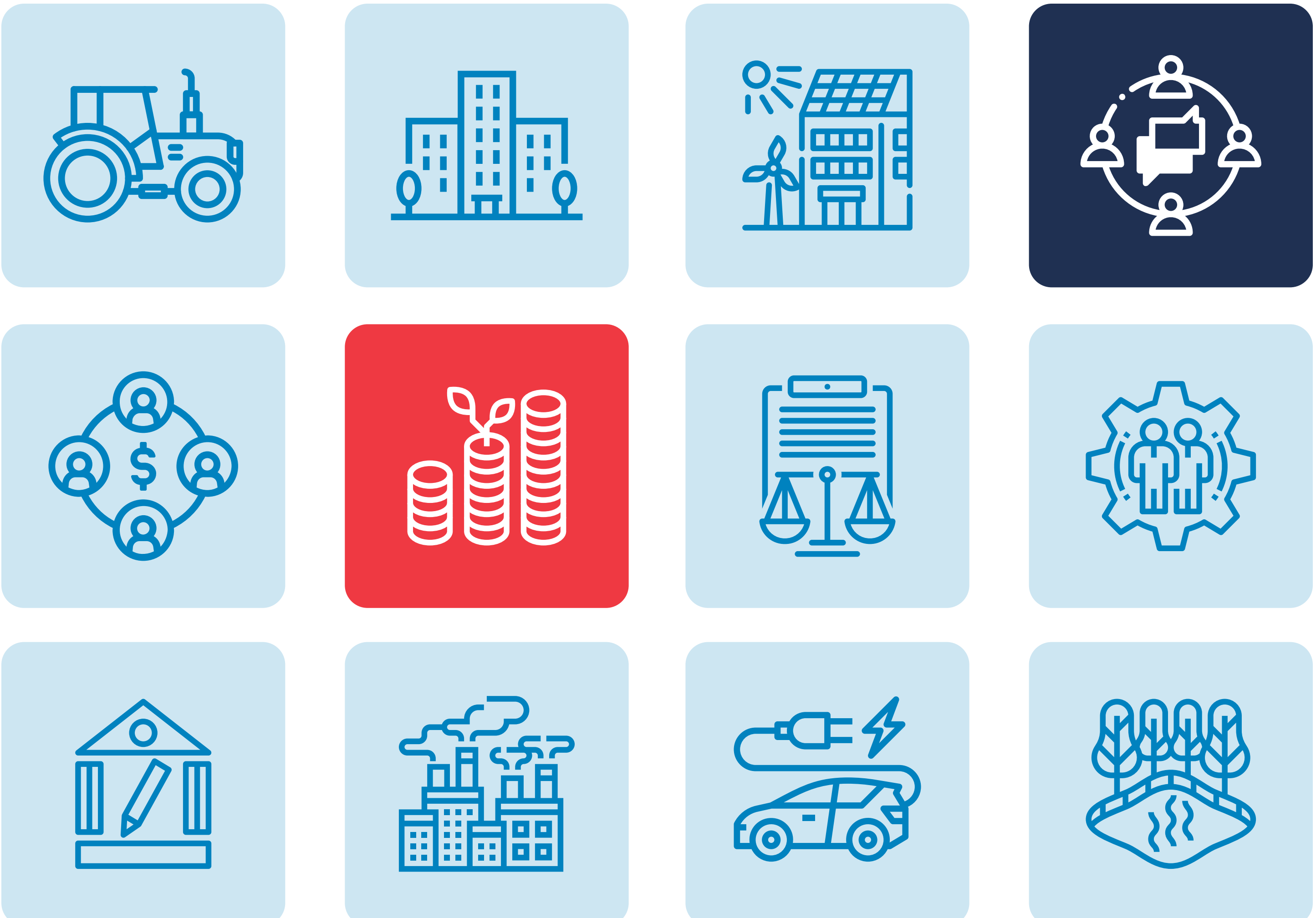

AN "ALL-IN" PATHWAY TO 2030:

The Beyond 50 Scenario

Technical Appendix

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Authors

Alicia Zhao[1], Shannon Kennedy[1], Kowan O'Keefe[1], Maria Borreo[1], Kyle Clark-Sutton[2], Ryna Cui[1], Camryn Dahl[1], Grace Deye[1], John Feldmann[3], Kevin Kennedy[2], Haewon McJeon[1], Miguel Moravec[2], Dimitri Nilov[1], Sujata Rajpurohit[2], Joaquin Rosas[2], Claire Squire[1], Nate Hultman[1,4]

AMERICA IS ALL IN

Technical Appendix: *An "All-In" Pathway to 2030: The Beyond 50 Scenario*

Overview of GCAM-USA-AP

The estimates of economy-wide emissions reductions in this analysis are based on a version of the Global Change Analysis model (GCAM) with a detailed representation of the U.S. energy system at the state level (GCAM-USA). We refer to the version of GCAM-USA used in this study as GCAM-USA-AP.

The global version of GCAM is an open-source Integrated Assessment Model (IAM) that represents the energy and economic systems for 32 geopolitical regions, including the United States.[1] GCAM represents land use and agriculture in 384 land regions nested within 235 water basins. GCAM tracks emissions of a range of greenhouse gases (GHGs) and air pollutants from energy, agriculture, land use, and other systems.

GCAM-USA is a version of GCAM that disaggregates the U.S. energy and economy components into 50 states and the District of Columbia while maintaining the same level of detail in the rest of the world and for water and land sectors. The energy system formulation in GCAM-USA consists of detailed representations of depletable primary sources such as coal, gas, oil, and uranium, in addition to renewable resources such as bioenergy, hydropower, wind, and geothermal.

GCAM-USA also includes representations of the processes that transform these resources into final energy carriers, such as oil refining and electric power. These energy carriers, in turn, are used to deliver services to end users in the buildings, transportation, and industrial sectors. The electric power sector includes representations of a range of power generation technologies, including those fueled by fossil fuels, renewables, bioenergy, and nuclear power.

GCAM-USA is a market equilibrium model. The equilibrium in each period is solved by finding a set of market prices such that supplies and demands are equal to one another in all markets as the actors in the model adjust the quantities of the commodities they buy and sell. GCAM operates in 5-year time-increments, with each new period starting from the conditions that emerged in the last.

GCAM-USA-AP is based on the open-source release of GCAM-USA 5.3.[2] GCAM-USA-AP has been modified for the purposes of this study, for example, to reflect the latest renewable energy costs and vehicle technology costs. It is also calibrated to the latest non-CO_2 marginal abatement cost curves from the U.S. Environmental Protection Agency.[3]

Overview of modeling approach

To develop our modeled scenarios, we used bottom-up aggregation tools and data analysis to evaluate and quantify the impacts of policies and climate actions in isolation and within specific sectors. These methods remove potential areas for double counting of potential emissions reduction drivers from nested governance levels. We then used this information in GCAM-USA-AP to estimate the economy-wide implications of these associated policies. The overall modeling approach used was consistent with previous analysis, including Fulfilling America's Pledge (2018), Accelerating America's Pledge (2019), An All-In Climate Strategy Can Cut U.S. Emissions by 50% by 2030 (2021), and Blueprint 2030 (2021).[4,5,6,7]

The modeled scenarios were produced by changing parameters in GCAM-USA-AP, either directly or based on information from bottom-up aggregation analysis. For several policy drivers included in the analysis, bottom-up aggregation was either not feasible or not required given the relatively small scale of potential impacts. Impacts of policies on activity drivers were directly implemented into GCAM-USA-AP. For example, a phase-out of coal power in the "Beyond 50" scenario was modeled directly in GCAM-USA-AP by setting a national constraint on coal generation to reach zero by 2030, though this phase-out could also be affected through a number of bottom-up policy measures from utilities, states, and consumer demand, and from recent policies enabled by new spending unlocked from the Inflation Reduction Act (IRA) of 2022. On the other hand, unlike in the Beyond 50 scenario, the coal power emissions levels in the "Existing Policies" scenario were modeled through a combination of these diverse policies, which is partly why the Existing Policies scenario included a range of possible 2030 outcomes.

By contrast, nuclear capacity retention is an example of a policy lever that was explicitly modeled using a more bottom-up approach. Nuclear power plants at risk of retirement before 2030 were identified on a state-by-state basis. A combination of state and federal measures was then evaluated and assumed to allow for all at-risk nuclear capacity to remain online through 2030. In addition, it was assumed that Vogtle units 3&4 in Georgia, the only new nuclear plants currently scheduled to come online in the U.S., would begin operating at full capacity by 2030. This assessment was then translated to state-level capacity and generation values by year, which were integrated into GCAM-USA-AP.

All policies explicitly included in the analysis were modeled at the state and/or national levels. City, business, and institution-based policies were aggregated at the state level or assumed to be embedded within or supportive of the national and state policies and, therefore, not explicitly modeled to remove risk of double-counting. As an example of state-level aggregation, the impacts of renewable targets from states, cities, and electric power utilities were aggregated together at the state level, with city and utility targets being counted as additional in situations where a higher percentage of renewable generation was targeted by the smaller-scale entity. More details on specific policies included and how we approached aggregation can be found in Supplementary Tables 2-6.

As has been the case historically, not all states act equally or with the same urgency on climate. An example of this in our analysis is non-federal ZEV sales targets. Therefore, to facilitate our scenario analysis, we grouped states into three different tiers depending on their current policies and historical willingness to lead on climate. We modeled leading states, Tier 1, to typically include California, Colorado, Connecticut, Delaware, the District of Columbia, Hawaii, Illinois, Maine, Maryland, Massachusetts, Minnesota, New Hampshire, New Jersey, New Mexico, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington. States that are currently taking some measures to reduce emissions but not as quickly are categorized as Tier 2. We modeled nine Tier 2 states, typically including Arizona, Iowa, Michigan, Missouri, Nevada, North Carolina, Ohio, Virginia, and Wisconsin. Finally, we anticipate that Tier 3 states that have done little with respect to passing climate policies will, for the most part, continue the status quo, even if those new policies would be cost effective. We modeled 22 Tier 3 states, typically including Alabama, Alaska, Arkansas, Florida, Georgia, Idaho, Indiana, Kansas, Kentucky, Louisiana, Mississippi, Montana, Nebraska, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, Texas, Utah, West Virginia, and Wyoming. While each of these states do have some clean energy and lands efforts underway, for the purposes of this analysis, we assume they will continue at a slower pace.

Finally, we note that the purpose of this analytical activity is to assess the overall emissions impact of the modeled actions at the national level in the United States. This means that we modeled actions at the non-federal scale only to the extent that doing so would help create a meaningful impact on the overall national outcome. In some cases, we did not distinguish among states when implementing policies – for example, in implementing electric buses – because assessing the national impact with confidence did not require state-level precision. An important implication of this approach is that confidence in national results is higher than confidence in results for specific states or regions.

The Existing Policies scenario

In our Existing Policies scenario, we modeled a combination of existing federal and non-federal policy actions, including many of the climate-related provisions from the Infrastructure Investment and Jobs Act (IIJA) and the recently enacted IRA. Our modeling assumptions for all policies that we modeled in GCAM-USA-AP are shown in Supplementary Tables 2-5. A full list of the IRA provisions that we modeled is shown below.

Overall, we find that the IRA, in concert with other existing federal and non-federal policies, can reduce emissions 39% below 2005 levels by 2030. A detailed sector-by-sector breakdown of these reductions in the Existing Policies scenario is shown in Supplementary Table 1. However, we find that if IRA and existing policies can accelerate the retirement of coal-fired power plants so that the United States achieves a full coal phaseout by 2030, the economy-wide reduction in emissions by 2030 relative to 2005 could reach 42%. On the other hand, if the impacts of IRA on power sector emissions reductions are not fully realized until after 2030, we estimate that IRA and existing policies can cumulatively reduce emissions to 37% below 2005 levels by 2030.

Policies from the (IRA) modeled in the Existing Policies scenario

Electricity Sector

- Section 13101 – Production tax credit (PTC) extension
- Section 13102 – Investment tax credit (ITC) extension
- Section 13015 – PTC for existing nuclear
- Section 13701 – New clean electricity PTC
- Section 13702 – New clean electricity ITC
- Section 50144 – Energy community reinvestment financing

Transportation Sector

- Sections 13201/13202 – Extension of incentives for biofuels
- Section 13203 – Sustainable aviation biofuels
- Section 13401 – Clean vehicle credit
- Section 13403 – Commercial clean vehicle credit
- Section 13404 – Alternative refueling property credit
- Section 13704 – Clean fuel PTC

Buildings Sector

- Section 13302 – Residential clean energy credit
- Section 13303 – Energy efficient commercial building deduction
- Section 13304 – Energy efficient home credit
- Section 50121 – Home energy efficiency credit
- Section 50122 – High efficiency home rebate program

Industry and Other Sectors

- Section 13104 – 45Q: extension of credits for captured CO2
- Section 13204 – 45V: production credits for clean hydrogen
- Section 21001 – Additional agricultural conservation investments
- Section 60113 – Methane emissions reduction program

The Beyond 50 scenario

The IRA, along with additional policies and actions from Congress, the federal government, states, cities, and businesses, collectively provide a major boost to climate action in the United States. Yet these existing policies will not be enough on their own for the United States to meet its 2030 climate target. Our analysis finds that the target can be met through enhanced non-federal and federal actions that build on the policy framework in the Existing Policies scenario. Thus, our Beyond 50 scenario models GHG emissions reductions achievable under a comprehensive, "all-in" climate strategy with enhanced action from all levels of government. Altogether, these actions have the potential to deliver a 52% reduction in GHG emissions from 2005 levels. A sector-by-sector breakdown of the results for this scenario is shown in Supplementary Table 1 alongside results from our Existing Policies scenario. The modeling assumptions underlying this scenario are listed in Supplementary Tables 2-5.

Supplementary Table 1. Results by Sector

Sector/GHG	Emissions 2005 ($MMTCO_2e$)	Emissions 2020 ($MMTCO_2e$)	Emissions 2030 ($MMTCO_2e$)		Change from 2005 to 2030 ($MMTCO_2e$)		Change relative to 2005 (%)		Contribution to total reductions relative to 2005 (%)	
			Existing Policies	Beyond 50	Existing Policies	Beyond 50	Existing Policies	Beyond 50	Existing Policies	Beyond 50
Electricity CO_2	2417	1457	680	409	-1737	-2008	-72%	-83%	-26%	-30%
Transport CO_2	1869	1580	1357	1262	-512	-607	-27%	-32%	-8%	-9%
Industry CO_2	1190	1103	1016	929	-175	-261	-15%	-22%	-3%	-4%
Buildings CO_2	586	543	455	413	-131	-173	-22%	-29%	-2%	-3%
Other CO_2	71	31	28	23	-44	-48	-61%	-68%	-1%	-1%
CH_4	697	650	614	448	-83	-249	-12%	-36%	-1%	-4%
N_2O	446	418	515	466	68	20	15%	4%	1%	0%
F-Gases	146	190	115	107	-32	-40	-22%	-27%	0%	-1%
LULUCF	-790	-759	-757	-895	33	-105	-4%	-13%	0%	-2%
Net GHG Total	**6634**	**5213**	**4022**	**3163**	**-2612**	**-3472**	**-39%**	**-52%**	**-39%**	**-52%**

Supplementary Table 2. GCAM Implementation of Policy Assumptions in the Electricity Sector

Modeled Policy		Existing Policies Scenario	Beyond 50 Scenario
Renewable/clean electricity	Federal incentives	**IRA's production tax credit (PTC) extension (section 13101)** is modeled as a $26/MWh subsidy for solar, wind and geothermal technologies through 2024. We assume that all projects pay prevailing wages. A 7.5% reduction in the credit value is assumed due to the transferability provision.	
		IRA's investment tax credit (ITC) extension (section 13102) is modeled as a 30% subsidy for offshore wind and storage technologies through 2024, with the simplifying assumption that all projects pay prevailing wages. A 7.5% reduction in the credit value is assumed due to the transferability provision.	
		IRA's new clean electricity PTC and ITC (sections 13701 and 13702) are modeled in the same way as sections 13101 and 13102 through 2030, with phasedown after 2030.	
		IRA's residential clean energy credit (section 13302) is modeled by updating the rooftop ITC, which results in an additional 0.7GW/yr increase in electricity generation from rooftop PV on the lifetime of the credit through 2035.	
	Non-federal mandates and procurement	Current state-level renewable portfolio standards (RPS) are modeled. City- and utility-level goals were assumed to be supportive of these state-level targets and additional only in cases where a higher percentage is targeted. These were implemented by setting a minimum % of total electricity load to be met by renewable generation.	RPS targets of at least 60% by 2030 for high ambition states and 50% for moderate ambition states are assumed. City- and utility-level goals were assumed to be supportive of these state-level targets and additional only in cases where a higher percentage is targeted. These were implemented by setting a minimum % of total electricity load to be met by renewable generation.
Nuclear	Federal and non-federal incentives	**IRA's PTC for existing nuclear (section 13015)** is modeled as a $15/MWh subsidy for nuclear technologies through 2030, with the simplifying assumption that all projects pay prevailing wages. We assume that these incentives, in combination with non-federal incentives and zero-emission credits, prevent the economic retirement of nuclear plants. As such, we model Georgia Vogtle units 3&4 coming online by 2025, and maintain nuclear capacity at today's levels.	

Coal	Federal incentives	**IRA's energy community reinvestment financing (section 50144)** is modeled as $250 billion in loans and guarantees used to accelerate the retirement of coal-fired power generation and fund the construction of renewable electricity-generating capacity. We estimate this to accelerate the retirement of 38 GW of additional coal-fired capacity beyond already-scheduled retirements by 2030.	Coal is phased out by 2030 due to a combination of market forces, state coal-exit policies, and regulatory compliance costs.This was modeled by setting a national constraint on coal power to reach zero by 2030, and by prohibiting the buildout of new coal plants in all states.
	Federal and non-federal regulations	No additional policies were explicitly modeled in this scenario beyond the scheduled retirements of existing coal plants.	
CCS	Federal incentives	**IRA's extension of credits for captured CO2 (section 13104 - 45Q)** at $85/ton is implemented through 2030. We assume this subsidy will result in sequestration levels consistent with analyses by Rhodium Group and Edmonds et al.[8,9] We modeled this exogenously by specifying sequestration across various industrial sectors, resulting in 130 $MTCO_2$ and 140 $MTCO_2$ annual sequestration in Existing Policies and Beyond 50, respectively,	
Gas	Federal standards	No policies were explicitly modeled in this scenario.	New federal standards require at least 90% CCS for any new baseload natural gas builds in all states. We modeled this by prohibiting natural gas plants without CCS starting in 2025. Retention and investment in low capacity factor peaking plants were assumed to be supportive of these measures and were not explicitly modeled.

Supplementary Table 3. GCAM Implementation of Policy Assumptions in the Transportation Sector

<table>
<tr><th colspan="2">Modeled Policy</th><th>Existing Policies Scenario</th><th>Beyond 50 Scenario</th></tr>
<tr><td>LDV Combustion Engine Performance</td><td>Federal standards</td><td>Internal combustion engine GHG performance standards are modeled to reflect efficiency improvement rates from recently updated Corporate Average Fuel Economy standards so that nationally, fuel efficiency reaches 166 gCO_2/mi for new passenger cars and 219 gCO_2/mi for new SUVs by 2030. Note: these are based on the NHTSA minimum standard and are not inclusive of ZEVs.</td><td>Federal internal combustion engine GHG performance standards are improved so that nationally, fuel efficiency reaches 143 gCO_2/mi for new passenger cars and 193 gCO_2/mi for new SUVs by 2030.</td></tr>
<tr><td rowspan="3">Passenger Vehicle Electrification</td><td rowspan="3">Federal EV incentives</td><td colspan="2">IIJA's $10.7 billion investment in LDV EV charging infrastructure is implemented as an $802 reduction in per vehicle charging infrastructure cost, based on modeled vehicle fleet size in GCAM-USA-AP.</td></tr>
<tr><td colspan="2">IRA's clean vehicle credit (section 13401) has a maximum value of $7,500 with an EV being eligible for half of the credit if its battery meets domestic assembly requirements and other half of the credit is contingent upon a specific share of the minerals used in the battery being sourced for North American or other free trade countries. We assume that the US auto manufacturing sector will reorient itself so that all new EVs produced by 2030 will meet these requirements, and that by 2025, half of EVs sold will meet these requirements. If the car meets the battery assembly and mineral sourcing requirements, a consumer can receive the full value of the tax credit provided that their income does not exceed the income eligibility threshold and that the sales price of the car does not exceed MSRP eligibility thresholds. We find that 89% of Americans meet the income requirement and further assume that they would only purchase EVs that meet the MSRP threshold. Altogether, this yields an EV tax credit with an effective value of $6,673, implemented as a capital cost reduction.</td></tr>
<tr><td colspan="2">IRA's alternative refueling property credit (section 13404) is assumed to be a $1,000 property credit available for LDV charging infrastructure for individuals in rural and low-income census tracts. Based on census data, 17.4% of Americans live in counties that are either rural or low-income, so the $1,000 property credit is modeled as a weighted average national subsidy of $174 for capital infrastructure cost for EVs.</td></tr>
</table>

	Non-federal mandates and targets	California and New York achieve their passenger car sales target of 68% electric in 2030 (on track to 100% in 2035), along with 18 other states that have already implemented less ambitious sales targets.	We assume that leading states achieve EV sales shares equivalent to targets set by California. In addition to leading states achieving EV sales shares consistent with California's, we assume that the remaining states achieve these sales shares, but on a delayed schedule, 2 to 4 years later than leading states.
	Non-federal incentives	Major existing incentives for LDV ZEVs at the state-, utility-, and district-level from the Alternative Fuels Data Center are modeled at the state-level as reductions in per vehicle capital cost. Altogether, these are equivalent to a national average capital cost reduction for LDV EVs of $826 per vehicle.	
Freight Truck Combustion Engine Performance	Federal standards	Internal combustion engine GHG performance how standards are modeled to reflect efficiency improvement rates from the proposed rules for more stringent GHG emissions standards for heavy duty gasoline- and diesel-powered engines.	The 2025-2030 improvement rate in the GHG performance standards is increased by 4-5% more than in the Existing Policies scenario.
Freight Truck Electrification	Federal incentives	**IIJA's $4.24 billion investment in medium- and heavy-duty truck EV charging infrastructure** is implemented as a $9,211 reduction in per vehicle charging infrastructure cost, based on fleet size in GCAM-USA-AP.	
		IRA's commercial clean vehicle credit (section 13404) is modeled as a $40,000 capital cost reduction for electric heavy duty freight trucks, and a $7,500 capital cost reduction for electric medium duty and light duty freight trucks.	
	Non-federal mandates and targets	California achieves its sales targets for electric trucks in 2030, along with the five other states that have already implemented similar targets.	All states adopt California's ZEV sales targets, achieving 50% electrification for medium-duty trucks and 30% for heavy-duty trucks by 2030. These policies were modeled by exogenously specifying the total service from ZEV to reach 12% of the total stock of medium-duty trucks and 9% of the total stock of heavy-duty trucks by 2030.
Bus Electrification	Federal and non-federal incentives and	**IIJA's $5 billion investment in school bus electrification** is implemented as a $25,000 reduction in per vehicle purchase cost. **A $2.625 billion investment in transit bus electrification** is	A combination of federal and non-federal investments and fleet procurement targets lead to 100% electrification of new bus sales in 2030.This was modeled by raising the national-level sales shares to reach 100% electric by 2030.

	procurement	implemented as a $29,167 reduction in per vehicle purchase cost.	
Biofuels	Federal incentives	**IRA's extension of incentives for biofuels (sections 13201-13203)** were implemented as subsidies for biodiesel, cellulosic ethanol, FT biofuels, cellulosic ethanol with CCS, and FT biofuels with CCS. We assume that jet fuel is the first market for FT biofuel, and FT biofuels therefore receive the aviation fuel credit.	
VMT Reductions	Federal investment and non-federal planning	No policies were explicitly modeled in this scenario	Federal investment, state and local planning lead to annual average per capita VMT reductions ranging from 0.5% to 1% in all states from 2025-2030 (consistent with current ambition in leading states). Annual average per capita VMT reductions were modeled as state-level service demand reduction rates in the transport sector.

Supplementary Table 4. GCAM Implementation of Policy Assumptions in the Buildings Sector

<table>
<tr><th colspan="2">Modeled Policy</th><th>Existing Policies Scenario</th><th>Beyond 50 Scenario</th></tr>
<tr><td rowspan="4">Efficiency</td><td>Non-federal energy efficiency standards</td><td>Current state-level energy efficiency resource standards (EERS) were modeled by reducing state-level building service demands. However, the energy savings yielded are insignificant at the national level.</td><td>Heightened EERS and building codes, in line with “high achievable” estimates from EPRI analysis[10] (values ranging from 0 to 2.7% annual savings depending on the state), were modeled by reducing state-level building service demands. This leads to national energy savings of 9.5% for residential buildings and 14.2% for commercial buildings by 2030.</td></tr>
<tr><td rowspan="3">Federal incentives</td><td colspan="2">IRA’s energy efficient commercial building deduction (section 13303) is estimated to reduce commercial HVAC costs by 3%. We modeled this provision as a 3% subsidy for commercial high-efficiency heating and cooling technologies in 2025 and 2030.</td></tr>
<tr><td colspan="2">IRA’s nonbusiness energy property credit (section 13301 – 25C), energy efficient home credit (section 13304), and home energy efficiency credit (section 50121) are modeled by improving shell efficiency in residential buildings based on the AEO 2022 “Alternative Policies – Extended Credit” case.[11]</td></tr>
<tr><td colspan="2">IRA’s high efficiency home rebate program (section 51022) is modeled as a subsidy to high-efficiency technologies in residential buildings in 2025 and 2030. We assume that two-thirds of consumers are eligible for this credit, so we implemented this as a weighted average across all consumers with the effective value of the credit modeled to be 66% of each of the following: $1,750 to electric heat pump water heaters, $4,000 to electric heat pumps for space heating, $420 to electric ovens, $420 to electric heat pump clothes dryers, $1,600 for high-efficiency air conditioning.</td></tr>
<tr><td>Electrification</td><td>Federal and non-federal incentives and regulations</td><td>No policies were explicitly modeled in this scenario</td><td>Combined federal and state buildings appliance standards, heat pump incentives, and bans on natural gas hookups drive appliance sales to 100% electric across all states in residential and commercial buildings by 2030. City stretch codes and corporate targets were assumed to be supportive of state-level electrification rates. These policies were modeled by raising state-level consumer preferences</td></tr>
</table>

			for electric appliances to achieve 61% electrification overall in the building sector by 2030.

Supplementary Table 5. GCAM Implementation of Policy Assumptions in Industry and Other Sectors

<table>
<tr><th colspan="2">Modeled Policy</th><th>Existing Policies Scenario</th><th>Beyond 50 Scenario</th></tr>
<tr><td colspan="2">CCS</td><td colspan="2">IRA's extension of credits for captured CO_2 (section 13104 – 45Q) at $85/ton is implemented through 2030. We assume this subsidy will result in sequestration levels consistent with Rhodium Group analysis.[12] We modeled this exogenously by specifying sequestration across various industrial sectors, resulting in 93 $MtCO_2$ and 89 $MtCO_2$ annual sequestration in Existing Policies and Beyond 50, respectively,</td></tr>
<tr><td rowspan="2">Hydrogen</td><td>Federal incentives</td><td colspan="2">IRA's production credit for clean hydrogen (section 13204) is modeled as different subsidies to hydrogen technologies depending on their carbon intensities. We assume that fossil hydrogen without CCS doesn't qualify and fossil hydrogen with CCS claims 45Q instead, and that 50% of projects pay prevailing wages.</td></tr>
<tr><td>Non-federal standards and procurement</td><td>No policies were explicitly modeled in this scenario</td><td>Hydrogen tax credits accelerate green hydrogen deployment and shift the fertilizer market toward green fertilizer. By 2030, fertilizer made from green hydrogen reaches 50% of market share.</td></tr>
<tr><td rowspan="2">Methane</td><td>Federal regulations</td><td>IRA's methane emissions reduction program (section 60113) has a fee of $1,500/$tCH_4$ ($60/$tCO_2e$) on fugitive methane, which was modeled to reduce 2.92 $MtCH_4$ (73 $MTCO_2e$) in the oil and gas sector, using the EPA's MAC curves for methane.[13] Because this fee only applies to sources covered under the EPA's GHG Reporting Program, we assume that only 39% of the emissions reductions are achieved,[14] resulting in a reduction of 1.14 $MtCH_4$ (28 $MtCO_2e$) by 2030.</td><td rowspan="2">We modeled an economy-wide methane fee of $1,500/$tCH_4$ ($60/$tCO_2e$), using the EPA's MAC curves for methane and the activity reduction drivers for oil & gas, coal, and waste as calculated in our previous report on methane emissions reduction potential in the U.S.,[15] we find this to deliver 9.07 $MtCH_4$ (227 $MtCO_2e$) in methane emissions reductions. This successfully achieves the U.S. methane target of 30% reductions below 2020 levels by 2030.</td></tr>
<tr><td>Federal investments</td><td>IRA's additional agricultural conservation investments (section 21001) allocates $8.5 billion to Environmental Quality Incentives Program, in which distribution of funds is prioritized for reducing enteric methane emissions from ruminants. This was modeled as a 0.63 $MtCH_4$ (16 $MtCO_2e$) reduction in livestock methane emissions in 2030.</td></tr>
</table>

Other non-CO_2	HFCs	National HFC phasedown is implemented consistent with the AIM Act, reducing emissions up to 40% from baseline trajectory by 2030 (consistent with analysis and modeling results developed by CARB)[16].	National HFC phasedown is implemented consistent with the AIM Act. Leading cohort of states achieves additional reductions through more comprehensive measures including SNAP and RMP programs, reducing emissions up to 65% from baseline trajectory by 2030 (consistent with analysis and modeling results developed by CARB)[12].
	N2O	No policies were explicitly modeled in this scenario.	
Cement	Federal standards	No policies were explicitly modeled in this scenario.	Industry makes rapid progress switching away from coal and petcoke, incorporating higher shares of supplementary cementitious materials, and meeting demand using lower-GHG mixes. Federal "Buy Clean" programs reduce cement emissions by 22% by 2030, consistent with analyses from EFI, McKinsey and IEA.[17,18,19] State-, city- and corporate-level policies were assumed to be supportive of federal policies.
LULUCF		With funding for voluntary conservation programs, forest management, and ecosystem restoration from IIJA and IRA, we assume the 2030 sequestration potential is retained at -812 $MtCO_2e$.	Combined reforestation, forest restocking, soil carbon, and other natural and working lands strategies allow for significant improvement in carbon sequestration levels by 2030, consistent with state-level sequestration potential estimates from Nature 4 Climate, derived in part from Fargione et al. (2018).[20,21] 2030 sequestration levels of \$10-\$50/ton CO_2 were implemented by state, based on historic and current state ambition. Impacts were aggregated together, yielding total national 2030 LULUCF emissions of -950 $MtCO_2e$ (up from present-day baseline derived from EPA Greenhouse Gas Inventory).[22]

Economy-wide GHG Targets	The achievement of economy-wide GHG targets for the leading cohort of states was implicitly assumed. Since these targets were generally found to be met or exceeded through the achievement of sector-specific policies elsewhere in this table, they were not modeled directly, with the exception of California.

Bottom-up aggregation of non-federal climate actions

This analysis relies on a previously developed methodology for aggregating the impact of non-federal climate actions across state, city, and business actors. Impacts are quantified sector-by-sector and across each actor group, and aggregated to the state level, accounting for overlaps, before then being integrated with GCAM-USA-AP for simulation of full economy-wide impacts. A brief summary of the methodology is given below, followed by a table of key policies evaluated and underlying data sources (Supplementary Table 3). For a more detailed description of the aggregation and overall modeling methodology, please see the Accelerating America's Pledge Technical Appendix (2019)[23] and Hultman, et al. *Nature Communications* paper (2020) and accompanying supplementary information.[24]

The approach synthesizes current policies and commitments at multiple scales as well as the potential for accelerated and expanded policies. Non-federal entities implement emissions-related policies for many reasons, including cost savings, consumer benefits, health, economic growth, and climate. For simplicity, in this analysis we refer to any policy that reduces GHG emissions as a climate policy and overall categories of actions as policy sectors. The approach to quantifying the impact of city, state, and business actions was informed by existing protocols and methodologies such as the Non-State and Subnational Action Guide developed through the Initiative for Climate Action Transparency[25], the Compact of Mayors Emission Scenario Model[26], and the Greenhouse Gas Protocol Policy and Action Standard[27], among others.

Overall, the bottom-up aggregation process can be summarized as follows:

1. Survey, at a minimum, all 50 states and the 285 most populous cities in the U.S.
2. Identify a subset of high-impact actions for inclusion in the analysis
3. Collect the necessary data to quantify each action
4. Estimate a reference "no policy" scenario for each actor and emissions sector through 2030
5. Calculate combined impacts for each actor level (e.g., cities and states) for a "current measures" scenario reflecting only on-the-books actions
6. Calculate combined impacts for each actor level (e.g., cities and states) for "enhanced" scenarios that assume additional policy ambition beyond present-day levels
7. Aggregate impacts within each sector to the state level, taking into account overlaps.
8. Pass the information to GCAM-USA-AP.

From that point, the larger model will use the bottom-up and federal policy information to assess overall outcomes in terms of emissions plus many other activities within the U.S. economy, across all sectors and gases.

Supplementary Table 6. Summary table of transportation sector climate policies and actions included in aggregation analysis and key data sources

Policy Sector	Key climate policies/actions evaluated	Key underlying data sources
Vehicle electrification	State-level ZEV mandates; city-level fleet procurement targets; state, city, utility, and district EV rebates, tax credits and exemptions, vehicle fee exemptions, additional fees, scrappage incentives, and bill credits	AFDC[28]; CARB[29,30,31,32]; EIA[,33,34]; EV HUB[35]; FHWA[36]; NREL[37,38]; EV HUB[39]
Vehicle fuel economy/tailpipe emissions standards	State-level vehicle emissions standards	CARB[40]; EDF[41]; ICCT[42]
Vehicle miles traveled (VMT) reduction	State-level VMT reduction targets; city-level VMT reduction targets	ACEEE[43]; FHWA[44]; DOE/NREL[45]
Renewable electricity generation	State-level renewable portfolio standards and clean electricity standards; city-level renewable electricity targets; utility-level renewable electricity/emissions reduction targets	ACEEE[46], LBL[47]; EIA[48]; Sierra Club[49]; DOE/NREL[50]
Oil and gas methane abatement	State-level regulations covering new and existing facilities; business-level reductions reported through EPA Natural Gas STAR	EDF[51]; EPA[52]
Nuclear fleet retention	State-level zero-emission generation incentives and other nuclear fleet retention measures	EIA[53]; UCS[54]
HFC phasedown	State-level SNAP and RMP policies; business-level reductions reported through EPA GreenChill program	EPA[55]; CARB[56]; WRI[57]
Energy efficiency	State-level EERS policies; State-level building code adoption; city-level energy savings targets; city-level building code adoption; industry energy management standards	ACEEE[58,59]; EIA[60,61]

Core Assumptions

The results of this study depend on many assumptions about how the U.S. and the world might evolve in the future. This study uses a set of core assumptions for drivers including economic growth, population growth, fossil fuel prices, and EV sales (Supplementary Table 6). Our core assumptions draw from a set of data sources that are referenced in the report and other parts of this technical appendix, for example EIA's *Annual Energy Outlook*[62] and Rhodium Group[63]. Economic impacts associated with COVID-19 in 2020 and subsequent recovery in the following years have also been incorporated into these assumptions.

Supplementary Table 6. Core Assumptions for GCAM-USA-AP Analysis

Drivers	**Scenario assumptions**
Economic Growth	Overall GDP decreases by 3.5% year-on-year in 2020, then increases by 2.2% per year through 2030.
Population Growth	Population grows by 0.65% per year through 2030.
Fuel Prices	Gas price is assumed to drop by 19.5% year-on-year in 2020, increase by 89% in 2021, then decrease at an average rate of 6.4% per year through 2026. From 2027 to 2030, prices increase by 4.2% per year on average. Oil price is assumed to drop by 33.9% year-on-year in 2020, increase by 78.4% in 2021, then decrease at an average rate of 7.9% per year through 2023. From 2024 to 2030, prices increase by 2.8% per year on average.
Transportation Energy Demand	Transport sector energy demand is assumed to decrease by 14.7% from 2015 levels in 2020, with recovery through 2030.
Industry Energy Demand	Industry sector energy demand is assumed to decrease by 4.1% from 2015 levels in 2020, with recovery through 2030.
Buildings Energy Demand	Buildings sector energy demand is assumed to decrease by 1.7% from 2015 levels in 2020, with recovery through 2030.
Technology Costs	Technology costs are updated with NREL Annual Technology Baseline 2020 assumptions. Solar and wind base technology costs decrease by 49% and 42% from 2015 levels by 2030, respectively.

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