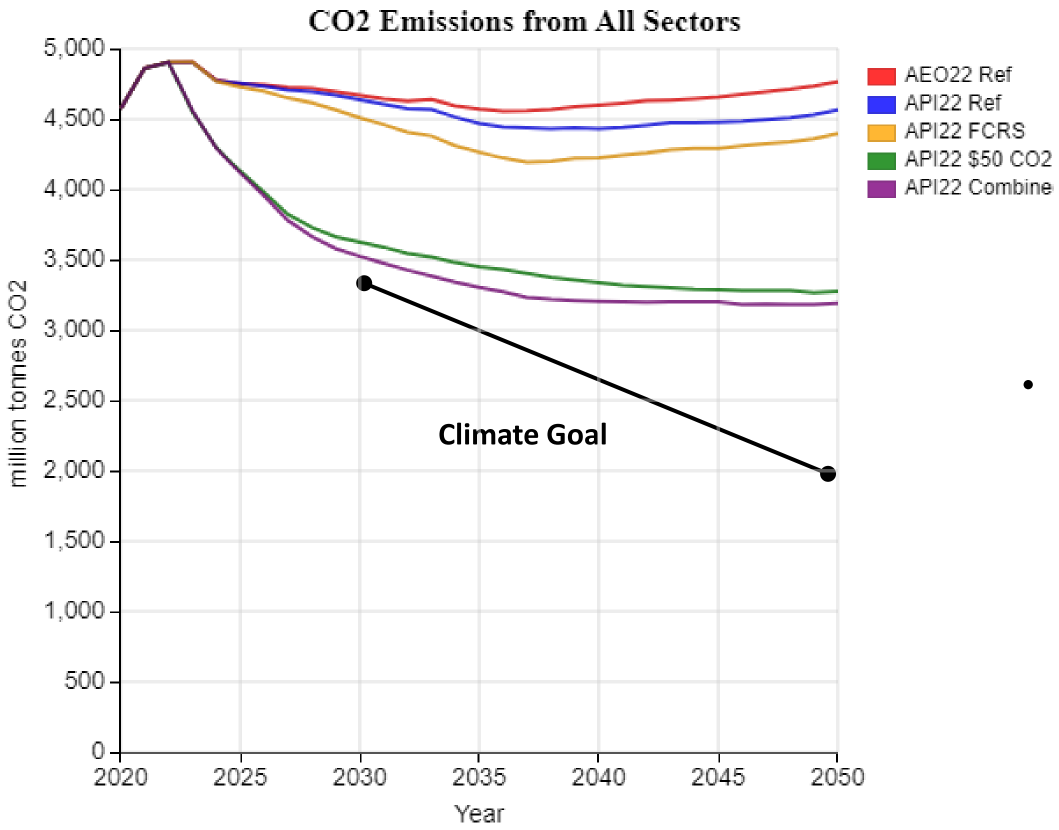
- President Biden's climate goals are to reduce greenhouse gas (GHG) emissions 50-52% below 2005 levels by 2030 (reaching roughly 3.3 gigatons CO_2e or 3,300 MMT by 2030) and achieve net-zero GHG emissions by 2050 economy-wide.
- The White House issued its Long-Term Strategy report in November 2021* which includes this waterfall chart illustrating a representative pathway for achieving the 2050 climate goal.
- Some of the important long-term and potentially more expensive mitigation technologies outlined in this pathway are not represented in API22-NEMS, including extensive electrification, hydrogen production, non-CO_2 gases, land sinks, and CO_2 removal technologies.
- When these elements are removed, the adjusted net-zero emissions goal for the energy system is estimated to reach an equivalent of 2.0 gigatons CO_2e per year by 2050.



** The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050, November 2021.*

Economy-Wide CO_2 Emissions

- The chart shown here illustrates economy-wide CO_2 emissions for all five scenarios to highlight the incremental effect of the policy and technology assumptions included in each of the four tracks.
- Policy updates included in the API22 Ref case result in about 200 MMT reduction in emissions by 2050, and the FCRS policy results in an additional reduction of 170 MMT, primarily from reductions in petroleum use.
- Emissions decline rapidly in the CO_2 Price and Combined Policy scenarios compared to the Reference case. The Combined Policy emissions decline to about 3,500 MMT CO_2 by 2030 and 3,200 MMT by 2050. Reductions taper off as the cost of mitigation increases.
- President Biden's economy-wide climate goals shown here are estimated based on the Administration's Long-Term Strategy and adjustments described on a previous slide.* CO_2 reductions in the API Combined scenario come close to meeting the 2030 goal of 3,3000 MMT but fall short of the longer-term adjusted goal of 2,000 MMT by 2050.

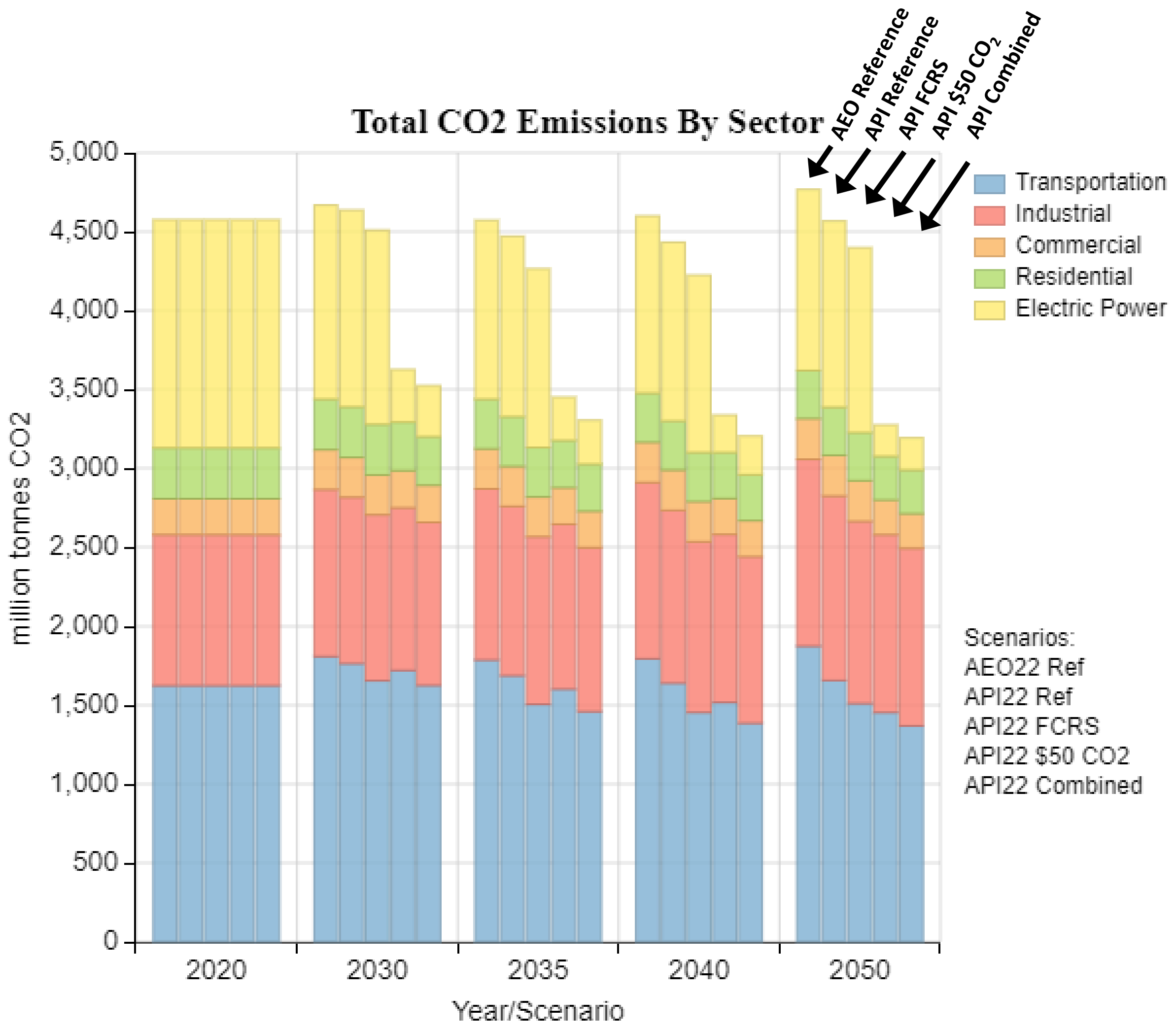


- Note: CO_2 is the largest component of greenhouse gases (roughly 80 percent); other GHGs were not considered in the model, although energy-related methane emissions are estimated in an off-line analysis.

* *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050, Nov 2021.*

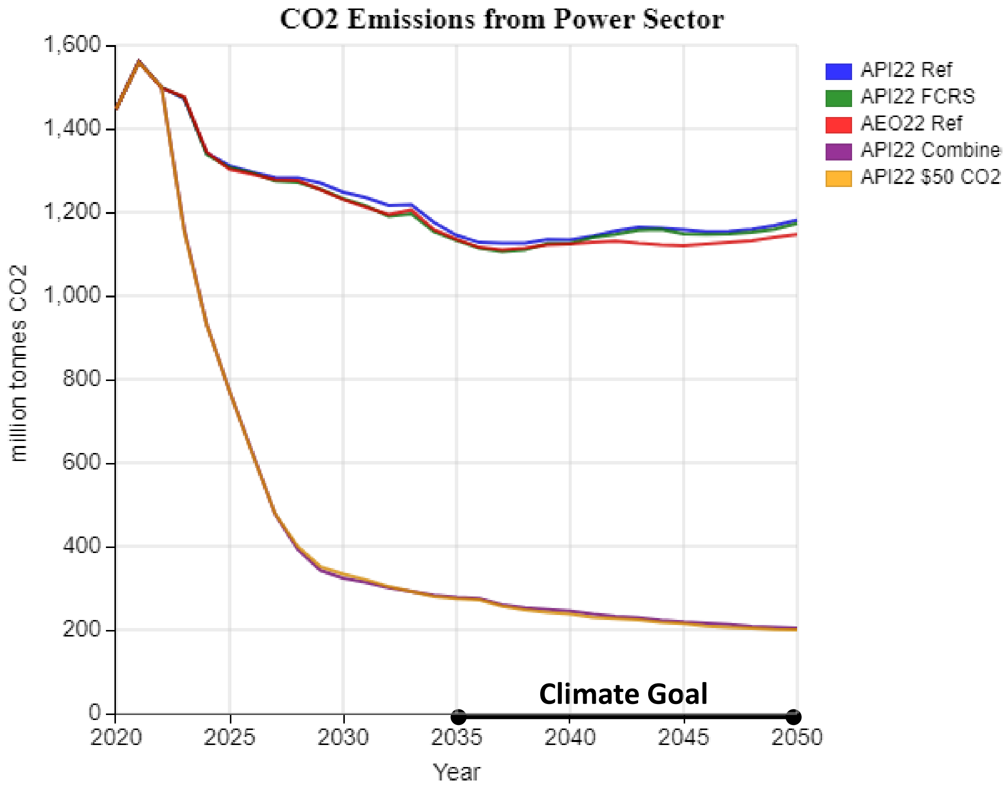
Economy-Wide CO_2 Emissions by Sector

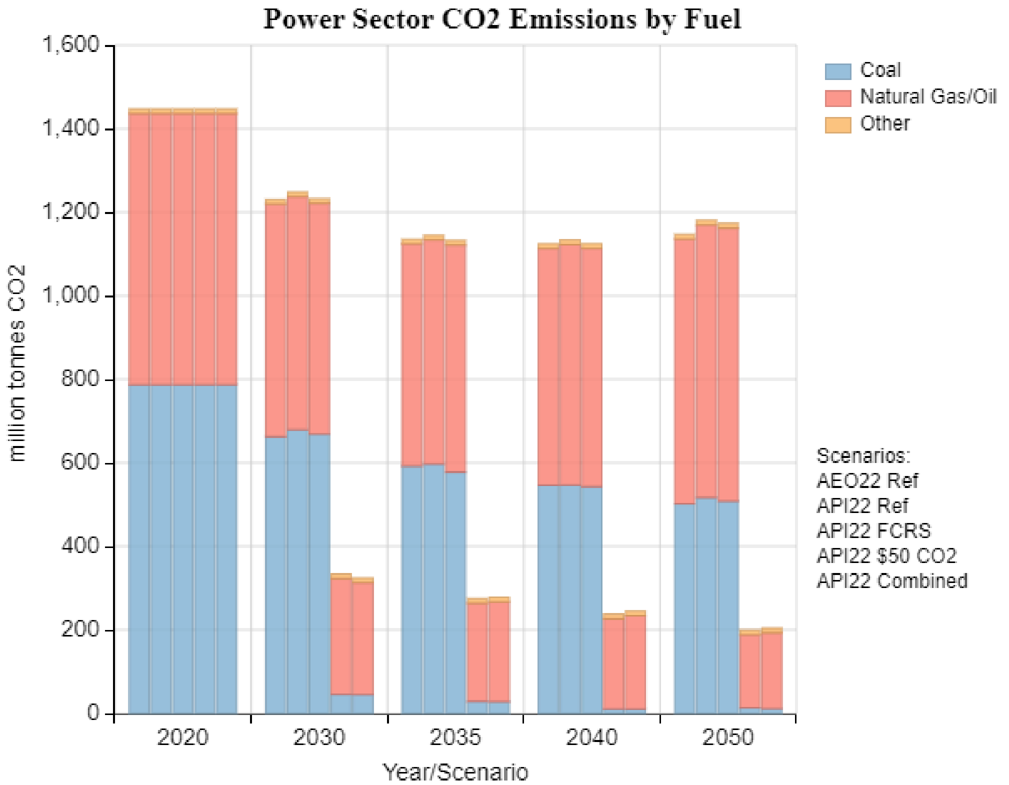
- Most CO_2 reductions occur in the power and transportation sectors in all scenarios.
- In the power sector, CO_2 declines about 1,000 MMT in both the CO_2 Price and Combined Policy scenarios, with no significant change in the other scenarios.
- In the transportation sector, CO_2 declines about 200 MMT in the CO_2 Price scenario and another 80 MMT in the Combined scenario due to the FCRS policy. The FCRS scenario by itself achieves a greater reduction of 150 MMT. Liquids demand is lower in the Combined scenario than the FCRS scenario which leads to a smaller impact of the intensity standard.
- The buildings and industrial sectors also contribute some emission reductions, about 100 MMT by 2050 in the Combined scenario, mainly from behavioral price response, fuel switching, and energy efficiency improvements but these sectors have fewer cost-effective options for reducing emissions.



Power Sector CO_2 Emissions

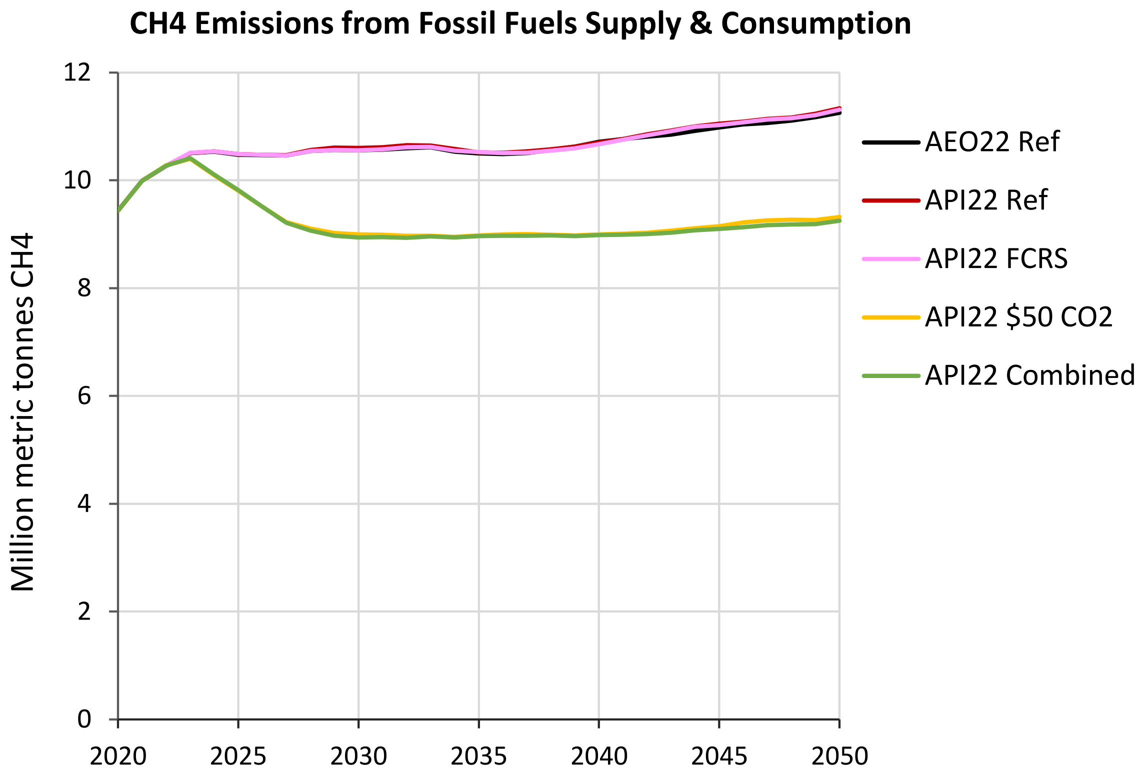
- Power sector emissions decline rapidly in the CO_2 Price and Combined scenarios due to reduced coal and natural gas use, then reductions begin to taper off after 2030. Emissions reach about 200 MMT (an 83% reduction from reference case levels) by 2050. Remaining emissions are primarily from natural gas generation.
- CO_2 reductions in the Combined scenario come close to but fall short of achieving the Biden Administration's climate goal of a CO_2 emissions-free power sector by 2035.





Methane Emissions from Fossil Fuels

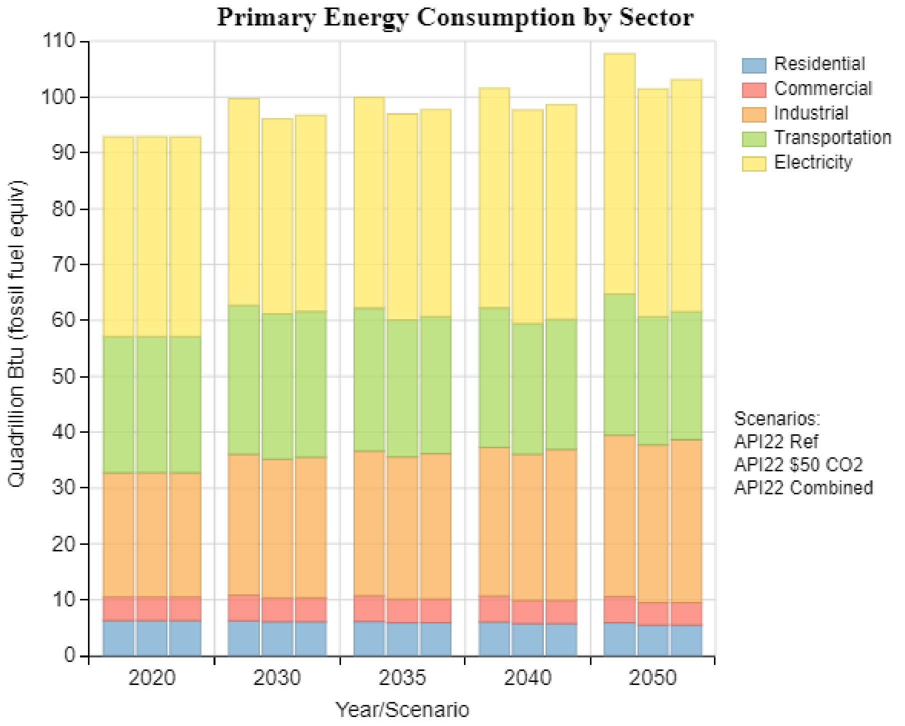
- Methane (CH_4) emissions from coal, oil, and gas supply and consumption in the AEO22 and API22 Reference cases and FCRS scenario are nearly identical. Emissions reach 10.6 MMT (265 MMT CO_2e*) in 2030 and 11.4 MMT (285 MMT CO_2e) in 2050.
- In the $50 CO_2 Price and Combined Policy scenarios, methane emissions decline to 9 MMT (225 MMT CO_2e) by 2030 and remain relatively flat through 2050 as CO_2 pricing drives away fossil fuel consumption.
- Emissions from natural gas production and consumption account for 63% to 73% of total fossil fuel methane emissions from 2020 to 2050.
- The methane emission factors for fossil fuels production and consumption are assumed to be constant from 2020 to 2050 with no additional mitigation measures applied.
- For more information about factors used to estimate methane emissions, see Appendix A.

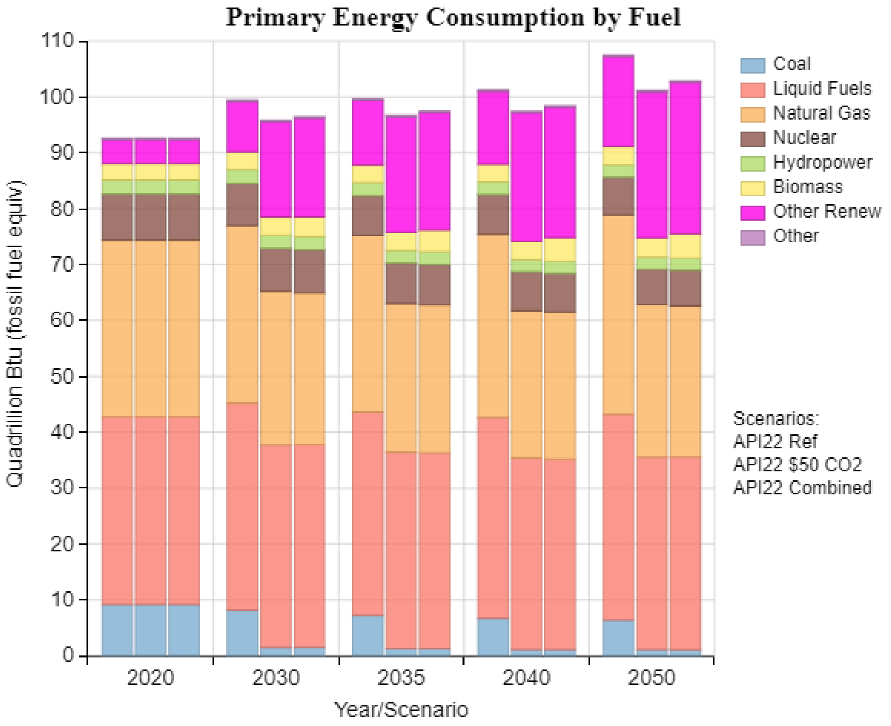


* Global Warming Potential (GWP) factor used to convert CH_4 to CO_2-equivalent is assumed to be 25 over 100 years, in line with guidance from the Intergovernmental Panel on Climate Change.

Energy Consumption by Sector and by Fuel

- Primary energy consumption declines by 4-6% by 2050 in the CO_2 price and Combined scenarios due to efficiency gains and reduction in energy service demands (e.g., lowering thermostats). Total energy consumption continues to rise despite rising CO_2 prices, albeit at a slower rate than in the Reference case.
- The majority of CO_2 reductions is driven by the shift from carbon intensive fuels such as coal to low- or carbon-free sources such as renewables, especially in the power sector. “Other renewables” include wind and solar energy* which increase significantly in the CO_2 Price and Combined Policy scenarios. Consumption in the Combined scenario is slightly higher than in the CO_2 Price case because biofuels are more energy-intensive to produce than conventional petroleum liquids.

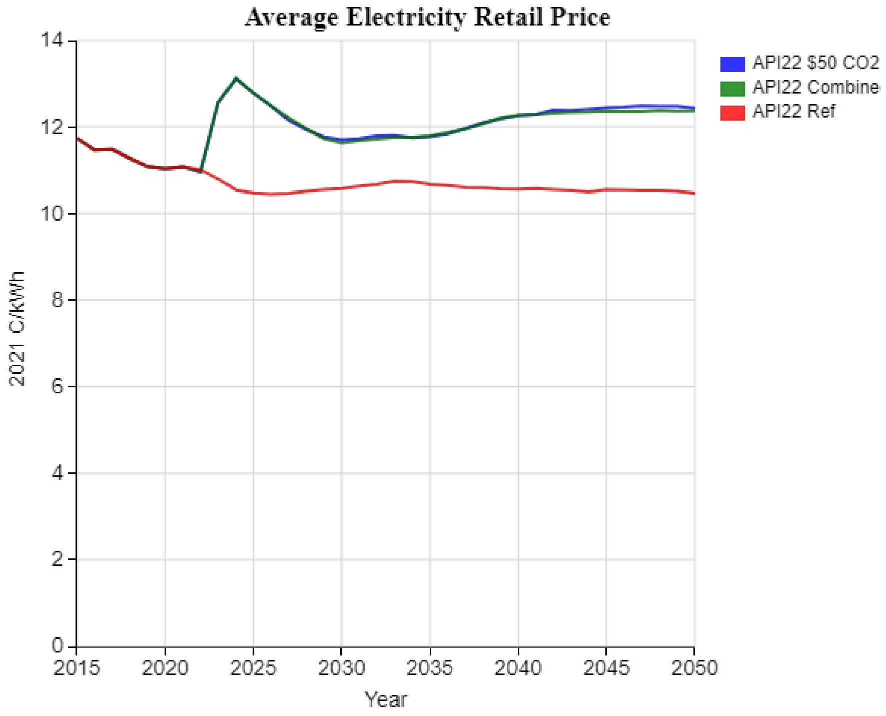


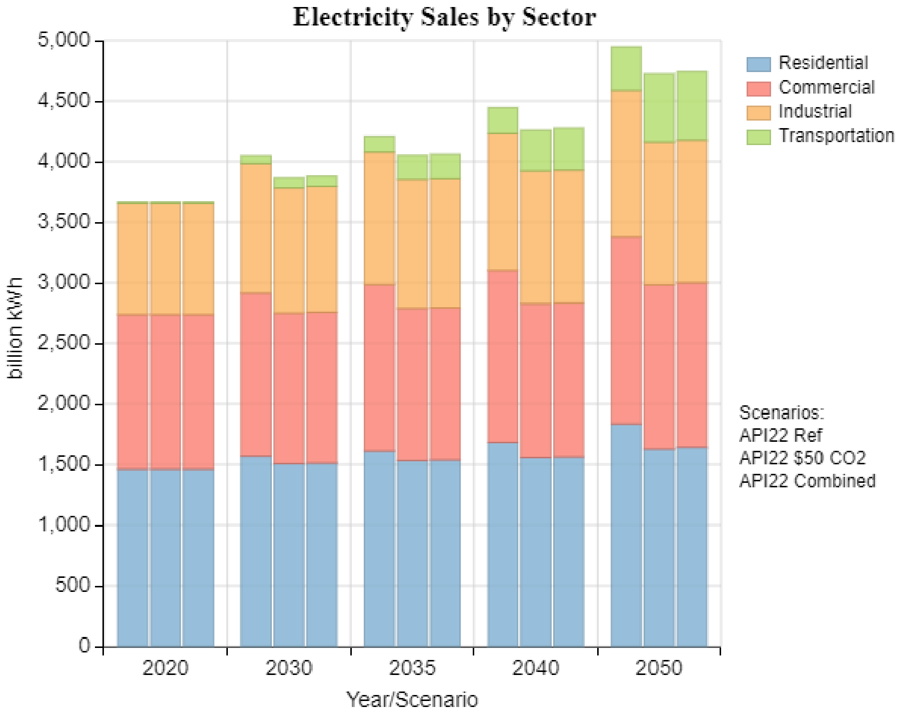


** Solar and wind energy consumption is reported on a fossil equivalent basis.*

Average Electricity Prices and Sales

- Average electricity prices are higher in the CO_2 price and Combined scenarios in all years compared to the Reference case because of higher capital expenses due to more stock turnover and higher fuel expenses that reflect the price of CO_2.*
  - The price impact is initially large as higher natural gas prices lead to higher marginal electricity prices and fuel costs, but as the power system transitions away from fossil fuels, the effect of rising CO_2 prices is mitigated in the mid-term. Prices begin to rise again in later years as natural gas generation levels off and CO_2 prices continue to rise.
- Electricity sales decline in all sectors in both scenarios compared to the Reference case except for transportation where electricity sales increase due to greater adoption of lower-cost electric vehicles.

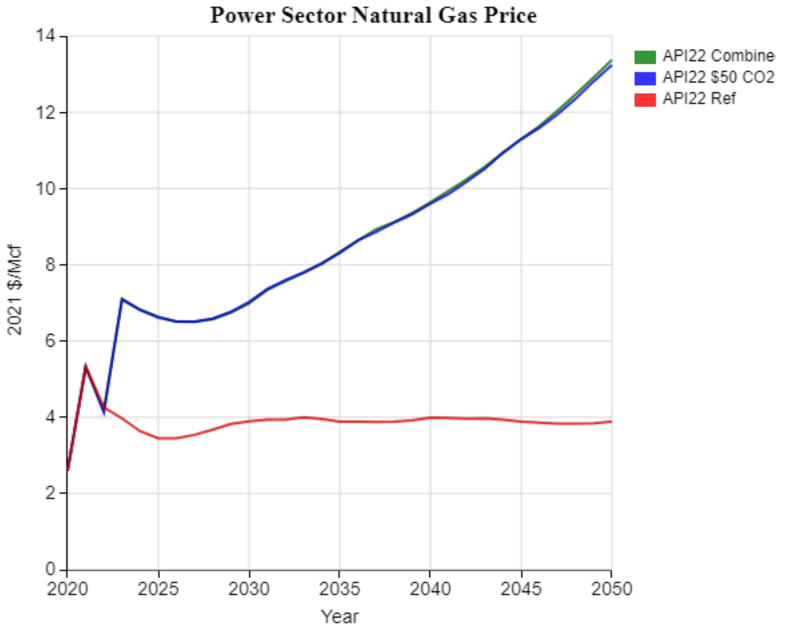


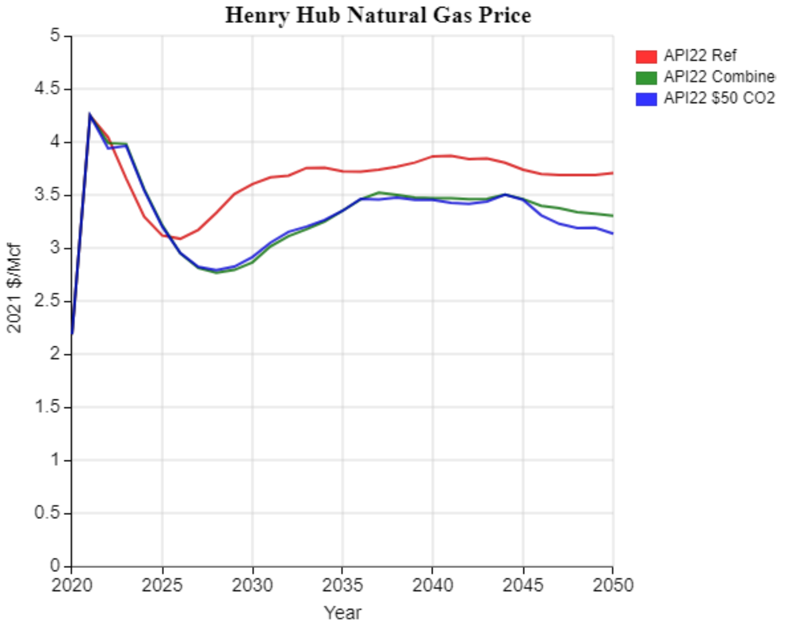


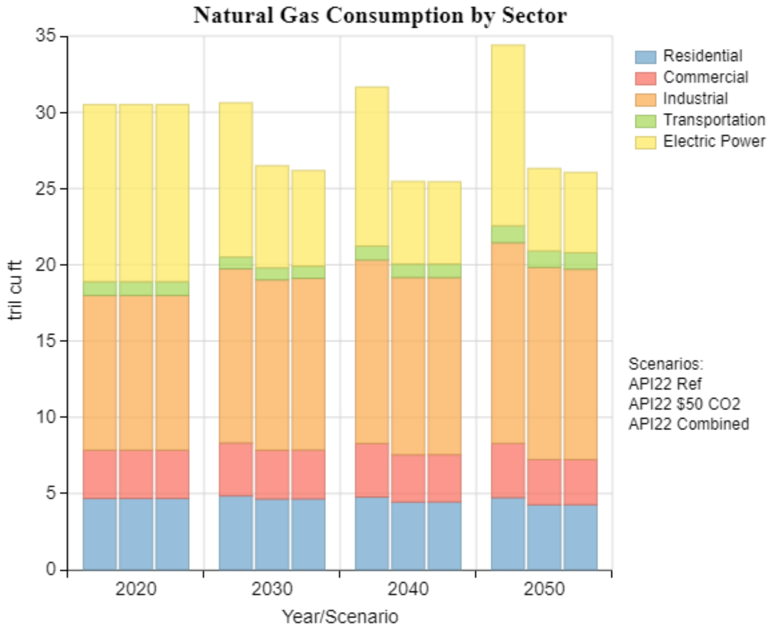
** The price of CO_2 is reflected in the delivered price of fossil fuels based on their carbon content. This cost is passed to electricity consumers through the fuel or marginal energy components of electricity prices.*

Natural Gas Prices and Consumption

- Delivered natural gas prices, to the power sector and all consumers, reflect the price of CO_2 and therefore rise sharply over time in the CO_2 price and Combined scenarios, reaching more than $13 per thousand cubic feet (2021$/MCF) by 2050.
- After a small increase, Henry Hub wholesale prices (which do not include the CO_2 price) dip in early years as consumers switch away from the higher delivered prices, then wholesale prices rebound but at a lower level than the Reference case.
- Natural gas consumption declines in all sectors in the policy scenarios, especially in the power sector where consumption declines about 55% by 2050 compared to the Reference case. Total natural gas consumption declines about 24% by 2050.
- Henry Hub prices in the two policy scenarios are virtually identical until the last 5 years at which point the generation mix in the power sector changed slightly, causing the price to increase and consumption to decrease slightly in the Combined scenario.*



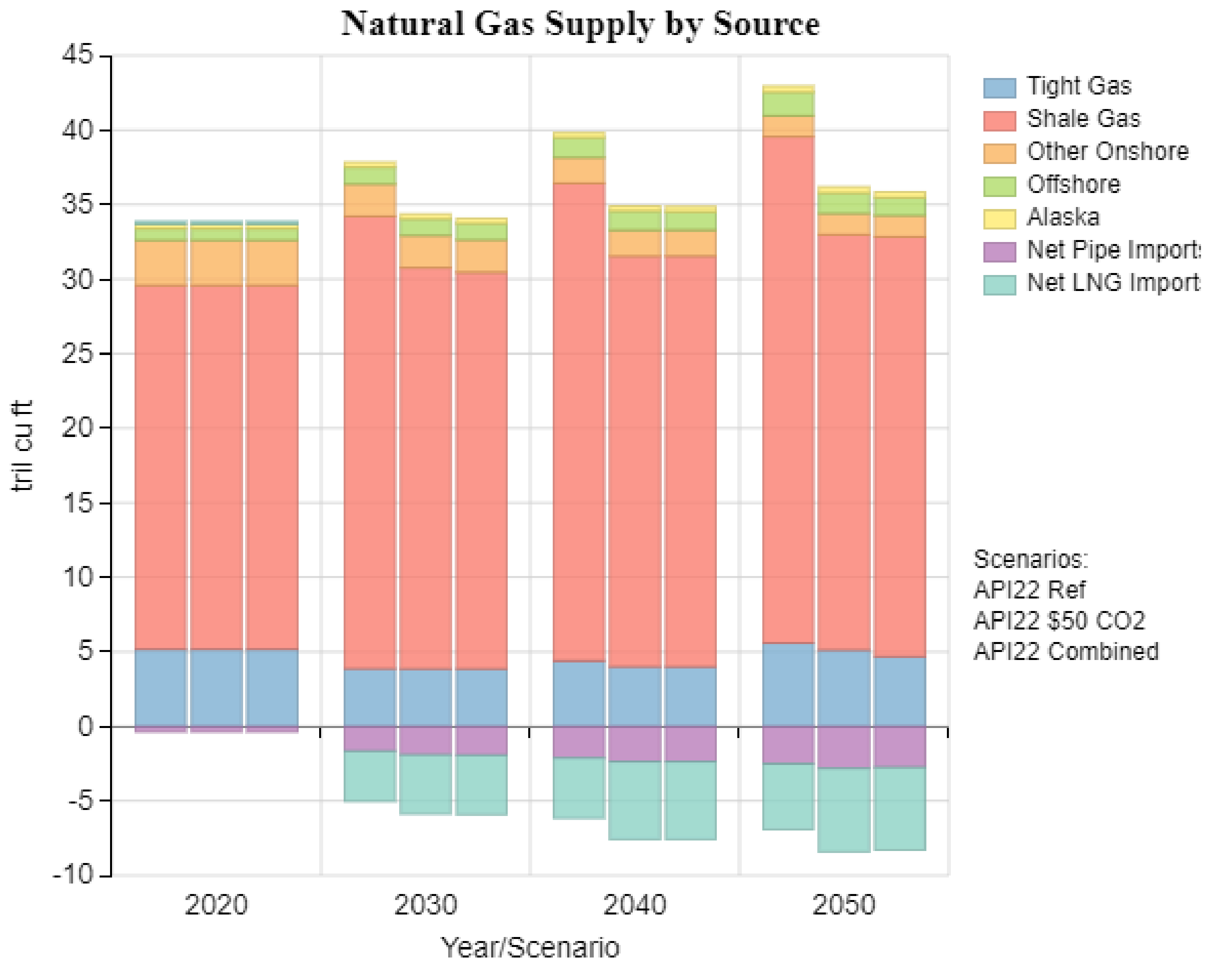




** Note, this result is likely due to "model noise" and therefore is not significant from a policy perspective.*

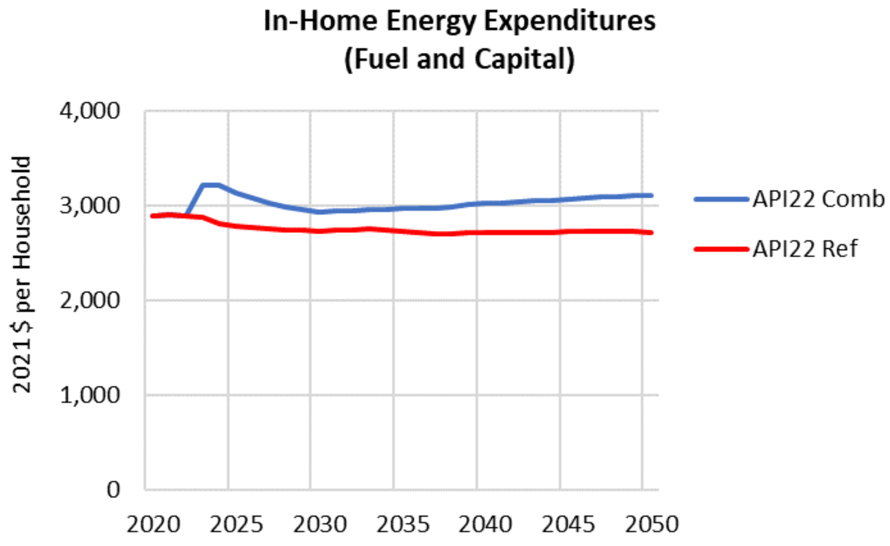
Natural Gas Supply

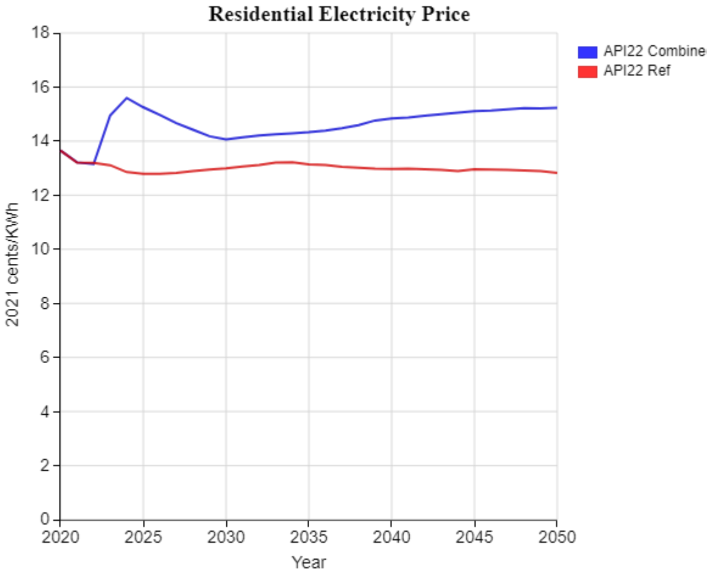
- U.S. natural gas supply declines in the CO_2 price and Combined scenarios as consumption declines. The majority of reductions are in shale gas production (about 18% from Reference case by 2050), while net LNG exports increase about 25%.
- Note, this analysis does not consider disruptions in natural gas markets due to recent world events. See “Modeling Challenges and Caveats” for more information.

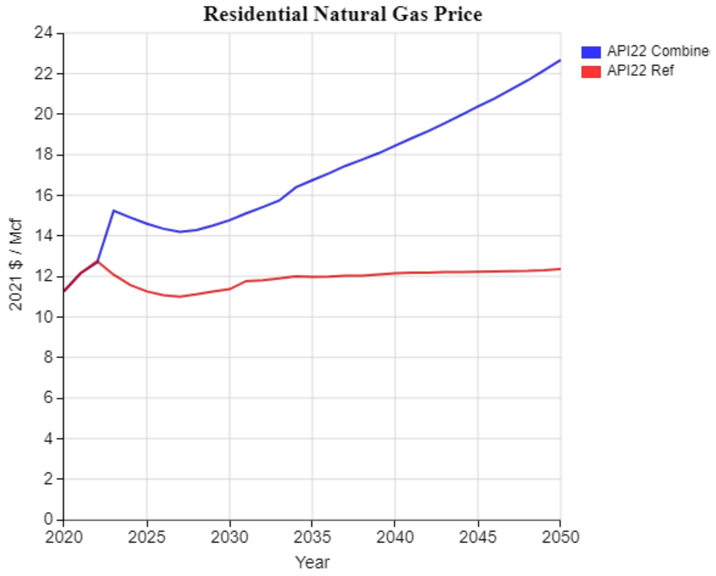


Household In-Home Energy Expenditures and Prices

- Residential energy expenditures per household* per year are higher in the Combined Policy scenario than the Reference case due to higher delivered electricity and natural gas prices that include the impact of the CO_2 price.
- In 2050, average in-home energy expenditures per household increase from $2,700 per year in the Reference case to $3,100 in the Combined scenario (about a 14% increase). Most of the increase is in fuel expenditures, a 19% increase by 2050. Electricity bills make up a large portion of these costs.
- In-Home expenditures* reflect the cost of heating and cooling, water heating, and other household energy services as well as the cost of new or upgraded energy equipment and other home investments in energy efficiency (such as added insulation).



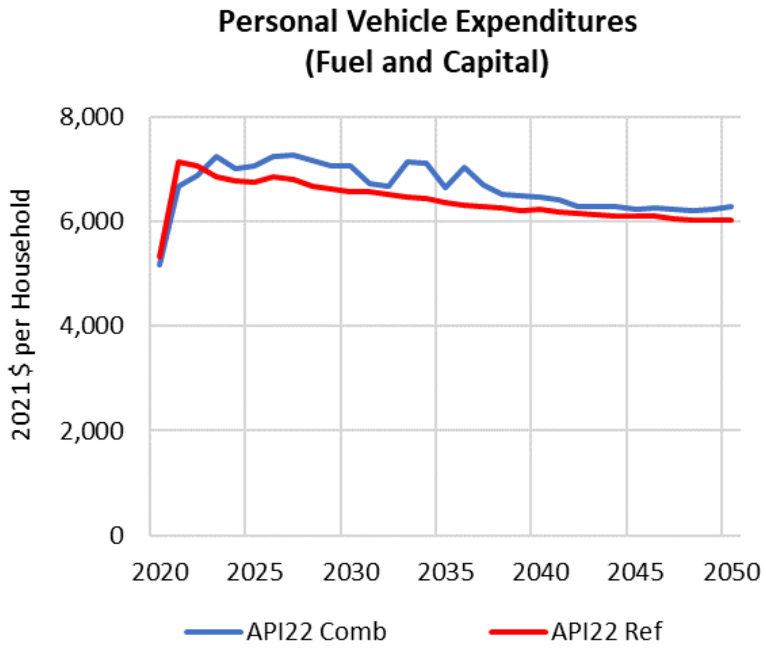


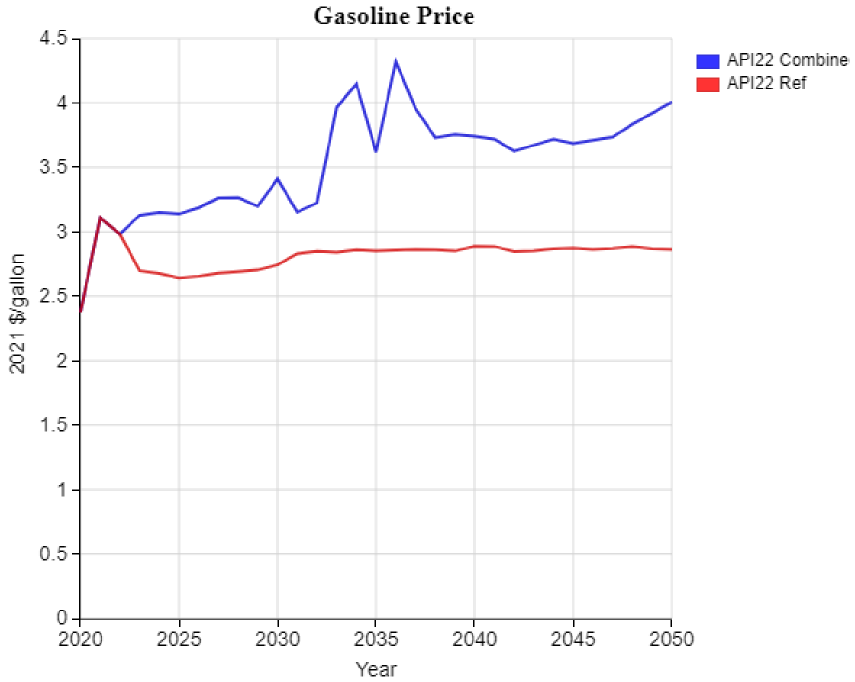


*Household energy expenditures shown here do not include transportation-related expenditures.

Household Vehicle Expenditures

- Household expenses for transportation fuels and vehicle purchases increase from $6,000 in 2050 in the Reference case to $6,300 in the Combined Policy scenario, a 5% increase, due to higher gasoline prices that reflect the CO_2 price and the FCRS policy. The FCRS increases gasoline prices especially in the period from 2033 to 2037 when additional biofuels are needed to meet the increasing stringency of the carbon intensity standard.
  - Fuel expenditures increase from about $1,920 to $2,370 in 2050, a 23% increase.
  - Average vehicle purchase costs decline by about 4% by 2050 in the Combined scenario due to lower electric vehicle (EV) prices, reducing the total impact on expenditures.
- Household vehicle expenditures* shown here reflect the annual cost of driving and vehicle purchases but do not include maintenance costs of the vehicle(s) or other transportation costs such as mass transit.

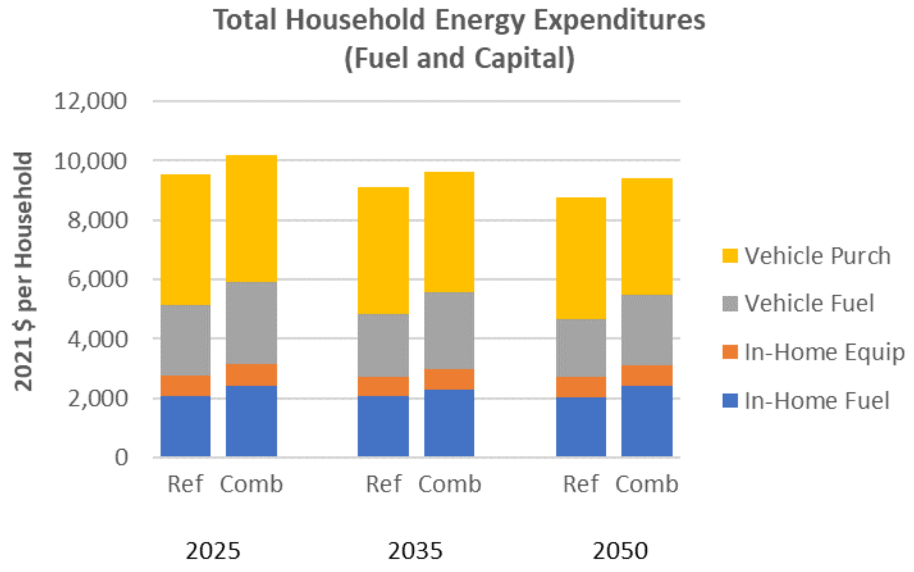


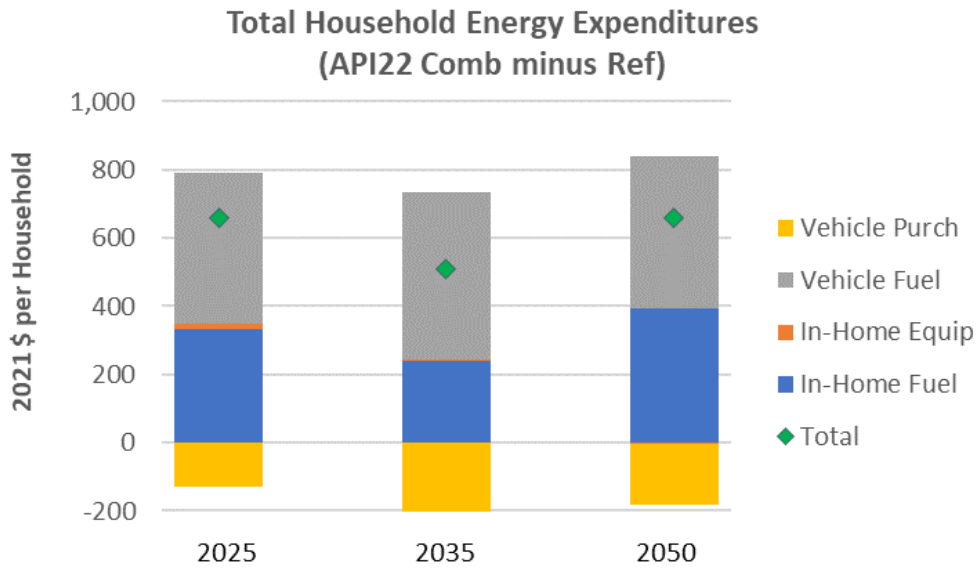


Household energy expenditures shown here do not include in-home expenditures.

Total Household Energy Expenditures*

- When in-home energy expenditures and personal vehicle expenditures are combined, the total average energy cost per household rises from $8,750 in 2050 in the Reference case to about $9,400 per year in the Combined Policy scenario, an increase of $660 or about 8%.
- Most of the increase in cost is due to fuel expenditures, both in-home and vehicle fuel, which increase significantly by 2025 even as consumers reduce demand in respond to the higher prices. Then expenditures increase more slowly through 2035 as electricity price increases diminish. Expenditures increase again after 2035 as CO_2 prices continue to rise causing electricity and natural gas prices to rise further. The FCRS impact is greatest between 2032 and 2038.
- Home energy equipment costs stayed about the same between cases and the average vehicle cost declines compared to the Reference case as electric vehicles become cheaper from assumed technology R&D advances. Vehicle price improvements level off after 2030 – see Appendix B for more information about R&D assumptions.

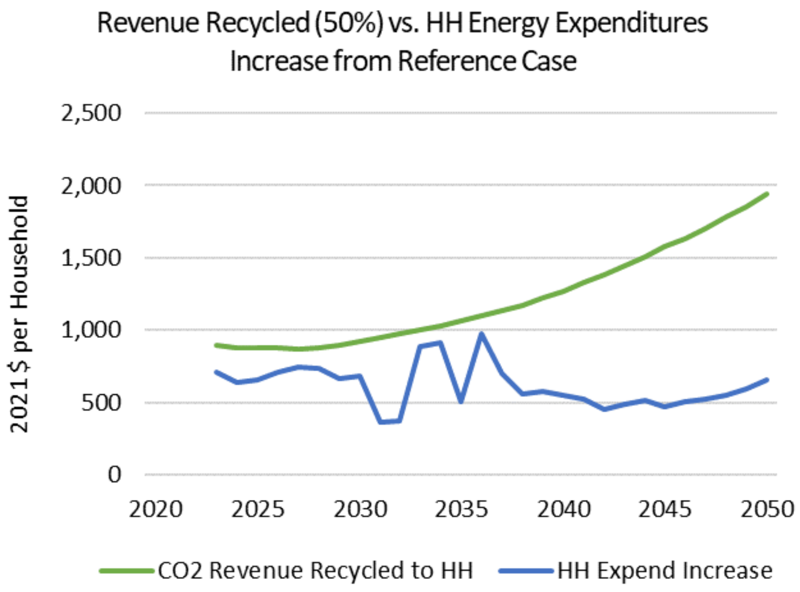


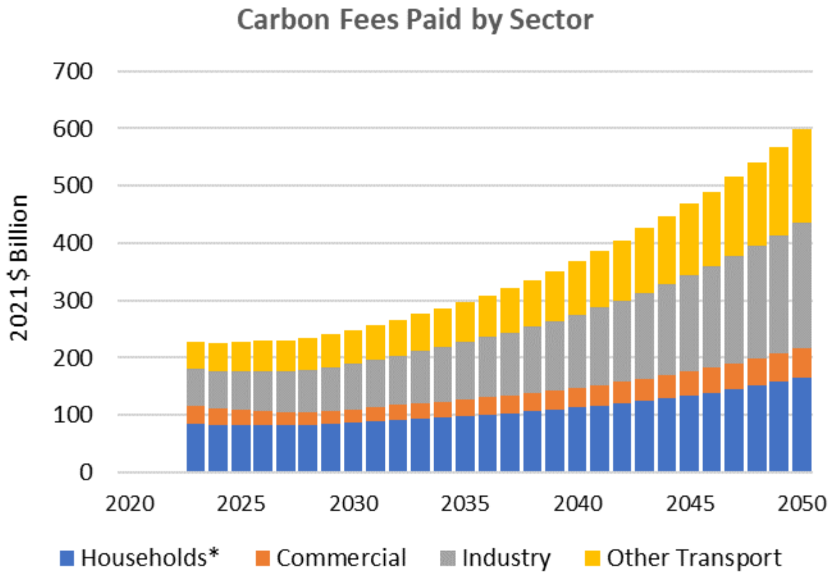


See Appendix D for more information about household energy expenditures.

CO_2 Revenue vs. Increase in Household Expenditures

- Total household energy expenditures (including fuel and capital) are $660 per household higher by 2050 in the Combined scenario compared to the Reference case. In all years, the CO_2 revenue collected from all energy sectors that is returned to households (50% of total revenue) is greater than the incremental increase in household energy expenditures. HH expenditures shown here do not include non-energy goods and services.
- CO_2 revenue collected from households* makes up about 28% of total revenues with the biggest share paid by industry (37%) and transportation other than personal vehicles (27%) including freight, air, rail, etc. Most of the fees paid by these sectors would likely get passed on to consumers through higher costs of goods and services, but this impact is only partially captured in the API22-NEMS model (and not shown here).
- Household expenditures also reflect higher gasoline prices caused by the FCRS policy, especially prior to 2038.

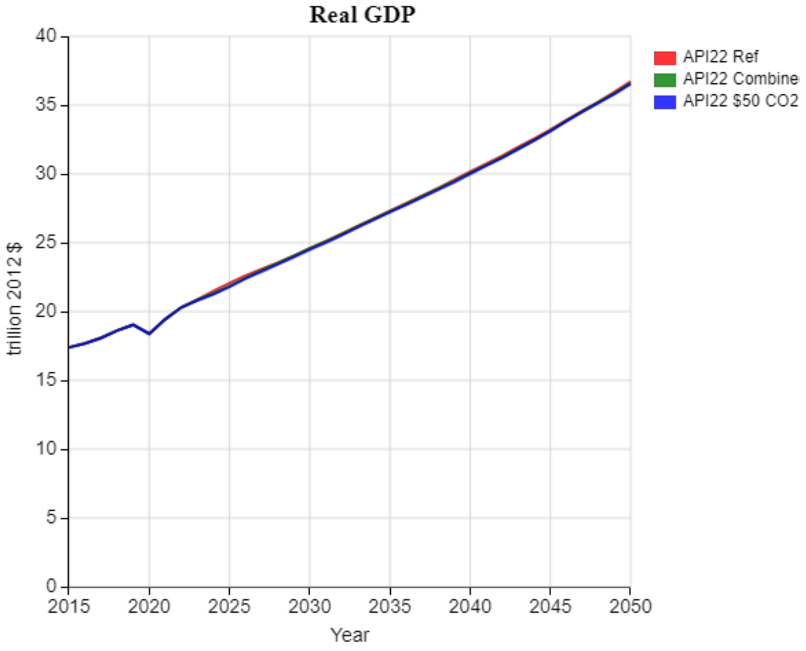


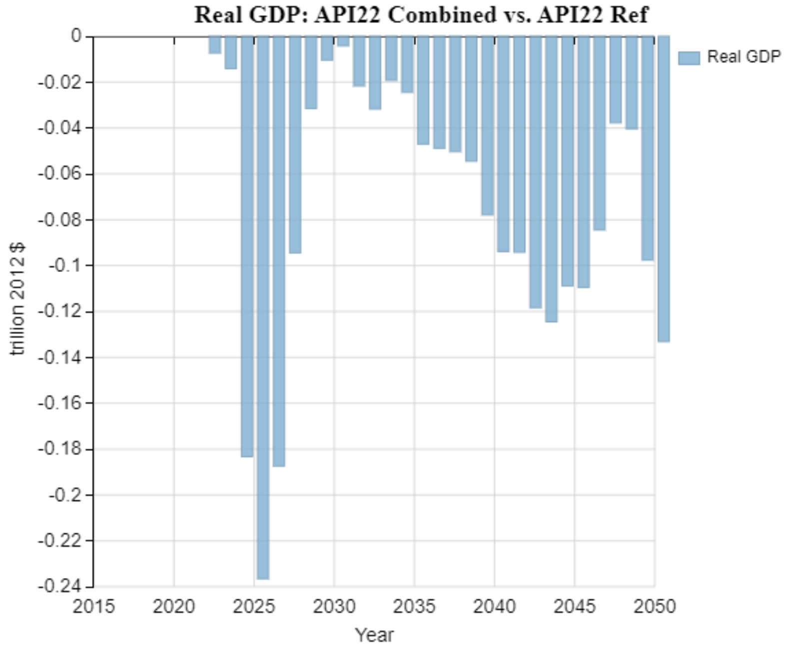


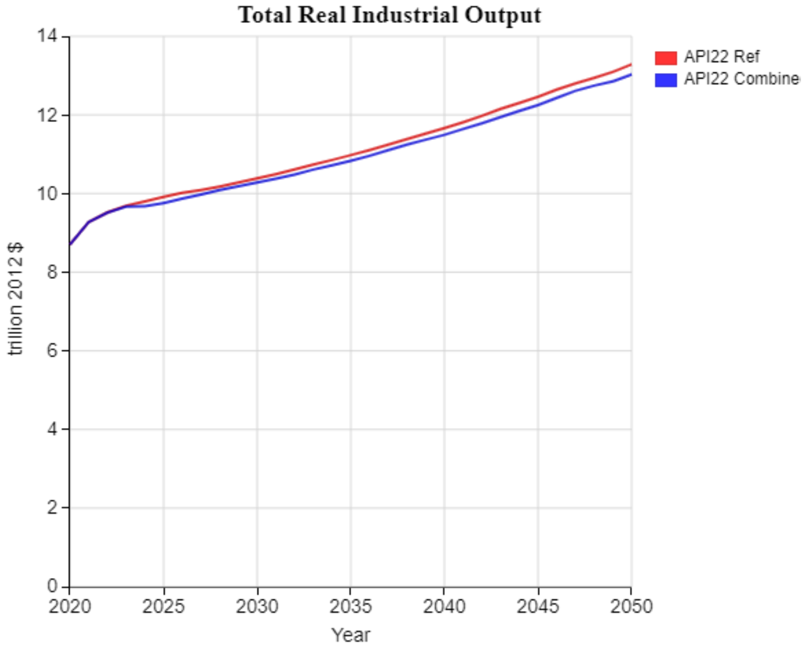
** Household carbon fees include those paid through home and personal vehicle energy expenditures. See Appendix D for more information.*

Real Growth in GDP and Industrial Output

- Real GDP growth is expected to slow under the Combined policy, with a projected loss of more than $130 billion annually by 2050 (expressed in chain-weighted 2012$) or roughly $155 billion in current 2021$ compared to Reference case. The biggest impact is expected to occur in the first few years after the polices are enacted. Real industrial output also slows compared to the Reference case (roughly 2% or $300 billion in 2021$) by 2050.
- Note: The GDP results shown here do not account for the full macroeconomic impact of the policy due to limitations within the model. The macroeconomic model used in API22-NEMS responds to changes in energy demand and prices but does not consider the projected policy-induced investments in energy equipment, so the projected impacts on GDP are based on limited information. See "Modeling Challenges and Caveats" for more information.



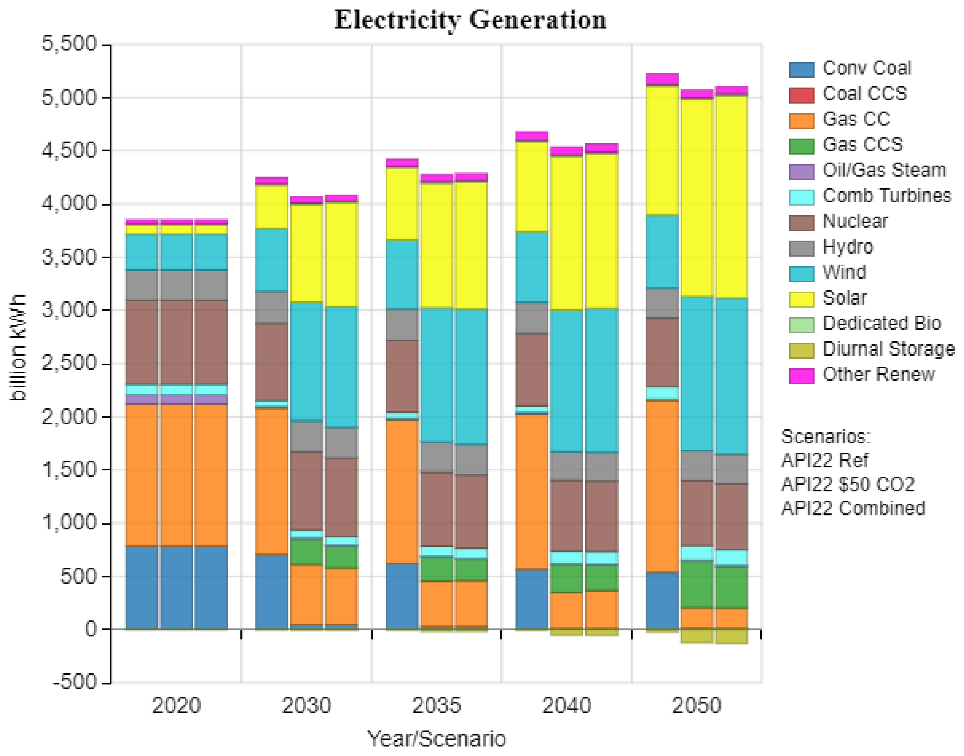


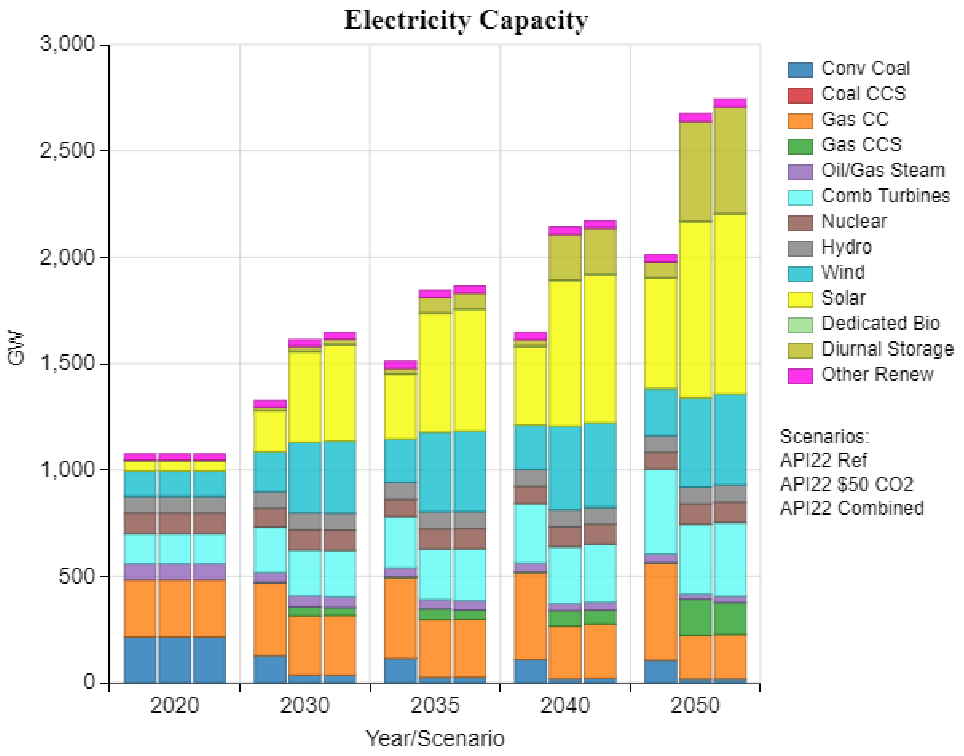


Note the difference in scales between the charts.

Electricity Generation and Capacity Mix

- The share of electricity generation from carbon-free renewable energy (especially solar and wind), nuclear power, and fossil fuel with carbon capture increases significantly in the CO_2 Price and Combined scenarios compared to the Reference case, and conventional fossil fuel generation decreases as these plants retire.
- The total amount of capacity in the policy scenarios is higher than the Reference case due to the lower capacity utilization for variable generation renewables and their low contribution to reserve requirements.

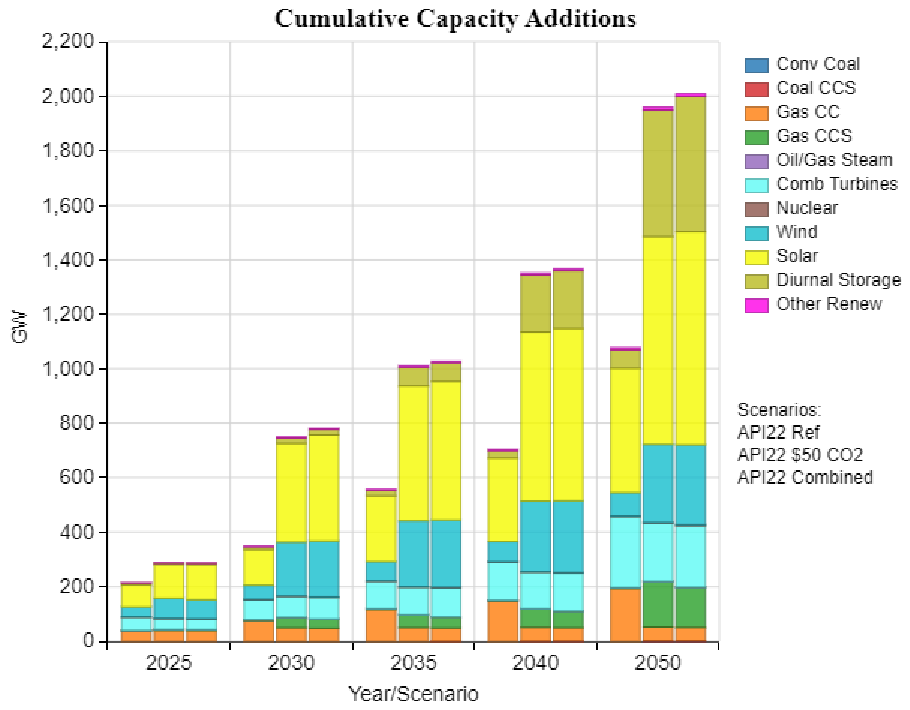


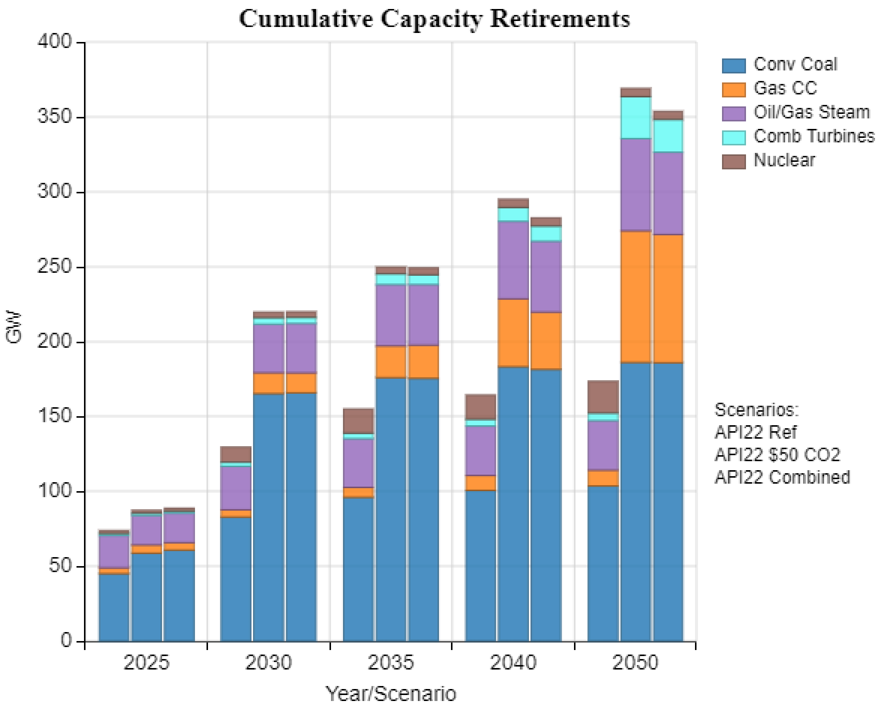


Notes: Diurnal (battery) storage produces net negative generation due to energy losses. "Other Renewables" include geothermal, landfill gas, and municipal solid waste.

Electric Capacity Additions and Retirements

- Capacity additions in the CO_2 Price and Combined scenarios are dominated by wind, solar, diurnal (battery) storage. Gas with carbon capture and storage (CCS) replaces most of the conventional gas combined cycle (CC) additions. Additions also include some conventional gas turbines used to meet peak demand and for grid reliability, but fewer than are added in the Reference case.
- The policy scenarios also lead to more conventional coal and gas retirements than the Reference case. Fewer nuclear plants retire due to their improved financial prospects under the CO_2 policy.

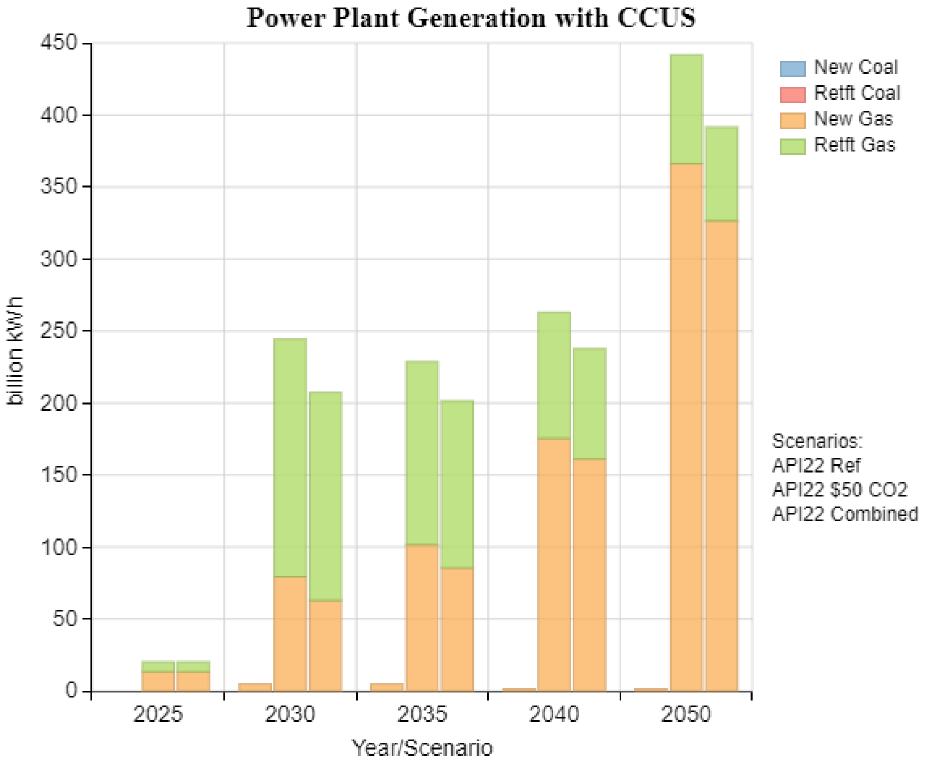


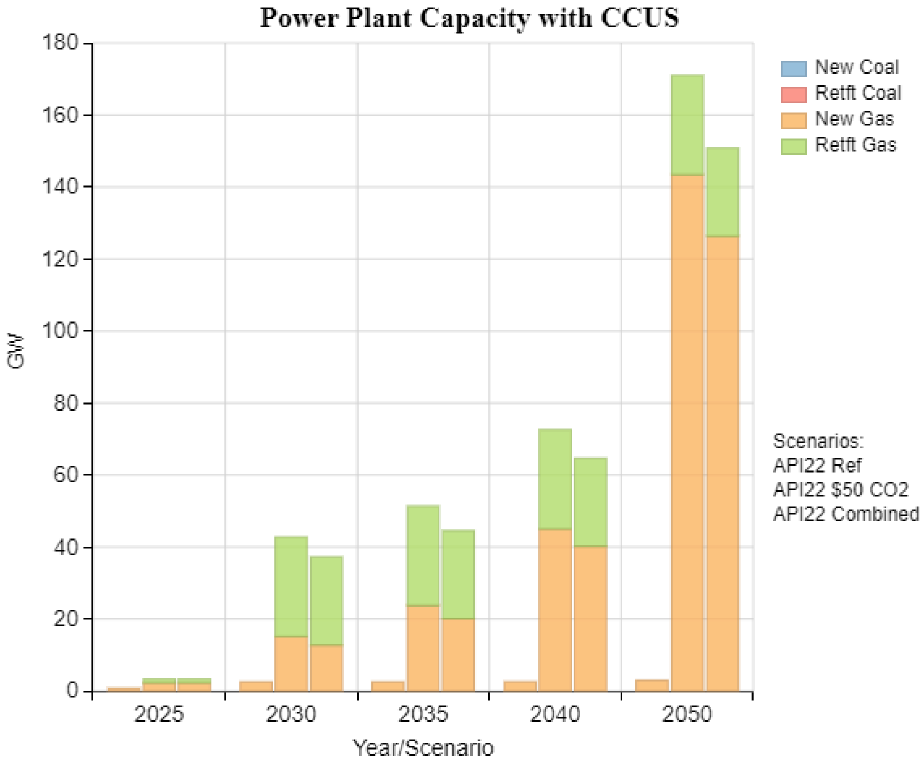


Note the difference in scales between the two charts.

Generation and Capacity with CO_2 Capture

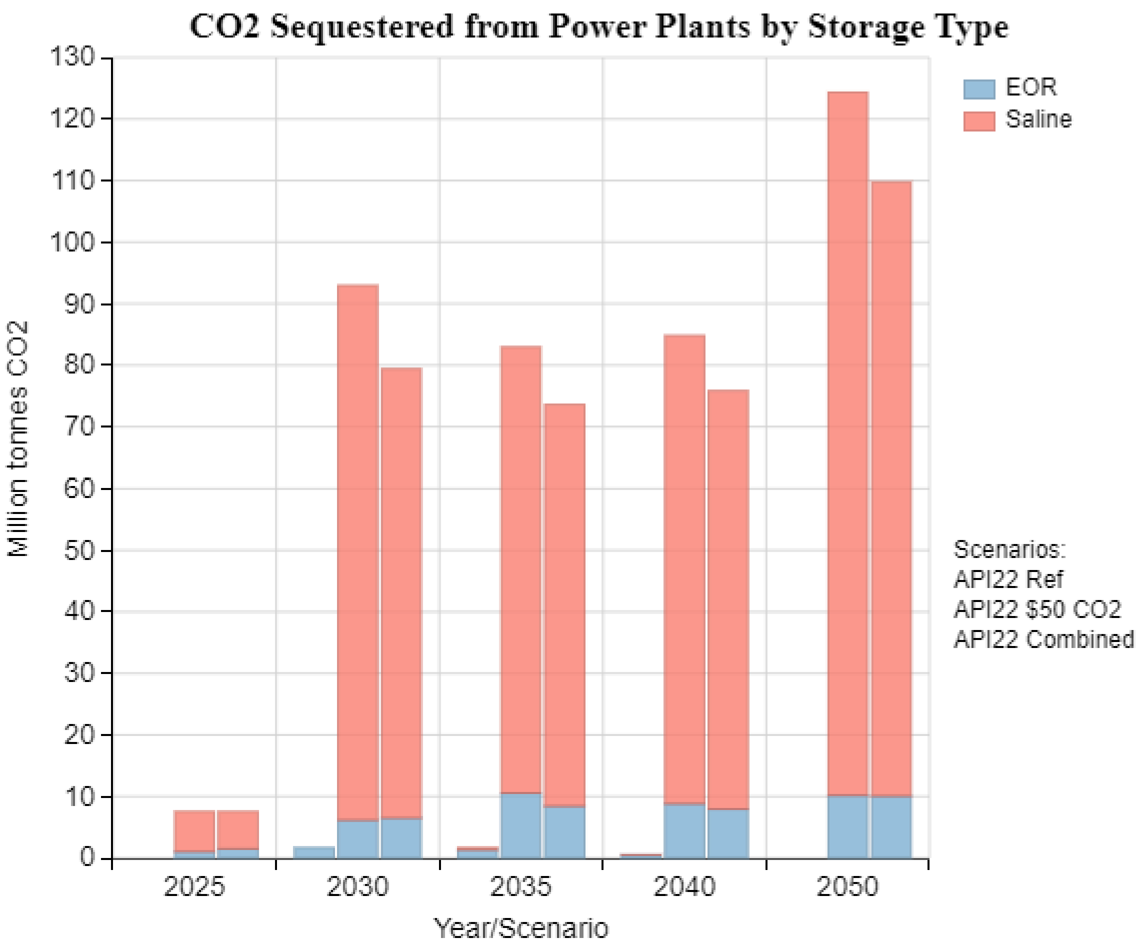
- Generation and capacity with carbon capture in the CO_2 Price and Combined scenarios is a mix of new and retrofit natural gas-fired plants, with no deployment of coal CCS. New CCS capacity and generation increases over time, especially after 2040 as CO_2 prices rise, while retrofit generation declines after the 45Q sequestration credits end.
- Reference case CCS deployments are planned additions resulting from IIJA funding for demonstration and pilot facilities. The 45Q sequestration tax credits are not enough to incentivize additional CCS capacity without a CO_2 policy.





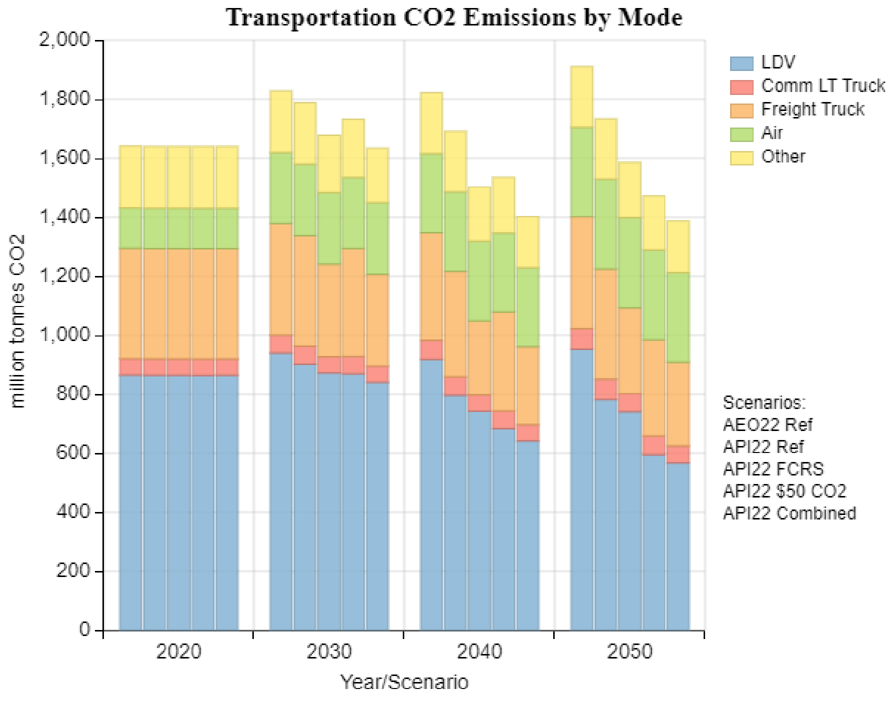
CO_2 Sequestered

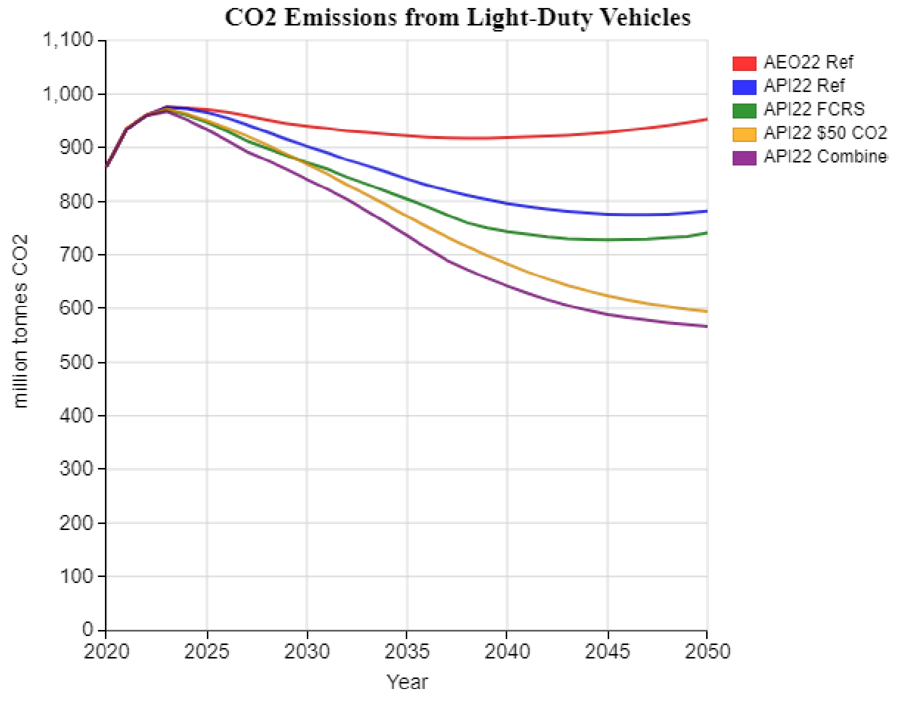
- The amount of CO_2 sequestered from CCS power plants in the CO_2 Price and Combined scenarios declines a bit after 2030 as 45Q credits expire but then increases to more than 110 MMT CO_2 by 2050. CO_2 sequestered from the IIJA-funded plants in the Reference case is relatively low.
- In all cases the majority of captured CO_2 is stored in saline formations due to the limited market for CO_2 used in enhanced oil recovery (EOR). CO_2 transport and storage costs are lower in these cases due to the IIJA provisions.



Transportation CO_2 Emissions

- CO_2 emissions from transportation are lower in all scenarios compared to the AEO22 Reference with LDVs contributing the largest share of emission reductions.
- A combination of vehicle efficiency improvements and higher Zero Emission Vehicle (ZEV) mandates results in lower emissions in the API22 Reference case. In the policy cases, the FCRS primarily reduces the carbon intensity of liquid fuels while the carbon pricing and R&D impacts increase the sales of EVs and lower demand for travel.
- Indirect emissions from electric vehicles are also reduced in the carbon pricing scenarios; emissions shown here do not include emissions at petroleum refineries or land use impacts from biofuels.

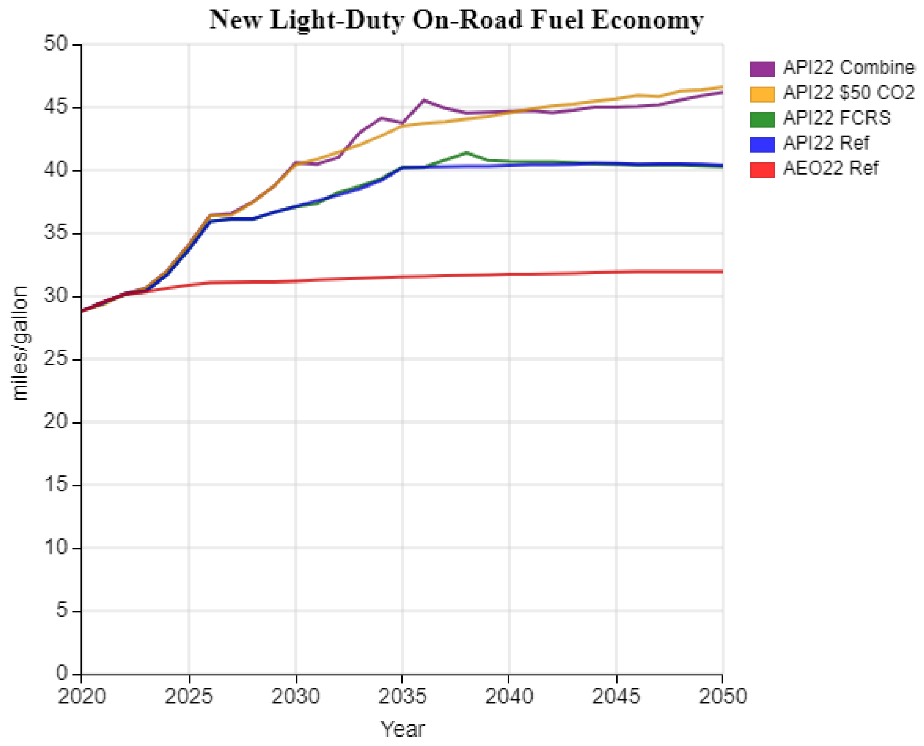


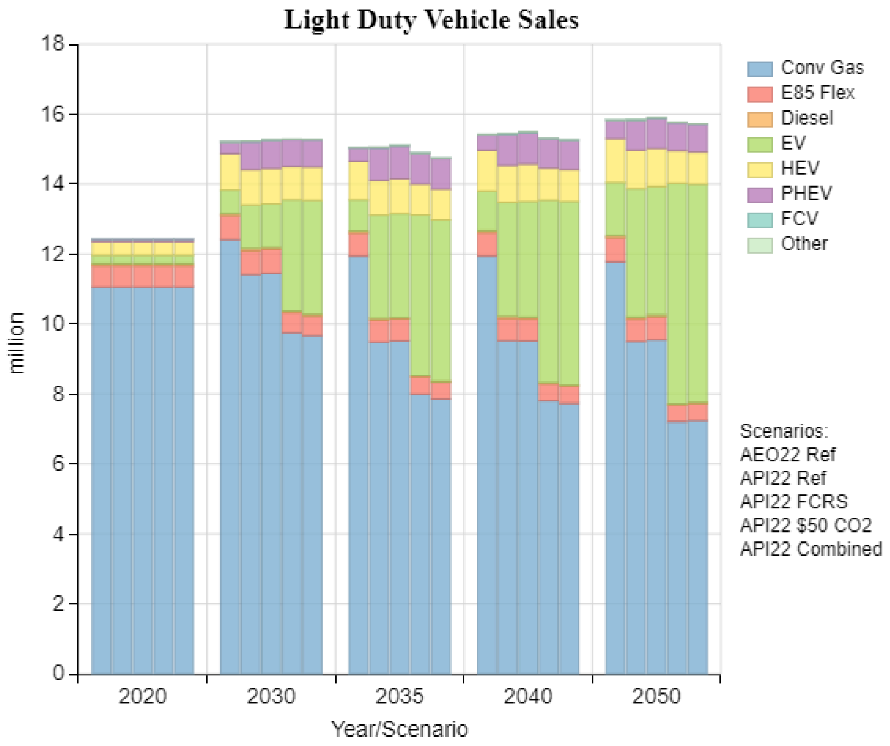


Note the difference in scales between the two charts.

Light-Duty Vehicle Fuel Economy and Sales

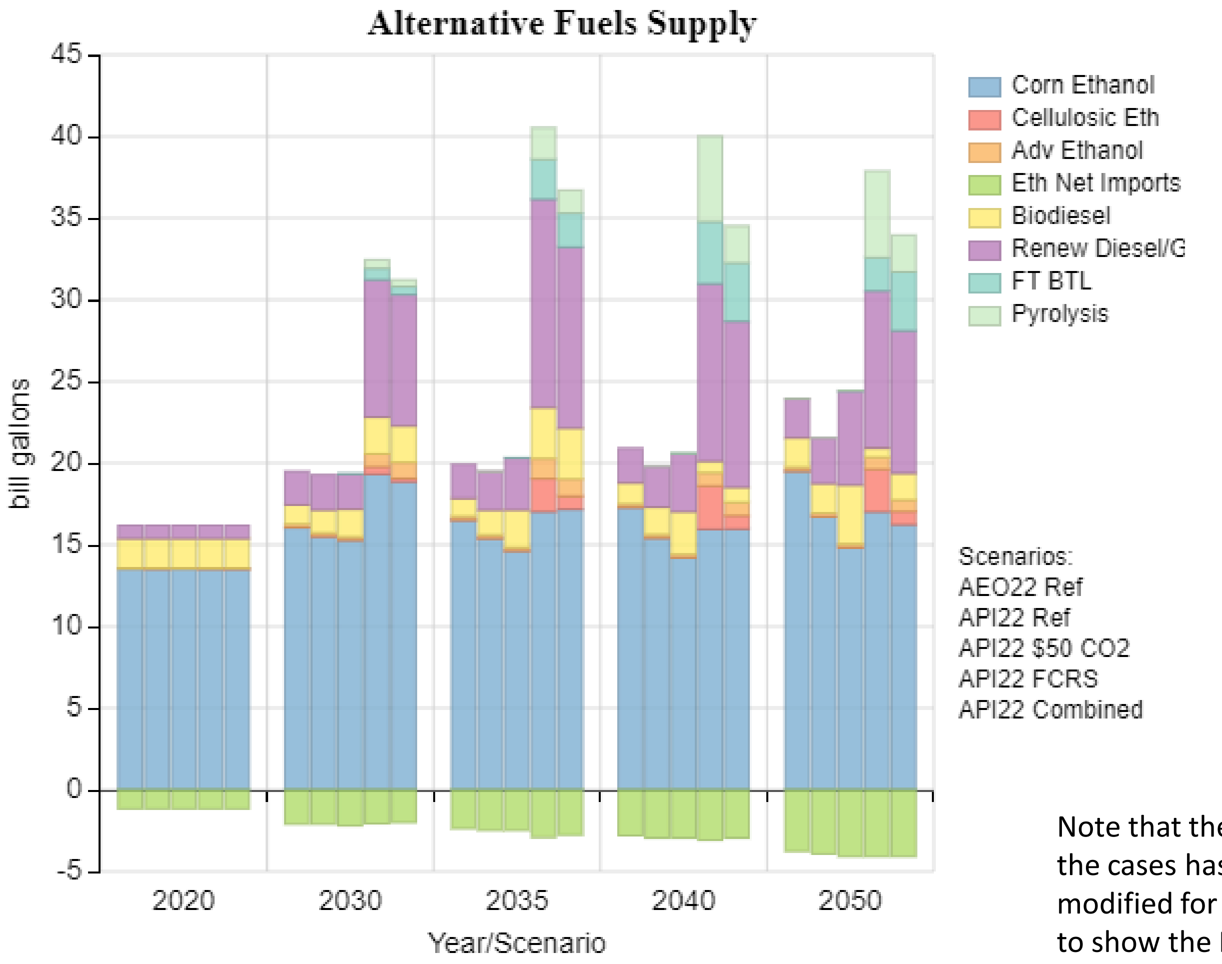
- After 2026, new LDV fuel economy in the CO_2 Price and Combined Policy scenarios increases relative to the reference case primarily due to increased sales of electric vehicles stimulated by lower cost EVs and higher fuel prices due to the CO_2 price. Smaller increases in gasoline prices from the FCRS lead to slightly higher new fuel economy as well.





Biofuels Supplied

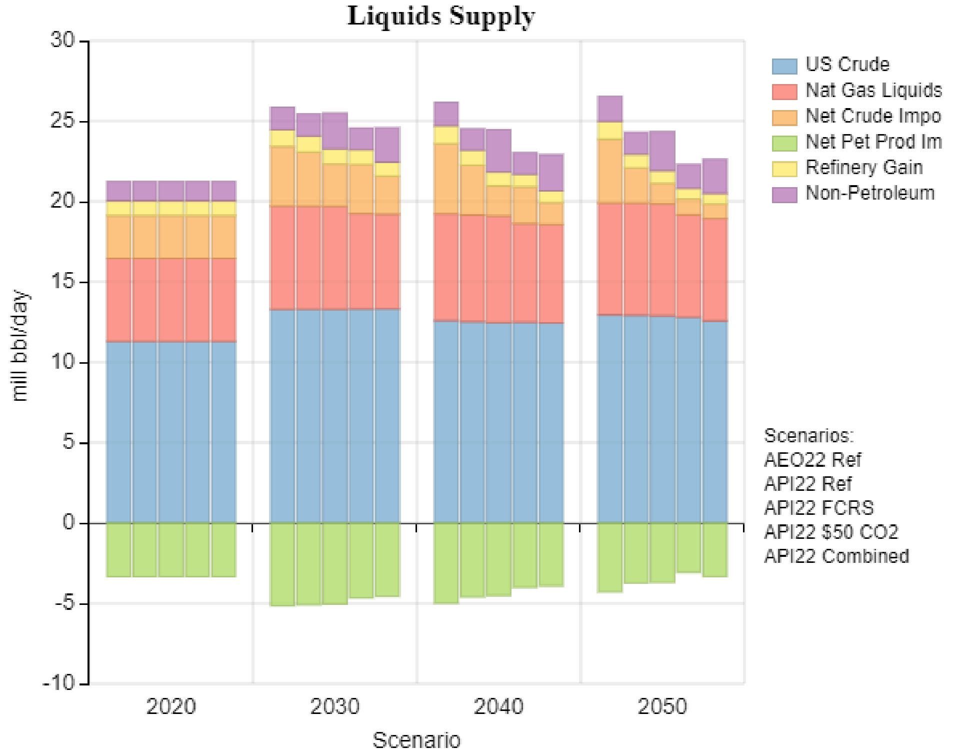
- The FCRS stimulates a significant increase in biofuels including second-generation fuels such as cellulosic ethanol and Fisher-Tropsch (FT) biomass-to-liquids and pyrolysis that use cellulosic biomass feedstocks.
- The CO_2 price incentivizes a small increase in biofuels demand that is comprised mostly of renewable diesel and traditional biodiesel.
- Total biofuels in the Combined case are lower than the FCRS case because the volume of liquid demand is lower, and the carbon intensity standard can be met with less biofuels.

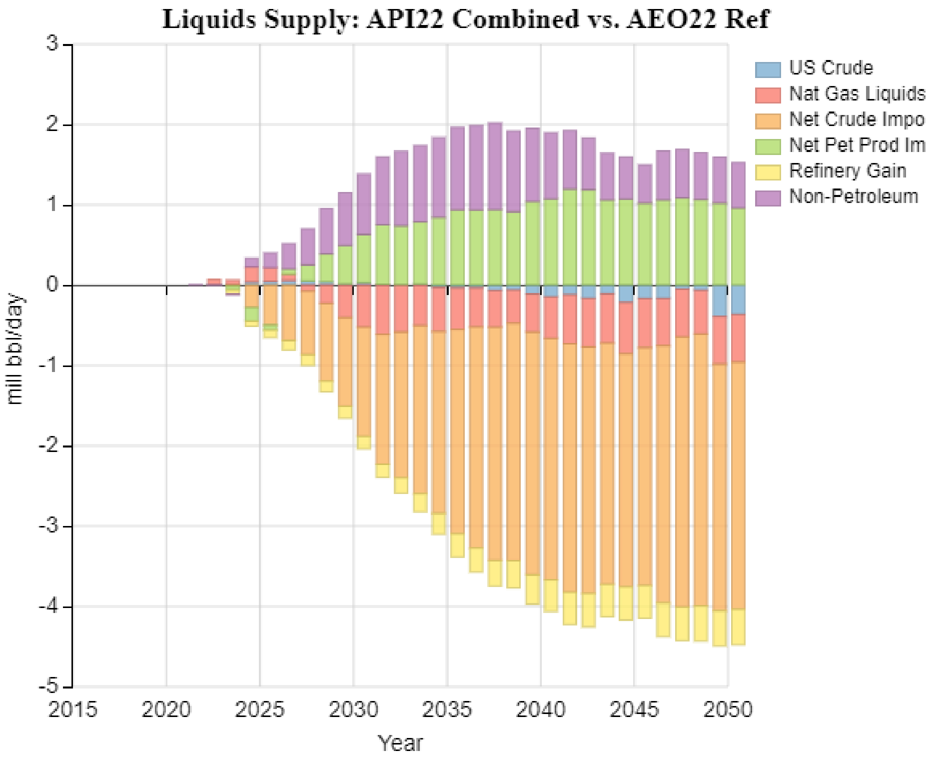


Note that the order of the cases has been modified for this chart to show the FCRS second from last.

Liquid Fuels Supplied

- Total liquids demand declines in the CO_2 price case and Combined Policy cases. The FCRS policy increases non-petroleum liquids (i.e., biofuels) that displaces net crude imports while also increasing petroleum productions. The carbon pricing policy also reduces natural gas liquids production as natural gas demand and wellhead prices are lower.





Modeling Challenges and Caveats About the Analysis

- This analysis is intended to reflect the most significant components of the API Climate Framework. However, some aspects of the framework not covered by this analysis may have a minor impact on our model results.
- Significant improvements in technology costs and performance were assumed in the CO_2 Price and Combined Policy scenarios to reflect the 50% of CO_2 revenue recycled to government-sponsored technology R&D. The uncertainty in the effectiveness of federal funding for R&D to improve technology cost and performance is not captured in the analysis.
- The electricity model of API22-NEMS is designed to represent the current and evolving power grid but may not fully address the operational challenges caused by major shifts in the electricity generation mix. Variable generation and curtailment impacts on grid reliability are represented as a simplified abstraction and therefore subject to uncertainty in costs and grid performance.
- All scenario assumptions used in this analysis reflect policies and market conditions that existed at the time of this study. Major world events, such as the continued global pandemic and wars disrupting energy supplies can have a significant impact on future energy prices and other market conditions in the U.S. and are not reflected in this analysis. The analysis and its conclusions primarily focus on the difference in results between scenarios that is likely to be less sensitive to these uncertainties than is the baseline projection.
- The analysis does not include provisions from the recently passed Inflation Reduction Act (IRA) which will have a broad impact on the energy economy. Policies included in the IRA will likely alter model results such as the technology mix in the electricity and transportation sectors, energy efficiency improvements in the buildings and industrial sectors, and the level of government spending in the macroeconomic sector. Further analysis is needed to understand the full implications of this legislation on CO_2 emissions and overall conclusions presented here.

Modeling Challenges and Caveats (continued)

- The NEMS-Macro model interface is somewhat limited and therefore may not reflect the nuances of some aspects of the CO_2 price response. For example, energy prices and quantities projected by energy modules of API22-NEMS are passed to the macro model but not the investments in energy equipment. However, we feel that the overall response is generally reasonable. Other factors to consider:
  - The overall impact on GDP growth of changes in energy prices and quantities is expected to be small given that energy is only one small part of the entire US economy. In addition, the US economy has been shifting to fewer manufacturing industries and more service industries in recent decades. While energy consumption plays a role in services, an increase in energy prices will have less impact on services than on manufacturing.
  - The impact on GDP is also likely moderated somewhat by API's other framework principles, such as revenue recycling of 50% to consumers and maintaining relative prices with US trading partners at baseline levels with export and import demands only changing in response to changes in output (representing the border adjustment).
- Some long-term and potentially more expensive mitigation technologies are not represented in API22-NEMS, including extensive electrification, hydrogen production, non-CO_2 gases, land sinks, and CO_2 removal technologies. However, many of these technologies may not be cost-effective in the range of CO_2 prices considered here so model results are unlikely to change significantly if these technologies were available.

Appendix A: API22-NEMS Modeling Methodology Reference Case

Modeling Methodology and Assumptions

- OnLocation created the API22-NEMS[1] model to perform an integrated modeling assessment of the API Carbon Pricing Framework. The model is based on the Annual Energy Outlook (AEO) 2022 version of NEMS. All assumptions used in the analysis are based on the AEO 2022 Reference case unless otherwise noted.
- The API22-NEMS Reference case has been modified to incorporate the following policy assumptions that were not included in the AEO 2022:
  - Provisions from the Infrastructure Investment and Jobs Act (IIJA)[2] related to funding for carbon capture, transport and storage infrastructure;
  - The recently enacted EPA/NHTSA CAFE standards that increase average fuel economy for new cars and light trucks in 2024-2026;
  - Updated state-based Zero-Emission Vehicle (ZEV) requirements to reflect the end of the moratorium on state programs and new more ambitious goals set by California, Washington, New York, and Virginia.
- Methane emissions from fossil fuel production and consumption were estimated based on emission factors derived from EPA sources. Other greenhouse gas emissions were not considered in this study.

[1] API22-NEMS is based on the National Energy Modeling System (NEMS), a model developed by the U.S. Energy Information Administration at the Department of Energy. The model has been modified by OnLocation for this analysis and does not represent the views of EIA. For more information about NEMS and AEO 2022, visit https://www.eia.gov/outlooks/aeo/.

[2] For more information about the Infrastructure Investment and Jobs Act, see https://www.congress.gov/bill/117th-congress/house-bill/3684

IIJA Assumptions Included in AEO 2022

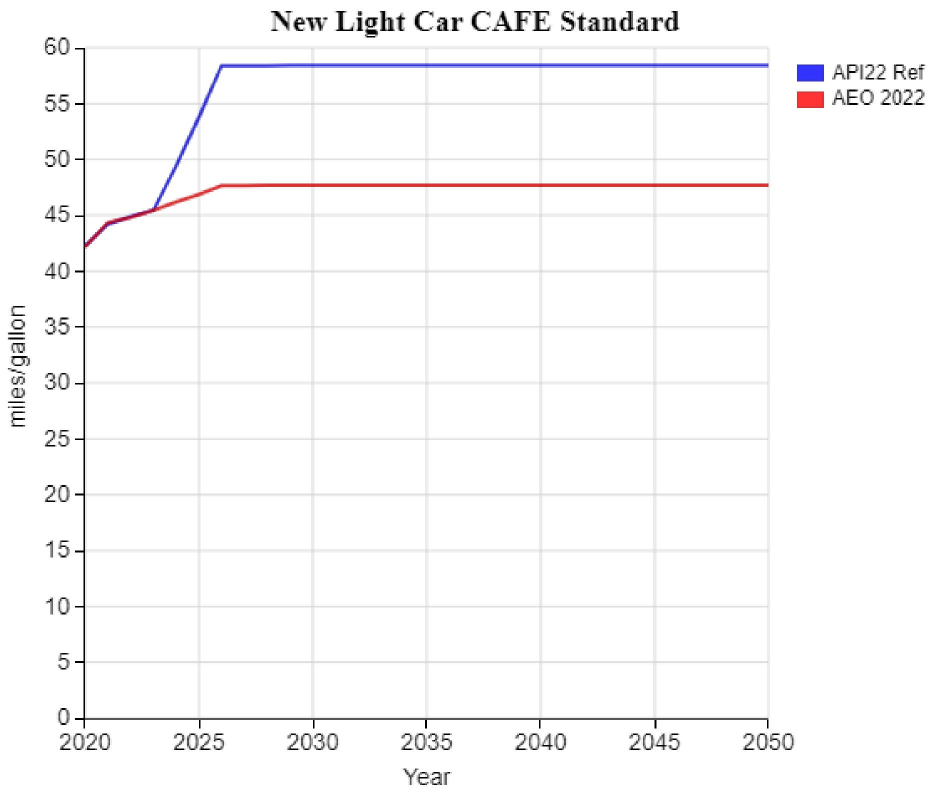
- The AEO 2022 Reference case includes a representation of the following provisions from the Infrastructure Investment and Jobs Act (IIJA):
  - Civil Nuclear Credit Program - Funding over four years to assist nuclear power plants that might close because of economic factors
  - Strategic Petroleum Reserve (SPR) drawdown and sale - Criteria for SPR drawdown and sale from 2028 to 2031
  - Overall Infrastructure bill-related spending - Increases in government spending as a result of the infrastructure bill, which affects overall economic activity
  - Industrial output, services, and mining revisions - Changes to economic activity as a result of changes to government spending related to the production of raw materials, intermediate and final goods, services, and potentially mining of fuels
- For more information about the IIJA provisions included in the AEO 2022, see https://www.eia.gov/outlooks/aeo/pdf/AEO2022_BIJ_Law.pdf

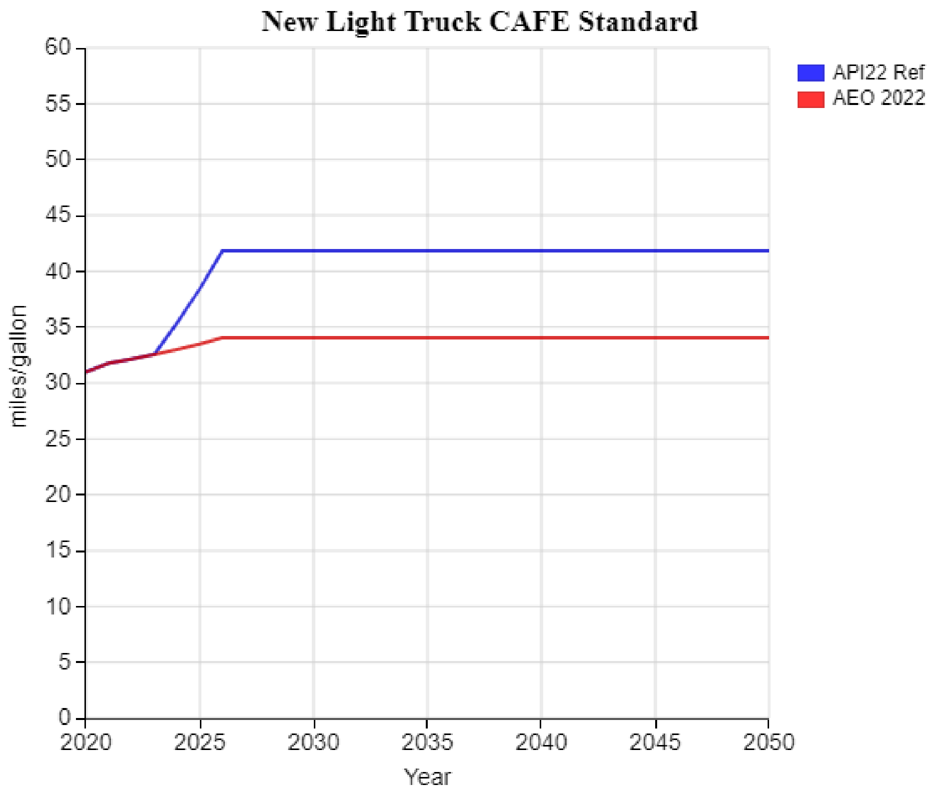
IIJA Carbon Capture, Transport & Storage Assumptions

- The new law also provides grants for various stages of carbon capture, transport, and sequestration infrastructure development which were not included in the AEO 2022 that have been added to API22-NEMS.
- We modeled a representation of cost-sharing for carbon capture demonstration and pilot projects, based on the allocation of $3.5B in FY 2022-2025.
  - Funding was used for 2.55 GW of new gas-fired carbon capture power plant capacity added as planned new construction in four states: Texas, Florida, Ohio and California.
  - Early adoption of carbon capture spurs innovation and drives down costs in the model.
- We incorporated the provisions for the federal credit instruments and grants mechanism to design and build carbon transport infrastructure. This provision allocates $2.1B+ towards building out this infrastructure and allows for delayed loan repayments 5 years after start.
  - Funding and delayed loan repayments were used to reduce the cost of building new CO_2 pipelines.
- We also incorporated the provisions for grants towards feasibility, permitting and construction of carbon sequestration storage sites and associated Class VI wells. This provision allocates $2.5B+ of spending over the years 2022-2026 for this purpose.
  - Funding was used to reduce the cost of building new carbon storage sites.

EPA/NHTSA Light-Duty Vehicle CAFE Standards

- The AEO 2022 includes the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026.
- The API22-NEMS Reference case includes the new NHTSA 2024-2026 fuel economy standards* for LDVs. The CAFE footprint standards yield roughly 58 mpg for new cars and 42 mpg for new light trucks by 2026.





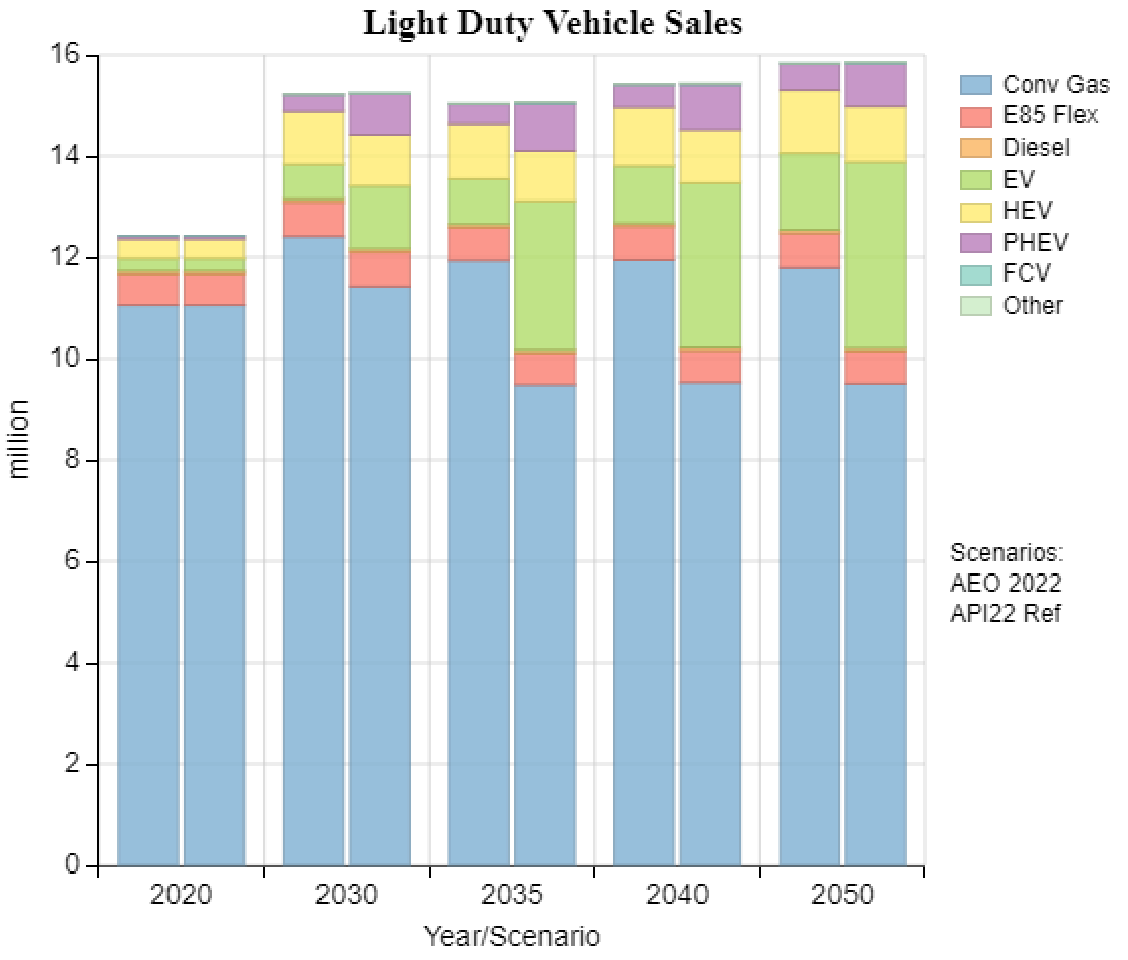
* For information about the Final Rule for CAFE Standards MYs 2024-2026, see https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy#40466

Zero Emission Vehicle Policy

- In AEO 2022, the state-based Zero-Emission Vehicle (ZEV) requirements are removed after 2019.
- The API22-NEMS Reference case removes the moratorium on state programs and includes the following ZEV policy assumptions:
  - ZEV targets for California and 15 other states (CT, ME, MD, MA, NJ, NY, OR, WA, RI, VT, VA, MN, DE, CO, NV) are:
    - 100% ZEVs by 2035 for CA, NY, VA (80% electric vehicles (EVs) and 20% plug-in hybrid vehicles (PHEVs))
    - 100% ZEVs by 2030 for WA (80% EVs and 20% PHEVs)
    - 16% EVs and 6% PHEVs constant from 2025 to 2050 for the other 12 states based on Section 177 of the Federal Clean Air Act.
  - The traveling ZEV credits between California and Section 177 states are removed after 2018.
  - Manufacturers' earned credits per ZEV type (e.g., 4 for EV300) are assumed to linearly ramp to 1 credit per vehicle by 2035.
  - Note that new regulations have not yet been finalized by states that have announced 100% targets, so these assumptions were selected as a simple representation of what may be enacted.

Zero Emission Light Duty Vehicle Sales

- The expanded ZEV mandates result in more electric vehicles (EVs) and plug-in hybrid EVs (PHEVs) compared to the AEO 2022.
  - In AEO 2022, national LDV ZEV sales shares reach 9% in 2035 and 13% in 2050.
  - In API22-NEMS Reference case, national LDV ZEV sales shares rise to 26% in 2035 and 29% in 2050.



Methane Emission Factors

- Methane emission factors for fossil fuels (oil, natural gas, coal) combustion are drawn from 2022 EPA Greenhouse Gas Emission Factors Hub (https://www.epa.gov/system/files/documents/2022-04/ghg_emission_factors_hub.pdf).
- Methane emission factors for fossil fuels supply are calculated based on the ratio of methane emissions from each activity in the fuel supply system to the amount of fuel produced in 2019.
- The methane emission factors are assumed to remain constant from 2019 to 2050.

Sources:
CH_4 in 2019: EPA Inventory of U.S. GHG and Sinks: 1990-2019;
Fuel production in 2019: AEO 2021 Reference Case

		thousand metric ton CH4/trillion cubic feet natural gas production
Activity	Exploration	0.62
	Production	
	Onshore	113
	Offshore	32.6
	Processing	14.7
	Transmission & Storage	43.7
	Distribution	16.6

		thousand metric ton CH4/million barrels per day oil production
Activity	Exploration	0.63
	Production	
	Onshore	85.8
	Offshore	91.9
	Transportation	0.52

		thousand metric ton CH4/million short tons coal production
Activity	Underground mining	5.13
	Surface mining	0.60
	Post-mining (UG)	0.77
	Post-mining (Surface)	0.13

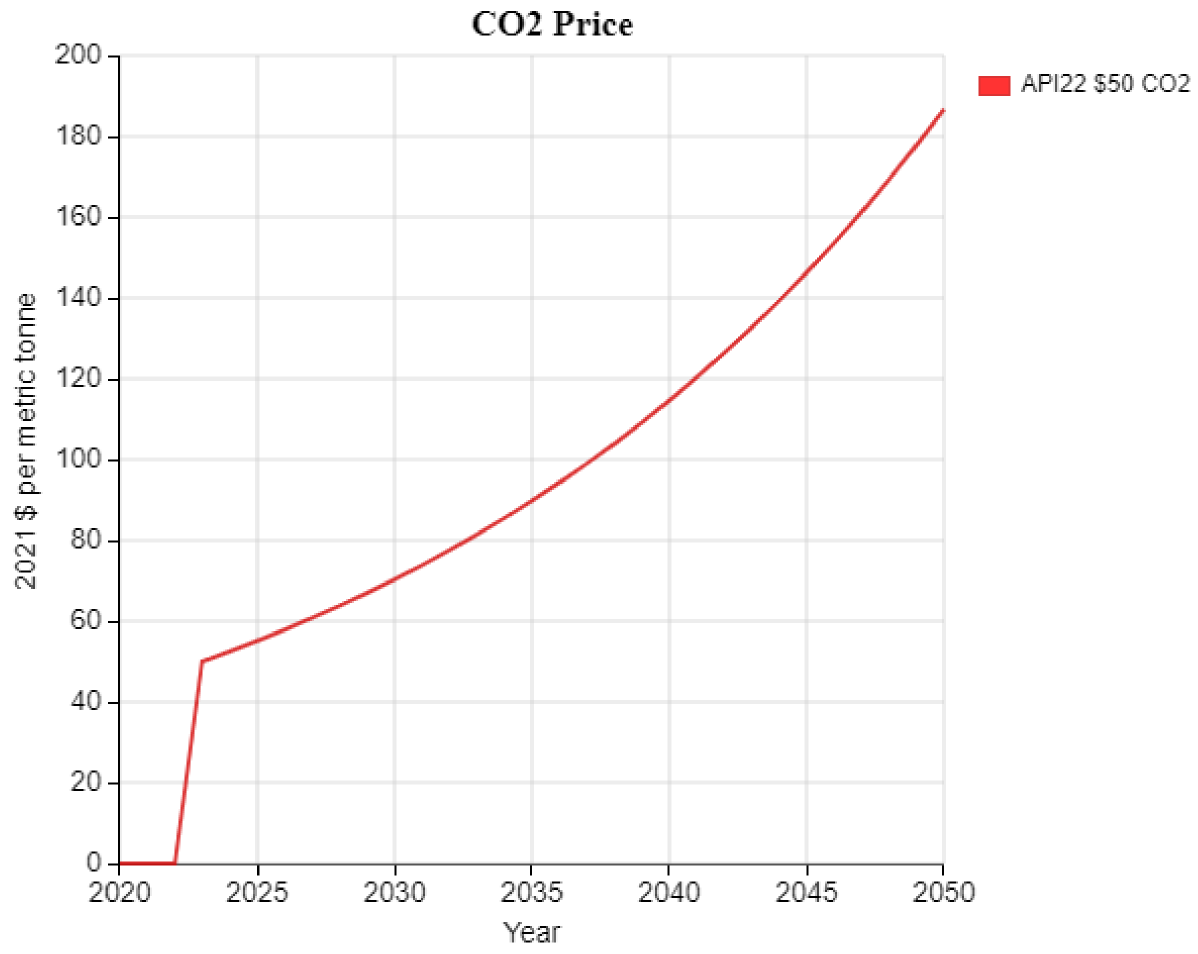
Appendix B: API22-NEMS Modeling Methodology
CO_2 Price Scenario and Technology R&D

Modeling Methodology and Assumptions

- The API22-NEMS CO_2 Price case incorporates all changes included in the Reference case in addition to a CO_2 price and technology improvements
  - The case includes an economy-wide CO_2 price of $50 per metric tonne (2021$) starting in 2023 and rising at 5 percent per year above inflation
  - Technology assumptions were modified in the power and transportation sectors to reflect improvements expected in low CO_2-emitting technologies from the use of 50% of CO_2 revenues for research and development.
    - Assumptions are based on published studies that project improved costs and characteristics that these technologies might achieve with substantial R&D funding and innovation. These costs are used to override the model's endogenous learning functions for the selected technologies.
    - For most technologies, costs are assumed to remain at AEO 2022 levels through 2025 and decline linearly to the advanced cost projections by 2030.

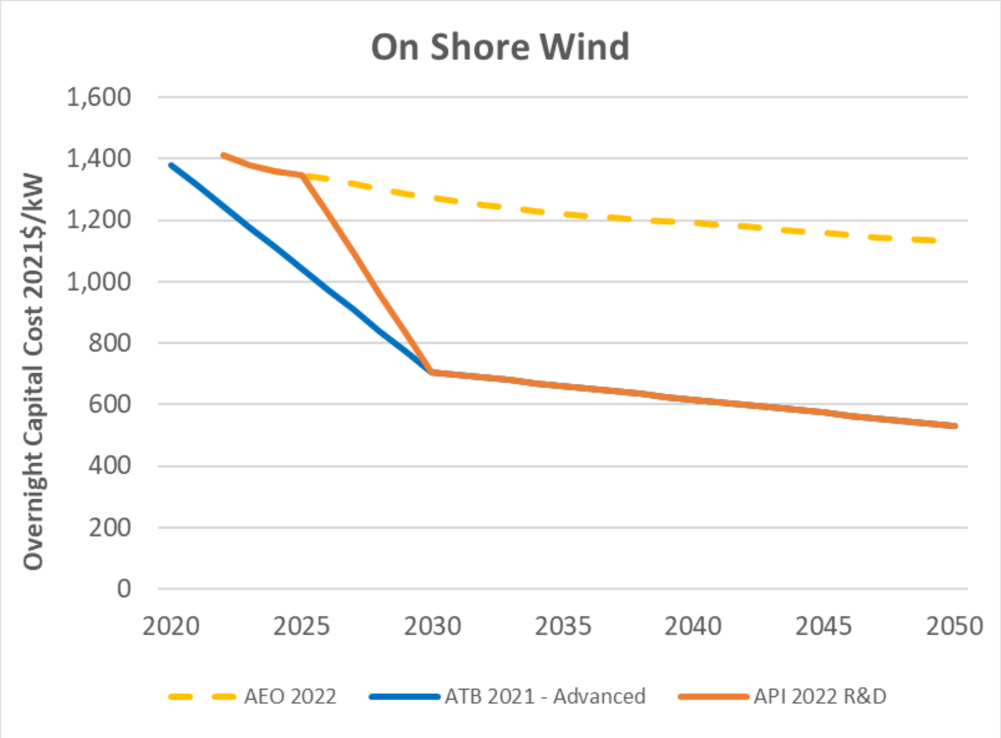
CO_2 Price

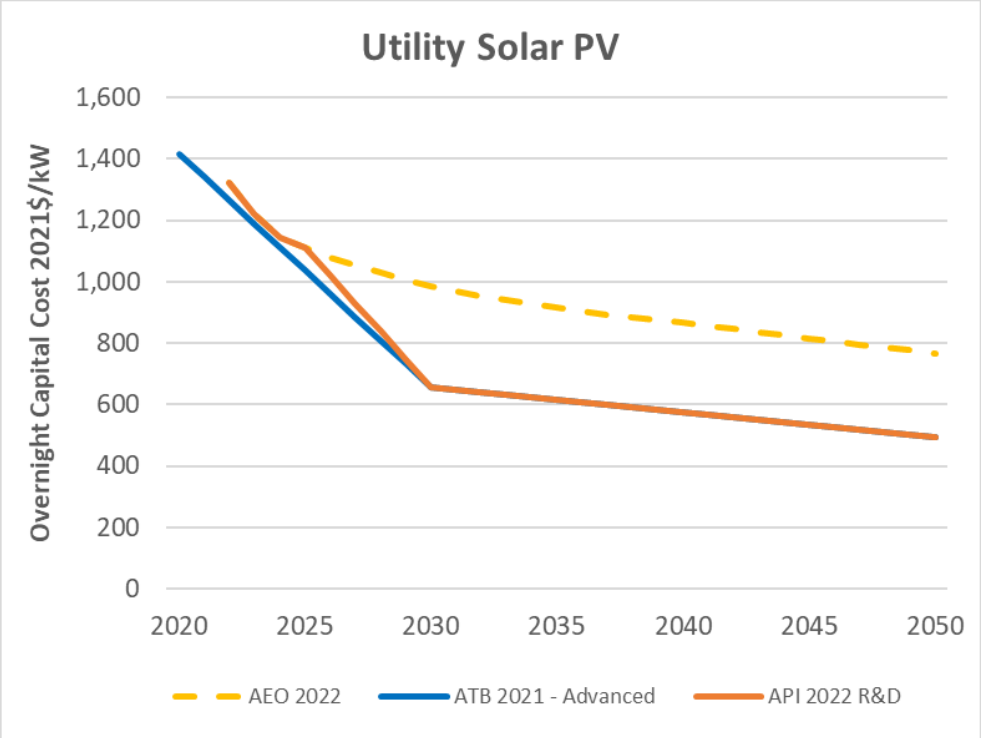
- The API22-NEMS CO_2 Price case includes an economy-wide CO_2 price starting at $50 per metric tonne in 2023 and rising at 5 percent per year above inflation. The price reaches $187 per tonne by 2050.
- The CO_2 price is reflected in delivered energy prices based on the carbon content of the fuel.
- We also assumed that 50 percent of CO_2 revenues are returned to households each year as a lump sum reduction in total personal taxes paid to the government.
- The model's international trade parameters were set to assume that the rest of the world also implements similar carbon policies which is approximately equivalent to assuming border adjustments.



Power Sector Technologies: Renewables

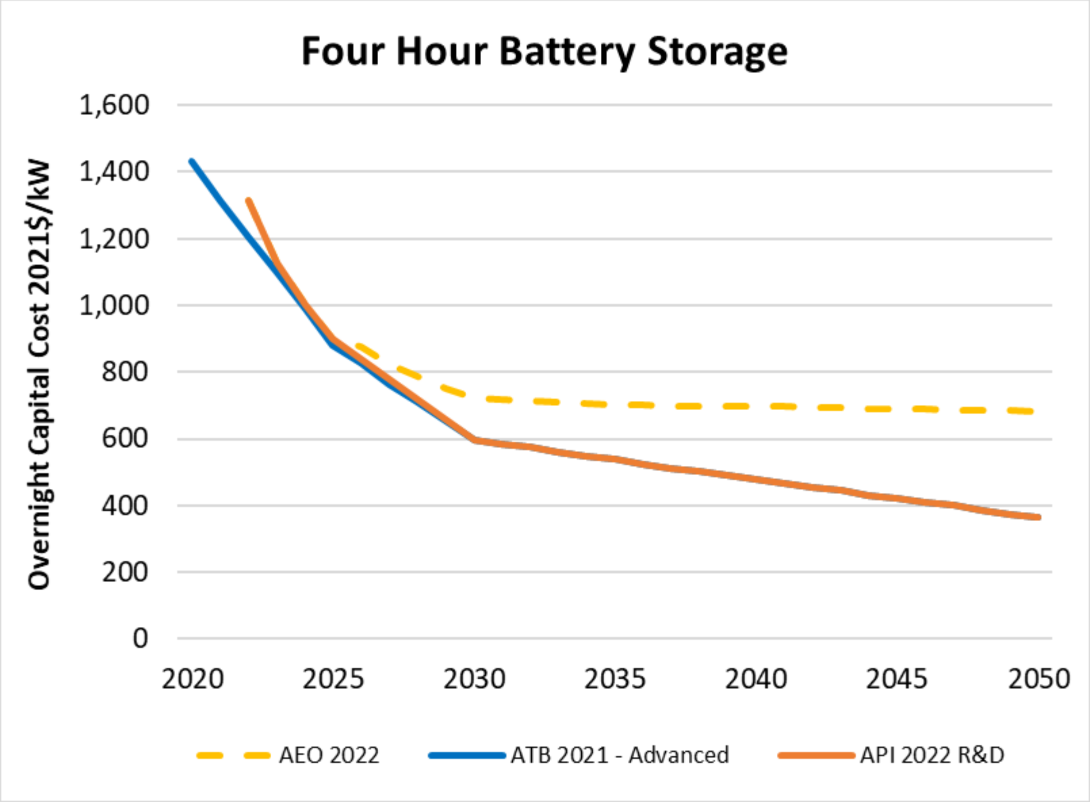
- The API22-NEMS CO_2 Price case includes significant capital cost reductions for renewable technologies such as utility-scale onshore wind and solar PV (shown here) as well as improved O&M costs and higher capacity factors for wind. Other renewable technologies with improved characteristics include utility-scale solar PV with onsite battery storage, offshore wind, and rooftop PV.
- *Source: NREL (National Renewable Energy Laboratory), 2021 Annual Technology Baseline, Advanced Case.*





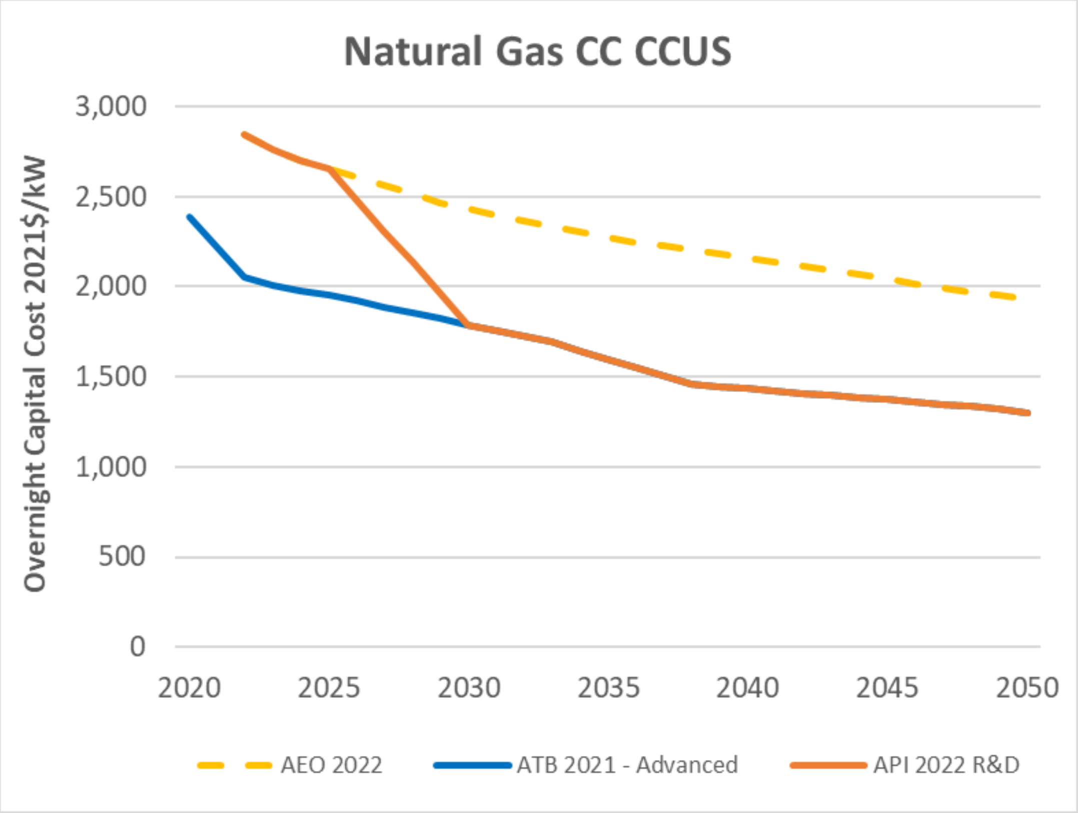
Power Sector Technologies: Battery Storage

- The API22-NEMS CO_2 Price case includes reductions in capital costs (shown here) and O&M costs for battery storage. This technology is assumed to deliver four hours of storage per day at an efficiency rate of 85 percent (i.e., 15 percent energy losses).
- *Source: NREL (National Renewable Energy Laboratory), 2021 Annual Technology Baseline, Advanced Case.*



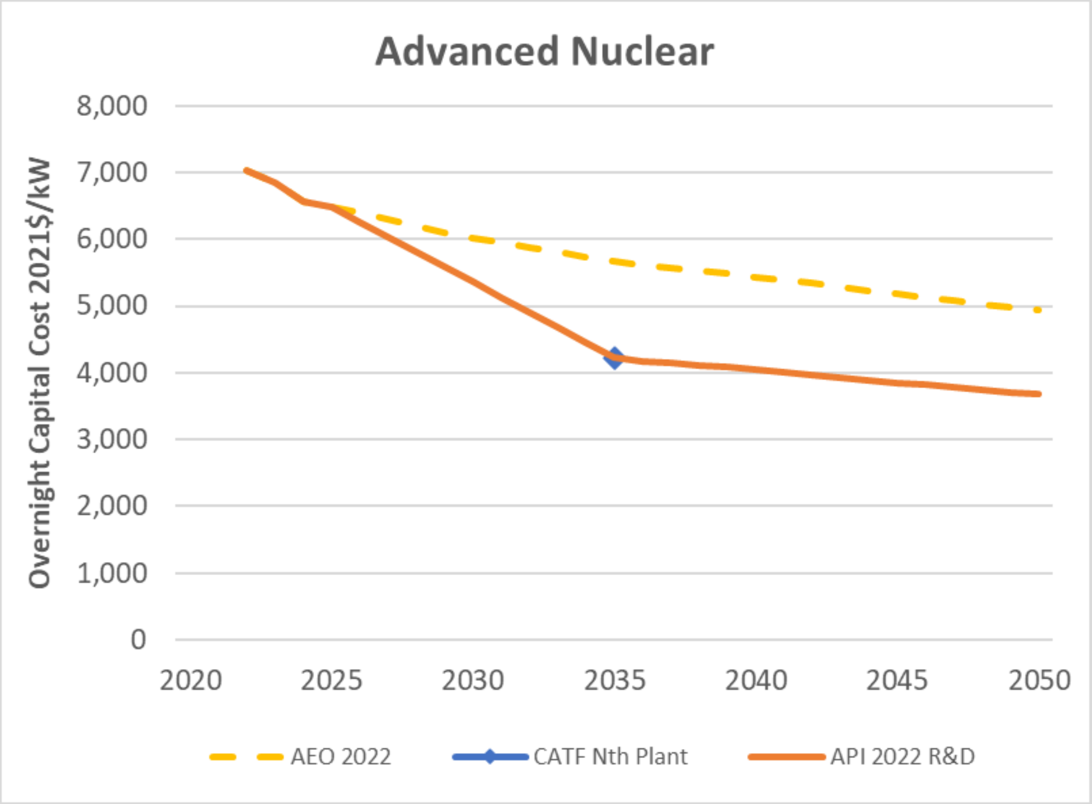
Power Sector Technologies: Carbon Capture and Storage

- The API22-NEMS CO_2 Price case includes capital cost reductions (shown here) as well as improved O&M costs and heat rates for natural gas combined cycle with 90 percent carbon capture. Captured CO_2 is either purchased for enhanced oil recovery or transported to a saline aquifer for permanent storage.
- *Source: NREL (National Renewable Energy Laboratory), 2021 Annual Technology Baseline, Advanced Case.*



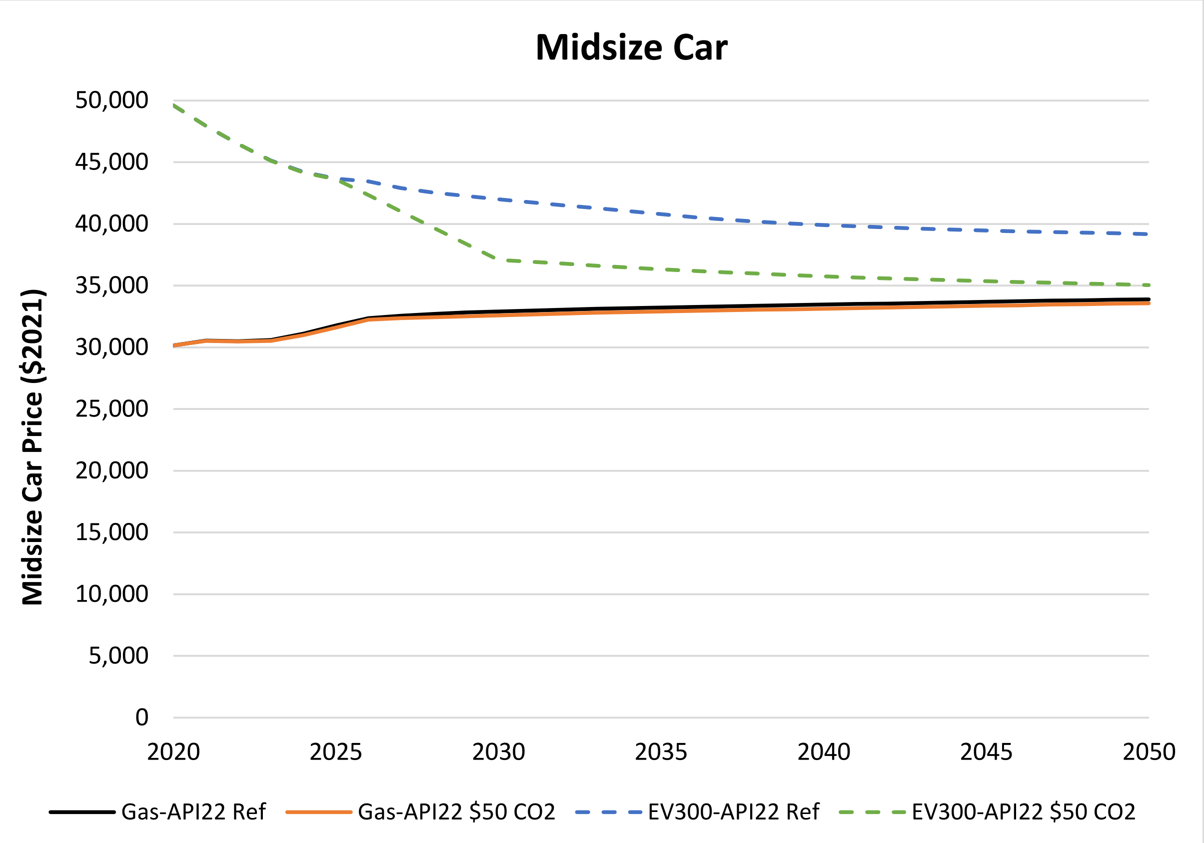
Power Sector Technologies: Nuclear Power

- The API22-NEMS CO_2 Price case includes capital cost reductions (shown here) as well as improved O&M costs for advanced light-water nuclear power. The CATF Nth plant cost was assumed to be achieved in 2035, with costs declining modestly thereafter at the same annual rate as the AEO 2022 projected costs.
- *Source: Clean Air Task Force (CATF), "Advanced Nuclear Energy: Need, Characteristics, Projected Costs, and Opportunities," April 2018.*



Transportation Technologies: Electric Vehicles

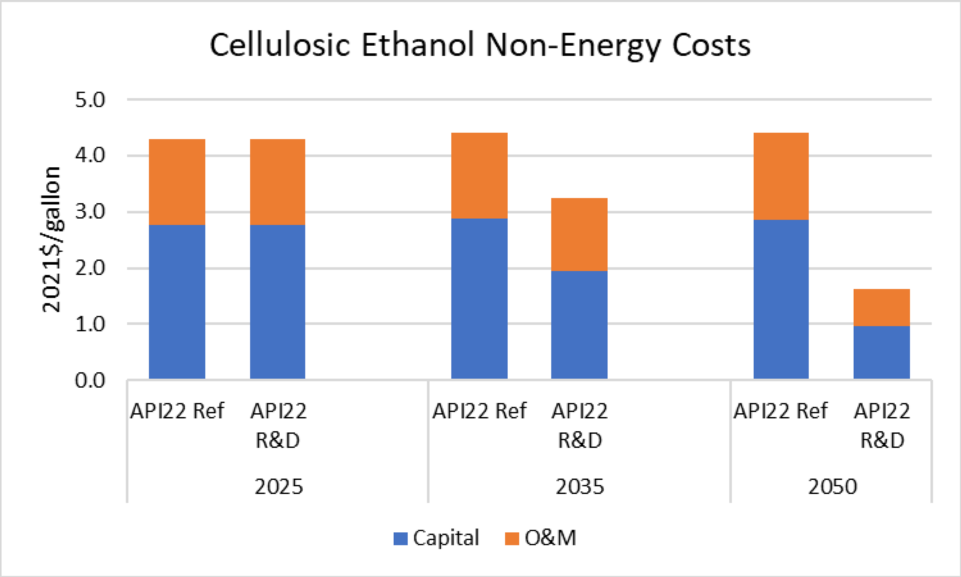
- EV300 midsize car prices are the same for API22 Reference and \$50 CO_2 price case from 2020 to 2025.
- In the CO_2 price case from 2026 to 2050, EV300 midsize car prices are calculated based on the EV300 midsize car price ratio of AEO2022 Reference case to NREL ATB-Adv in 2025. This ratio is multiplied by EV300 midsize car price in AEO2022 Reference case in each time period.
- Other EV300 size classes costs are adjusted based on the non-battery cost ratio of each size class to midsize car.
- After 2040, EV300 prices are below conventional gasoline vehicle prices in a few size classes (large and 2-seater car).
- EV100 and EV200 midsize car prices follow the same decline pattern as EV300 car prices over time.

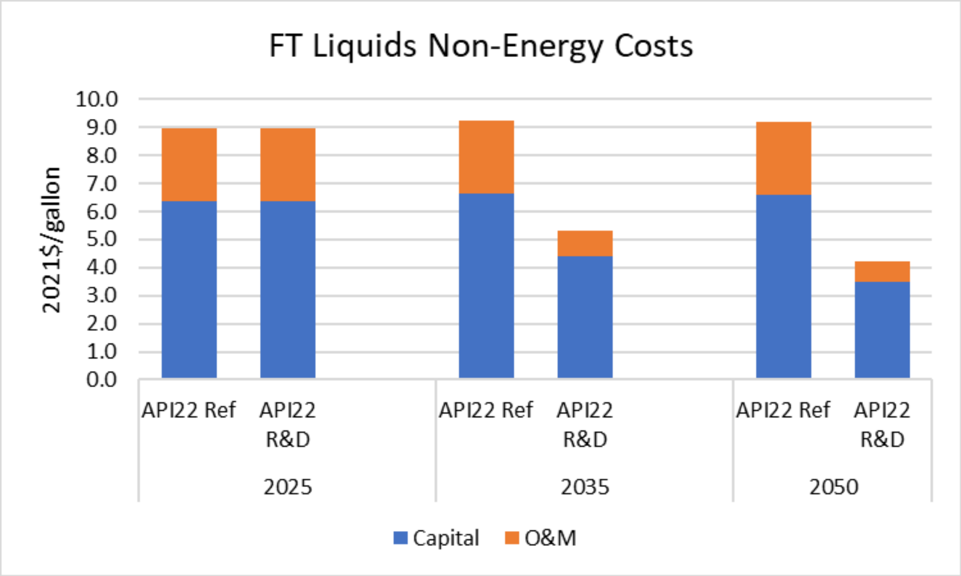


Source: NREL (National Renewable Energy Laboratory), 2021 Annual Technology Baseline, Advanced Case (ATB-Adv) with adjustments.

Liquid Fuels: Biofuel Costs

- The API22-NEMS CO_2 Price case includes capital and O&M cost reductions for cellulosic ethanol and Fischer-Tropsch (FT) Liquids starting in 2030. FT liquids are also assumed to have an improved efficiency of 40% with no excess power production.
- *Source: IEA, Advanced Biofuels – Potential for Cost Reduction, 2020. The Optimistic Potential Future case was used for cellulosic ethanol and the High case for FT liquids.*





Note the difference in scales between the two charts.

Appendix C: API22-NEMS Modeling Methodology
Federal Carbon Reduction Standards (FCRS) Scenario

FCRS Scenario Definition

- We modified the API22-NEMS to include the capability to represent the FCRS policy in a similar manner as the California low carbon fuel standard (LCFS).
- The FCRS scenario incorporates all changes included in the Reference case in addition to the new FCRS standard, which is defined as follows:
  - FCRS covers gasoline and diesel fuels with individual annual standards and credit trading (combined standard) with no banking of credits
  - Carbon intensity (CI) requirement declines by 1 percent per year for 15 years starting in 2023
  - The FCRS cost containment price was set to $10,000 per tonne CO_2 (designed to be non-binding)
  - Carbon intensity factors except electricity and selected other fuels are assumed to be the same as those used for the California LCFS (see next slide for more information)
- Other changes made to the API Reference case assumptions include:
  - The maximum shares for E15 were increased to allow 100% shares by 2027
  - Agricultural biomass supply curves was increased to reflect the NREL 2016 Billion Ton Study
  - Advanced biofuels capacity maximum growth rates have been increased relative to the AEO 2022 reference case
- AEO 2022 reference case biofuel production costs were assumed
- Existing policies are assumed to remain in place, including California LCFS and RFS standards as represented in the AEO 2022 with relatively constant targets

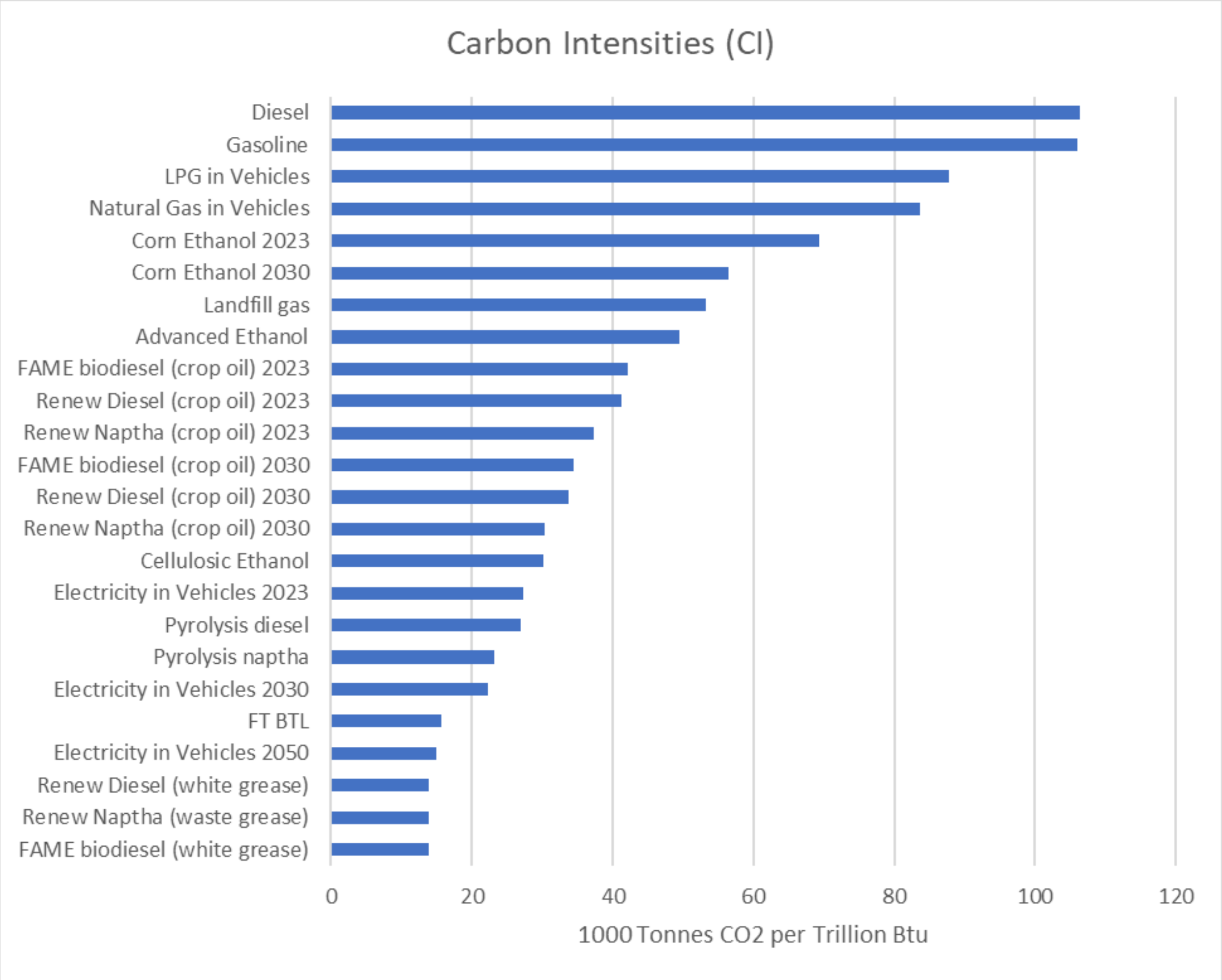
** Note, all monetary values in this analysis are expressed in real 2021$ unless otherwise indicated.*

Carbon Intensity Factors

- Carbon factors for electricity and selected other fuels are assumed to be the same as those used for the California LCFS except
  - Carbon intensities (CIs) for gasoline, diesel, corn ethanol, pyrolysis, FAME biodiesel and renewable diesel were modified to reflect values provided by API
    - CIs for corn ethanol and processes using soybean oil decline by 5% per year through 2027
    - As provided, these factors decline for 14 years although assuming carbon capture for ethanol starting in 2027, but we felt it was unrealistic to assume continuing declines at no additional cost in our modeling (carbon capture for ethanol is not represented in API22-NEMS)
  - The carbon factor for electricity set equal to the national average carbon intensity for electricity used in transportation with an EER of 3.4 included

Carbon Intensity Factors

- Diesel and gasoline have the highest carbon intensities while Fischer-Tropsch BTL and biomass pyrolysis are among the lowest intensities
- Carbon intensity factors for corn ethanol and for biodiesel and renewable diesel using soybean oil are assumed to fall by 5% per year until 2027, based on assumptions provided by API.
- Electricity factors (including an EER of 3.4) are higher for the U.S. average than for California. The factors decline from 27 thousand tonnes CO_2 per trillion Btu to 15 by 2050.



Biofuels Available in API22-NEMS

Table 9. Alternative fuel technology product type

Technology	Product type	Feedstock	Product yield (percentage by volume)
Biochemical			
Corn ethanol	Fuel grade	Corn	100% ethanol
Advanced grain ethanol	Fuel grade	Grain	100% ethanol
Cellulosic ethanol	Fuel grade	Stover	100% ethanol
Biobutanol	Fuel grade	Corn	100% biobutanol
Thermochemical catalytic			
Methyl ester biodiesel	Fuel grade	Yellow or white grease, or seed oil	98.5% biodiesel 1.5% glycerol
Non-ester renewable diesel	Fuel grade	Yellow or white grease, or seed oil	98% renewable diesel 2% renewable naphtha
Pyrolysis	Fuel grade	Agriculture residue, forest residue, or urban wood waste	60% distillate 40% naphtha
Thermochemical Fischer-Tropsch			
Gas-to-liquids (GTL)	Fuel grade and refinery feed	Natural gas	52% diesel 23% kerosene 24.5% naphtha 0.5% liquid petroleum gas (LPG)
Coal-to-liquids (CTL)	Fuel grade and refinery feed	Coal	51% diesel 21% kerosene 28% naphtha
Biomass-to-liquids (BTL)	Fuel grade and refinery feed	Biomass	22% diesel 46% kerosene 32% naphtha

Source: U.S. Energy Information Administration, Office of Energy Analysis

Source: EIA, Assumptions to the Annual Energy Outlook 2022: Liquid Fuels Market Module

Biofuel Technology Characteristics

Table 10. Non-petroleum fuel technology characteristics[a]

AEO2022 2025 basis (2021$)	Nameplate capacity[b] b/sd	Overnight capital cost[c] $/b/sd	Thermal efficiency[d] percentage	Utilization rate[e] percentage	Cost of capital[f] (WACC) percentage	Fixed O&M cost[g] $/d/b/sd	Non-feedstock variable O&M cost[h] $/b
Biochemical							
Corn ethanol	6,800	$27,500	49%	100%	11%	$7	$7
Advanced grain ethanol	3,400	$65,500	49%	100%	11%	$20	$3
Cellulosic ethanol	4,400	$206,600	28%	85%	11%	$42	$1
Biobutanol (retrofit of corn ethanol plant)	6,500	$14,300	62%	90%	11%	$2	$7
Thermochemical catalytic							
Methyl ester biodiesel (FAME)	1,200	$29,800	21%	100%	11%	$23	$8
Non-ester renewable diesel (NERD)	2,100	$42,300	21%	95%	11%	$24	$8
Pyrolysis	5,200	$420,400	60%	90%	11%	$73	$7
Thermochemical Fischer-Tropsch							
Gas-to-liquids (GTL)[i]	24,000	$209,300	55%	85%	11%	$36	$10
Coal-to-liquids (CTL)	24,000	$260,500	49%	85%	14%	$44	$12
Biomass-to-liquids (BTL)	6,000	$474,700	38%	85%	11%	$78	$8

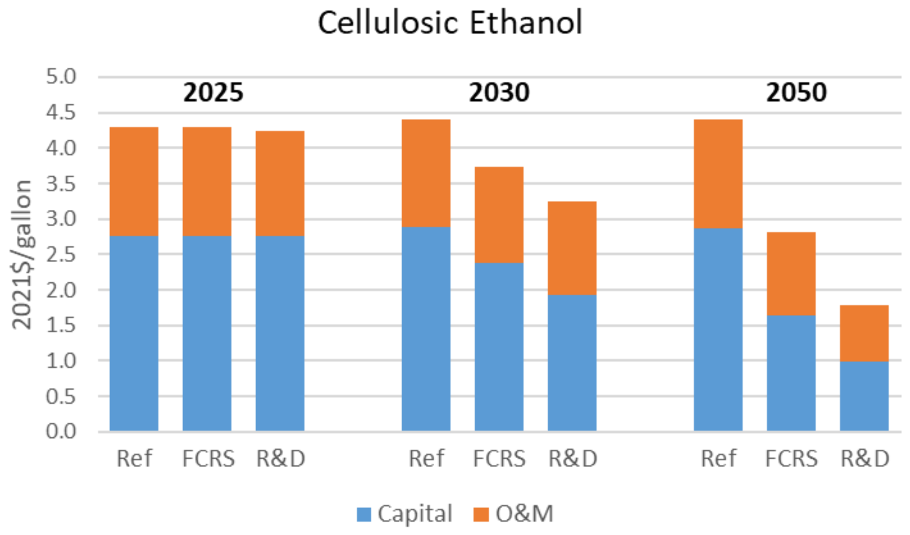
Source: U.S. Energy Information Administration, Office of Energy Analysis

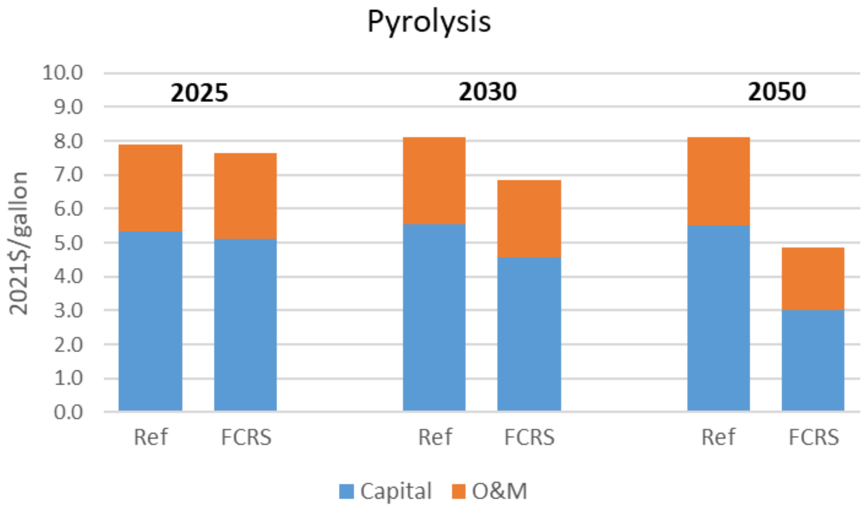
[a] This table is based on the *Annual Energy Outlook 2022* (AEO2022) Reference case projections for year 2025.

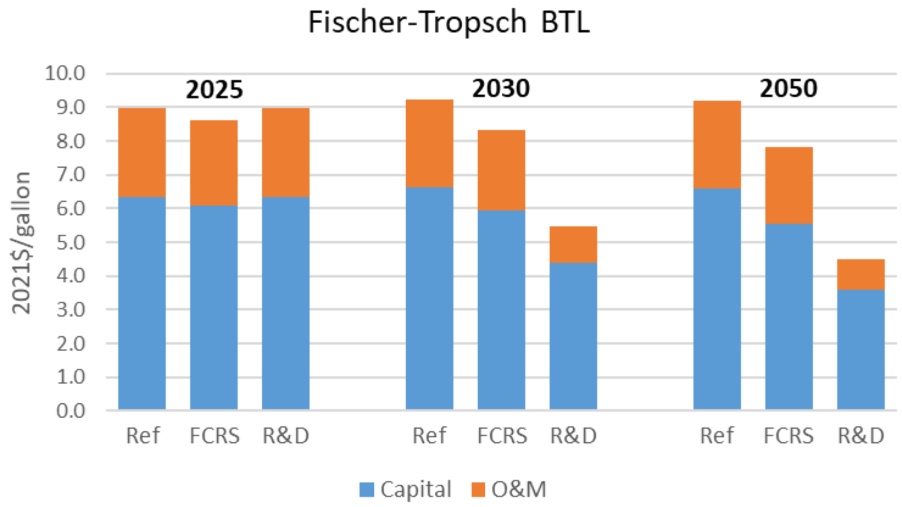
Source: EIA, Assumptions to the Annual Energy Outlook 2022: Liquid Fuels Market Module

Biofuel Costs with Learning

- The cost of second-generation biofuels decline through learning-by-doing as production capacity expands.
  - Long run costs remain higher than in the API22-NEMS CO_2 Price case where additional R&D was assumed to reduce these costs starting in 2030 (see Appendix B).







Note the difference in scale in the Cellulosic Ethanol chart.

Appendix D:
Methodology for Calculating Household Expenditures

Methodology Overview

- Household energy expenditures for the U.S. and for each Census region are calculated using results from the API22-NEMS model for each scenario. These expenditures are distributed across income groups based on historical proportions as reported in published surveys. The proportion of households in each income group and the distribution of expenditures are held constant over time.
- In-home expenditures include energy bills, new and replacement energy equipment, improvements in energy efficiency in homes such as additional insulation or more efficient windows, and rooftop solar PV installations. Expenditures for non-energy goods and services are not included.
- Vehicle expenditures include fuel expenses and the cost of new vehicle purchases for personal use. Expenditures on vehicle maintenance, finance, registration/tax, and insurance are not included, as well as expenses for other modes of transportation such as mass transit or air travel.
- Annual CO_2 revenue is also calculated using results from the model.
- This analysis does not estimate how households might spend the extra income from CO_2 revenue recycling nor does it include the effect of how CO_2 pricing might impact the cost of energy-related equipment or other goods and services