
Drawdown Georgia: Identifying the Most Promising Drawdown Solutions for Georgia

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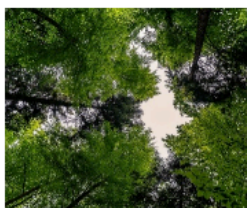
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ABSTRACT

The Drawdown Georgia project aims to identify the most promising solutions to significantly reduce Georgia's carbon footprint by 2030 while providing economic development opportunities and other benefits. Our approach involves (1) understanding Georgia's baseline carbon footprint and trends, (2) identifying the most impactful Georgia-specific carbon-reduction solutions based on the global framework of Project Drawdown®, (3) estimating the greenhouse gas (GHG) reduction potential of these high-impact 2030 solutions for Georgia, and (4) highlighting costs and benefits of these solutions, including how they impact societal priorities beyond carbon. These high-impact 2030 solutions provide a strategy for reducing the state's carbon footprint in the next decade using market-ready technologies and practices. Ultimately, we hope to inspire a transformational vision that will motivate households, businesses, neighborhoods, municipalities, and leaders across the state to take advantage of opportunities that exist today and in the near future to reduce their carbon footprints.

Drawdown Georgia



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1 Introduction to Drawdown Georgia

Climate change poses significant risks to communities, businesses, and ecosystems in Georgia. Most notable is the triad of (1) warming temperatures and heat waves, (2) flooding, storms, and sea-level rise, and (3) droughts and forest fires. Georgia's climate is already changing, and these impacts are currently being experienced across the state.

Warming Temperatures and Heat Waves:

- For the State of Georgia as a whole, 2019 was the warmest year on record since observations began in 1895.¹ In 2019, the Atlanta metro area experienced 91 days with temperatures above 90 degrees F, far above the average of 37 days in a single year and exceeding the previous record set in 1980.²
- According to Congressional Testimony by Atlanta Mayor Keisha Lance Bottoms, "More than 310,000 Georgia residents are vulnerable to extreme heat, which is deadlier than any other weather-related hazard.... By 2050, the average summer high temperature in Atlanta is projected to jump 4.1 degrees to 92.6 degrees F."³
- In 2017, Georgia lost roughly 80% of its peach crop because winter temperatures were too warm, and the peaches had too few "chill hours".⁴ Similarly, for several years, blueberry farmers have taken big hits because warmer winters have led to early blooms that then left their berries more susceptible to frost.⁵

Flooding, Storms, and Sea-Level Rise:

- On Georgia's coast, sea levels are 8 to 10 inches higher now than they were 80 years ago.⁶
- "Sunny day flooding" on the coast is now a regular occurrence. In recent years, this flooding has often cut off Highway 80, the only road that connects Tybee Island to the rest of Georgia. As a result, the Georgia Department of Transportation is planning to raise portions of the road by up to 8 inches, for a total estimated cost of \$100 million.⁷
- Increasingly severe storms have had a devastating impact on Georgia's farms. Hurricane Michael is estimated to have caused \$2.5 billion in losses for the state's agriculture industry, including major damage to cotton, pecans, and timber.⁸

¹ <https://www.noaa.gov/news/2019-was-2nd-wettest-year-on-record-for-us>

² <https://www.11alive.com/article/weather/atlanta-record-temperatures-record-time/85-9f72a8c4-4b4a-46d8-a24d-0e0a9cd1c32b>

³ <https://www.democrats.senate.gov/imo/media/doc/Atlanta%20Testimony%2007.17.19.pdf>

⁴ <http://www.georgiacrop.com/georgia-farmers-enjoying-improved-peach-crop>

⁵ <https://www.bizjournals.com/atlanta/news/2018/05/16/hard-pill-to-swallow-georgia-blueberry-crop-sees.html>

⁶ <https://toolkit.climate.gov/image/2450>

⁷ <https://www.savannahnow.com/news/20190406/low-lying-and-narrow-us-80-awaits-improvements>

⁸ <https://www.nytimes.com/2018/10/19/us/hurricane-michael-cotton-agriculture-climate-change.html>

- The National Weather Service reported that the Atlanta Flood of 2009, likely a 500-year scale event, resulted in \$500 million in damages and the loss of 10 lives.⁹

Droughts and Forest Fires:

- A 2007 drought in Georgia caused an estimated \$787 million in agricultural production losses (Flanders et al., 2007).
- The 2007 droughts contributed to historic wildfires in the state that year. Wildfires burned for more than two months and destroyed \$65 million in timber.¹⁰
- Drought conditions in Georgia are expected to continue to have disproportionate effects on society because of increased population and water usage (Campana et al., 2012).

Climate disasters in the Southeast surpass other regions of the United States annually in magnitude and scale by a ratio of approximately 4:1 in recent decades (Comou and Rahmsdorf, 2012; Emrich and Cutter, 2011). The entire region, including Georgia, is impacted by these trends. However, they pose heightened challenges to the state's most vulnerable populations (Binita et al., 2015). This includes people at risk due to their locations, available services, and economic situations (NCA, 2018). As noted by the Intergovernmental Panel on Climate Change (IPCC) (2014), extreme weather events have exposed many communities to hardships, but impacts tend to be greater and more long-lasting in environmental justice (EJ) communities. EJ communities tend to have increased sensitivity to climate impacts and reduced adaptive capacity—the ability to respond to adverse circumstances. Addressing these vulnerabilities will require strategic climate adaptation and resilience investments across Georgia.

Strategies to address warming temperatures and heat waves might include more pervasive and efficient home air conditioning systems, strategically located cooling centers, more urban trees and green spaces, cool roofs, and shifting planting and harvesting schedules (Zhou and Shepherd, 2010; Berisha et al., 2017; Hondula et al., 2018). Common strategies to address flooding, storms, and sea-level rise include limiting development in low-lying coastal, wetland, and flood-plain areas to reduce climate risks, as well as protective measures such as restoring or planting mangroves in coastal embankment areas to reduce damage from storm surges, improving environmental monitoring, weather prediction, and early warning systems for floods and other natural disasters (Rosenzweig et al., 2018). Strategies to address droughts and forest fires could include shifting to more drought-resilient crops, enhancing water conservation,

⁹ https://www.weather.gov/ffc/atlanta_floods_anniv

¹⁰ Georgia Forestry Commission (2008) Georgia's *Historic* 2007 Wildfires. Georgia Forestry Commission, Dry Branch, GA. Website: <http://www.gfc.state.ga.us/resources/publications/Historic%202007%20GA%20Wildfires.pdf>

stormwater capture, and long-term storage, expanding smart irrigation, and investing in forest fire protection (Brown and Sovacool, 2014; NCA, 2018).

Researchers are documenting these trends and continuing to learn about what a changing climate means for Georgia. For example, Rudd et al. (2018) assessed the key climate-related research priorities in the state for practitioners, stakeholders, and scientists. This includes research priorities about climate-related impacts, mitigation opportunities, and pathways for adaptation. Looking ahead, additional and stronger climate impacts are forecast (NCA, 2018).¹¹ For instance, the southeastern U.S. can expect new and more virulent diseases associated with extreme heat and humidity. In addition, scientists anticipate more frequent and intense droughts in coming decades as well as more flooding and stronger hurricanes.¹²

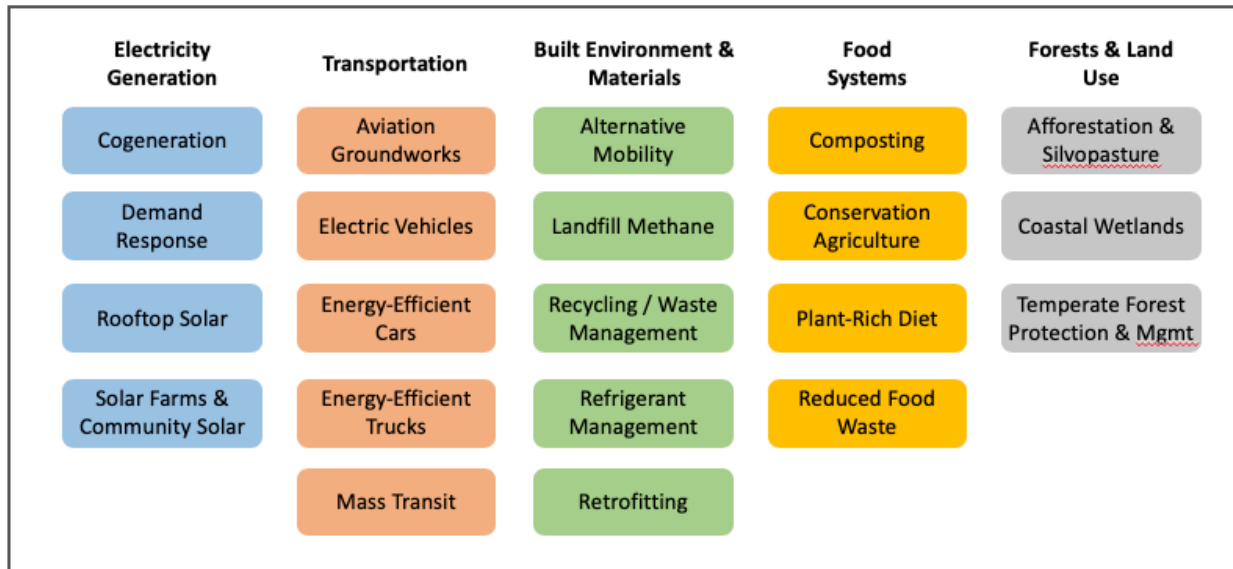
In order to stave off the worst impacts from climate change, the global community of scientists represented by the IPCC has concluded that significant reductions of greenhouse gas (GHG) emissions are needed (IPCC, 2018). Many of the most detailed analyses highlighting pathways for achieving these reductions are at a global or national scale. One of these global frameworks is Project Drawdown® (Hawken, 2017). Recognizing that there is also much work to be done at the sub-national level, it is useful to ask how these global frameworks might enrich state and local efforts. Motivated by this goal, Drawdown Georgia was initiated in 2019 to systematically examine the global framework of Project Drawdown® with the aim of revealing the most promising opportunities to reduce net emissions in the state of Georgia, while providing economic development opportunities. Net emissions refer to the difference between the release of carbon dioxide (CO₂) from fossil fuels and other “sources,” and the sequestration of CO₂ by forests, soils, and other “sinks”.

We begin this working paper by describing the Project Drawdown® framework that is the point of departure for Drawdown Georgia. Our approach involves understanding Georgia’s baseline carbon footprint and trends, assessing the global solutions identified by Project Drawdown® to identify high-impact 2030 solutions for Georgia, and examining that subset to estimate their carbon reduction potential in Georgia, as well as their costs and benefits, including how they impact societal priorities beyond carbon. These solutions provide an evidence-based pathway for reducing the state’s carbon footprint in the next decade using market-ready technologies and practices. The 21 high-impact 2030 solutions that were down-selected for Georgia are shown in Figure 1.1, and are discussed in more detail throughout this paper.

¹¹ <https://nca2018.globalchange.gov/>

¹² <https://www.nap.edu/catalog/21852/attribution-of-extreme-weather-events-in-the-context-of-climate-change>

Figure 1.1 Drawdown Georgia's 21 High-Impact 2030 Solutions



2 The Drawdown Georgia Approach

Many different approaches have been used to identify strategies for reducing net GHG emissions. Signatories to the 2015 Paris Agreement committed to limiting global temperature rise to 1.5°C-2°C above pre-industrial levels. As part of the Paris Agreement, the IPCC was invited to analyze pathways for limiting global temperature rise to 1.5°C. The IPCC released its analysis in 2018. The analysis considered a range of modeling scenarios that highlight the need to cut emissions in all sectors of the economy, including land, energy, industry, buildings, transportation, and cities. This includes significant near-term emission cuts, culminating in global, net-zero GHG emissions by midcentury (IPCC, 2018).

Other groups, such as Princeton University, have also analyzed pathways for reducing global GHG emissions. Princeton's Stabilization Wedge Framework¹³ considers how deploying a portfolio of existing technologies can collectively keep global emissions from rising while meeting projected growth in global energy demand (Socolow and Pacala, 2006). The effort highlights 15 strategies that each have the potential to reduce global carbon emissions by at least 1 billion tons per year by 2060. This includes strategies such as doubling fuel efficiency of 2 billion cars from 30 to 60 mpg or installing 100 times the current capacity of solar electricity. A combination of strategies is needed to achieve the stabilization goal.

We take as our point of departure, the Project Drawdown's® global framework for reducing net global GHG emissions (Hawken, 2017).

¹³ <https://cmi.princeton.edu/wedges>

2.1 Point of Departure: Project Drawdown®

Project Drawdown® was founded in 2014 to measure and model promising emission reduction solutions. It highlights global solutions that could be deployed to achieve “drawdown,” or the point when the concentration of GHGs in the atmosphere start to decline. This includes solutions across the economy and across the globe, highlighting numerous solutions such as retrofitting buildings, increasing solar power, and deploying electric vehicle. Project Drawdown® also looked well beyond these “traditional” engineering solutions and highlighted social-ecological-technological opportunities such as educating women and girls, plant-rich diets, and reducing food waste that have not been part of the traditional IPCC carbon mitigation measures (Table 2.1).

Project Drawdown® is a useful global framework that provides a playbook of valuable solutions, a suite of analytical approaches, and much more. Nonetheless, when applied to the particularities of a specific country, state, city or community much additional work is required. The global perspective must be tailored to meet the needs, resources, economies, and capabilities of specific localities and their potentially different priorities and preferences. As one key example, Project Drawdown® rank-ordered solutions based on their ability to impact global GHG emissions by 2050. In the case of Drawdown Georgia, the focus is on one state and the timeframe is one decade.

Table 2.1 Project Drawdown’s® 102 Solutions, by Sector

ELECTRICITY GENERATION	BUILT ENVIRONMENT & MATERIALS	FOOD SYSTEMS
Artificial Leaf*	Alternative Cement	Biochar
Biomass	Bike Infrastructure	Clean Cookstoves*
Cogeneration	Bioplastic	Composting
Concentrated Solar	Building Automation	Conservation Agriculture
Energy Storage (Distributed)	Building with Wood	Farming Irrigation
Energy Storage (Utilities)	Direct Air Capture	Farmland Restoration
Geothermal	District Heating	Improved Rice Cultivation*
Grid Flexibility	Enhanced Weathering of Minerals	Ocean Farming*
Hydrogen-Boron Fusion*	Green Roofs	Managed Grazing
In-Stream Hydro	Heat Pumps	Marine Permaculture*
Methane Digesters (Large)	Household Recycling	Multistrata Agroforestry*
Methane Digesters (Small)	Industrial Hemp	Nutrient Management
Micro Wind	Industrial Recycling	Pasture Cropping*
Microgrids	Insulation	Perennial Crops*
Nuclear	Landfill Methane	Plant-Rich Diet
Rooftop Solar	LED Lighting (commercial)	Reduced Food Waste
Smart Grids	LED Lighting (household)	Regenerative Agriculture
Smart Highways*	Living Buildings	Silvopasture
Solar Farms	Net Zero Buildings	System of Rice Intensification*
Solar Water	Recycled Paper	Tree Intercropping
Solid-State Wave Energy*	Refrigerant Management	Tropical Staple Trees*
Waste-to-Energy	Retrofitting	
Wave and Tidal	Smart Glass	
Wind Turbines (Offshore)	Smart Thermostats	
Wind Turbines (Onshore)	Walkable Cities	

	Water Distribution Water Saving	
TRANSPORTATION	FORESTRY AND LAND USE	Women and Girls
Airplanes Autonomous Vehicles Cars Electric Bikes Electric Vehicles High-Speed Rail Hyperloop* Mass Transit Ridesharing Ships Telepresence Trains Trucks	A Cow Walks onto a Beach* Afforestation Bamboo Coastal Wetlands Forest Protection Indigenous Peoples' Land Mgmt Intensive Silvopasture Microbial Farming* Peatlands Perennial Biomass Repopulating the Mammoth Step* Temperate Forests Tropical Forests	Educating Girls Family Planning Women Smallholders

* Judged to be out-of-scope for Drawdown Georgia without additional analysis.

2.2 Overview of the Drawdown Georgia Approach

For Drawdown Georgia, we developed a methodology to systematically assess the global solutions identified by Project Drawdown® and highlight the most promising opportunities to reduce net carbon emissions in the state of Georgia over the next decade. We began our translation of Project Drawdown® lessons to the state of Georgia by examining the baseline of Georgia's consumption of fossil fuels, the energy requirements of its end-use sectors, and its GHG emissions. We also conducted a series of surveys to elicit the preferences of the public and experts. We then developed and applied the systematic approach to examine the Project Drawdown® solutions to identify a curated set of solutions that capture the most promising opportunities to reduce net carbon emissions over the next decade in Georgia while providing valuable "beyond carbon" benefits such as economic development opportunities, health and environmental benefits, and reduced inequities. Each of these steps is described below, followed by an overview of our conclusions and a description of next steps.

3 Baseline Analysis of Georgia's Energy Economy and GHG Emissions and Sinks

This section summarizes Georgia's energy economy and GHG emissions and sinks based on existing data sources. Sankey diagrams are used here to link sources of energy and GHG emissions and sinks, to the end-use sectors and economic activities that consume energy and are responsible for the emissions and sinks. In addition, we have produced preliminary baseline forecasts for Georgia in 2030 covering a majority of the state's energy and GHG emissions. The baseline forecast is the product of projections from Georgia Tech's National Energy Modeling System (GT-NEMS) and forecasts of the U.S. Environmental Protection Agency's (EPA) SIPS tool and other models. More detail about those forecasts will be included in the next phase of analysis.

3.1 Georgia's Energy Economy

We focus particular attention on Georgia's energy economy because the combustion of fossil fuels is the largest source of the state's CO₂ emissions, and CO₂ emissions account for approximately 82% of GHG emissions in the United States. All four sectors of Georgia's economy are major consumers of energy and emitters of CO₂—transportation, homes, businesses, and industry. Over the next decade, the greatest growth in CO₂ emissions is forecast to come from transportation and industry, and the greatest reductions are expected to come from the electricity sector as coal plants are retired.

Georgia's total energy consumption in 2017 is estimated to be 2.80 quads (including interstate flows of electricity). This represents 2.9% of U.S. consumption (97.6 quads) in 2017.

Table 3.1 The U.S. and Georgia Energy Economy in 2017*

	U.S. Non-Renewable Energy Expenditures in 2017 (billion \$2017)	Georgia Non-Renewable Energy Expenditures (billion \$2017)
Industrial	\$190 (1.05%)	\$4.43 (0.87%)
Commercial	\$184 (1.02%)	\$5.51 (1.08%)
Residential	\$246 (1.36%)	\$8.62 (1.69%)
Transportation	\$514 (2.85%)	\$15.46 (3.03%)
TOTAL EXPENDITURES	\$1,136 (6.29%)	\$34.01 (6.68%)
Gross Domestic Product	\$18,050	\$509.4

Source: EIA, State Energy Data System (SEDS): 1960-2017 EIA, <https://www.eia.gov/state/seds/seds-data-complete.php?sid=US#PricesExpenditures> (Tables E9-E13 State Expenditure Estimates, 2017, Georgia; Tables ET2-ET6 Federal Expenditure Estimates, 2017, United States)

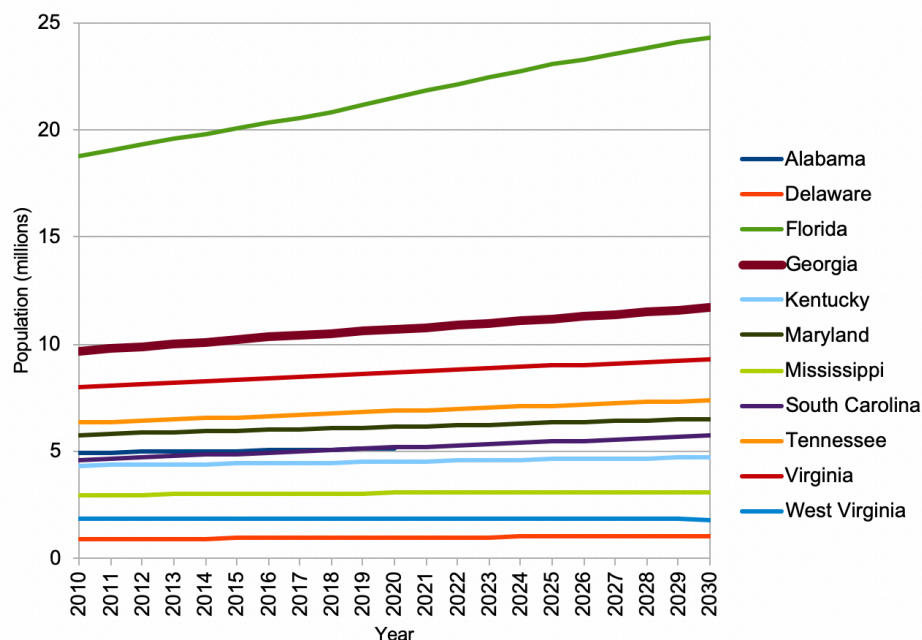
In 2017, the U.S. population was 325.7 million and the population of Georgia was 10.6 million.¹⁴ By 2030, the U.S. population is forecast to grow to 335.1 million,¹⁵ at a compound average annual growth rate (CAGR) of 0.67%. Georgia is forecast to grow at a slightly higher rate (0.77%) to a population of 11.7 million in 2030.¹⁶ Among the states in the Southeast, Georgia is second only to Florida both in size and rate of growth of its population (Figure 3.1).

¹⁴ <https://www.census.gov/quickfacts/GA>

¹⁵ <https://www.census.gov/content/dam/Census/library/publications/2020/demo/p25-1144.pdf>

¹⁶ Georgia Governor's Office of Planning and Budget, 2019; <https://opb.georgia.gov/document/document/state-residential-projections-2018-2063/download>

Figure 3.1. Population Trends of States in the South Atlantic Census Division



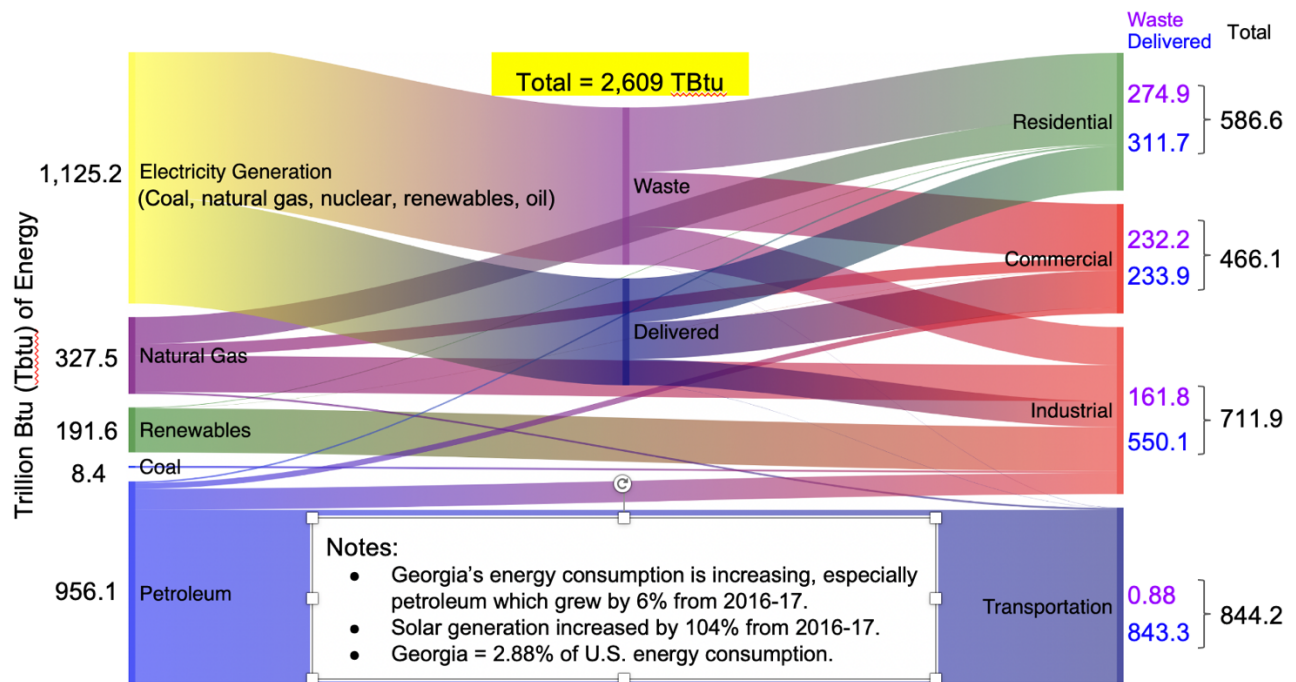
Non-renewable energy expenditures in Georgia in 2017 totaled an estimated \$34.0 billion, accounting for 6.7% of the Georgia's gross state product (GSP) of \$509.4 billion (Table 3.2). They represented 3.0% of U.S. energy costs, indicating that Georgia spends about 1% more per quad of energy than the average U.S. state. Georgia's GSP accounts for 2.8% of U.S. GDP, indicating that the state's economy is slightly more energy-intensive than the U.S. economy.

3.2 Baseline of GHG Emissions and Sinks in Georgia

Georgia's energy consumption in 2017 was 2,609 Trillion Btu, or 2.88% of U.S. energy consumption. As Figure 3.2 illustrates, the vast majority of this energy budget was fossil fuels. Transportation is the largest consumer of energy in Georgia, followed by industry, homes, and businesses. This is the same rank order of energy use in the U.S. as a whole.

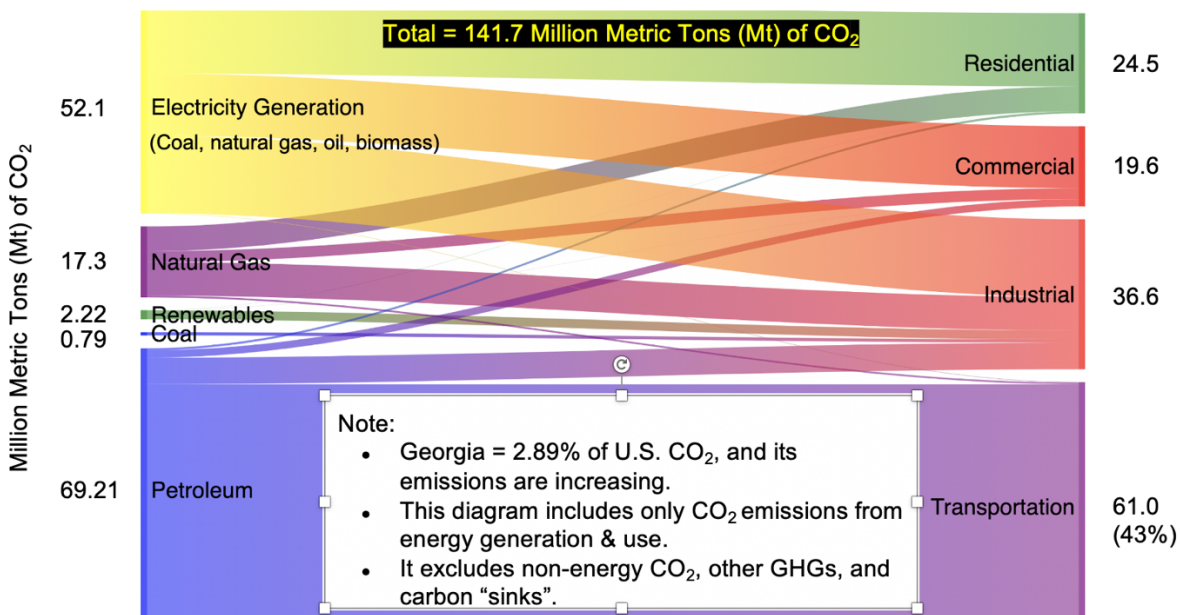
CO₂ emissions from fossil fuel combustion in 2017 was 141.7 Mt CO₂ (Figure 3.3). This reduces to approximately 130 Mt CO₂ when the net exports from interstate flows are omitted. Georgia's CO₂ emissions represent approximately 2.6-2.89% of U.S. CO₂ emissions from fossil fuels (4,912 Mt CO₂), depending on whether or not net exports are omitted.

Figure 3.2. Georgia's Energy Consumption in 2017



Data source: SEDS <https://www.eia.gov/state/seds/seds-data-complete.php?sid=GA#Consumption>

Figure 3.3. Georgia's CO₂ Emissions from Energy Consumption in 2017



Data sources: GT-NEMS and

https://epd.georgia.gov/air/sites/epd.georgia.gov/air/files/related_files/document/ghg_inventory2012.pdf

The EPA estimates that total CO₂ emissions in Georgia in 2017 were approximately 72.4 Mt CO₂ from non-petroleum fuels and 69.2 Mt CO₂ from petroleum. Of these emissions, 80.7 Mt CO₂ came from end users in the residential, business, and industry sectors and 61 Mt came from the transportation sector. The electricity sector is one of the largest emitters of GHGs: in addition to being the source of about 52 Mt CO₂ in 2017, it also was responsible for 47,604 tonnes of SO₂, and 41,504 tonnes of NO_x.

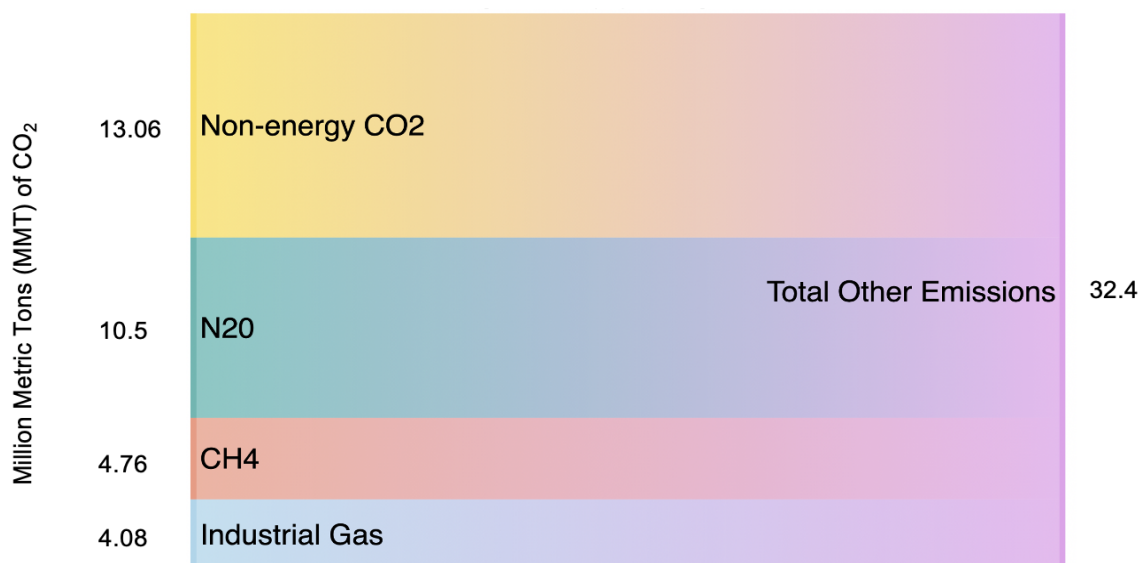
There are additional non-energy sources of CO₂ emissions in Georgia, which the EPA estimates totaled 13.06 Mt CO₂ (Figure 3.4) in 2017. One of the largest of these non-energy sources of CO₂ is cement. The Portland Cement Association estimates that roughly 1.8 Mt CO₂ was emitted by Georgia's cement industry in 2015. Adding together the energy- and non-energy sources of CO₂ brings Georgia's carbon footprint to 154.8 MT CO₂.

Negative emissions of CO₂ (often called "carbon sinks") are a function of Georgia's land use change and forestry (LUCF), including the uptake of CO₂ in forests and agricultural soils and emissions from wood biomass, bio-ethanol, and bio-diesel consumption. The World Resources Institute (WRI, 2011) estimates annual sequestration of roughly 46 Mt CO₂ in Georgia in 2011. That is equivalent to about 32% of Georgia's CO₂ emissions from fossil fuels in 2017. Assuming that this value holds true in 2017, Georgia's net carbon footprint would have been 108.8 Mt CO₂ in 2017.

In addition to CO₂, there are several other sources of GHGs. EPA's 2017 national GHG emissions inventory (EPA-2)¹⁷ estimated that Georgia emitted 174.1 Mt CO₂-e, of which 6% was NO_x, 2.7% was methane, and 2.3% was from fluorinated gas. Altogether, the three non-CO₂ sources of GHG emissions contributed an estimated 19.3 Mt CO₂-e or 11% of Georgia's total GHG emissions. The remaining 89% of Georgia's total emissions are from CO₂. This is a higher percentage of CO₂ than the U.S. as a whole. CO₂ represents 82% of U.S. GHG emissions. EPA's 2017 national GHG emissions inventory (EPA-2) estimated that the U.S. emitted 6,457 Mt CO₂-e in 2017, of which 5,270 (82%) was CO₂, 10% was methane, 6% was from NO_x, and 3% from fluorinated gas, totaling 18% of non-CO₂ GHGs.

¹⁷ <https://www.epa.gov/ghgemissions/overview-greenhouse-gases>

Figure 3.4. Georgia's Non-Energy CO₂ and Other GHG, in 2017



Sources:

https://epd.georgia.gov/air/sites/epd.georgia.gov.air/files/related_files/document/ghg_inventory2012.pdf

https://www.epa.gov/sites/production/files/2019-04/documents/2019_fast_facts_508_0.pdf

4 Survey of the Public and Experts

From the beginning, Drawdown Georgia has engaged with the expert community and interested members of the public to enable a broad communications pipeline. Via in-person and virtual collaboration, this process has helped to ensure that key issues are not overlooked.

The Drawdown Georgia team set the tone for this collaboration early in the research effort by hosting an Introduction to Drawdown Georgia Webinar. The webinar was held on August 2, 2019, and brought together 147 participants. In addition, we began to take public comments about the project on the Drawdown Georgia website and invited citizens to take a survey about drawdown solutions. This survey was promoted through targeted emails, affiliate newsletters, and social media.

Experts in electricity sector, transportation, built environment and materials, food systems, forestry and land use, and beyond carbon issues were also invited to engage with the project. Experts included people from academia, non-profit organizations, government, consultants, as well as the business community. Each expert group was invited to rate solutions and identify missing solutions via an online survey. After results were tabulated, experts were then invited to participate in phone calls to review survey results. On November 6, 2019, this expert

community came together for an in-person event at Georgia Tech where a preliminary list of high-impact 2030 solutions was revealed and discussed.

Expert and public opinion through surveying was very important because Project Drawdown® was conducted at the global scale (i.e., not specific to the United States or Georgia), and responses helped inform which drawdown solutions might be most applicable to Georgia. The survey instrument was deployed using Qualtrics software.¹⁸ The survey was reviewed and approved by the Institutional Review Board at the Georgia Institute of Technology.

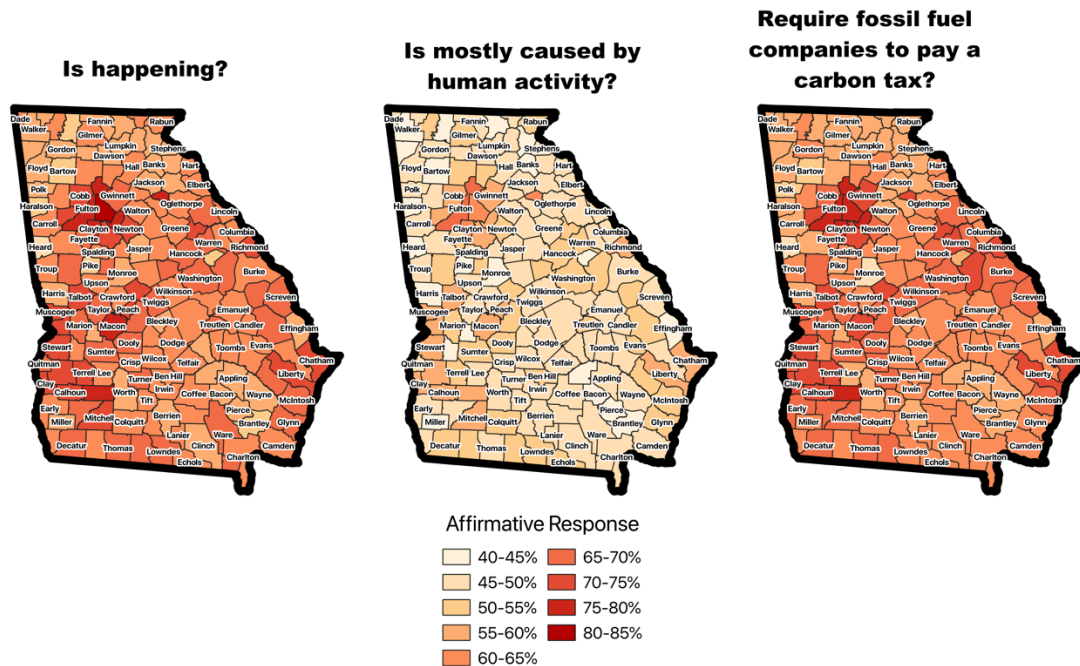
The survey results showed public enthusiasm for many of the top solutions identified by Drawdown Georgia. However, the results were not identical to the solutions selected by the experts and advisors. Generally, the top two solutions were consistent among expert and public opinion, but lower-order priorities were often different. A comparison of the two rankings is found below. Details of the expert survey rankings can be found in the appendices.

4.1 Views and Priorities of the Public and Experts

According to the most recent Yale and George Mason University survey on climate change opinions (Leiserowitz, et al., 2019), 72% of Americans think that global warming is happening, and 59% believe that it is mostly human-caused. Drawdown Georgia’s county-level analysis of this data suggests that citizens across Georgia believe that global warming is happening, but the levels of certainty are lower in rural counties. Compared to the average American, Georgia residents are less certain that climate change is caused by human activity: in particular, a majority of residents in most rural counties do not agree that climate change is caused by humans. Nevertheless, a majority of the survey respondents from Georgia are in favor of requiring fossil fuel companies to pay a carbon tax (Figure 4.1).

¹⁸ Qualtrics, Provo, UT, USA. <https://www.qualtrics.com>

Figure 4.1. Public Opinion Regarding Global Warming in Georgia, 2019



Source: Maps created by Drawdown Georgia from data provided by Yale and George Mason Universities

Drawdown Georgia sought to build on our understanding of state-level preferences and opportunities by inviting feedback on promising solutions to reduce Georgia's net carbon emissions. The general public was invited to provide input to the Drawdown Georgia project through a crowdsourced survey. Participants navigated through solutions in five sectors related to carbon emissions and a cross-cutting question on beyond-carbon considerations. The survey was posted on the Drawdown Georgia website from October 15, 2019, to December 31, 2019. In total, 280 surveys were completed, answering questions pertaining to 1 or more of the 5 sectors. On average, each of the 5 sectors was fully completed by 91 individuals. The results are summarized in Figures 4.2 and 4.3.

Participants were asked four key questions: 1) which sector(s) do you consider yourself an expert in? 2) select five solutions that are most promising to reduce carbon emissions in Georgia by 2030, 3) nominate solutions for Georgia that were missed by Project Drawdown®, and 4) describe beyond-carbon considerations: economic development, health impact, environmental impact, and equity. A final question asked for demographic information. Table 4.1 describes the respondent demographics. Respondents to the public survey tended to be better educated and more affluent than the average resident of Georgia.

Fig. 4.2 Top 10 Solutions Based on the Public Survey (N=280)

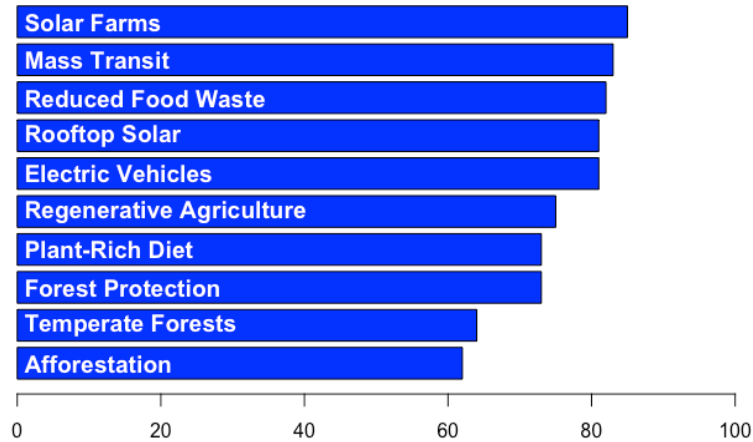


Fig. 4.3 The Top 15 Solutions for Each Sector, Based on the Public Survey (N=280)

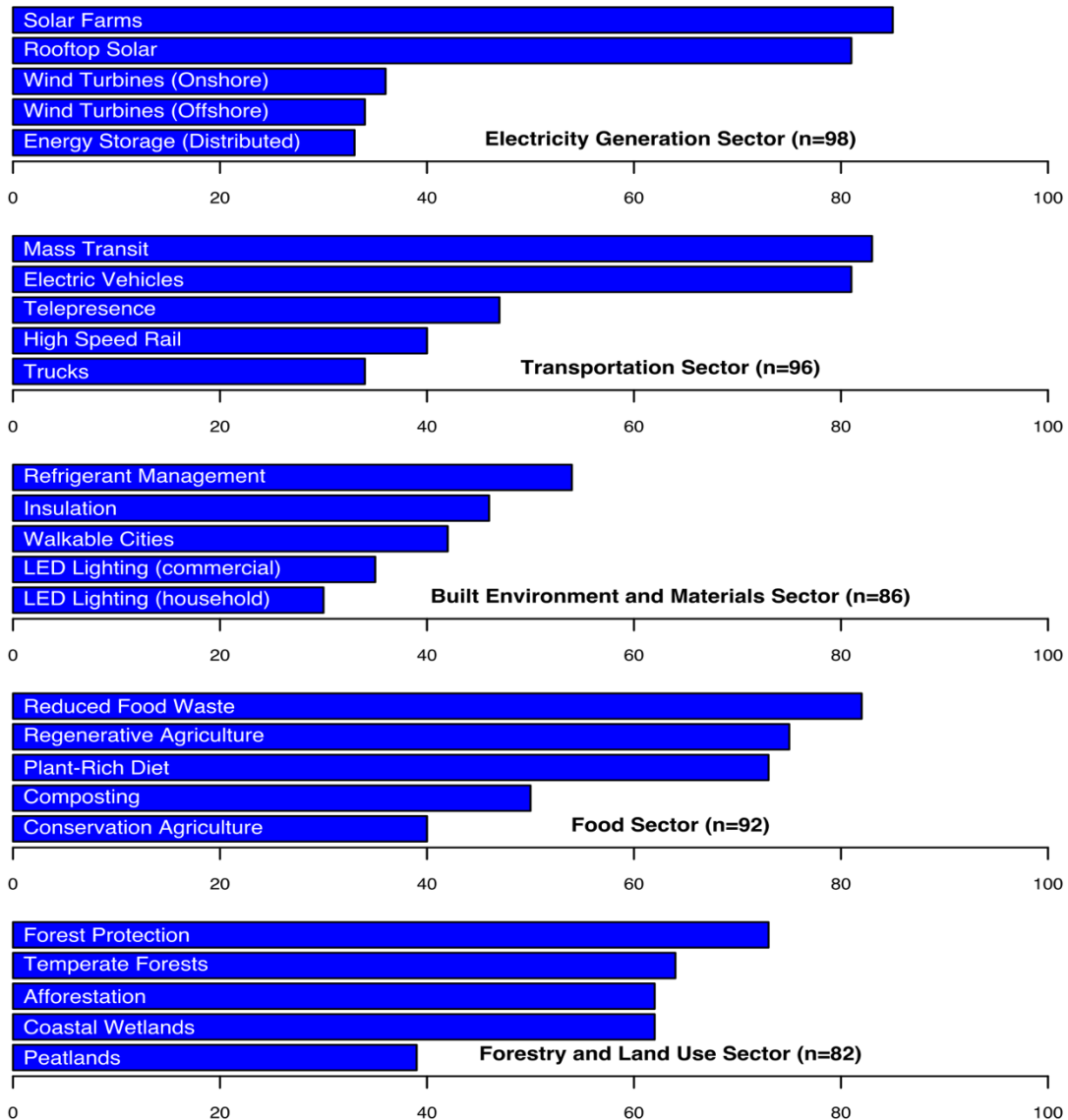


Table 4.1 Demographics of Respondents to the Public Survey

Age	37% (24-39)	32% (40-55)	25% (56-64)	
Education	95% have a bachelor’s degree or higher			
Gender	51% Female	48% Male	1% Non-Binary	
Income	26% (<\$50k)	25% (\$50k-75k)	25% (\$125k+)	24% (\$75k-125k)
Race	85% white, non-Hispanic	7% other, non-Hispanic	4% black, non-Hispanic	4% Hispanic

4.2 Priorities of Experts Surveyed

Experts in each of the five sectors were invited to provide input to the Drawdown Georgia project through a closed survey. Participants navigated through their sector of expertise related to carbon emissions as well as a cross-cutting question on beyond-carbon considerations. The surveys were administered by email invitation between August 24, 2019, and November 5, 2019. In total, one to four of the sectors were evaluated by 372 experts, and 41 experts contributed feedback on all five sectors via the survey.

Participants were asked five key questions: 1) rate each solution for its GHG emission reduction, 2) rank the top five solutions by cost effectiveness, 3) nominate solutions for Georgia that were missed by Project Drawdown®, 4) provide justification for rankings, and 5) describe beyond-carbon considerations.

Experts responding to the surveys came from the following types of organizations and industries:

- Utility Companies and Trade Organizations
- City/State/Regional Government Agencies
- U.S. Department of Energy and National Labs
- Industry
- Consulting Firms, Think Tanks, and Non-Governmental Organizations (NGOs)
- Universities

The strongest agreement between expert and public opinion was in the Forests and Land Use sector (80%) (Table 4.2). The Transportation as well as Built Environment and Materials sectors had above average correlation (60%). The weakest correlation of top five solution ranking were in the Electricity Generation sector (where on- and off-shore wind and energy storage were in the top five for the public but were not for the experts) and the Food Systems sector (where

regenerative agriculture, plant-rich diet, and composting were in the top five for the public but were not for the experts).

Table 4.2 Overlapping High-Priority Solutions of Experts and the Public

	EXPERT TOP-5	PUBLIC TOP-5	OVERLAP
ELECTRICITY GENERATION			40%
1	Solar Farms	Solar Farms	
2	Rooftop Solar	Rooftop Solar	
3	Nuclear	Wind (Onshore)	
4	Energy Storage (Utility)	Wind (Offshore)	
5	Cogeneration	Energy Storage (Distributed)	
TRANSPORTATION			60%
1	Mass Transit	Mass Transit	
2	Electric Vehicles	Electric Vehicles	
3	Trucks	Telepresence	
4	High Speed Rail	High Speed Rail	
5	Trains	Electric Bikes	
BUILT ENVIRONMENT AND MATERIALS			60%
1	Refrigerant Management	Refrigerant Management	
2	Insulation	Insulation	
3	Walkable Cities	Walkable Cities	
4	District Energy	LED Lighting (Commercial)	
5	Building Automation	LED Lighting (Household)	
FOOD SYSTEMS			40%
1	Conservation Agriculture	Reduced Food Waste	
2	Reduced Food Waste	Regenerative Agriculture	
3	Nutrient Management	Plant-Rich Diet	
4	Managed Grazing	Composting	
5	Farmland Irrigation	Conservation Agriculture	
FORESTS AND LAND USE			80%
1	Temperate Forests	Forest Protection	
2	Afforestation	Temperate Forests	
3	Forest Protection	Afforestation	
4	Peatlands	Coastal Wetlands	
5	Perennial Biomass	Peatlands	

5 The Methodology for Down-Selecting Solutions for Georgia

Drawdown Georgia developed a systematic and replicable methodology for down-selecting the most promising solutions to meaningfully reduce net GHG emissions in the state over the next decade. The 2030 timeline provides important guardrails for the types of solutions highlighted through this process. In order to deliver meaningful emissions reductions in Georgia by 2030, solutions must be mature, cost-competitive technologies, ready to be deployed in the state. The result of this analysis is a set of high-impact 2030 solutions specific to Georgia. However, additional strategies will likely be required to further reduce emissions out to midcentury. This analysis does not attempt to predict all of the solutions that will be viable in decades to come due to declining technology costs and innovation. Instead, this work highlights how Georgia can embark on a no-regrets path to begin reducing net emissions in the near term.

In order to identify the set of high-impact 2030 solutions, Drawdown Georgia created six expert working groups to evaluate sector-specific solutions. This includes: Electricity, Transportation, Built Environment and Materials, Food Systems, Forests and Land Use, and Beyond Carbon. In the initial phase of work described in this document, these working groups:

1. Defined the universe of solutions under consideration,
2. Conducted an initial review of each solution,
3. Filtered solutions through a four-step down-selection process,
4. Considered beyond-carbon impacts, and
5. Engaged with experts and the interested public.

This process has delivered a set of high-impact 2030 solutions for Georgia discussed below. The next phase of work will focus on a deeper analysis of the selected solutions and their beyond-carbon implications.

5.1 Defining the Universe of Solutions under Consideration

A foundational step in this initiative was defining and refining the list of solutions under consideration. Drawdown Georgia began by examining all of the global solutions identified by Project Drawdown®. The list was then reviewed by working groups and outside experts to evaluate 1) whether additional solutions should be added to the mix or 2) if solutions identified by Project Drawdown® should be defined differently to better fit the state. For example, Project Drawdown® considered the impact of adopting more fuel-efficient airplanes. Since emissions related to air travel are difficult to confine to state boundaries, Drawdown Georgia refined this solution to examine emission reduction opportunities for ground operations at airports.

In addition, working groups identified a series of solutions that, on their own, are unlikely to deliver meaningful emission reductions in Georgia over the next decade. However, if

considered as a set, these solutions have the potential to contribute meaningfully. As a result, Drawdown Georgia created bundles of solutions to evaluate, including a set of retrofitting options for existing buildings, a set of recycling and waste management practices, and a set of alternative mobility options that could replace emissions-intensive vehicle miles traveled. Finally, some solutions were refined to capture important interactions between technologies. For example, Drawdown Georgia is considering storage technologies bundled with other drawdown options, instead of evaluating these technologies on their own. After these additions and revisions, a total of 75 solutions were considered by Drawdown Georgia.

5.2 The Four-Step Down Selection Process

Working groups put each of the 75 solutions through an initial qualitative and quantitative review. This included a literature review to further define the solution, identify Georgia-relevant data, establish the technology and market maturity of the solution, capture cost projections, and summarize relevant projects in Georgia and the southeast. In addition, working groups conducted initial calculations of the solutions' carbon reduction potential in the state. This included an estimation of how deployment of each solution could reduce carbon emissions in the state by 1 MT a year by 2030.

All solutions were then passed through a four-step filter.

Step 1: Is the solution technology & market ready for Georgia?

The first step of the down-selection process was to drop solutions that were either 1) relevant on a global scale but not pertinent to Georgia or 2) not technology and market ready, and therefore very unlikely to be deployed in Georgia by 2030. For example, the solutions "improved rice cultivation" and "system of rice intensification" were dropped at this phase because Georgia is not a rice-producing state. In addition, the solution "autonomous vehicles" was dropped at this phase because the technology is unlikely to be ready for wide-scale deployment in Georgia by 2030.

Step 2: Is there sufficient local experience and available data?

Remaining solutions were then evaluated on whether there is a track record of deploying the solution in Georgia or the southeastern United States. This metric provided an additional screen for local relevance as well as a proxy for predicting whether a project has the potential to be deployed in the near term. For example, the solution "offshore wind turbines" was dropped at this phase because no offshore wind farms have been sited in Georgia or the southeast to date. No solutions were dropped at this stage due to data availability.

Step 3: Does the solution provide ~1 Mt CO₂-e reduction annually by 2030?

Solutions must be able to provide meaningful emission reductions in Georgia by 2030. The 1 Mt CO₂-e threshold represents about 1% of the annual net emissions for Georgia in 2017. Solutions failed to meet this standard for a variety of reasons, including if they could not be built and operated in the 2030 timeframe, if they required substantial changes in near-term consumer preferences, or if they were poor matches for Georgia’s natural resources or economy. For example, the solutions “living buildings,” “net zero buildings,” and “building with wood” were all dropped because the new construction of these buildings in Georgia in the next decade is not expected to be sufficient to meet the 1 MtCO₂ threshold. “Family planning” and “educating girls” also fell in this category. “Nuclear” was dropped at this step because it is unlikely that additional new nuclear reactors could be permitted, built, and operated in Georgia by 2030. The analysis, however, does assume that the two nuclear units currently under construction at Plant Vogtle will be completed in the current decade.

Step 4: Is the solution cost competitive?

Finally, solutions must be cost competitive with other solutions impacting the relevant sector. Each sector defined cost competitive using relevant metrics. For example, electricity sector projects were compared on their levelized cost of electricity, while forestry and land use solutions were evaluated on the cost per metric ton (“tonne” or “t”) of sequestered CO₂.

The result of this four-step down selection process is a set of 21 high-impact 2030 solutions for Georgia. These solutions would all contribute meaningfully to GHG emissions reductions in Georgia. How these solutions are deployed, however, can impact societal priorities beyond carbon. As a result, a working group is focused on how deployment could impact equity, public health, environment, and economic development. In this phase of analysis, the Beyond Carbon working group conducted an initial mapping of potential beyond-carbon impacts for each of the high-impact 2030 solutions. This mapping was based on a literature review and a survey of experts. Additional analysis will continue into the next phase of research.

6 Results

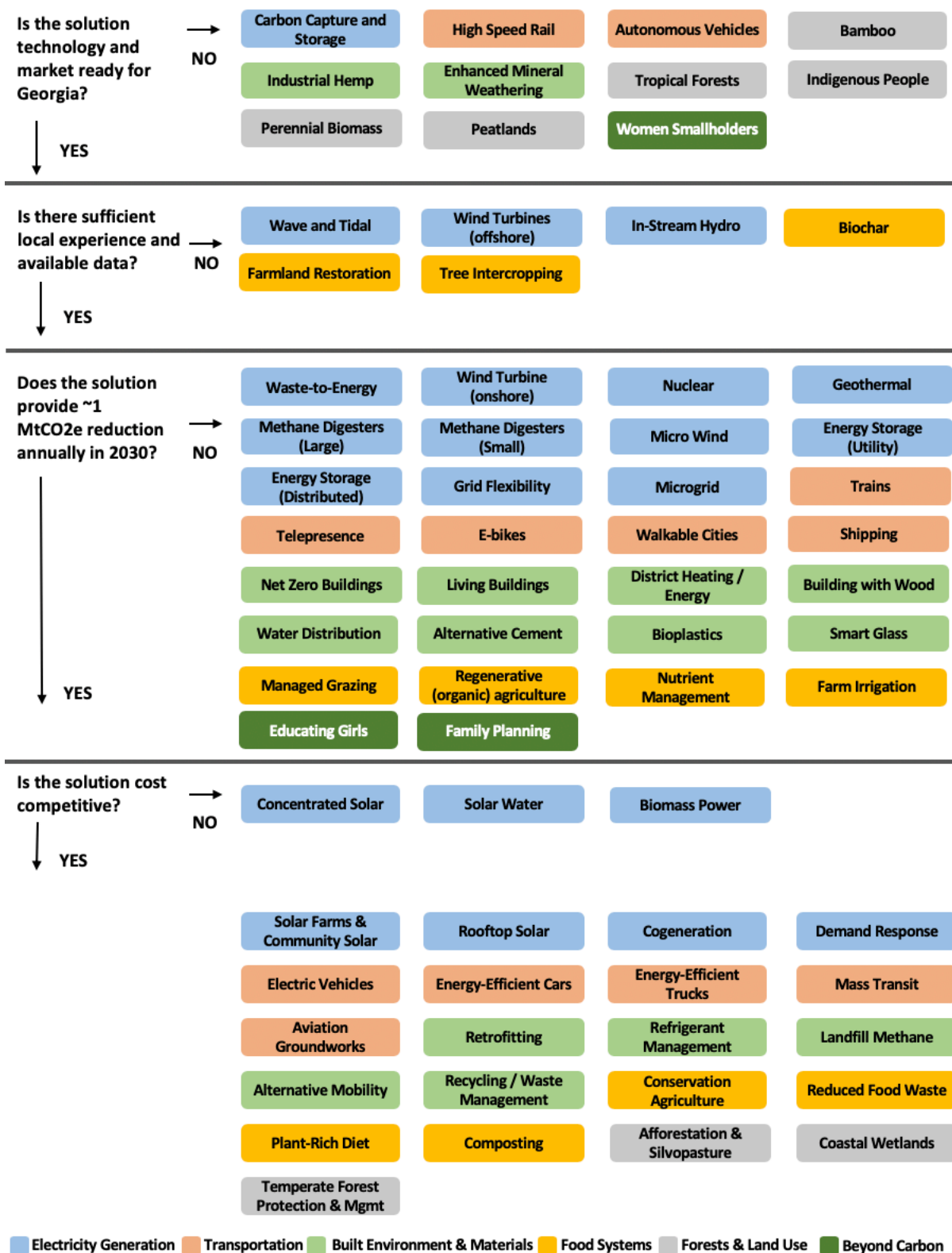
The Drawdown Georgia team concluded that many of Project Drawdown’s® 102 Solutions are not relevant to Georgia, in general (such as improved cookstoves and tropical forests) or were not going to be ready in the 2030 timeframe (such as the artificial leaf and hydrogen-boron fusion). The remaining 75 solutions were evaluated using the four down-select criteria (Figure 6.1). Based on analysis by the Drawdown Georgia team and feedback from public respondents, experts, and an internal working group review process, 21 of these were selected as high-impact 2030 solutions (Figure 1.1).

6.1 Down-Select by the Drawdown Georgia Team

The down-select results are summarized in Figure 6.1. The figure shows at which point in the down-selection process solutions dropped out of consideration, leading to the 21 high-impact 2030 solutions.

It is important to note that a handful of the Project Drawdown® solutions that are shown in Table 2.1 are merged into bundles of high-impact 2030 solutions that are retained for further analysis. In several cases, a solution implemented on its own was anticipated to fall short of the annual emission reduction threshold of 1 Mt of CO₂ by 2030 in Georgia. By creating a bundle of complementary solutions, the threshold could be achieved. Bundled solutions include: alternative mobility, recycling/waste management, retrofitting, afforestation and silvopasture, and temperate forest and forest management. Alternative mobility is perhaps one of the more complex bundles. Telepresence, e-bikes, and walkable cities are seen as offering modest levels of carbon reduction by 2030. However, the 1 Mt CO₂ threshold could likely be met by packaging them into an alternative mobility solution, which considers replacing emissions-intensive vehicle miles traveled (VMTs) with zero- or low-carbon alternatives such as bicycling, walking, or teleworking. This bundle includes bike infrastructure, walkable cities, telepresence, and e-bikes (as well as the addition of e-scooters), with a specific focus on replacing short-distance vehicle trips with these alternatives.

Figure 6.1 Drawdown Georgia Down-Select Flow Chart of Solutions



Note: These solutions are each described in the Appendix to this working paper.

In another instance, the original solution (energy storage) is an enabler but not a direct contributor to carbon emission reductions. Therefore, as a standalone solution, it fell short of the 1 MT CO₂ threshold. However, while it was dropped from consideration on its own, the analysis of solar farms, rooftop solar, and demand response includes the possibility of pairing solar panels with batteries to enable more impactful and cost-competitive solutions. The solution “demand response” was re-labeled from the term “microgrid” to reflect its broader scope. Energy storage, therefore, is part of at least three bundled solutions.

- The bundled solutions also provided an opportunity to expand the range of the solutions beyond those modeled in Project Drawdown®. For example, the building retrofit bundle was expanded to include high-efficiency windows, recommissioning/retro-commissioning of commercial buildings, and dead-band range expansion.

6.2 Assessment of Beyond-Carbon Attributes

Implementation of the 21 high-impact 2030 solutions will likely entail a range of impacts and benefits beyond carbon mitigation. We have organized these impacts and benefits into four “beyond carbon” categories: environment, equity, economic development/jobs, and public health—and have conducted a preliminary qualitative assessment for each solution based on peer-reviewed literature and expert input, which is synthesized in Figures 6.2 and 6.3. While these four categories have been developed as organizing principles, we recognize that these dimensions are cross-cutting and best considered as integrated attributes of a solution, rather than as stand-alone categories.

6.2.1 Environment

Several findings are derived from this analysis. First, air quality improvements are one of the primary benefits associated with the vast majority of solutions. In addition, food system and forestry and land use solutions offer benefits in water quality and quantity as a result of greater efficiencies in water requirements and reduced soil erosion (Trabucco et al., 2008). Finally, the disposition of hazardous materials, including PV panels and batteries, are important challenges to address in the solar, cogeneration, electric vehicle, and several other transportation solutions (Chowdhury et al., 2020).

6.2.2 Equity

Equity considerations relate principally to the extent of access to the solutions along with the potential impact on affordability, across different segments or communities (but with particular focus on underserved populations). While many communities may derive other benefits from

solutions (such as air quality or public health), the degree of benefit varies and some solutions have the potential, if not implemented with equity in mind, to exacerbate equity challenges. For example, Deborah et al. (2019) found racial and ethnic differences in rooftop solar adoption in the U.S., even after accounting for income and household ownership. A report from the National Renewable Energy Laboratory (NREL) analyzes the impact of electricity rate design to recover fixed utility costs due to low net electricity consumption after residential PV penetration, which may also exacerbate the “energy burden” experienced by lower income households who purchase all of their electricity from the grid (McLaren, et al., 2015). Land use and environmental justice issues associated with U.S. power technologies are comprehensively covered by Massetti, et al. (2017), including climate vulnerability impacts on environmental justice communities.

6.2.3 Economic Development and Jobs

The vast majority of the solutions present job opportunities, such as for waste management personnel, solar installers (National Solar Jobs Census, 2019), or home retrofit contractors (Brown, Li, and Soni, 2020). However, there can be displacement impacts, as these solutions replace current practices, which need to be considered as part of any implementation assessment. Given the increased cost competitiveness of many of the solutions (such as solar farms and community solar) compared to existing alternatives, we do not envision significant adverse impacts on energy prices.

6.2.4 Public Health

Many of the solutions offer direct and indirect material public health impacts on mortality and morbidity (e.g., asthma, mental impairment) rates. These benefits are largely related to projected improvement in air quality metrics, and are most pronounced in the electricity (Millstein et al., 2017), transportation, built environment and materials, and several of the forestry solutions. In contrast, alternative agricultural and food systems solutions tend to offer diverse benefits that impact quality of life, education, and public safety.

Figure 6.2 Beyond Carbon: Environment and Equity Considerations

	Environment					Equity				
	Air Quality	Water Quality & Quantity	Land Use	Ecosystem / Biodiversity	Material Disposability	Affordability	Distribution Economic Development	Public Health Impacts	Accessibility of Solutions	Cultural Fit & Way of Life
Electricity Generation	Solar Farms	Green	Red	Yellow		Red	Yellow			
	Rooftop Solar	Green				Red			Red	
	Cogeneration	Green				Red	Green			
	Demand Response	Yellow					Green		Green	
Transportation	Electric Vehicles	Green				Red	Red		Yellow	
	Mass Transit	Green		Yellow	Yellow		Green		Green	Green
	Energy Efficient Trucks	Green								
	Aviation Groundworks	Green								
	Energy Efficient Cars	Green				Red	Red			
Built Environment & Materials	Refrigerant Management		Green				Green	Green	Green	
	Waste Management		Green	Green				Green	Green	
	Retrofitting	Green							Red	
	Landfill Methane	Green				Yellow	Green	Green		
	Alternative Mobility	Green		Red		Yellow		Green		
Food Systems	Reduced Food Waste		Green	Green	Green		Yellow		Green	
	Plant Rich Diet		Green	Green			Green			Yellow
	Conservation Agriculture		Green	Green			Green			Yellow
	Composting	Green	Green	Green		Green		Green	Yellow	
Forestry & Land Use	(*)Temperate Forests Protection & Management	Green	Green	Green		Green		Green	Green	Green
	(^)Afforestation & Silvopasture	Green	Green	Green		Red	Green		Red	Yellow
	Coastal Wetlands		Green		Green			Green		

Note: Potential co-benefits are marked in “green,” potential negative impacts are marked in “red” and areas to watch are marked in “yellow.” Cells that are left blank have not been identified as material for the particular solution.

Figure 6.3 Beyond Carbon: Economic Development, Jobs, and Public Health Considerations

		Economic Development & Jobs						Public Health				
		Local Economy & Employment	Input Prices	Workforce Composition	Wages and Benefits	Property Values/Tax	Infrastr. Requirmnts	Premature Mortality	Morbidity	Quality of Life	Education	Public Safety
Electricity Generation	Solar Farms	Green	Yellow			Yellow			Green			
	Rooftop Solar	Green							Green			
	Cogeneration	Green	Green						Yellow			
	Demand Response		Green				Yellow		Green			
Transportation	Electric Vehicles	Green	Yellow	Green						Yellow		
	Mass Transit	Green				Green	Yellow	Green				Yellow
	Energy Efficient Trucks	Green	Green									
	Aviation Groundworks	Green	Yellow		Green				Green			
	Energy Efficient Cars	Green	Yellow						Green			
Built Environment & Materials	Refrigerant Management				Red				Green			
	Waste Management	Green	Yellow						Green	Green		
	Retrofitting	Green				Green			Green			
	Landfill Methane	Green							Green			
	Alternative Mobility	Green	Red				Yellow	Yellow	Green	Green		Green
Food Systems	Reduced Food Waste	Green	Yellow	Yellow				Green	Green		Yellow	Green
	Plant Rich Diet		Green	Yellow				Green	Green	Green		
	Conservation Agriculture	Green			Green				Green			
	Composting	Yellow	Yellow	Green						Green		
Forestry & Land Use	(*)Temperate Forests Protection & Management	Green		Red		Green			Green	Green		
	(^*)Afforestation & Silvopasture		Yellow	Red	Green				Green		Green	Green
	Coastal Wetlands	Green		Green						Green		Green

Note: Potential co-benefits are marked in “green,” potential negative impacts are marked in “red” and areas to watch are marked in “yellow.” Cells that are left blank have not been identified as material for the particular solution.

7 Highlights of Findings, by Sector

7.1 Electricity Generation

The list of high-impact 2030 solutions includes four solutions from the electricity sector:

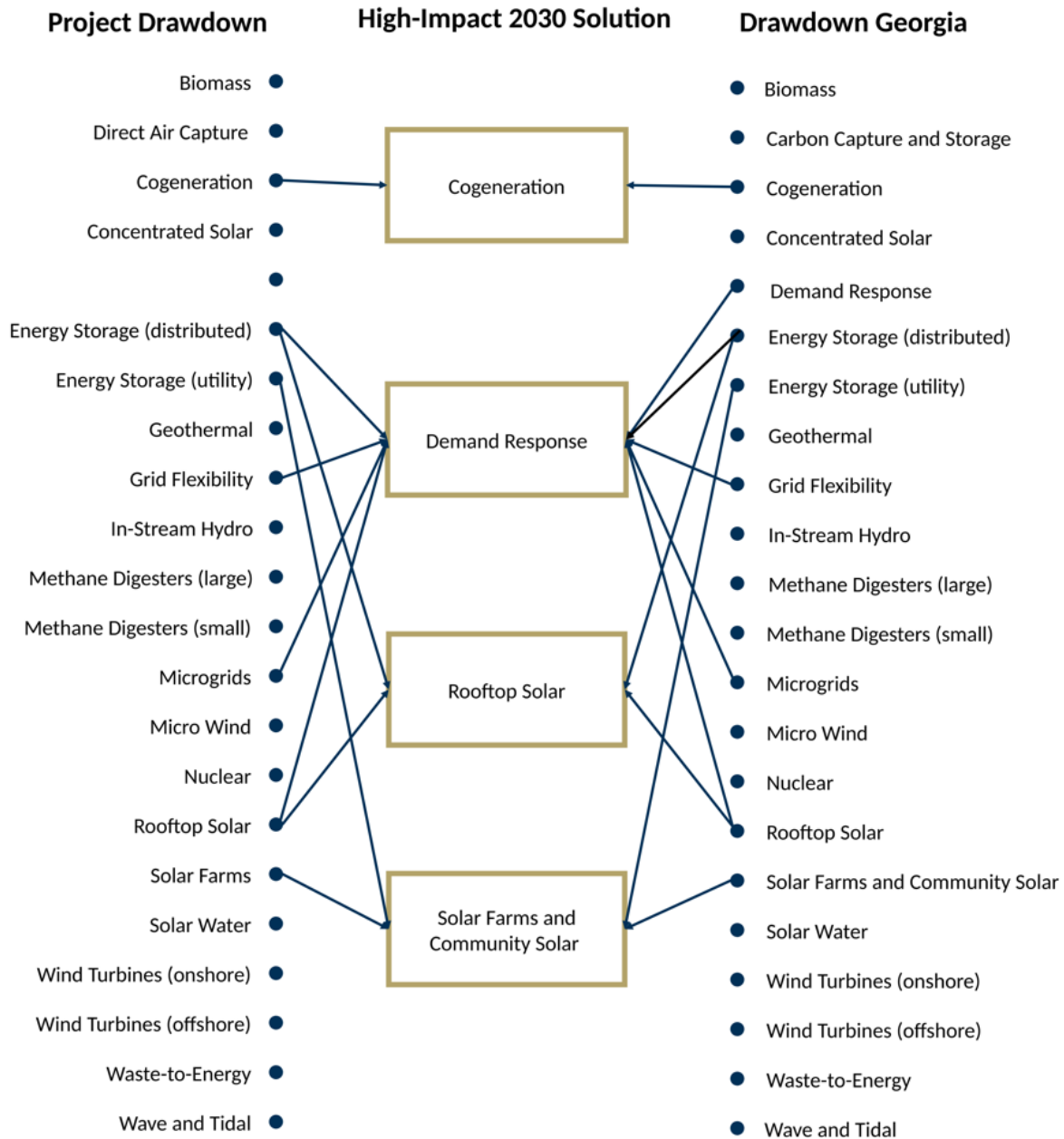
1. **Cogeneration:** Cogeneration involves the co-production of beneficial heat and electricity. It

can involve capturing waste heat that is a byproduct of coal- and gas-fired power production, where the captured heat can be used to heat water or buildings, manufacture products, or create more electricity. It can also involve the capture of waste heat from an industrial or commercial process that is then used to generate electricity, as in the pulp and paper industry. Cogeneration reduces emissions by displacing the consumption of fossil fuels that would otherwise have been used.

2. **Demand Response:** Demand response programs serve to “adjust the timing and amount of electricity use” and can help utility companies reduced peak load, shift load, or reduce overall usage. This changes electric usage by end-use customers to be responsive to changes in the price of electricity over time, or as incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.
3. **Rooftop Solar:** Solar photovoltaic systems convert solar energy into electricity. Rooftop solar systems are small-scale installations that can produce electricity primarily for onsite use. When combined with storage, additional benefits can accrue.
4. **Solar Farms:** Solar photovoltaic systems can convert solar energy into electricity. This solution includes utility-scale solar, defined as any ground-mounted solar panel facility that has a capacity rating larger than 5 MW, as well as community-scale solar, which generally has a capacity of 0.5-5 MW. This solution also considers the possible advantage of coupled onsite storage to enhance reliability.

These four were derived from evaluating the 22 Drawdown Georgia solutions shown in Figure 7.1. Note the addition of one solution—demand response—that was not included in the Project Drawdown® list. It is a bundled solution that has features drawn from four of the original electricity solutions (see the arrows from the left). Cogeneration is the only high-impact 2030 solution that is not bundled with other electricity solutions. In addition, one of the Project Drawdown® solutions called “direct air capture,” was renamed “carbon capture and sequestration,” to consider a broader range of technologies available for capturing CO₂ such as bioenergy carbon capture and storage (BECCS).

Figure 7.1 Crosswalk of Drawdown Solutions in the Electricity Sector



Note: Artificial Leaf, Hydrogen-Boron Fusion, Smart Highways, and Solid-State Wave Energy were “Coming Attractions” in Project Drawdown® that were judged “out of scope” for Drawdown Georgia.

7.1.1 Electricity Sector Down-Selection Process

Each of these 22 solutions was filtered through the four-step down-selection process. At each step, solutions were dropped out of consideration.

Down selection question	Solutions Dropped
Is the solution technology and market ready for Georgia?	Carbon capture and storage
Is there sufficient local experience and available data?	In-stream hydro, wave tidal and wind turbines (offshore)
Does the solution provide about 1 Mt of CO ₂ -e reduction annually?	Energy storage (distributed), energy storage (utility), geothermal, grid flexibility, methane digesters (large), methane digesters (small), microgrid, micro wind, nuclear, waste-to energy and wind turbine (onshore)
Is the solution cost competitive?	Concentrated solar, biomass power, and solar water

7.1.2 Key Takeaways

The criterion that each solution be able to provide at least 1 Mt of CO₂-e reduction annually by 2030 caused 11 of the 22 solutions to drop out of consideration. This was based on preliminary estimates of carbon reduction potential. These estimates showed an interesting span of investments that would be required to achieve the 1 Mt CO₂ minimum requirement in the electricity sector. For example:

- 4 new parabolic trough concentrated solar power plants
- 10 new biomass power plants, each @ 50 MW, burning biomass waste
- 10 additional 100 MW solar farms and 36 additional 5 MW solar farms
- 216 typically sized methane digester projects
- 1,227 local geothermal energy projects like Roosevelt Warm Springs
- 187,000 households in a demand response activity
- 215,000 micro wind turbines
- 294,000 in-stream hydro generators
- 295,000 new home solar systems @ 5 KW
- 7.1 million homes (70% of GA's households) with solar water heating

An initial beyond-carbon analysis was conducted for each of the four retained electricity solutions. This analysis begins to map how the deployment of the solution could impact equity, public health, economic development, and the environment. For example, the beyond-carbon analysis for solar farms suggests significant air quality and jobs benefits but also flags potential concerns around water usage for cleaning PV panels and end-of-life disposal issues for solar

arrays as well as associated energy storage, and uncertain impacts on energy prices, property values, and land use.

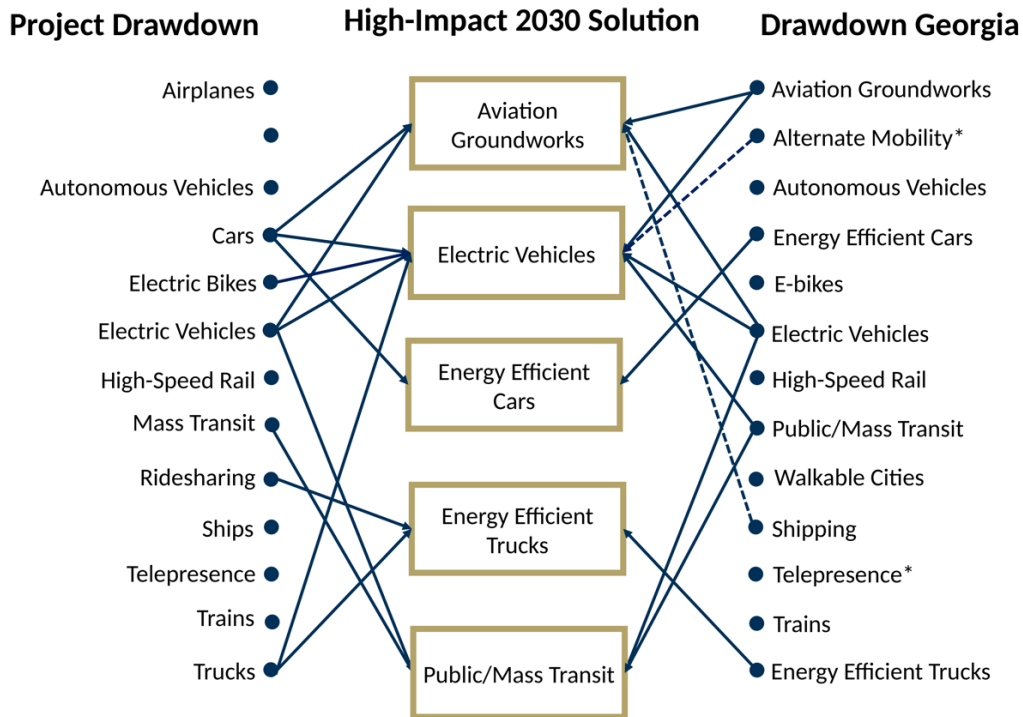
7.2 Transportation

The list of high-impact 2030 solutions includes five solutions from the transportation sector:

1. **Aviation groundworks:** Airports' energy needs can lead to GHG emissions. This includes gasoline and diesel consumption in airport vehicles, coal- and gas-fired power plants that generate electricity, and jet fuel for airplane auxiliary power while parked or taxiing. Airports can reduce emissions in numerous ways, including energy efficiency measures and the substitution of conventional vehicles with electric vehicles.
2. **Electric vehicles:** Electric vehicles are powered by electric batteries instead of conventional fuels such as gasoline and diesel. The emissions profile of these vehicles is lower; however, the exact emissions vary depending on the generation mix providing the electricity.
3. **Energy efficient cars:** A range of cost-effective technologies are available to reduce or replace petroleum fuel use in light duty vehicles, including cars and pickups. Among these, hybrid cars deliver the most substantial reductions, by pairing an electric motor and battery with an internal combustion engine. The combination enables the vehicle to regenerate braking loss and operate both engine and motor at greater efficiency, improving fuel economy and lowering emissions.
4. **Energy efficient trucks:** U.S. trucks consume about 50 billion gallons of diesel fuel each year. Trucks consume a disproportionate quantity of fuel relative distances traveled. Increasing fuel efficiency for both new and existing trucks can lead to significant emission reductions. Numerous fuel-saving technologies are available at compelling paybacks.
5. **Public/mass transit:** Public mass transit includes modes such as buses, trains, and streetcars. When people rely on mass transit instead of cars, it reduces GHG emissions.

These solutions were part of the 13 transportation sector solutions evaluated by Drawdown Georgia. The complete list includes:

Figure 7.2 Crosswalk of Drawdown Solutions in the Transportation Sector



Notes: Solid lines represent direct linkages and dashed lines represent indirect linkages.

*See Built Environment and Materials.

The “alternate mobility” solution is a bundle of related solutions that Drawdown Georgia is considering as a group. For this project, we define alternate mobility to include a combination of bike infrastructure, walkable cities, telepresence, and e-bikes (as well as the addition of e-scooters), with a specific focus on replacing short-distance vehicle trips with these alternatives. This solution spans both the transportation and built environment sectors. It is included as part of the built environment solution set and discussed in Section 7.3.

7.2.1 Transportation Down-Selection Process

Each of these transportation technologies was filtered through the four-step down selection process. Solutions dropped out at two of the four stages of evaluation.

Down selection question	Solutions Dropped
Is the solution technology and market ready for Georgia?	Autonomous vehicles, high-speed rail
Is there sufficient local experience and available data?	
Does the solution provide about 1 Mt of CO ₂ -e reduction annually?	E-bikes, shipping, telepresence, trains, walkable cities
Is the solution cost competitive?	

7.2.2 Key Takeaways

Electric vehicles are gaining market share nationwide and in Georgia, but the higher price of EVs remains a deterrent to more rapid diffusion. Cost reductions and policy stimulation are needed to accelerate the transition so that 1 MT CO₂ can be diverted annually by 2030. The decarbonization of the grid is improving the environmental benefits of EVs. Smart charging to reflect the power sector's hourly dispatch can help optimize the results. The addition of more nuclear power will enable low CO₂ charging during off-peak hours, and solar additions will enable lower CO₂ recharging during early afternoon hours. Costs to utilities of delivering these services can be controlled since the electricity system has adequate capacity.

The baseline forecast for public transit is less encouraging. Even with better infrastructure, public transition solutions might be sidelined for other modes, especially ride sharing services. Infrastructure investments and public policies can perhaps turn the tide.

Energy-efficient cars and trucks and aviation groundworks can benefit from a host of technology advances that could enable significant CO₂ reductions, again assuming that effective policy accelerators and enablers can be applied to the marketplace.

7.3 Built Environment and Materials

The list of high-impact 2030 solutions includes five solutions from the built environment and materials sectors:

1. **Alternative mobility:** Replacing emissions-intensive vehicle miles traveled (VMTs) with zero or low-carbon alternatives such as bicycling, walking, or teleworking can reduce GHG emissions. This bundle includes the following Drawdown solutions: bike infrastructure, walkable cities, telepresence, and e-bikes (as well as the addition of e-scooters), with a specific focus on replacing short-distance vehicle trips with these alternatives.
2. **Landfill methane:** Landfills are a major source of methane emissions. This GHG is created from anaerobic digestion of municipal solid waste in landfills. The gas can be

captured and then used to generate electricity. This process can prevent methane emissions and replace conventional electricity-generating technologies such as coal and natural gas.

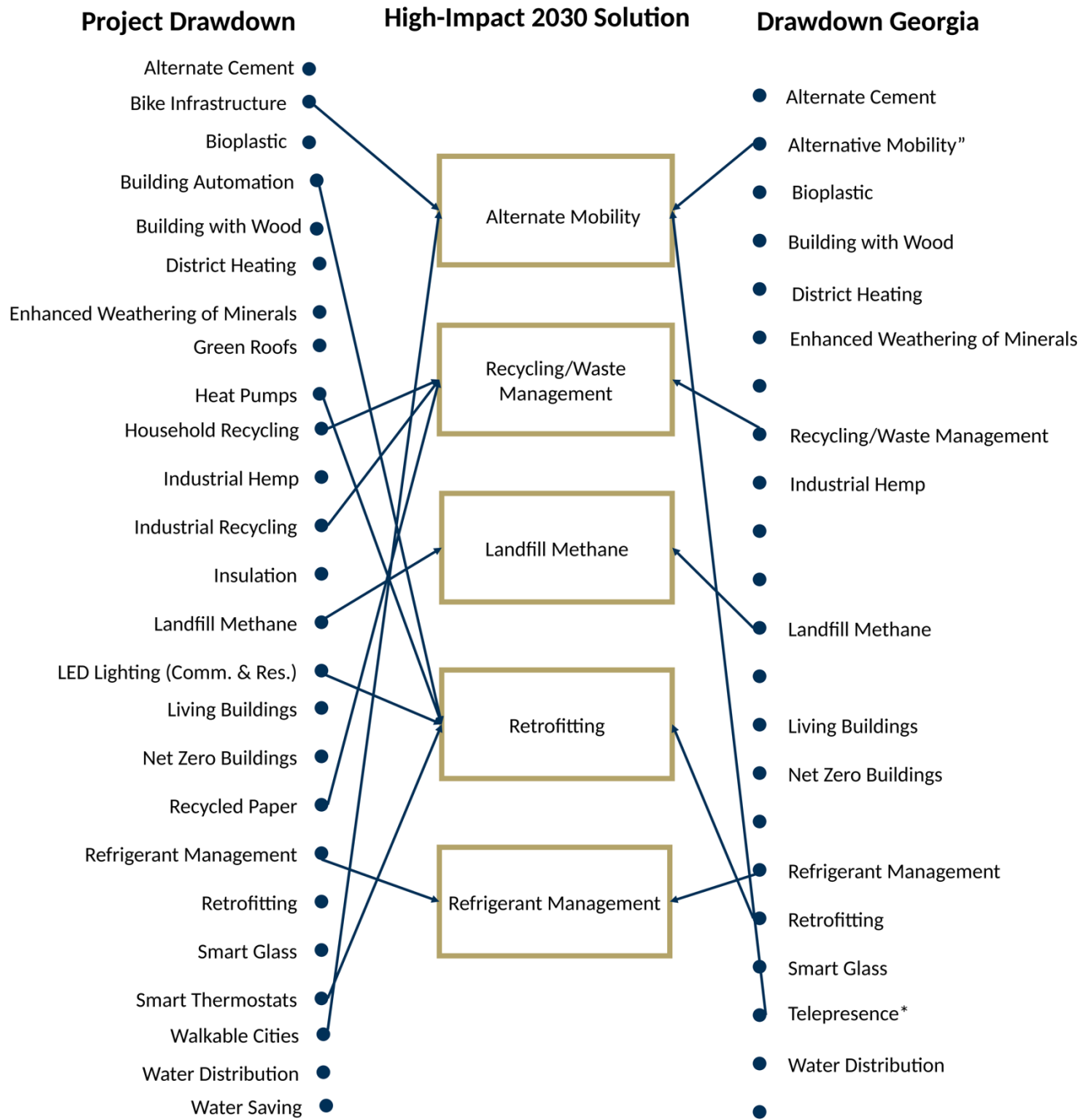
3. **Recycling/waste management:** Recycling can reduce GHG emissions because recycling is often less energy intensive than producing new items. This solution considers increases in: recycling at the household level, increases in industrial and commercial recycling, and a focus on increasing paper recycling.
4. **Refrigerant Management:** Hydrofluorocarbons (HFCs) are chemicals used to cool refrigerators and air conditioners. They are also an extremely potent GHG. Efforts to control leakages and replace HFCs with alternative refrigerants and to properly dispose of and recycle existing HFCs would lower GHG emissions.
5. **Retrofitting:** Buildings use electricity and natural gas for heating, ventilation, and cooling (HVAC), water heating, lighting, and to power appliances and electronic devices. Retrofitting existing buildings to reduce energy demand can lower the GHG emissions due to these energy uses.

Three of these solutions involve bundling solutions from Project Drawdown®, and in a few cases new solutions for Drawdown Georgia were added (Figure 7.3). The retrofitting bundle is the most complex. It includes:

- improving insulation of existing buildings;
- replacing conventional lighting with LED lighting in both residential and commercial buildings;
- replacing conventional HVAC systems and gas and oil-fired furnaces with high-efficiency heat pumps;
- installing water-saving devices such as low-flow fixtures and efficient appliances;
- replacing conventional thermostats with smart thermostats;
- using automated control systems in existing commercial buildings that can regulate heating, cooling, lighting, appliances, and more to maximize energy efficiency; and
- using alternative roof designs such as green roofs, which line a roof with soil and vegetation, as well as cool roofs, which reflect solar energy to reduce a building's electricity demand and therefore reduce emissions.

In addition, solutions that were not originally considered by Project Drawdown® will also be considered under the retrofitting bundle for the Drawdown Georgia project. These include replacing conventional windows and water heaters with high-efficiency units, recommissioning/retro-commissioning of existing commercial buildings, and dead-band range expansion.

Figure 7.3 Crosswalk of Drawdown Solutions in the Built Environment and Materials Sector



Note: *See Transportation.

Of these solutions, three are a bundle of smaller solutions that Drawdown Georgia considered as a bundled set. This includes: 'alternate mobility,' 'recycling/waste management,' and 'retrofitting.' These solutions are defined above.

One notable gap in the solutions described in Project Drawdown® is the technologies available to reduce emissions from manufacturing and industrial processes (aluminum smelting, pulp and paper, chemicals, metal fabrication, iron and steel,...).

7.3.1 Built Environment and Materials Down-Selection Process

These solutions were part of the 15 built environment and materials sector solutions evaluated by Drawdown Georgia. Each of the 15 technologies was filtered through the four-step down selection process. Solutions dropped out at two of the four stages of evaluation.

Down selection question	Solutions Dropped
Is the solution technology and market ready for Georgia?	Industrial hemp, enhancing weathering of mineral
Is there sufficient local experience and available data?	
Does the solution provide about 1 Mt of CO ₂ -e reduction annually?	Building with wood, net zero buildings, living buildings, district heating/district energy, smart glass, water distribution, alternative cement, bioplastics
Is the solution cost competitive?	

7.3.2 Key Takeaways

The down-select process and initial estimates of carbon drawdown potential highlighted several findings from the Built Environment. First, while technological solutions such as refrigerant management and landfill methane emissions do not get much attention in the popular press or academic literature, their high global warming potential highlight the need for increased attention to these sources of GHGs and potential solutions. These solutions are also hampered by a lack of regulations or incentives for investments in improved performance, as well as a lack of information on the management approaches, potential costs, and important stakeholders in these sectors.

Second, among other solutions, each solution or technology in Project Drawdown® has diffuse impacts on GHG emissions. Without steps to consider joint technologies or to bundle technologies, few, if any, energy efficiency technologies or alternative mobility technologies individually make a sufficient impact to GHG emissions in Georgia by 2030 to be worthy of serious consideration. While grouping technologies allowed for scenario analysis that leads to significant GHG reductions, these findings emphasize the large number of levers that

policymakers may need to pull, requiring a large amount of administrative burden, high transaction costs, and significant regulatory and legislative efforts. Alternative approaches, such as a price on carbon, do not require the administrative burden, expertise, or costs as efforts to promote individual technological solutions while targeting all of the technologies simultaneously.¹⁹

Finally, our efforts highlight the challenges associated with producing these analyses. Many of these solutions lack basic national or local data regarding the extensiveness of these practices or costs associated with these practices. This lack of information makes defining an economically efficient or achievable scenario quite challenging. Because many of our solutions do not have incentives or regulations attached to them, it hampers their viability without additional policy intervention.

7.4 Food Systems

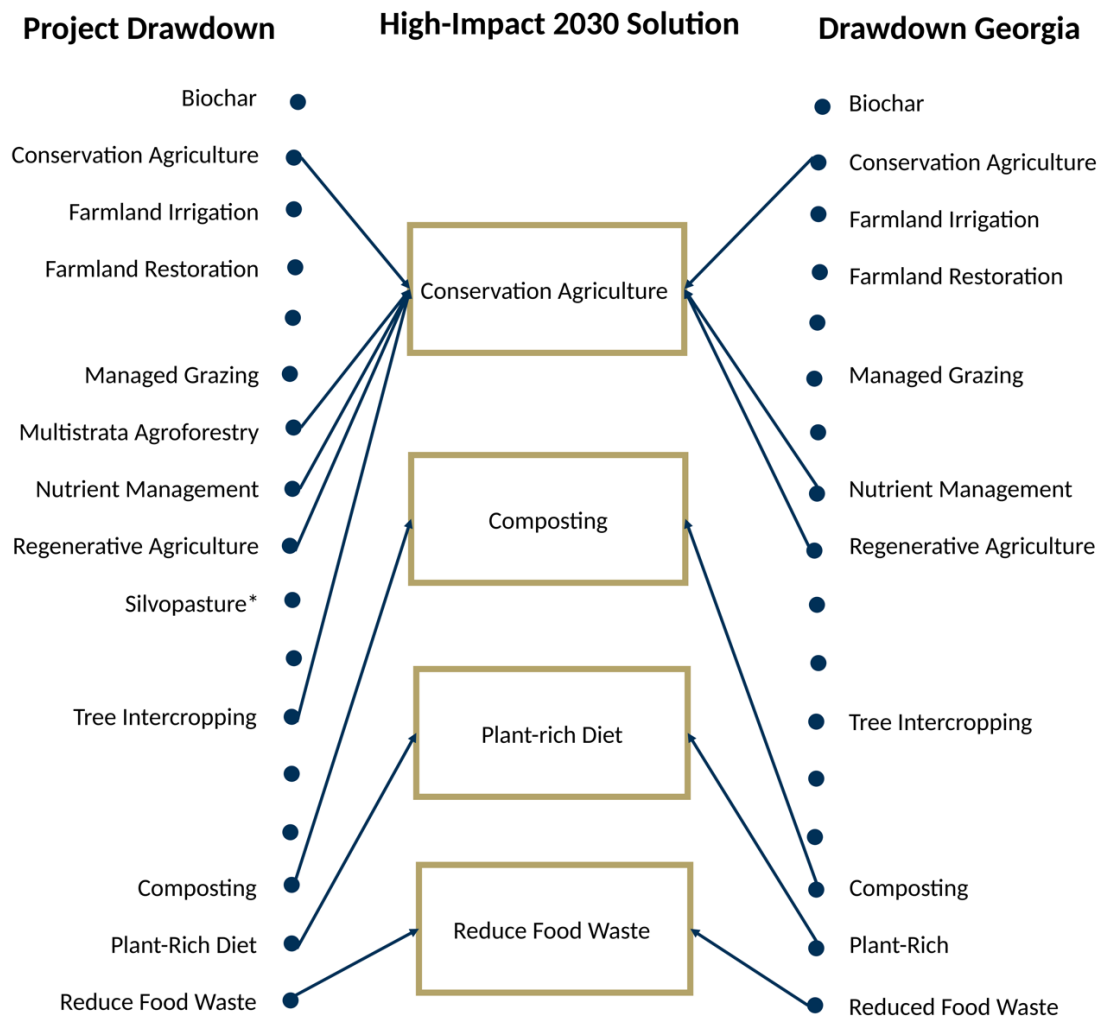
The list of high-impact 2030 solutions includes four solutions from the food systems sectors:

1. **Composting:** When organic matter decomposes in landfills, it releases methane, a potent GHG. Composting allows for organic matter to be broken down by microbes. The process sequesters carbon and produces fertilizer.
2. **Conservation agriculture:** Conservation agriculture refers to a set of agricultural practices that supports bio-sequestration via crop rotation, cover cropping, and reduced tillage.
3. **Plant-rich diet:** A plant-rich diet, such as a vegetarian or vegan diet, would reduce emissions associated with meat production. This solution assumes people 1) maintain a 2,500 calorie per day nutritional regime; 2) meet daily protein requirements; and 3) purchase locally produced food when available.
4. **Reduced food waste:** Food waste refers to food that is produced but not eaten. This can occur for a variety of reasons such as people purchasing more food than they need or customers rejecting bruised or misshaped produce. Food waste also can occur when food rots on farms or in the distribution process. Food waste generates GHGs in every step of the food production and distribution process. Organic matter also produces methane, a potent GHG, when it decomposes in landfills.

These solutions were derived from the 11 food systems solutions evaluated by Drawdown Georgia (Figure 7.4).

¹⁹ There are additional market failures and barriers that a carbon price would not address, and it would still make sense to consider ways to improve the adoption potential of promising technologies.

Figure 7.4 Crosswalk of Drawdown Solutions in the Food Systems Sector



Note: *See Forestry and Land Use.

The 'conservation agriculture' and 'composting' solutions are bundles of related solutions that Drawdown Georgia is considering as a group.

7.4.1 Food Systems Down-Selection Process

These solutions were part of the 11 food systems solutions evaluated by Drawdown Georgia. Each of the 11 solutions was filtered through the four-step down selection process. Solutions dropped out at two stages of evaluation.

Down selection question	Solutions Dropped
Is the solution technology and market ready for Georgia?	
Is there sufficient local experience and available data?	Biochar, farmland restoration, and tree intercropping
Does the solution provide about 1 Mt of CO ₂ -e reduction annually?	Farm irrigation, managed grazing, nutrient management, regenerative agriculture
Is the solution cost competitive?	

7.4.2 Key takeaways

Reduced food waste, in particular, is an emissions-reduction opportunity that has gained national and local attention. In Georgia, the estimated food waste in 2018 is about 2.03 million tons a year. We assumed that, on average, each ton of food waste diverted would decrease CO₂ emissions by 1.35 tons (ReFED 2016). Therefore, if Georgia could reduce 50% of its food waste by 2030, it would decrease emissions by 1.38 Mt CO₂ in 2030.

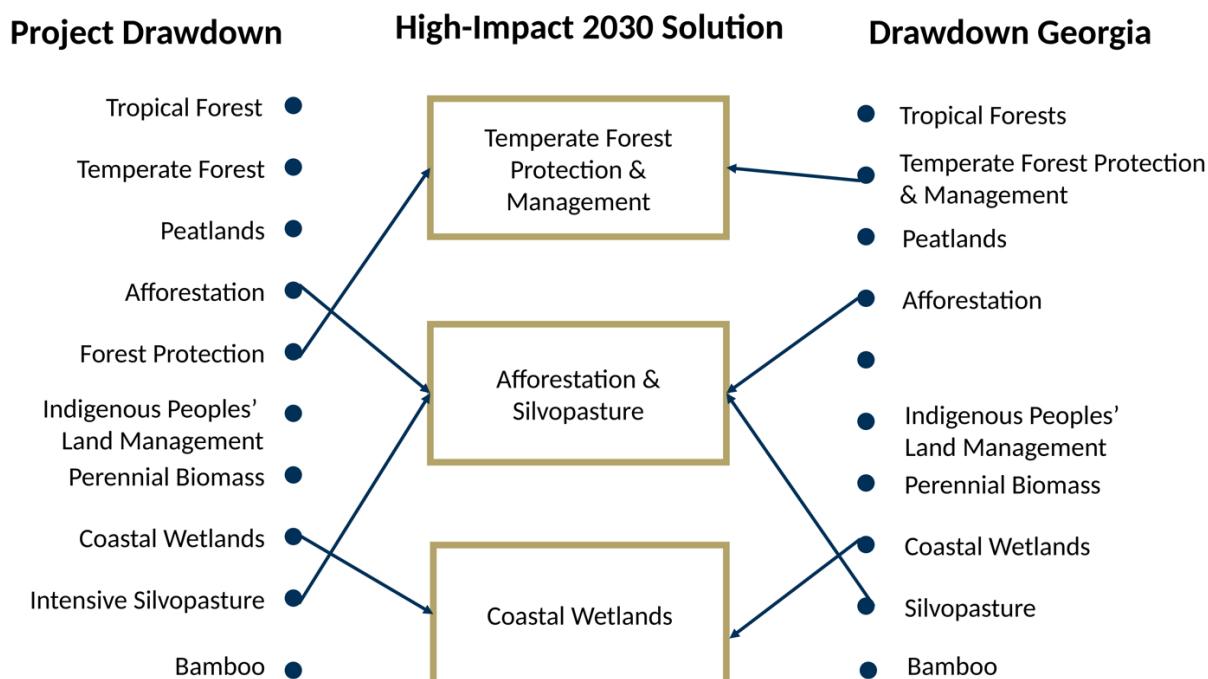
7.5 Forestry and Land Use

The list of high-impact 2030 solutions includes three solutions from the food systems sectors:

- 1. Afforestation & Silvopasture:** Afforestation is the process of creating forests in places that are no longer forested. This could include planting trees on degraded agricultural or on pasture lands (i.e., silvopasturing) and planting in urban areas. Forests sequester carbon in trees, soil, and other vegetation.
- 2. Coastal Wetlands:** Coastal wetlands, including mangroves, seagrasses, tidal salt marshes, and freshwater marshes, are effective carbon sinks. These ecosystems sequester carbon in plants and soils.
- 3. Temperate Forest Protection & Management:** Restoring and managing temperate-climate forests has many benefits, including carbon sequestration from trees, soil, and other vegetation. Protecting existing forests, including old growth forests, can reduce deforestation rates, and safeguard carbon sinks. This includes legal protections as well as market-driven programs.

These solutions were derived from the 8 forestry and land use solutions evaluated by Drawdown Georgia (Figure 7.5).

Figure 7.5. Crosswalk of Drawdown Solutions in Forestry and Land Use



7.5.1 Forestry and Land Use Down-Selection Process

These solutions were part of the 8 forestry and land use solutions evaluated by Drawdown Georgia. Each of these solutions was filtered through the four-step down selection process. Solutions dropped out at the first stage of evaluation.

Down selection question	Solutions Dropped
Is the solution technology and market ready for Georgia?	Bamboo, Indigenous Peoples' Land Management, Peatlands, Perennial Biomass, Tropical Forests
Is there sufficient local experience and available data?	
Does the solution provide about 1 Mt of CO ₂ -e reduction annually?	
Is the solution cost competitive?	

7.5.2 Key Takeaways

Georgia's forests are already a large-scale carbon sequestration ecosystem. Based on Forest Inventory and Analysis (FIA) data, between 2007 and 2017 Georgia forests accumulated an average of 27 Mt CO₂ annually in living tree biomass above and below ground.²⁰ A preliminary estimate of annual carbon uptake in state soils is 3 Mt CO₂ (Richter et al. 1999, Carey et al. 2016, Crowther et al. 2016, Machmuller et al. 2018). This brings the total estimated annual carbon sequestration of Georgia's forests to an estimated 30 Mt CO₂.

More carbon sequestration in the forests and soils of Georgia is possible. For example, by returning Georgia's current forest coverage to its coverage in 1974, 3.5 MT CO₂ of additional sequestration would result.

8 Discussion and Next Steps

While this initial phase of the Drawdown Georgia project has achieved a great deal, more work is needed. This concluding section begins by discussing the strengths and limitations of the down-select process used to identify high-impact 2030 solutions for Georgia. The paper ends with a short discussion of planned next steps.

8.1 Discussion of the Down-Selection Process

This working paper documents the first assessment of the Project Drawdown®'s 102 global solutions in terms of their applicability and potential if implemented in an individual U.S. State. By developing, executing, and documenting a rigorous and replicable methodology for identifying high-impact solutions for 2030, Drawdown Georgia paves the way for other states to jumpstart similar assessments.

As other states consider replicating this process, the strengths and weaknesses of Drawdown Georgia's down-selection process must be considered. Key among the strengths of Drawdown Georgia is its use of public domain data and publicly available analytical tools, as described in this publicly posted working paper. The authors of this paper are all academics with no conflicts of interest that might cause bias in the design and conduct of this study.

Another strength of Drawdown Georgia is its innovative assessment of bundles of solutions. Without bundling, the use of a 1 Mt CO₂ minimum threshold would have precluded many modestly impactful solutions that, if implemented today, could lead to significant reductions on their own by 2050. In an effort to not exclude numerous small-scale solutions, bundles of solutions were considered. For example, retrofitting of existing buildings includes a group of solutions, such as improving building insulation and installing LED lighting. These solutions were

²⁰ Forest Inventory Analysis (FIA) USDA Forest Service. Knoxville, TN. Weblink: <https://www.fia.fs.fed.us/>

unlikely to meet the 1 Mt CO₂ threshold individually but are able to make significant reductions when considered as a group.

On the other hand, there are at least four limitations that warrant consideration as our findings are examined by stakeholders in Georgia and elsewhere.

First, the down-selection process emphasizes the ability of solutions to deliver carbon reductions by the year 2030. This timeframe excludes solutions that may not be technologically- or market-ready in Georgia in the near-term but have real potential to play a meaningful role in later decades. This includes solutions such as off-shore wind and direct air capture of CO₂. Our focus on the near-term should not divert attention away from the need to consider these solutions going forward. Other solutions are too small on their own to meet the 1 Mt CO₂ threshold individually, and bundling is not a logical solution. 1 Mt CO₂ threshold individually. Examples are the construction of zero-energy buildings and the use of engineered wood in construction. It is unlikely that enough new buildings will be constructed by 2030 to meet the emission reduction threshold we set. We recognize that today's challenges are largely a product of past investment patterns and caution that near-term solutions may "lock-in" and pose barriers to the deployment of different longer-term, transformative changes. Thus, even solutions with smaller annual impacts should be nurtured.

Second, examining each drawdown solution in isolation can lead to over- or under-estimates of carbon reduction potential. For example, if the electricity sector continues to decarbonize over the next decade, then the carbon reduction potential from retrofitting buildings would be smaller. Each MWh of electricity saved would displace an increasingly clean fuel. At the same time, under that scenario, the carbon reduction potential of electric vehicles would be higher because petroleum fuels would be displaced by an even cleaner source of energy. Subsequent work needs to examine key social-ecological-technological systems interactions.

Third, our analysis to date does not consider all of the potential leakage or life-cycle impacts of each drawdown solution that can occur outside of Georgia. Perhaps the simplest example of potential carbon leakage is if a drawdown solution were to increase energy prices in Georgia. If this change results in an energy-intensive industry relocating to another state with a more carbon-intensive energy system, then the net savings of the solution should be diminished, but we do not make such an adjustment. A first step toward addressing this limitation would be to consider if the emissions occur in Georgia or out-of-state (i.e., deemed emissions or logistic emissions) or if they are the result of goods and services consumed in the state (i.e., direct emissions) or consumed out-of-state (i.e., responsible emissions) (Sovacool and Brown, 2010). In national accounting of carbon metrics, the IPCC distinguishes between territorial-based and

consumption-based approaches (IPCC, 2014, Figure 5.14). The approach used in the Drawdown Georgia assessment is more territorial than consumption-based, although inconsistencies occur because necessary data and modeling tools are sometimes unavailable.

Finally, our incomplete consideration of social costs and benefits may have resulted in the selection of high-impact 2030 solutions that have significant co-costs, or the failure to select solutions that have significant co-benefits. Subsequent analysis is needed to determine the magnitude of this limitation.

8.2 Future Research Needs

The next phase of research should focus on conducting deeper analysis of the 21 high-impact 2030 solutions. It should also explore feedbacks and relationships among the 21 solutions. This could be done by examining key solution combinations where interactions are likely to be strong.

The team should continue to not only analyze the GHG emissions impacts but also the benefits that go beyond carbon: providing new economic opportunities for citizens of Georgia, advancing equity, supporting other environmental priorities, and improving public health. By understanding beyond-carbon attributes, drawdown solutions also can be optimized in ways that will enable and stimulate their carbon reduction impacts.

Finally, future research should identify barriers that hinder the adoption of the high-impact 2030 solutions and enablers and accelerators that might promote their utilization. This would lay the groundwork for implementation and policy and stakeholder analysis. Continuing engagement of experts and stakeholders, and especially the business community, is vital in this next phase of work. In particular, a stakeholder engagement process should be initiated, with the goal of encouraging collective impact commitments.

Ultimately, we hope to inspire a transformational vision that will motivate businesses, neighborhoods, municipalities, and civic leaders across the state to reduce their carbon footprint.

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- 1 Georgia Institute of Technology
- 2 Emory University
- 3 University of Georgia

GEORGIA DRAWDOWN INITIATIVE ORGANIZATIONAL CHART

