Working Paper Series

Appendix to "Translating a Global Emissions Reduction Framework for Sub-National Climate Action: A Case Study from the State of Georgia"

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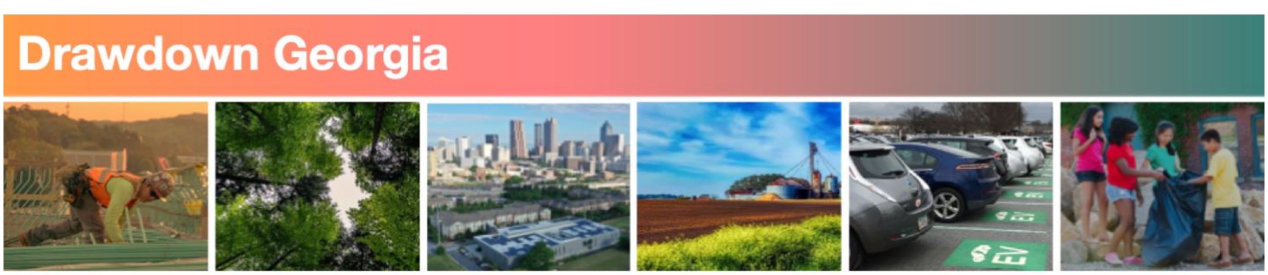
PAPER ABSTRACT

Sub-national entities are recognizing the need to systematically examine options for reducing their carbon footprints. However, few robust and comprehensive analyses are available that lay out how U.S. states and regions can most effectively contribute. This paper describes an approach developed for Georgia – a state in the southeastern United States. Called "Drawdown Georgia," our research involves (1) understanding Georgia's baseline carbon footprint and trends, (2) identifying the universe of Georgia-specific carbon-reduction solutions that could be impactful by 2030, (3) estimating the greenhouse gas (GHG) reduction potential of these high-impact 2030 solutions for Georgia, and (4) estimating associated costs and benefits while also considering how the solutions might impact societal priorities, such as economic development opportunities, public health, environmental benefits, and equity. We began by examining the global solutions identified by Project Drawdown. The resulting 20 high-impact 2030 solutions provide a strategy for reducing Georgia's carbon footprint in the next decade using market-ready technologies and practices and including negative emission solutions. This paper describes our systematic and replicable process and ends with a discussion of its strengths, weaknesses, and planned future research.



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OVERVIEW OF APPENDIX

This appendix includes short descriptions of the solutions that Drawdown Georgia evaluated for possible carbon reduction impacts as well as costs and benefits in Georgia, focusing on the period 2020-2030. The solutions are derived from the more than 200 global solutions highlighted by Project Drawdown®. We describe them by sector: electricity, transportation, buildings & materials, food & agriculture, land sinks, and beyond carbon.

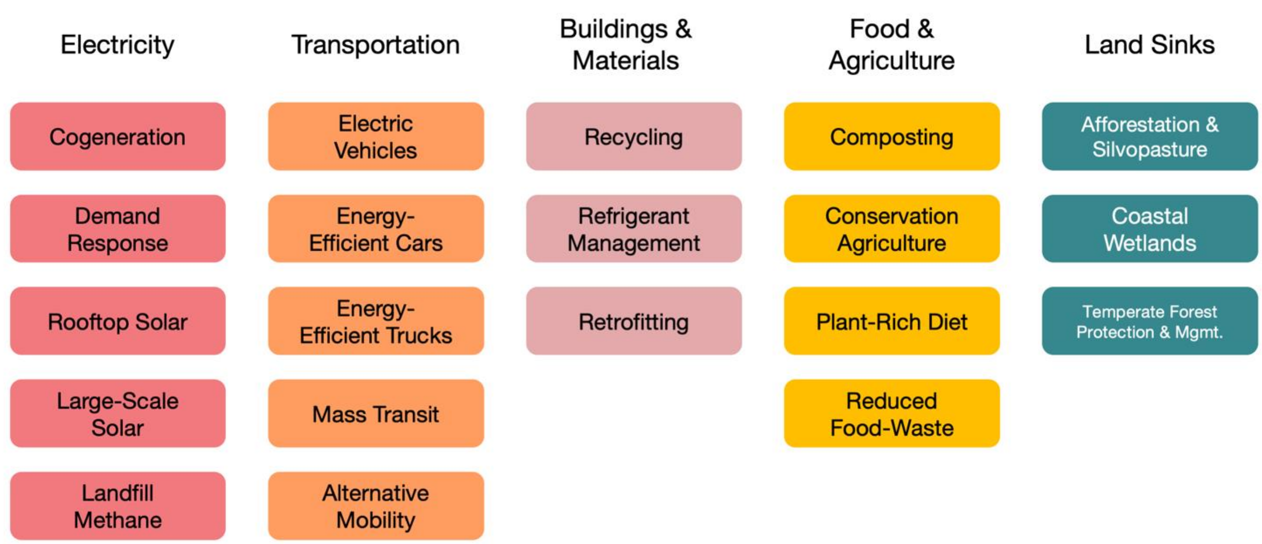
Each solution was evaluated on five key metrics:

1. Technology & market readiness
2. Local experience & data availability
3. Technically achievable CO_2 drawdown potential
4. Cost competitiveness
5. Other (beyond carbon) attributes

Since the application of these metrics can differ across the sectors, each section of this appendix begins with a description of the specific metrics used.

Solutions that rose to the top after sorting through these analytic filters were identified as high-impact 2030 solutions for Georgia. The next phase of research will further characterize these 20 high-impact solutions.

High-Impact 2030 Solutions for Georgia



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A Appendix A: Electricity

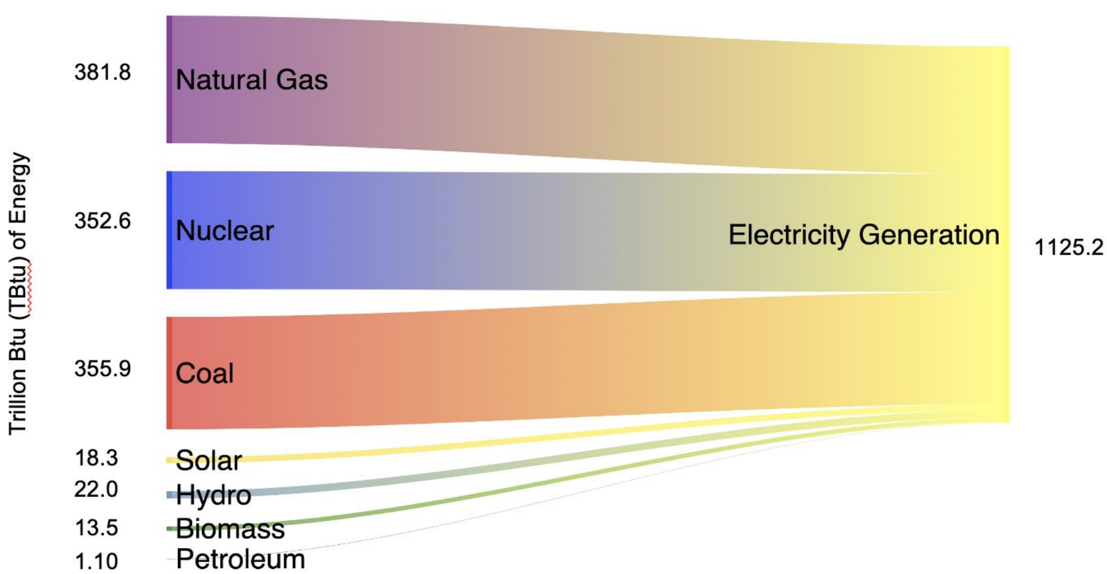
A.1 Solution List

- Wind Turbines (Onshore)
- Large-Scale Solar
- Rooftop Solar
- Geothermal
- Nuclear
- Wind Turbines (Offshore)
- Concentrated Solar
- Wave and Tidal
- Methane Digesters (Large)
- Biomass
- Solar Water
- Landfill Methane
- In-Stream Hydro
- Cogeneration
- Methane Digesters (Small)
- Waste-to-Energy
- Micro Wind
- Energy Storage (Utilities)
- Energy Storage (Distributed)
- Grid Flexibility
- Microgrids
- Demand Response
- Carbon Capture and Storage

A.2 Down-Select Criteria for Electricity Solutions:

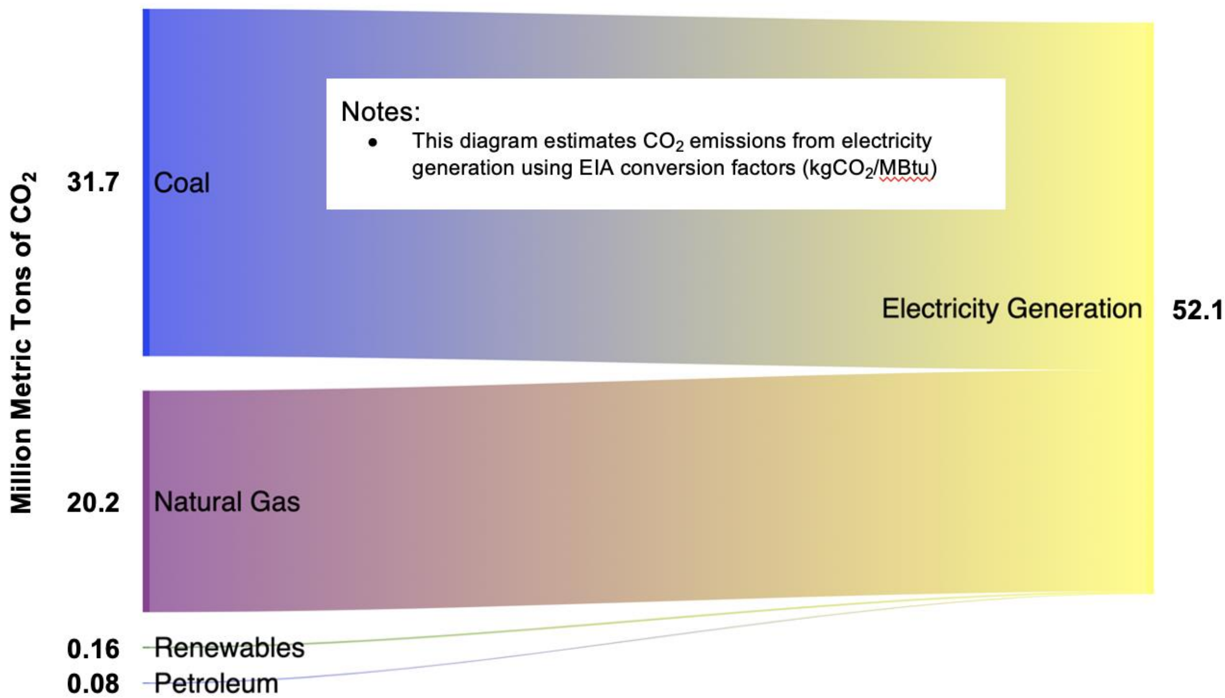
6. **Technology & Market Readiness** - Are the components of the Solution ready enough to be launched at significant scale over the next decade? (Can innovation, technology, and policy developments make the Solution workable by 2030, if it is not already?)
7. **Local Experience & Data Availability** - Is there sufficient data or qualitative analysis to adequately consider the Solution in a Georgia context? Is there local or regional familiarity with the technology? Are there any local pilot or demonstrations to study? Is the level of complexity of the Solution manageable so that it can be credibly assessed?
8. **Technically Achievable CO_2 Reduction Potential** - Could the Solution achieve significant carbon reductions in the 2030 timeframe as compared to other Solutions available to this sector? (A threshold of 1 Mt CO_2e annually is used--about 1% of Georgia's 2017 CO_2 emissions from fossil fuels.)
9. **Cost competitiveness** - Is the Solution's levelized cost of electricity (LCOE) in Georgia competitive with other Solutions available to the sector? Are the up-front capital costs affordable? Is the payback period competitive with other Solutions?
10. **Other ("Beyond Carbon") Attributes** – What are the major co-benefits or co-costs beyond carbon on four dimensions: environment, economic development, public health, and equity?

Georgia's Electricity Generation by Energy Source, in 2017



Data source: SEDS https://www.eia.gov/state/seds/seds-data-complete.php?sid=GA#Consumption
Conversion factors: Page 3 https://www.epa.gov/sites/production/files/2019-04/documents/2019_fast_facts_508_0.pdf

CO_2 Emissions from Electricity Production in Georgia, in 2017 (in $MtCO_2$)



Data source: SEDS https://www.eia.gov/state/seds/seds-data-complete.php?sid=GA#Consumption
Conversion factors: Page 3 https://www.epa.gov/sites/production/files/2019-04/documents/2019_fast_facts_508_0.pdf

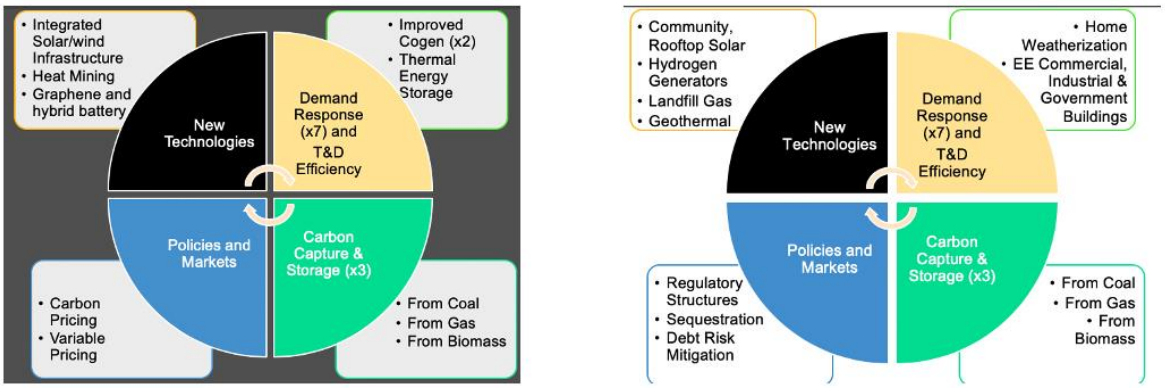
Key assumptions about the electricity sector that underpin calculations in some of the 2-pagers:

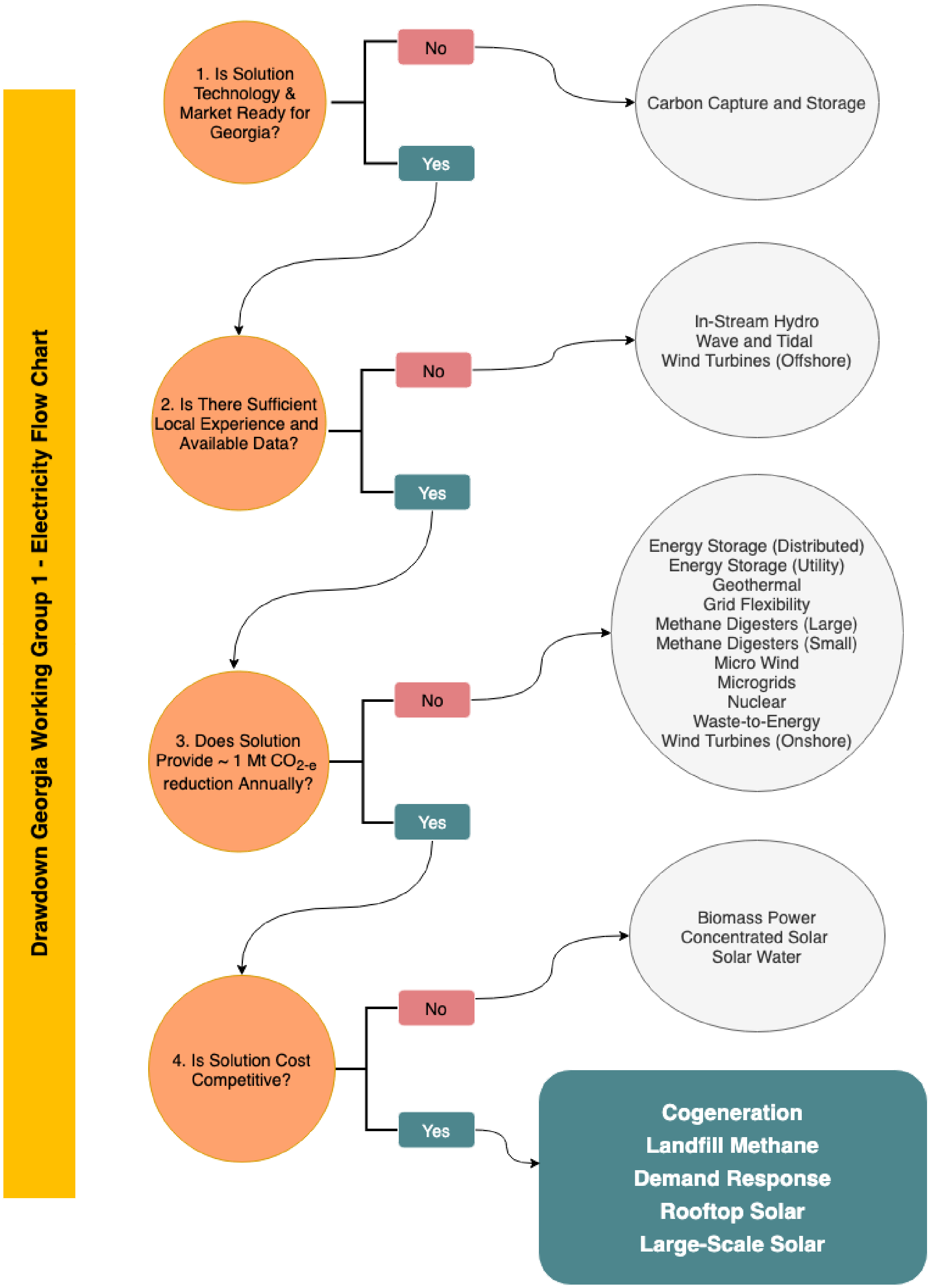
GT-NEMS analysis of the SERC-SE region was used to provide a baseline forecast of the future carbon intensity of electricity generation in Georgia. SERC-SE represents the territory served by the Southern Company, which is the "balancing authority" for electricity generation in Georgia. GT-NEMS provides a baseline forecast of electricity generation and CO_2 emissions from electricity for the SERC-SE region. This enables a baseline foreast of the carbon intensity of electricity generation in Georgia. In 2030, it is assumed that 388 tCO_2 will be emitted per gigawatt hour (GWh) of electricity generated in Georgia. At this projected carbon intensity in 2030, 1 $MtCO_2$ could be avoided by adding 2,580 GWh of zero-carbon electricity. In 2018, electricity was much more carbon intensive: 425 tCO_2 was emitted per GWh of electricity; at that rate, 2,355 GWhs would have needed to be displaced by carbon-free electricity to avoid emissions 1 $MtCO_2$.

According to S&P data, SERC-SE (i.e., the Southern Company) generated 254,000 GWh of electricity in 2018, and 104,000 GWh (40.9%) of this total was produced by Georgia Power

Company. In the same year, SERC-SE had 66 GWs of generating capacity, with 30.5 gigawatt (GW) (46.2%) of this total owned by Georgia Power Company. Georgia has additional generation and generating capacity (in particular, two dams) in the northern tier of the state, which is owned and operated by the Tennessee Valley Authority.

Possible New Solutions for Georgia: Experts (left) vs the Public (right)





Note: Large-Scale Solar includes solar farms and community-scale solar. Rooftop Solar is a bundled solution with nergy Storage. Demand Response is a bundled solution with Grid Flexibility and Microgrid.

Down-Select Steps to Identify High-Impact 2030 Solutions

A.3 Down-Select Results for Electricity Solutions

A.3.1 Wind Turbines (Onshore) | Down-Select

Wind energy can be used to generate electricity. Advances in wind turbine technology have decreased costs and improved performance. In many parts of the country, onshore wind energy is one of the least expensive sources of electricity. However, wind resources vary by location.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	The technology is mature and market ready. In the United States and globally, onshore wind capacity is growing rapidly. Wind capacity has increased by around 20% each year since 2009 (Shearer, Yussuff, & Gouveia 2019). But in Georgia, wind resources are sufficient only at 80 meter heights and above. Success with such systems will require new manufacturing for on-site assembly of wind turbines. Such assembly approaches do not exist today, but it is expected that they will be developed over the next decade.
Local Experience & Data Availability (2)	**Yes**	As of today, there are only two onshore wind farms in the Southeast. The first is Buffalo Mountain Wind Farm in Tennessee, which started in 2001 with three small wind turbines. In 2004, 15 larger turbines were added, bringing the wind farm's capacity to about 29 MW. Desert Wind near Nags Head North Carolina came on line in 2016 with 104 turbines and an operating capacity of 208 MW (The Wind Power, 2019). [1] Due to its larger scale, Desert Wind serves as a case study in determining the potential of wind power in the state of Georgia. While there is limited on-the-ground local experience in the Southeast, there is a great deal of data from other regions.

Technically Achievable CO2 Reduction Potential (3)	**No**	Georgia has modest wind resources compared with many other parts of the United States.[3,4] At an 80 meter hub height, Georgia's inland winds are in the 4-5 m/s category, leading to a wind resource potential of 130 MW (30% capacity factor). However, using new technology to harness wind at greater heights, this can increase to 294 MW (at 100 meters and 30% capacity factor). Desert Wind Farm's turbines have a hub height of 93 meters, whereas the majority of wind resource in Georgia is higher in altitude, near 140 meters. Given the total available wind resource of 294 MW in Georgia with a capacity factor of 30%, the maximum potential for CO_2 reduction is 0.3 Mt $CO_{2\text{-}e}$ per year. This is smaller than 1 Mt $CO_{2\text{-}e}$ goal or 1% CO_2 reduction in 2030. Lopez, et al. (2012, Table 6) estimates that the total technical potential for onshore wind power in Georgia is <1 GW and 323 GWh.
Cost Competitiveness (4)	**No**	Based on an analysis of data from S&P Global,[1] the LCOE of Desert Wind Farm with no federal investment tax credit (ITC) is $50/MWh. This is mostly in line with the global weighted average LCOE for wind of $56/MWh. With an ITC of 12% and 30%, the LCOE of Desert Wind Farm is $44.6/MWh and $36.6/MWh (Weed, 2019). At current hub height around 80 meters, EIA cost estimates for new generation in the SERC-SE Region is $36.6/MWh x 0.94 = $34.4/MWh. There are no reliable estimates for 100-meter hubs, but the logistics of erecting 100-meter hubs are more challenging and costly.
Beyond Carbon Attributes (5)		Societal costs of on-shore wind farms include bird kills, high land intensity (acres per MWh), noise and landscape pollution, and destruction of wildlife and ecological environment that often give rise to strong backlash from local residents. Co-benefits include income for rural landowners and jobs (the Desert Wind Farm the farm employs around 10 permanent positions for continued operations). The land around the wind turbines of the farm could also be used for the grazing of cattle or for another agricultural purpose that requires little labor from the farmer. For example, Desert Wind Farm is located on 500 acres, but the turbines and related infrastructure take up less than 1% of that. The construction of wind farms in rural areas in Georgia could inject millions

		of dollars into local economies, the tax revenue from which could be directed to fund schools, police and fire departments, infrastructure improvements, or public spaces such as parks.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

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Lopez, Anthony, Billy Roberts, Donna Heimiller, Nate Blair, and Gian Porro. (2012) *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis* National Renewable Energy Laboratory, NREL/TP-6A20-51946, https://www.nrel.gov/docs/fy12osti/51946.pdf

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4. The link to the 100m wind speed map from NREL is https://www.nrel.gov/gis/assets/pdfs/wtk_100_m_2017_01.pdf.
5. https://www.energy.gov/eere/wind/downloads/2018-wind-technologies-market-report

A.3.2 Large-Scale Solar | Down-Select

Solar photovoltaic systems can convert solar energy into electricity. Utility-scale solar is defined as any ground mounted solar panel facility that has a capacity rating larger than 5 MW. Community-scale solar generally has a capacity of 0.5-5 MW. This solution also considers the possible advantage of coupled on-site storage to enhance reliability.

<table>
<tr><th>Criteria</th><th></th><th>Comments</th></tr>
<tr><td>Technology and Market Readiness (1)</td><td>Yes</td><td>The technology is mature and market ready. In Georgia, the United States and globally, utility-scale solar is growing rapidly and costs have been declining. By mid-2019, total solar PV capacity in Georgia had risen to more than 1,570 MW, with more than 1,000 MW of that at utility-scale facilities. There is less experience with solar and storage projects in Georgia. Across the United States, at least 85 co-located solar and storage projects are in the planning stages, according to S&P Global Market Intelligence data,[1] pairing 4,175 MW of storage with 8,921 MW of solar. Roughly 40 such systems were in operation in the United States as of late September 2019, combining about 533 MW of storage with 1,242 MW of solar capacity. None of these hybrid facilities are proposed or currently located in Georgia (Hering, 2019).</td></tr>
<tr><td>Local Experience & Data Availability (2)</td><td>Yes</td><td>In 2014 Silicon Ranch Corporation and Green Power EMC constructed a solar farm located in Jeff Davis county in southeast Georgia near Hazlehurst, one of the first and largest solar farms in the Southeast. (Silicon Ranch is one of the nation’s largest independent solar power producers and the U.S. solar platform for Shell.) This solar farm sits on 135 acres of land with a capacity of 55.2 MW. Georgia now has 8 solar farms with an operating capacity above 50 MW totaling 559.4 MW. Three of the largest solar facilities in the state have capacities of 100 MW or greater. In 2018, utility-scale facilities produced almost 90% of the state's solar PV generation (EIA 2019). Thus, there is ample documentation of the performance of solar farms in the United States and the Southeast.

Georgia Solar Farms with an Operating Capacity above 50 MW
<table>
<tr><td>Jeff Davis, 55.2 MW</td><td>Butler Solar Project, 100 MW</td></tr>
<tr><td>Decatur Parkway Solar Project, 80 MW</td><td>White Oak, 76.5 MW</td></tr>
<tr><td>Hazlehurst Solar II, 52.5 MW</td><td>White Pine, 101.2 MW</td></tr>
<tr><td>Sand Hills, 143 MW</td><td>Live Oak, 51 MW</td></tr>
</table>
Source: S&P Global Market Intelligence[1]

Community solar projects range from a few hundred kW to a few MW on the distribution grid (i.e., non-customer-sited) and are administered by the utility or a third-party entity in which multiple customers can participate. In 2015, approximately 60 MW of community solar was operating in the United States</td></tr>
</table>

		(Funkhouser, et al., 2015). Several community solar projects are currently operating in Georgia.
Technically Achievable CO2 Reduction Potential (3)	**Yes**	Lopez, et al. (2012, Table 3) estimates that the total technical potential for rural utility-scale solar farms in Georgia is 3,088 GW and 5,492,000 GWh, covering 64,343 km^2. It estimates an additional technical potential for urban utility-scale solar that might be suitable for community projects, totaling 24 GW and 43,167 GWh, covering 506 km^2 (Lopez, et al., 2012, Table 2). These estimates exclude sites with slopes over 3%, <0.4 square miles of contiguous area, and wetlands, federal parks, wilderness areas, wildlife areas, and many other incompatible land uses. Based on these estimates, only 16 states are estimated to have higher technical potential than Georgia. According to the Solar Energy Industries Association (SEIA), Georgia is 11th in potential for future growth. Georgia's solar resource of 4.5-5.0 kWh/m2/day is slightly less than that of Florida (NREL, 2012). The Georgia Power IRP 2019 calls for 2,000 MW of new utility-scale solar by 2022. This would displace 1.36 Mt CO_2 in 2030.[1] GT-NEMS forecasts a growth of solar farms in Georgia from 11,600 GWh or 7.9% in 2020, to 12,800 GWh or 8.9% in 2030 (Source: GT-NEMS modelling). This growth would displace 0.47 Mt CO_2 in the year 2030. To displace an additional 1 Mt CO_2 will require 2,580 GWh of additional solar generation. At a capacity factor of 25%, this would require 1,178 MW of new capacity, or 10 additional 100 MW solar farms and 36 additional 5 MW community solar projects. The total of these two estimates is a technical potential of 5,535,000 GWh from utility-scale solar. This could displace 2,145 Mt CO_2, which is more than 10 times the current GHG footprint of Georgia.
Cost Competitiveness (4)	**Yes**	EIA cost estimates for new generation in the SERC-SE Region is $37.6/MWh x 0.94 (regional multiplier) = $33.5/MWh. Utilizing data from S&P Global Market Intelligence and the Georgia Tech LCOE calculator, the estimated LCOE for utility-scale solar today is $85.6/MWh. Levelized energy prices for solar farms with lithium-ion batteries have dipped into the range of $30-$40/MWh for many projects scheduled to come online in the next few years in California, Arizona, and Nevada (Bolinger and Seel, 2018).
Beyond Carbon Attributes (5)		The environmental and public health benefits of solar farms relate to air quality improvements from the reduction of fossil fuel pollution, particularly SO_2 (a major contributor to acid rain), $PM_{2.5}$ (a respiratory health concern), and NO_X, besides CO_2 (Millstein et al., 2017).

[1] https://docs.google.com/spreadsheets/d/1TiUeJgrb_i-0rSrIbzQKkOBtAqWaJSbDYLq8ReyYoik/edit#gid=0
(This links to an external Google Spreadsheet)

		From an economic development standpoint, construction and operation of solar farms offer local and statewide employment. According to Georgia Solar Job Census 2018, there are 304 solar companies operating in Georgia. In 2019, Georgia was second to Florida in the number of new solar jobs, with 30% growth, bringing the total solar employment in Georgia to 4,798.[4] For many of the solutions noted in this document, displacement of jobs from coal or other sources will need to be considered/addressed against these positive economic benefits. Despite its jobs potential, the solar workforce is currently not yet representative of America's ethnic, racial, and gender diversity. Solar Jobs Census 2019[4] found that only 26% of the solar workforce was made up of women, and the racial breakdown is dominated by the workers who are White, comprising 73.2% of the overall solar workforce. Potential environmental costs may include the depletion of water resources due to solar panel cleaning (approximately 20 gal/MWh[5]), and land use concerns about displacement of native flora and fauna. While monitoring water use and seeking efficiencies are worthwhile endeavors, solar farms use of water is less intensive than traditional fossil fuel alternatives (Klise, et al., 2013).[6] On land use, solar farms in Georgia can produce 18.5 MW per square mile (Lopez, et al., 2012). Thus, 1 Mt CO_2 reduction via solar farms requires about 64 square miles of land. Potential impacts (both positive and genitive) of intermittent solar generation on retail electricity prices are supported by mixed research findings.[7,8] Similarly the property-value impacts near utility-scale solar farms needs to be explored further.[9] Given the scale of current and potential solar panel installations, end-of-life disposability of PV panels is a pertinent environmental issue (Chowdhury et al., 2020) due to toxic materials contained within the cell, for example, cadmium, arsenic, and silica dust. 13,000 tons of PV panel waste is expected to be produced by the United States in 2020.[10]
Down-select Decision	**Yes**	Retain for further analysis

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A.3.3 Rooftop Solar | Down-Select

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.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology is mature and market ready. In Georgia, the United States and globally, rooftop solar is "market ready" and is growing rapidly. With technology breakthroughs and cost reductions from "learning by doing," costs have been declining rapidly. Solar panels have become economically feasible, with the average price for a 6 KW solar system dropping from $51,000 to $17,880 in the past decade (Matasci 2019).
Local Experience & Data Availability (2)	**Yes**	Ample data are available for rooftop solar. NREL publishes maps of solar radiation, and there are rigorous and numerousmple assessments of the performance of rooftop solar in the United States and the Southeast. At the end of Quarter 3, 2019, Georgia had 1,202 MW of installed solar on rooftops (residential and commercial).[7] Solarize programs have been successful in Decatur-Dekalb (850 program participants), Atlanta (1,103 program participants), Athens (701 program participants), Carrollton-Carroll (239 program participants), Newton-Morgan (230 program participants), Roswell (148 program participants), Middle Georgia (291 program participants), and Dunwoody (*inactive, 282* program participants).[8] There are 304 solar companies in Georgia and 3,696 jobs are supported by the solar industry in Georgia (The Solar Foundation, 2019).[6]
Technically Achievable CO2 Reduction Potential (3)	**Yes**	In 2030, it is assumed that 388 tCO_2 will be emitted per GWh of electricity generated in Georgia. At this projected carbon intensity, 1 $MtCO_2$ could be avoided in 2030 by adding 2,580 GWh of zero-carbon electricity (source: GT-NEMS modelling). The median single family home floor area in Georgia is 2,200 square feet.[1] A 5-kW solar installation can use as little as 400 square feet and is therefore viable on the average home, assuming sufficient sunlight exposure and a sturdy roof. Assuming a capacity factor of 20% (or nearly 5 hours/day), a 5-kW rooftop system would generate 8.76 MWh/year. To generate 2,580 GWh of zero-carbon electricity in 2030 and displace 1 Mt CO_2 would require 295,000 5-kW solar rooftops. Fewer new systems would be needed if the industry continues to experience improvements to the efficiency of rooftop solar systems over the next decade. The Solar Energy Industries Association (SEIA) ranked Georgia 11th in

		potential for future growth. Lopez, et al. (2012, Table 4) estimates that the total technical potential for rooftop photovoltaics in Georgia is 25 GW and 31,116 GWh. Therefore, the goal of a 1 Mt CO_2e reduction in 2030 appears challenging, but achievable.
Cost Competitiveness (4)	**Yes**	Using the price estimate of $2.50 to $3.38 per watt, a 5 kW solar panel installation in Georgia would cost $12,500 to $16,900 each; and $1.95- $2.6 billion to reduce 1 Mt $CO_{2\text{-}e}$ by 2030.[3] Lazard (2018) estimates U.S. average LCOE for residential solar rooftop is $160-$267/MWh and for commercial and industrial solar rooftop, costs are lower at $81-$170 /MWh. EIA (2019) estimates slightly higher costs.
Beyond Carbon Attributes (5)		Environmental benefits of rooftop solar relate to air quality improvements from the reduction of fossil fuel pollution, particularly SO_2 (a major contributor to acid rain), $PM_{2.5}$ (a respiratory health concern), and NO_X, besides CO_2 (Millstein et al., 2017). From an economic development standpoint, construction and operation of solar solutions offer local and statewide employment. According to Georgia Solar Job Census 2018, there are 304 solar companies operating in Georgia. In 2019, Georgia was second to Florida in the number of new solar jobs, with 30% growth, bringing the total solar employment in Georgia to 4,798.[4] Rooftop PV systems with battery solutions have the potential to supply electricity during grid outages resulting from emergency situations, which offers benefits for electricity system resilence. Additionally, rooftop panels have been found to have a positive impact on property values (Adomatis, et al., 2015). Given the scale of current and potential solar panel installations, end-of-life disposability of PV panels is a pertinent environmental issue (Chowdhury et al., 2020) due to toxic materials contained within the cell, for example, cadmium, arsenic, and silica dust. 13,000 tons of PV panel waste is expected to be produced by the US in 2020.[5] In terms of potential adverse impacts related to equity and solution accessibility, Sunter et al. (2019) found significant racial and ethnic differences in rooftop solar adoption in the US, even after accounting for income and household ownership. NREL (2015) also analyzes the impact of rate design to recover fixed utility costs arising from lower net electricity consumption after residential PV penetration, which may exacerbate the “energy burden” experienced by lower income households who, without access to solar, continue to purchase all of their electricity from the grid.
Down-select Decision	**Yes**	Retain for further analysis

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A.3.4 Geothermal | Down-Select

Geothermal technology generates electricity by tapping into reservoirs of hot water that are found deep underground. This water is piped to the surface and used to drive the turbines that generate power.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	The technology is mature and market ready; the technologies of geothermal are well-developed. Global installed geothermal electric power capacity at the end of 2018 was at a total of about 14.6 GW with new additions from 8 countries led by Turkey and Indonesia.[8] Regions and countries near the "Ring of Fire" that have developed geothermal power include the western coast of the United States, Indonesia, Philippines, Japan, New Zealand, and Central America. Rift zone areas that have developed geothermal power include Iceland and East Africa (Ethiopia and Kenya).
Local Experience & Data Availability (2)	**Yes**	Geothermal development historically has been restricted to active heat-flow tectonic areas near plate boundaries, rift zones, and mantle plumes as well as hot spots that present thinner crust (MIT, 2006). Roosevelt Warm Springs Institute for Rehab. Pool & Spa is a Low Temperature Geothermal Facility in Georgia. Its annual generation is 2.10 GWh/year. At 388 metric tons per GWh of generation, that equates to 814.8 metric tons of CO_2 reduction.
Technically Achievable CO2 Reduction Potential (3)	**No**	Georgia would need 2,580 GWh/year of geothermal to reach 1 Mt CO_2 reduction. At the same small scale of the Roosevelt Warm Springs project, we would need 1,227 localized geothermal energy projects in Georgia; or we would need geothermal plants that produced at higher rates (Roosevelt is basically the size of a demonstration project and only provides electricity to meet its own needs). For comparison, one of the smallest California geothermal plants – Mammoth 1 – generates 70.2 GWh/year. Based on heat maps, possible places for the plants in Georgia include the lower Savannah River Area from Screven County down to Chatham. Based on geological formation, Georgia likely has newer granite sites in the piedmont area, such as Stone Mountain, which is 300-350 million years old granite. Also, there is a 20 square mile area of natural hot springs in in West Central Georgia. The question remains whether it is feasibie to build geothermal power plants at any of these sites (cost, political will, private property rights, etc.) to capture Georgia's geothermal possibilities by 2030. Lopez, et al. (2012, Table 10) estimates that the total technical potential for enhanced geothermal systems in Georgia is 45 GW or 353,206 GWh.
Cost Competitiveness	**No**	EIA estimates the LCOE for geothermal in the U.S. is \$86.6/MWh. This is quite a higher than for natural gas and solar, which tends to range from \$41-

(4)		78/MWh (Brown, et al., 2019). No Georgia-specific cost estimates are available. According to IRENA (2019, Figure S.1), the LCOE of conventional global geothermal power varied from \$0.05- \$0.10/kWh for projects operating in 2018. However, across the globe, only 540 MW of geothermal power generation capacity was added in 2018, making it difficult to estimate costs with confidence.
Beyond Carbon Attributes (5)		Minimal air pollution.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

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8. https://www.thinkgeoenergy.com/global-geothermal-power-generation-capacity-reaches-14600-mw-at-year-end-2018/

A.3.5 Nuclear | Down-Select

Nuclear power plants use fission to generate electricity. This is a process in which the strong bonds in the nucleus of an atom, typically uranium, are split. The energy released through this process can be used to create electricity.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology is mature and market ready. The technologies of nuclear are well-developed. Southern Company is constructing the first U.S. Westinghouse AP1000 technology – two AP1000 (1000 MW) nuclear units – at Plant Vogtle.
Local Experience & Data Availability (2)	**Yes**	Georgia Power's two AP1000 units will not be completed for several years, and after that their performance can be evaluated. There is regional experience with uprating nuclear power plants, based on the experience of the Tennessee Valley Authority at its Browns Ferry Plant in Alabama.
Technically Achievable CO2 Reduction Potential (3)	**No**	The two operating units at Plant Vogtle Nuclear Plant had a net generation in 2018 of 19,959 GWh/year. At 388 metric tons per GWh of generation, that equates to 7.7 Mt CO_2 reduction. We assume that the two nuclear units currently under construction at Plant Vogtle will be completed in the current decade. The long lead time of permitting and constructing new nuclear units makes it unlikely that additional new nuclear reactors could be permitted, built, and made operational in Georgia by 2030. However, there may be an opportunity to uprate the generation from Georgia's older existing nuclear units at Plants Hatch or Vogtle by perhaps 5%. For Vogtle Units 1 and 2, for example, that might reduce emissions by 0.39 Mt CO_2.
Cost Competitiveness (4)	**No**	EIA estimates that the LCOE for new advanced nuclear in Georgia is \$77.5/MWh. Lazard (2018) estimates the U.S. average LCOE to be \$112-\$189/MWh. Both sources estimate nuclear at quite a bit higher than the \$41/MWh for natural gas or solar. The LCOE of nuclear is 47% higher than the LCOE for natural gas and solar. These estimates are generally consistent with EIA (2018).
Beyond Carbon Attributes (5)		Co-costs include risk associated with long-term storage of hazardous waste. Co-benefit: minimal air pollution and small land footprint.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

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2. https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

A.3.6 Wind Turbines (Offshore) | Down-Select

Wind energy is used to generate electricity. Wind turbines can be built offshore where wind tends to be stronger and more uniform. These high wind speeds can produce relatively more electricity.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Off-shore wind farms are in a demonstration phase in the United States today. The global offshore wind capacity reached 22.5 GW in 2018 according to DOE's 2018 *Offshore Wind Technologies Market Report.* Therefore, globally, this technology is well beyond the technology demonstration phase.
Local Experience & Data Availability (2)	No	The technologies of wind turbines offshore are emerging and being demonstrated at some areas of the United States. No wind turbines offshore have been built in Georgia or the Southeast. There is only one project in the United States: the Block Island Project, off the coast of Rhode Island (~30MW). Others are being planned. Nine offshore wind projects are in planning stages, including one in Virginia and one in Maryland. The biggest is Vineyard Wind, off the coast of Massachusetts (DOE, 2018). A wind farm proposed to be built in wind lease areas off the coast of Central California is likely to become the first in the United States to use floating turbines at large scale (Iaconangelo, 2020).
Technically Achievable CO2 Reduction Potential (3)	**No**	There is a significant wind resource in the Southeastern United States for offshore wind (NREL, Wind Energy Resource Atlas of the United State), but further assessment of the resource is needed. Based on the capacity (30 MW) and capacity factor (43%) from the Block Island offshore wind farm, we can estimate that we need at least 23 offshore wind farms to reach 1 Mt $CO_{2\text{-}e}$ reduction. It is highly unlikely to realize in the 2020 to 2030 timeframe. Lopez, et al. (2012, Table 7) estimates that the total technical potential for offshore wind in Georgia is 59 GW and 220,800 GWh. However, an unknown portion of this potential is not cost-competitive.

Cost Competitiveness (4)	**No**	EIA estimates that the LCOE for off-shore wind in Southeast is $117.9/MWh, which is quite a bit higher than for natural gas or solar (EIA, 2019).
Beyond Carbon Attributes (5)		Co-costs: Interference with ocean ecosystem. Co-benefits: Improved air quality, lower water withdrawal from electric sector, annual lease/property tax payments to local economy, job creation particularly during the construction phase (DOE, 2018).
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

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2. The link to the 80-m wind speed map from NREL is https://www.nrel.gov/gis/images/80m_wind/awstwspd80onoffbigC3-3dpi600.jpg
3. The link to the 100m wind speed map from NREL is https://www.nrel.gov/gis/assets/pdfs/wtk_100_m_2017_01.pdf
4. https://www.boem.gov/renewable-energy/renewable-energy-program-overview

A.3.7 Concentrated Solar | Down-Select

Concentrated solar power (CSP) plants use mirrors to focus the sun's energy to drive conventional steam turbines or engines that create electricity.

Criteria		Comments
Technology and Market Ready? (1)	**Yes**	The technologies of CSP are well-developed, but there are not many installations in the United States. Examples include: Gila Bend, Arizona, and Solana Generating Station (2013), a parabolic trough solar plant in Florida that also has 6 hours of molten salt storage.[1,4]
Local Experience & Data Availability (2)	**Yes**	There are no CSP plants in Georgia. In 2010, The U.S. Department of Energy (DOE) issued a $1.45 billion loan guarantee to finance Solana, a 250-MW parabolic trough CSP plant in Florida with an innovative thermal energy storage system. Solana represents the first deployment of this thermal energy storage technology in the United States and is one of the largest projects of its kind in the world. It started commercial operations in October 2013.[2] Operated by Florida Power & Light at a hybrid plant in Martin County, Florida, the CSP unit has an array of approximately 190,000 parabolic trough mirrors on about 500 acres. The solar collectors feed heat to the existing steam plant, displacing gas generated electricity. It is the first CSP plant in the United States to store over 1,000 MWh of energy that is dispatchable on demand without sunlight.[2] The 2012 solar-derived production was about 89,000 MWh of power; it was expected to generate 800,000 MWh of clean energy per year.[2] Unfortunately, information on the CSP portion of the plant is not available in the S&P Energy Market Intelligence.[3]
Technically Achievable CO2 Reduction Potential (3)	**Yes**	If we assume that a CSP plant like Solana can generate 800 GWh annually in Georgia and that 388 metric tons are averted per GWh of generation, then the annual reduction of that plant in 2030 in Georgia would be 0.31 Mt CO_2/year. A Solana parabolic trough plant in Arizona has an average annual capacity of 250 MW. According to the National Renewable Energy Laboratory (NREL), the average annual insolation ratio between that part of Arizona and central Georgia is about 1.6:1. Therefore, a Solana-type plant located in Georgia would have a capacity of about 150 MW. To reach abatement of 1 Mt CO_2/yr, 294 MW average 2025 Georgia power avoided, would require approximately two Solanas at 100% capacity factor or four

		Solanas at 50% capacity factors. Our CO_2 estimate is based on building two CSP plants in Georgia by 2030, which seems feasible. Lopez, et al. (2012, Table 5) estimates that there is no technical potential for concentrating solar power in Georgia.
Cost Competitiveness (4)	**No**	LCOEs for Solana) in Arizona, and Crescent Dunes Solar (Tonopah) in Nevada with assumed capacity factors of 47.5% are \$143/MWh and \$86/MWh, respectively. Both plants have capacities >100 MW. Hybridizing CSP with agriculture fueled methane digesters can further decrease the LCOE and increase dispatchability and power stability (Zhang and Wang, 2016).
Beyond Carbon Attributes (5)		Co-benefit: storage capacity contributes to grid resilience. CSP power tower plants with capacity greater than 45 can be a competitive middle ground in the gap between clean and dispatchable technologies. As the grid transitions to increased levels of variable renewable energy sources, there is an increasing need for resilient storage systems that can smooth the supply of non-dispatchable technologies. The Solana plant supports 90 permanent jobs. Co-cost: large land footprint. Land Use Requirements: 7,712 acres for 4x 295 MW plants in Georgia.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

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A.3.8 Wave and Tidal | Down-Select

Energy from natural oceanic flows, including waves and tides, can be harnessed to generate electricity. Research is underway to develop these technologies and reduce costs.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Wave and tidal energy (WTE) systems are in a demonstration phase in the United States today. There are only specific sites where WTE systems can be installed. These sites are restricted due to resource availability, geography of the shoreline, technical constraints and economic viability. There is no agreement on a universal design which is essential for scaling up solutions, and for large-scale production (Singh, 2019).
Local Experience & Data Availability (2)	**No**	There is limited data and experience, and there are no WTE systems in the Southeast. The United States has only one established off-shore demonstration project, the Wave Energy Test Site in Kaneohe, Hawaii. A river turbine pilot system operated for several years in the East River in New York, but it has been dismantled. A tidal barrage operates in the Canadian Bay of Fundy. There are no systems in the coastal Georgia tidal zone.[1]
Technically Achievable CO2 Reduction Potential (3)	**Uncertain**	Jenne et al. (2015) estimates that six types of marine and hydrokinetic energy converters have the potential to meet approximately one-third of the total U.S. electricity demand of approximately 4,000 TWh per year. These six technologies include river and tidal turbines, as well as floating systems designed for off-shore sites. Jacobson (2012, Table 1) estimates that the South Atlantic Gulf has technically recoverable hydrokinetic energy of 38.5 TWh/year. There is questionable resource availability in off-shore Georgia. Savannah is a potential location for a WTE system in Georgia. One study (Defne, 2010; Defne, et al., 2011) estimates that coastal Georgia has the highest tidal power density across the Southeast, based on live data streaming about local tidal heights.[1] However, WTE systems are low-power and high maintenance systems. Also, complexities of permits and regulation could prevent significant new construction of these systems by 2030.
Cost Competitiveness (4)	**No**	Jenne et al. (2015) estimate the LCOEs of six 10-MW commercial-scale marine and hydrokinetic energy systems. The LCOEs range from \$0.31 to \$1.47/kWh, which make them cost-prohibitive. The systems have high upfront cost due to additional requirements such as laying underwater cables for transmission of electricity, construction of an

		offshore platform, and additional cost of trained personnel for maintenance and operation. In addition, the equipment is inherently more difficult to maintain due to the harsh and corrosive nature of the sea and its environment.
Beyond Carbon Attributes (5)		WTE systems could lead to loss of shoreline use. Areas where WTE systems are employed have to be cordoned off for shipping, fishing and other uses. Channels on which barrages are built are disrupted apart from the risk of destruction of an ecosystem that relies on the ebb and flow of tides, especially during the construction phase. There are also possible negative effects on estuarine environments.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

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2. https://www.drawdown.org/solutions/electricity-generation/wave-and-tidal

A.3.9 Methane Digesters (Large) | Down-Select

When organic waste decomposes, it releases methane, a powerful greenhouse gas (GHG). Methane Digesters create controlled environments for this decomposition where methane is not released. The process creates biogas as a byproduct. This biogas can be burned to generate electricity.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Large-scale digester systems are in a demonstration phase in the United States.
Local Experience & Data Availability (2)	**Yes**	There are three water resource recovery facilities (WRRFs) already accepting food waste into their digesters in Georgia: (1) The F. Wayne Hill Water Resources Center in Buford, Georgia, (2) The South Columbus Water Treatment Facility in Columbus, Georgia, and (3) The Lower Poplar Street WRF in Macon, Georgia.
Technically Achievable CO2 Reduction Potential (3)	**No**	Methane has an atmospheric warming effect up to 34 times greater than CO_2. By diverting organic wastes away from landfills, using anaerobic digestion to convert the waste into methane, and burning the methane in a controlled environment to produce electricity, urban and rural communities can make significant progress towards reducing their GHG emissions. A typical full-scale anaerobic digester of 4000 cubic meters--is able to reduce 46,420 tons CO_2/year (Wong, et al., 2009). An alternative source: CO_2 emission reduction of 1,554 ton/year (based on 4.26 t/d).[1] Another source suggests that the GHG emissions savings from methane digesters are 0.286 metric tons of CO_2/MWh, which is only slightly lower than Georgia's grid average of 0.388 metric tons/MWh in 2025.[2] Altogether there is great uncertainty that the 1 Mt CO_2 threshold could be met in Georgia by 2030.
Cost Competitiveness (4)	**Yes**	There are examples of cost-effective methane digesters. For example, the cost-effectiveness of the Napoleon Biogas is well documented. This anaerobic digester facility is located across the street from a Campbell's Soup plant in Township, Ohio. Assuming fuel costs in the $5-10/ton range and a $10/t$CO_2$ value, the LCOE of this facility ranges from $42-77/MWh. Other possibilities for food wastes may include an industrial composting facility or co-digestion of food waste at a nearby WWTP with excess capacity in their anaerobic digester. Rather than building an entirely new facility, anaerobic digesters can be added to existing facilities, including WRRFs. Many WRRFs already have anaerobic digesters. These digesters are already being used to process sewage so it is not difficult to add food waste to the digester as well. This is referred to as co-digestion. Experience with these at large scale in Georgia is limited.

Beyond Carbon Attributes (5)		Co-benefits: Good jobs multiplier and many environmental benefits. Methane digesters produce fertilizer as well as electricityThey are also a water-conserving solution.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Environmental Protection Agency (EPA). (2018, September). Anaerobic Digestion Facilities Processing

EPA. (2018). Food Waste in the United States in 2015. Retrieved from: https://www.epa.gov/sites/production/files/2018-08/documents/ad_data_report_final_508_compliant_no_password.pdf.

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Wong, B-T., K.Y. Show, D.J. Lee, and J.Y. Lai. (2009). "Carbon balance of anaerobic granulation process: Carbon credit," Bioresource Technology, 100 (5): 1734-1739.

Wood, E. (2012). CSP Gains a Foothold on US East Coast. Renewable Energy World; 4(15).

Endnotes:

1. https://www.sciencedirect.com/science/article/pii/S0956053X17306049).
2. https://www.sciencedirect.com/science/article/pii/S0048969713007109
3. https://www.drawdown.org/solutions/electricity-generation/methane-digesters-large

A.3.10 Biomass Power | Down-Select

Biomass is organic material that comes from plants and animals, and it is a renewable source of energy. Biomass contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat that can boil water, create steam, run a turbine, and generate electricity.

<table>
<tr><th>Criteria</th><th></th><th>Comments</th></tr>
<tr><td>Technology and Market Readiness (1)</td><td>Yes</td><td>Generating electricity using biomass feedstocks is a mature and market-ready system. Reflecting this, Georgia Power Company’s 2019 Integrated Resource Plan (IRP) proposes additional biomass generation, which would bring the total biomass generation in Georgia to 450 MW by the end of 2021.

NEMS, on the other hand, predicts no further additions after 2019. Biomass (wood, wood waste, agricultural residues) is widely available in the Southeast. Dedicated biomass-fired power plants of 50-100 MW in size are generally feasible.</td></tr>
<tr><td>Local Experience & Data Availability (2)</td><td>Yes</td><td>Numerous studies and lots of data are available to characterize biomass power. Electricity generation from biomass in the United States has grown significantly over the past decade, increasing from 54.3 TWh in 2005 to 62.6 TWh in 2016, also benefiting from policy incentives (Mayes, 2016). Much of the growth in biopower is occurring in southern states such as Virginia, Florida and Georgia. It is both a baseload and a dispatchable resource, enabling it to contribute to the flexibility of electricity systems (Mayes, 2016).

The following 6 new biomass plants illustrate the level of activity and size of facilities being built in the Southeast:<table><tr><td>Franklin County, GA, 58 MW (2019)[1]</td><td>Carnesville, GA, 66 MW (2019) [2]</td></tr><tr><td>Madison County, GA 65 (2019)[1]</td><td>Colbert, GA, 66 MS (2019) [2]</td></tr><tr><td>Lumberton, NC 40 MW (2022) [2]</td><td>Albany Green, GA, 5 MW (2017)[3]</td></tr></table></td></tr>
<tr><td>Technically Achievable CO2 Reduction Potential (3)</td><td>Yes</td><td>We considered the possibility of constructing 4 new plants fueled by biomass waste that are the same size as the 4 biomass plants currently operating in Virginia, which averaged 50-60 MW (Brown et al., 2019). In total, those plants generate 976 GWh/year. Assuming carbon neutrality, these plants would displace 0.38 Mt CO_2. Approximately 10 such plants would be needed to avoid 1 Mt CO_2.

Lopez, et al. (2012, Table 8) estimates that the total technical potential for biopower in Georgia is 2 GW and 16,903 GWh. Assuming carbon neutrality and an average of 388 metric tons per GWh of generation in 2025, this would avert 6,558 Mt CO_2.</td></tr>
<tr><td>Cost Competitiveness (4)</td><td>No</td><td>An LCOE of $96/MWh is estimated for biomass plants in Georgia, based on 4 biomass plants in Virginia that were evaluated by Brown et al. (2019). EIA</td></tr>
</table>

		estimates are comparable; Lazard estimates are much lower. One major consideration is obtaining fuel under a long-term contracts at a reasonable (and low) price. The plant may rely on gasification of biomass, followed by a CT to convert gas to electricity. Raw biomass tends to have a high transportation cost, due to its low energy-density. This places an upper limit on the size of a dedicated biomass-consuming power plant.
Beyond Carbon Attributes (5)		Co-benefits: These include energy diversity and the widespread availability of biomass fuel, which promotes system resilience. Co-costs: The "carbon neutrality" of biomass feedstocks is being challenged based on issues of biogenic carbon as the biogenic carbon footprint may not be favorable. While the CO_2 released from the combustion of the biomass is the same as the carbon absorbed by the biomass when it was growing, the time lag between growing and combusting and regrowing new stands of trees means that biomass combustion results in higher levels of CO_2 in the atmosphere for a period of time. One way this has been accounted for is through global warming potential approach, which weighys the impact of biogenic carbon based on its lifetime in the atmosphere compared to the emission of fossil carbon (Guest et al. 2013). The global warming potential for 11-year biomass with no storage and with a 100-year time horizon is 0.04. Fueling biomass plants with wood waste and agriculture residues is the most dependable way to achieve CO_2 emissions reductions. Other impacts include pollution from transporting fuel, and competition with land use for agriculture.
Down-select Decision	**No**	Do not retain for further analysis for the 2020-2030 timeframe.

References:

Brown, M.A., A. Favero, V.M. Thomas, and A. Banboukian. (2019). "The Economic and Environmental Performance of Biomass Power as an Intermediate Resource for Power Production," Utilities Policy, 58: 52-62. https://authors.elsevier.com/a/1YzH53Peo9VR76.

Guest G., Cherubini F., Stromman A. H. (2013). Global Warming Potential of Carbon Dioxide Emissions from Biomass Stored in the Anthroposphere and Used for Bioenergy at the End of Life. J. Indust. Ecol. 17 (1): 20-30. DOI: 10.1111/j.1530-9290.2012.00507.x; o

Lopez, Anthony, Billy Roberts, Donna Heimiller, Nate Blair, and Gian Porro. (2012) U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis National Renewable Energy Laboratory, NREL/TP-6A20-51946, https://www.nrel.gov/docs/fy12osti/51946.pdf

Mayes, Fred. (2016). Southern States Lead Growth in Biomass Electricity Generation. Today in Energy, U.S. Energy Information Administration (US EIA) May 25, 2016. Accessed July 2017. https://www.eia.gov/todayinenergy/detail.php?id=26392.

Endnotes:

1. http://biomassmagazine.com/articles/16087/the-twin-biomass-sisters-of-franklin-and-madison-counties

2. https://www.businesswire.com/news/home/20180403005935/en/Veolia-Grows-Biomass-Leadership-Operate-Additional-Projects
3. https://energynews.us/2017/06/16/southeast/why-biomass-remains-a-challenge-even-in-timber-rich-georgia/
4. https://www.nrdc.org/experts/sasha-stashwick/2019-kicking-biomass-out-clean-energy-club
5. EIA, Biomass Explained, https://www.eia.gov/energyexplained/biomass/

A.3.11 Solar Water | Down-Select

Solar water heaters expose water directly to the sun in order to heat the water. This can replace electric or natural gas-fired water heaters.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology and markets are mature and market ready.
Local Experience & Data Availability (2)	**Yes**	Less than 1% of U.S. households have solar water heating (EIA). Due to government mandates, Israel has 85% market penetration and Cypress has 90% market penetration.
Technically Achievable CO2 Reduction Potential (3)	**Yes**	Over 20 years, more than 50 tons of CO_2 emissions were avoided from replacing an electric water heater with solar water heater. Annual source energy savings in Atlanta, Georgia, are 44-47% for solar water heaters versus natural gas (NREL). Source energy savings potential of U.S. solar water heaters alone is more than 1 quadrillion Btu (quad), which corresponds to an emissions reduction potential of approximately 1% of total U.S. annual CO_2 emissions (Denholm 2007). Baseline = 1,202 kg CO_2/home per year in Georgia for water heating. Consider a scenario switching 10% of electric water heaters to solar water heaters = reduction of 130 kg CO_2/home per year = 0.14 tons CO_2 / home per year. 7x scenario = 1 Mt $CO_{2\text{-}e}$. To achieve this, 70% of homes would need to switch to solar water heaters. Because hot water service demand is more continuous in commercial and industrial settings, solar water heating should be more cost-competitive in these sectors, particularly agriculture (Chang, Lin, and Chung, 2018) and food services.
Cost Competitiveness (4)	**No**	Break-even costs for residential systems in Georgia ranges between \$3,420 - \$6,285. In 2010, 4 utility-based incentives were offered in Georgia ranging between \$400-\$500, and a state tax credit is available for \$2,299. The result was minimal market uptake. Industrial processes have a payback period less than the service life, making it financially viable. (Chang, et al., 2018)
Beyond Carbon Attributes (5)		Co-benefits: These include resilience from distributed resources and eliminating monthly bills for hot water heating. Co-costs: These include transaction costs associated with small-scale solutions, high maintenance costs, price competition between PV, and potential operability impacts due to rain and cold weather.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Cassard, Hannah, Paul Denholm, and Sean Ong. (2011) Break-even Cost for Residential Solar Water Heating in the United States: Key Drivers and Sensitivities. NREL/TP-6A20-48986

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Evaluating the energy and CO2 emissions impacts of shifts in residential water heating in the United States. Energy Volume 81, 1 March 2015, Pages 317-327.
K. Hudon, T. Merrigan, J. Burch and J. Maguire.(2012). Low-Cost Solar Water Heating Research and Development Roadmap. NREL/TP-5500-54793

Endnotes:

1. https://www.drawdown.org/solutions/electricity-generation/solar-water

A.3.12 In-Stream Hydro | Down-Select

Small-scale, in-stream hydro generates electricity by placing turbines in a free-flowing river or stream. The moving water turns the turbines. These systems do not require reservoirs.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	This technology is in a demonstration stage. The technologies are under development, and are likened by some to the status of wind power 15 years ago.
Local Experience & Data Availability (2)	**No**	There is no experience in the South, but there is some experience elsewhere in the United States. There is substantial global use. In Portland, Oregon, 3.5-foot-wide turbines inside underground pipes generates power for the local utility from water rushing down from the Cascade Range--conduit hydropower.
Technically Achievable CO2 Reduction Potential (3)	**No**	Reliable powers of 1 kW per underwater turbine generator appear feasible (one mfr claims 250-5000 W). To reach abatement of 1 Mt $CO_{2\text{-}e}$ requires displacing 294 MW of Georgia power. Georgia would need 294,000 in-stream hydro generators. For example, this would require almost 1,000 turbine generators per mile in the Savannah River, a row of 10 turbines every 54 feet. Technically recoverable hydrokinetic resource of the Tennessee River hydrologic region is estimated to be 0.9 TWh/year (EPRI, 2012, Table 5.1). However, the portion of this potential available to Georgia is small (we do not have data to estimate this precisely).
Cost Competitiveness (4)	**No**	Neither EIA (2019) nor Lazard (2018) have estimates of LCOE for in-stream hydro. EIA estimates the LCOE for traditional hydro in the United States is $39.1/MWh. It is quite a bit higher than for natural gas or solar. No site-specific cost estimates are available.
Beyond Carbon Attributes (5)		Co-benefits: These include being well-suited for rural and distributed applications, innovative water power technologies have the potential to increase the affordability of hydropower and marine energy and can deliver value to the grid. Co-costs: These include high maintenance costs, interference with recreation areas and strong fishing culture, and risk of seasonal variation in supply of energy, which challenges grid and climate resilience, inability to scale if demand increases. Another co-cost is negative impacts on freshwater biodiversity.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Energy Information Administration (EIA). (2019). Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2019.
Lazard. (2018). "Lazard's Levelized Cost of Energy Analysis." Version 12.0. (November), https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf

Endnotes:

1. https://www.drawdown.org/solutions/electricity-generation/in-stream-hydro

A.3.13 Cogeneration | Down-Select

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.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Cogeneration technologies and markets are mature and market ready. Cogeneration systems – also called combined heat and power (CHP) – are able to be used in individual buildings, in a district heating network or in manufacturing and electricity generation systems. They have long been viewed as beneficial along a variety of dimensions including grid reliability, energy efficiency, water conservation, and pollution reduction. As a result, countries around the world have increased subsidies for CHP and are expecting rapid growth (from 33 GW in 2015 to 74 GW by 2024 worldwide) (Navigant Research, 2015). With the 2012 U.S. Executive Order establishing national goals for CHP by 2020, CHP has been growing in the United States, as well (Brown, 2017). Numerous different types of cogeration systems are possible, including combinatons of (1) prime mover (e.g., microturbine, fuel cell), (2) renewable energy source (e.g., solar PV, wind turbine) and (3) energy storage (e.g., lithium-ion battery, compressed air energy storage). Most experience to date has been with natural gas-driven microturbines (EIA, 2020), but cogeneration with solar systems would appear to hold promise.
Local Experience & Data Availability (2)	**Yes**	In 2017, Georgia had 43 cogeneration facilities totaling 1.4 GW of capacity. Most of the largest facilities are industrial (e.g., pulp and paper), but some are commercial (such as the 3,000 KW system in the Bank of America Plaza in Atlanta). One cogeneration system run by Albany Green Energy is located at P&G's paper manufacturing facility; it provides 100% of the steam energy utilized in the manufacturing of Bounty paper towels and Charmin toilet paper. It also generates electricity for the local utility, Georgia Power, and powers an 8.5 MW electricity generator using steam at the Marine Corps Logistics Base in Albany (Holbrook, 2017). The plant can co-generate 394,000 MWh per year using wood waste from local forestry operations as fuel supply (CEO, 2017).
Technically Achievable CO2	**Yes**	Using NEMS, Brown, Cox and Baer (2013) estimated that industrial cogeneration had the technical potential to reduce CO_2 emissions in the

Reduction Potential (3)		United States by 1.9% by 2035, meeting 18% of U.S. electricity requirements, up from 8.9% in 2012. Given the sizeable and compatible industrial base in Georgia, a comparable level of penetration would seem achievable. Because of Georgia's amount of heavy industry, the opportunities for cogeneration should be greater in our state than elsewhere.
Cost Competitiveness (4)	**Yes**	Research has documented the cost competitiveness of district, industrial, and power generation CHP systems. The cost-effectiveness of commercial CHP depends on rate design and system ownership (Brown, 2017). Albany CHP LCOE is estimated to be \$127-132 (in \$2017)/MWh without including a value for the steam that is produced. A 35-year plant life brings the LCOE down to \$123/MWh. The cost competitiveness of CHP systems depend on whether they are customer or utility owned, and on the type of rate tariff that they operate under. Two possibilities that have been evaluated include a CHP system that is owned and operated by a customer, subject to a flat tariff, versus a CHP system that is owned and operated by a utility subject to time varying locational marginal prices. The latter was found to be more financially favorable (Brown, 2017).
Beyond Carbon Attributes (5)		Environmental benefits mainly relate to air quality improvements from efficient and clean electricity and thermal energy generation.[2] However, cogeneration may lead to greater local pollution, depending on the system design and the primary energy source (Bo Yang, et al., 2019). From an economic development perspective, research on The Job Generation Impacts of Expanding Industrial Cogeneration (Baer, et al., 2015) estimates: (for new CHP generation investments driven by a federal investment tax credit) first-order jobs of 0.08 full time equivenlent (FTE)/GWh from construction and installation, and 0.09 FTE/GWh from operations and maintenance; second-order jobs of 0.33 job- years/GWh from household and commercial re-spending. These gains are partially offset by a loss of 0.45 job-years/GWh from centralized plant generation. In addition to overall net jobs benefits, as a decentralized energy resource, cogeneration can also lead to lower infrastructure requirements/costs (T&D) and improve grid resilience as a source of reliable, base load generation. As a social benefit, cogeneration generally offers a competitive energy costing structure for its users (mainly commercial and industrial players) and reduces the wholesale electricity prices for the grid consumers.[3]
Down-select Decision	**Yes**	Retain for further analysis

References:

Baer, Paul, Marilyn A Brown, and Gyungwon Kim. "The Job Generation Impacts of Expanding Industrial Cogeneration." Ecological Economics 110 (2015): 141-53.

Bo Yang, Jiajun Gu, Tong Zhang, K. Max Zhang, 2019. Near-source air quality impact of a distributed natural gas combined heat and power facility, Environmental Pollution,Volume 246, https://doi.org/10.1016/j.envpol.2018.12.067.

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DOE. (2019). Combined Heat and Power Basics. Retrieved from https://www.energy.gov/eere/amo/combined-heat-and-power-basics

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Holbrook, E. (2017). From Scrap Wood to Steam: How Procter & Gamble is Using Renewable Energy to Make Toilet Paper. Retrieved from https://www.environmentalleader.com/2017/09/scrap-wood-steam-proctor-gamble-using-renewable-energy-make-toilet-paper/

Navigant 2015 *Combined Heat and Power for Commercial Buildings* (Boulder, CO: Navigant) https://doi.org/10.1016/j.ecolecon.2014.12.007.

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1. https://www.drawdown.org/solutions/electricity-generation/cogeneration
2. https://www.energy.gov/sites/prod/files/2013/11/f4/chp_clean_energy_solution.pdf
3. https://www.energy.gov/sites/prod/files/2017/11/f39/StateOfCHP-Georgia.pdf

A.3.14 Methane Digesters (Small) | Down-Select

When organic waste decomposes, it releases methane, a powerful GHG. Small-scale methane digesters create controlled environments for this decomposition where methane is not released. The process creates biogas as a byproduct. This biogas can be burned for cooking, lighting or heating and can reduce demand for other fuel sources such as wood and charcoal.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technologies are well-developed.
Local Experience & Data Availability (2)	**Yes**	Today, anaerobic digestion is used around the world at the backyard and farmyard scales. Additionally, it is on the rise in developing countries, such as China, where more than 100 million people have access to digester gas. Market penetration in the United States is much lower at the home and farm scale.
Technically Achievable CO2 Reduction Potential (3)	**No**	Large-scale adoption is unlikely given the disruptive nature of the technology. (EPA AgStar)
Cost Competitiveness (4)	**No**	Transaction and supply chain costs are high.
Beyond Carbon Attributes (5)		Co-costs include transaction costs associated with small-scale solutions.
Down-select Decision	**No**	Do not retain for further analysis for the 2020-2030 timeframe.

Endnotes:

1. https://www.georgiarecycles.org/assets/Uploads/Presentations/2014-Annual-Conf/2014-Conf-White-MPASS.pdf
2. https://www.epa.gov/agstar/guidelines-and-permitting-livestock-anaerobic-digesters
3. https://www.drawdown.org/solutions/electricity-generation/methane-digesters-small

A.3.15 Waste-to-Energy | Down-Select

Waste-to-Energy (WTE) is a process of turning trash into electricity through incineration, gasification, and pyrolysis. WTE facilities can help reduce GHG emissions by displacing coal- or gas-fired power and by preventing methane emissions that are released when organic matter decomposes.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	WTE systems are technology and market ready. Incineration, gasification, and pyrolysis are all well-developed technologies. They are an alternative to the preferable approach of reducing waste from the outset, or composting, recycling, and reusing waste. They are used particularly in cities that face the dilemma of dealing with large quantities of trash. According to Project Drawdown®: "Waste-to-energy is a transitional strategy for a world that wastes too much and needs to reduce its emissions." It is considered a "bridge" solution that will be replaced by preferable waste management solutions. Methane digesters, landfill methane, and composting are related solutions that have superior environmental attributes.
Local Experience & Data Availability (2)	**Yes**	There are numerous studies and lots of data is available.
Technically Achievable CO2 Reduction Potential (3)	**No**	WTE plants create energy that might otherwise be sourced from coal- or gas-fired power plants. Their impact on GHGs is positive when compared to landfills that produce methane emissions as organic wastes decompose. The $CO_{2\text{-}e}$ reduction potential depends on availability of trash and the selected technology. Transporting trash generates carbon emissions. WTE has GHG emissions equal to 0.36 kg of CO_2 per kilogram of municipal solid waste combusted. (EIA) Avoided emissions are dependant on the ability of trash to avoid methane release.
Cost Competitiveness (4)	**Yes**	The economics of WTE are dependent on the municipal solid waste stream composition, with paper and wood being advantageous, metal and glass being disadvantageous, and plastics, food, and yard waste being either advantageous or disadvantageous depending upon the avoided tipping fees. At $0 tipping fee, LCOE of WTE is $164/MWh. At an avoided tipping fee of $130/Mg municipal solid waste the LCOE decreases to zero. (Townsend and Webber, 2012)
Beyond Carbon Attributes (5)		Co-benefits: These include jobs and economic development. Many environmental advantages with possible economic viability are present including potential for renewable energy credits (RECs) to be sold for avoided carbon emissions.

		Co-costs: These include pollution from incineration. (Incineration, gasification, and pyrolysis are means of releasing the energy contained in trash). Some of the heavy metals and toxic compounds latent within the trash stream are emitted into the air, some are scrubbed out, and some remain in residual ash. This solution has a positive impact on GHG emissions, but social and environmental costs are harmful and high.
Down-select Decision	**No**	Do not retain for further analysis for the 2020-2030 timeframe.

References:

Beck, R. W. (2005). Georgia Statewide waste characterization study. Final report. Georgia Department of Community Affairs. Available at www.epd.georgia.gov

Global Market Insights. (2019). Waste to Energy (WTE) Waste to Energy (WTE) Market Size By Technology https://www.gminsights.com/pressrelease/waste-to-energy-wte-market

Townsend, A., Webber, M. (2012) An integrated analytical framework for quantifying the LCOE of waste-to-energy facilities for a range of greenhouse gas emissions policy and technical factors. Waste Management (32) (7) (Pgs. 1366-1377) https://doi.org/10.1016/j.wasman.2012.02.006

Endnotes:

1. https://www.drawdown.org/solutions/electricity-generation/waste-to-energy

A.3.16 Micro Wind | Down-Select

Wind energy can be used to generate electricity. Micro wind installations are small scale, 100 kilowatts or less, and can help meet localized electricity needs, such as the needs of a family or small farm.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	These technologies are well-developed. There is less than 100kW cumulative installation in Georgia. North Carolina, Virgina and Florida have adopted over 100kW but lower than 1 MW. New distributed wind projects were documented in 21 states in 2017 and have been documented in all 50 states, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, and Guam since 2003.
Local Experience & Data Availability (2)	**Yes**	There is little data on projects in Georgia. Hpwever, there are some very mature projects in other other states. DOE's 2017 Distributed Wind Market Report concluded that the aggregated capacity totals for sites that can generate a positive NPV in 2018 are 360 MW in Colorado, 1,950 MW in Minnesota, and 920 MW in New York. The economically viable aggregated system totals for small wind in 2018 are 1,600 systems in Colorado, 6,000 in Minnesota, and 4,950 in New York (McCabe et al. 2018).
Technically Achievable CO2 Reduction Potential (3)	**No**	Sonseo, a micro wind installer in Oregon, states that based on the current wind speeds in Georgia, 1 Skystream 3.7 turbine can support part of a household's power requirements (between 200 kWh at wind speed of 9 mph and 400 kWh at 12 mph of the required 1,000 kWh/month).[2] At 1,000 KWh/month, a household consumes 12,000 kwh/year. To replace electricity production of 2,580 GWh, we need 215,000 such microwind turbines (2580 GWh/12,000 KWh). If we take the 400 KWh/month generation, we would need 537,500 such plants.
Cost Competitiveness (4)	**No**	DOE reported that the small wind average LCOE after incentives was \$0.23/kWh (from 84 projects totaling 1.64 MW in rated capacity).
Beyond Carbon Attributes (5)		Co-benefits: This includes income for rural landowners. Co-costs: These include bird kills, high land intensity (acres per MWh) and landscape pollution.
Down-select Decision	**No**	Do not retain for further analysis for the 2020-2030 timeframe.

References:

Bergey, M. (2002). A 20-year Industry Plan for Small Wind Turbine Technology.

Orrell, A. C., Foster, N. A., Homer, J. S., & Morris, S. L. (2019). 2017 distributed wind market report (No. PNNL-25636). Pacific Northwest National Lab.(PNNL), Richland, WA (United States).

Wiser, R., & Bolinger, M. (2019). 2017 Wind technologies market report (No. DOE/GO-102011-3322). National Renewable Energy Lab.(NREL), Golden, CO (United States)

Endnotes:

1. https://www.drawdown.org/solutions/electricity-generation/micro-wind
2. http://www.soenso.com/wind-turbine-electricity

A.3.17 Energy Storage (Utilities) | Down-Select

Utility-scale energy storage encompasses storage technologies that could provide energy on a daily, multi-day, or even seasonal timeline. These technologies could reduce the need for gas-fired peaker plants and support variable renewable energy sources such as wind and solar. Examples include pumped hydro and innovative battery designs.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	These technologies are undergoing system and subsystem development. The technologies are generally well-developed and include a variety of characteristics: pumped hydro, flywheel energy storage, batteries, compressed air, phosphoric acid fuel cells (PAFC). Advanced High Temperature Fuel Cells – Molten Carbonate Fuel cell ("MCFC") and Solid Oxide Fuel Cell ("SCFC") can provide storage, but they typically use hydrogen reformed from natural gas.
Local Experience & Data Availability (2)	**Yes**	There is limited energy storage capacity in Georgia to date. However, it is a well tracked and researched set of technologies. One example is Babcock Ranch Solar Energy Center, a solar farm that came online in December 2016 with an operating capacity of 74.5 MW in Babcock Ranch, Florida. In March 2018, 10 MW of energy storage capacity was added to the facility. The solar farm powers a neighboring mixed-use commercial-residential community.
Technically Achievable CO2 Reduction Potential (3)	**No**	The CO_2 reduction associated with energy storage technology is associated with the genertation technologies it enables. GHG reductions are limited with respect to non-fossil fuel storage technologies. One example of a renewable/storage project is the Notrees Wind Storage Demonstration Project in Texas, which uses a 36 MW battery facility to help ensure stability of the power supply even when the wind isn't blowing. Batteries in combination with solar farms and community-scale solar could be one of the most cost-competitive non-fossil options for Georgia. Georgia's 2019 IRP approved construction of 80 MW of utility-scale energy storage. If all of this power can be generated from renewable energy sources, then it would avoid 0.031 tons CO_2 (much less than 1 Mt $CO_{2\text{-}e}$).
Cost Competitiveness (4)	**No**	Flywheel Energy Storage has high costs and better suitability for dispersed generation applications. Babcock Ranch Solar Energy Center in Florida has storage and is nearly cost competitive without subsidies, with LCOEs of $54-$71/MWh (with and without an ITC). Costs are dropping. Lazard (2018) estimates the LCOEs for storage alone at: wholesale $204~$390/MWh; Transmission $263~$471/MWh; PV+storage $108~$222/MWh.

Beyond Carbon Attributes (5)		Co-benefit: Lots of popular and political support. Co-cost: Possible vulnerabilities due to limited domestic lithium resources.
Down-select Decision	**No**	Bundle with utility-scale solar.

References:

Georgia Power Company. (2019). Integrated Resource Plan, Docket No. 42310.

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3. https://www.drawdown.org/solutions/electricity-generation/energy-storage-utilities
4. https://www.spglobal.com/marketintelligence/en/news-insights/trending/UlMh2otzI0d9KO4FwGjEXQ2 PSC adds renewables, EV battery pilot to Georgia Power's approved resource plan.

A.3.18 Energy Storage (Distributed) | Down-Select

Distributed energy storage allows for energy to be stored where it is produced through standalone batteries and electric vehicles. If these storage technologies enable increased reliance on renewable energy sources, such as rooftop solar, they can reduce GHG emissions.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	These technologies are undergoing system and subsystem development. The technologies are generally well-developed, and there are an increasing number of battery manufacturers.
Local Experience & Data Availability (2)	**Yes**	It is a well tracked and researched technology, including both standalone batteries and batteries paired with rooftop solar. However, there are still relatively few distributed energy systems in Georgia. Thus, there is limited experience with this in Georgia.
Technically Achievable CO2 Reduction Potential (3)	**No**	It is difficult to estimate the carbon implications of distributed energy storage due to the uncertainty about where the electricity to recharge the storage systems originates. Taking the example of a Tesla powerwall, one powerwall has the potential of 13.5 kWh. A 5 KW home battery system would provide 43.8 MWh per year, assuming a capacity factor of 100%. To offset 1 Mt $CO_{2\text{-}e}$ would require 59,000 5 KW home battery systems. This represents about 2% of the 3 million households in Georgia. In combination with rooftop solar, due to inefficiencies in energy storage and high CO_2 emissions associated with the manufacturing of batteries, the use of distributed energy storage might not imply a reduction in emissions when considered in isolation (e.g. not part of a solar installation).
Cost Competitiveness (4)	**No**	Battery storage can relieve grid pressures during peak periods, which means that utilities do not have to procure expensive power or build new ‘peaker’ plants, which are often natural gas plants. Battery costs are dropping. In Lazard (2018) estimates: standalone commercial & industrial \$829~\$1,225/MWh; commercial & industrial PV+storage: \$315~\$399/MWh; residential PV+storage \$476~\$735/MWh
Beyond Carbon Attributes (5)		Co-costs include low affordability and accessibility rates for low-income households.
Down-select Decision	**No**	Bundle with distributed solar.

References:

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1. https://www.drawdown.org/solutions/electricity-generation/energy-storage-distributed
2. https://microgridknowledge.com/white-paper/energy-storage-new-efficiency/
3. https://www.solarpowerworldonline.com/2015/08/what-is-the-best-type-of-battery-for-solar-storage/

A.3.19 Grid Flexibility | Down-Select

Grid Flexibility refers to a diverse set of changes in how electricity is generated and transported that could allow for increased use of renewable energy sources. For example, this could include investments in utility-scale and distributed energy storage, investments in transmission and distribution networks, and increased demand-response.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	These technologies are undergoing system and subsystem development. They are increasingly important as solar and wind resources gain market penetration across the United States. Investments in energy storage, transmission and distribution assets, and demand response are allowing the power systems in this country to become more diverse without harming reliability because of the reliability services they can provide (Hibbard, Tierney and Franklin, 2017).
Local Experience & Data Availability (2)	**Yes**	Record levels of generation from variable renewable energy are occurring, without interrupting service. For example, the Southwest Power Pool (SPP) set three wind- and renewable-related records on the morning of December 4, 2017. At 5:20 a.m., the regional transmission organization (RTO) set new records for both wind and renewable penetration: the amount of load served by wind generation and by all renewable fuel sources, respectively. Wind generation at the time was at 13,271 MW and served 56.25 percent of SPP's load (23,591 MW), beating SPP's previous wind penetration record of 54.47 percent set on April 24, 2017.
Technically Achievable CO2 Reduction Potential (3)	**No**	The emissions reductions associated with this solution would be counted in the variable reweneable energy solutions with storage and in the demand response solution.
Cost Competitiveness (4)	**Yes**	There are $10/MWh system integration costs associated with variable and non-dispatchable technologies (Brown et al., 2019). Integration costs are declining as the cost of battery storage drops (at a 20% learning rate), and costs of balance of systems including IT and communications are expected to continue to decline.
Beyond Carbon Attributes (5)		Co-costs are minimal if it relies on storage or demand response.
Down-select Decision	**No**	Bundle with solar solutions and demand response.

References:

Brown, M.A., A. Favero, V.M. Thomas, and A. Banboukian. (2019) "The Economic and Environmental Performance of Biomass Power as an Intermediate Resource for Power Production," *Utilities Policy,* 58: 52-62. https://authors.elsevier.com/a/1YzH53Peo9VR76

Hibbard, P., Tierney, S., & Franklin, K. (2017). Electricity Markets, Reliability and the Evolving U.S. Power System.

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1. https://www.drawdown.org/solutions/electricity-generation/grid-flexibility
2. Analysis Group. https://www.spp.org/newsroom/press-releases/spp-sets-wind-and-renewable-penetration-records/

A.3.20 Microgrids | Down-Select

A microgrid is a localized version of the larger electricity system. It matches localized electricity generation to localized demand. A microgrid can be a standalone entity or it can be connected to the larger grid. Microgrids that run on low- and zero-carbon generating sources can reduce emissions.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Microgrids are in a technology demonstration phase. In 2019, Georgia Power unveiled the first neighborhood microgrid in Georgia. Each of 46 homes has solar panels, batteries, and high efficiency appliances such as heat pump water heaters, managed and optimized using a novel, grid-interactive control system developed by Oak Ridge National Laboratory. Thermostats, security systems, and appliances can be controlled via the Pulte Group controls suite through a phone app. Alabama Power previously demonstrated a 62-home Smart Neighborhood microgrid in suburban Birmingham featuring a similar approach. Homes in the community are around 39% more efficient than standard new homes, with similar equipment. Georgia Power installed a 1.4 MW microgrid on Georgia Tech's campus in 2019 to serve as a living lab in the CODA building in Tech Square. It includes fuel cells, battery storage, diesel generators and a natural gas generator. Perhaps the biggest prior pilot is by Sonnen in Arizona, where 3,000 new homes will be fitted with similar equipment. It will provide 23 MWh capacity with an output of 11.6 MW.
Local Experience & Data Availability (2)	**Yes**	Microgrids are being studied, but minimal operational data is available. Alabama Power and Georgia Power are using data from their microgrids to provide greater understanding of energy management and insights into how homes can be built and function more efficiently.
Technically Achievable CO2 Reduction Potential (3)	**No**	Germany has 150,00- home storage systems with PV that provide about 100 GWh. If we assume that by 2030 Georgia could install 100 times that capacity, it would would reduce carbon emissions by 0.039 Mt $CO_{2\text{-e}}$. Thus, a large transformation in a decade would not meet the 1 Mt $CO_{2\text{-e}}$ threshold.
Cost Competitiveness (4)	**No**	Microgrids allow for local energy production with limited, if any, transmission and closer controlled distribution. This reduction in infrastructure results in some savings to that part of the investment package compared to expanding traditional grids. That can provide security benefits. However, the LCOE of a microgrid is high, ranging from \$430-\$860/MWh (Nagapurkar and Smith, 2019). For comparison, combined cycle natural gas is much lower at about \$41/MWh (Lazard, 2018).
Beyond Carbon Attributes (5)		Co-benefits: This includes grid security and resilience. This extra energy security is why microgrids can be seen powering hospitals, university research facilities, critical city infrastructure (emergency response, water treatment, communications structures, etc.), and military bases. Co-costs: This include low affordability and accessibility rates for low-income

		households.
Down-select Decision	**No**	Bundle with demand response

References:

Krueger, Morgan. "The Pros and Cons of Microgrids." Pacific Data Integrators, www.pacificdataintegrators.com/insights/microgrid-pros-and-cons.

Lazard. (2018). "Lazard's Levelized Cost of Energy Analysis." Version 12.0. (November), https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf

Nagapurkar, P., and Smith, J, (2019). Techno-economic optimization and social costs assessment of microgrid-conventional grid integration using genetic algorithm and Artificial Neural Networks: A case study for two US cities. Journal of Cleaner Production. (229) (pg. 552-569) https://doi.org/10.1016/j.jclepro.2019.05.005

Wood, Elisa. (2017). "Microgrids: What Businesses and Institutions Use Them? And Why?" Microgrid Knowledge, 21 Aug. 2017, microgridknowledge.com/microgrids-businesses-institutions/. https://microgridknowledge.com/massachusetts-battery-storage-energy-efficiency/

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6. CODA Microgrid: https://www.southerncompany.com/newsroom/2019/march-2019/georgia-power-announces-microgrid-project-georgia-tech.html

A.3.21 Demand Response | Down-Select

Demand response programs serve to "adjust the timing and amount of electricity use" and can help utility companies reduce peak load, shift load, or reduce overall usage. This can include changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Demand response (DR) is in a technology demonstration phase. DR has been used extensively in industrial and commercial sectors since the 1970s, but today's DR is being transformed by technology and market innovations. Wholesale markets are incentivizing DR to participate in markets, smart grid technologies and dynamic pricing are enabling faster and better control of DR resources, and increasingly system aggregators are enabling smaller entities to participate. Many agree that DR can, on the one hand, reduce daily peak loads and contribute to system reliability, and on the other hand, reduce the cost of electricity supply. DR's impact on carbon emissions, by contrast, is less well understood (Smith and Brown, 2015).
Local Experience & Data Availability (2)	**Yes**	Georgia Power operates DR programs with industrial customers, and it has used direct load control of water heaters in the residential and commercial sectors. Georgia Power's Integrated Resource Plan proposes two new residential programs (demand response and low-income qualified energy efficiency) and one new "behavioral" commercial program. By 2022 its energy efficiency programs "are designed to help reduce peak demand approximately 1,600 MW, which is 10% of the company's current peak demand." DR is also an aspect of its microgrid smart community in Atlanta called "Altus at the Quarter" by load shifting demand for electricity from heat pump water heaters. This is a first-of-a-kind demonstration project for Georgia. We assume that DR can shift one hour of electricity from an on-peak hour that is served by natural gas to 30 minutes that is served by solar (perhaps via home storage) and 30 minutes of curtailment through appliance cycling (i.e., reduction in consumption). That reflects the goals of some DR programs such as the Microgrid Pulte Homes community in Atlanta. We also assume that the peak load for each family is 4.39 kW (Georgia Power, 2019).[1]
Technically Achievable CO2 Reduction Potential (3)	**Yes**	We used GT-NEMS to model DR as an increase from 3% to 20% maximum peak load shift in 2030. This produced a total reduction of 3.6 $MtCO_2$ in the SERC SE region, which equates to 1.63 Mt CO_2 in Georgia. This peak load shift produced a reduction of summer peak demand of 365 MW. This would result

		in an estimated reduction of 164 MW summer peak load in Georgia. Based on shifting 20% of the 4.4 KW peak load of an average household in Georgia, this reduction in summer peak is equivalent to 187,000 households in Georgia participating in a demand response program.
Cost Competitiveness (4)	**Yes**	Smith and Brown (2015) found that DR is likely to defer significant amounts of expensive, aging peak capacity such as single-cycle natural gas. Georgia Power conducts EE education initiatives as a pillar demand side management (DSM) and DR program and as a way of achieving flexibility and clean energy goals. One form of digitally-connected 'smart' energy technology such as NEST thermostats and home energy management systems (HEMS), can enable consumers to visualize, monitor and manage electricity consumption within their household. Smith and Brown (2015) provide evidence that "suggests that demand response can serve as a long-term, low-cost alternative for peak-hour load balancing without increasing carbon emissions."
Beyond Carbon Attributes (5)		Together with microgrids, grid flexibility solutions, and distributed energy resources, DR can improve resiliency and flexibility to mitigate climate change impacts on the grid (resulting from extreme weather temperatures, intense storms, etc.)[2,3] From an environmental and public health standpoint, adoption of demand response solutions can lead to air quality improvements over existing alternatives. For example, simple cycle gas turbines or coal power plants that run during peak hours, tend to be inefficient and higher-emitting. Offsetting these peaking plants with demand response can significantly reduce environmentally-harmful emissions.The degree of air quality benefit should, however, be assessed on a case-by-case basis because results vary significantly depending on the energy source utilized. The social and economic benefits of demand response include affordability and potentially greater accessibility by low-income households (versus for example rooftop solar). Besides moderate upfront costs, some studies found that residential demand response technologies generate overall energy savings in addition to shifting demand to low rate off-peak hours.[4] DR solutions requiring high adoption rates of lithium-ion batteries may impose environmental risks regarding their end-of life disposability (EPA, 2013).
Down-select Decision	**Yes**	Retain for further analysis

References:

Balijepalli, Murthy; Pradhan, Khaparde (2011). "Review of Demand Response under Smart Grid Paradigm". IEEE PES Innovative Smart Grid Technologies.
EPA. (2013). Application of Life- Cycle Assessment to Nanoscale Technology: Lithium-ion Batteries for Electric Vehicles
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4. https://dotearth.blogs.nytimes.com/2012/11/05/how-natural-gas-kept-some-spots-bright-and-warm-as-sandy-blasted-new-york/

A.3.22 Carbon Capture and Storage | Down-Select

Natural gas-, coal- and petroleum-fueled power plants release CO_2 as a byproduct. Carbon Capture and Storage (CCS) technologies cancapture a large portion of these emissions and stores them underground, preventing the CO_2 emissions from being released into the atmosphere. Other CCS options are available to the electricity sector such as bioenergy carbon capture and storage (BECCS).

Criteria		Comments
Technology and Market Readiness (1)	**No**	CCS is in a demonstration stage of development. The Linde-BASF technology was tested from 2009 to 2017 at two facilities including the National Carbon Capture Center in Wilsonville, Alabama.
Local Experience & Data Availability (2)	**No**	Southern Company has been awarded approximately $5.8 million from DOE to conduct a Front-End Engineering and Design (FEED) study evaluating the application of commercial-scale CO_2 capture units on existing natural gas power plants. The study will specifically evaluate installing the Linde-BASF OASE® blue advanced aqueous amine solvent-based technology at an existing Southern Company natural gas plant of at least 375 MWe. As prime contractor, Southern Company provides project management, scope definition, design and engineering of components, and cost estimation. BASF will provide the solvent technology design package; Linde will design the CO_2 capture and compression plant. Sites under consideration are Plants Barry in Alabama and Plant Daniel in Mississippi.
Technically Achievable CO2 Reduction Potential (3)	**No**	The planned demonstration does not include carbon storage, sequestration, or re-use. Until that part of the CCS system is available, the CO_2 reduction potential is 0.
Cost Competitiveness (4)	**No**	Adding a CCS system to a coal of natural gas plant increases LCOE of coal by 70% and NG by 40% (Zhai and Rubin, 2016). In 2018, the U.S. Congress expanded credits under Section 45Q of the tax code for CCS technologies. These credits are expected to promote CCS projects in the future. However, the U.S. Treasury Department took two years to release the Internal Revenue Service guidance; more comprehensive regulation is expected soon (Anchondo, 2020).
Beyond Carbon Attributes (5)		Increased energy use of CCS systems may increase ecological impacts from extraction, transportation, and processing (Cathre, et al., 2012). In addition, adding a CCS system to a coal or natural gas plant increases power plant water demand for cooling (Zhai and Rubin, 2016).
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Anchondo, Carlos, (2020) “Federal CCS guidance stirs concerns about industry's future” Energywire, February 20, 2020. https://www.eenews.net/energywire/2020/02/20/stories/1062397869

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2. https://www.c2es.org/content/carbon-capture/

A.3.23 Landfill Methane | Down-Select

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.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology is mature and market ready. Landfill gas can be extracted from landfills using wells and a blower/flare system. The system transports the gas to a central point where it can be processed and treated according to the ultimate use for the gas. Landfill gas can be used to generate electricity through different process like reciprocating internal combustion engines, fuel cells, turbines, microturbines and cogeneration. The electricity generated can be used on site or sold to the grid. Nearly 72% of operating landfills in the U.S. generate electricity. Currently in the United States, landfill methane is collected from 352 landfills, producing 11 billion kWh of electricity, or 0.3% of electricity production[1]. Landfill gas can also be directly used to replace another fuel like natural gas or coal in a boiler, dryer or other thermal applications. About 18% of operating landfills use landfill gas to offset the use of other fuels. Lastly, landfill gas can be upgraded to renewable natural gas by increasing its methane content through treatment processes. Renewable natural gas can be used as compressed natural gas, pipeline-quality gas or liquified natural gas. Around 10% of operating landfills upgrade landfill gas.[1] Landfill Methane has been in use for decades and there are ample sites that are candidates in the United States and in Georgia for potential implementation of this technology. Given the high global warming potential of methane (34 CO_2-e), opportunities to capture methane can produce significant CO_2-e reductions.
Local Experience & Data Availability (2)	**Yes**	In 2019, Georgia had 92 landfills totaling more than 495 Mt of waste. The landfills are categorized as: operational (25), candidate (20), future potential (5), low potential (23), construction (1), planned (1) and shutdown or unknown (17). The operational landfills in Georgia have in total 239 Mt of waste. The one with the most waste has 21 Mt while the one with the least has 1 Mt in place. Out of the 25 operational landfills, 18 generate electricity, 4 use landfill gas directly and the other 3 upgrade landfill gas to renewable natural gas. The total installed capacity of the operational landfills that generate electricity is 66 MW.[2] There are several active landfill-to-gas retrofit projects in Georgia (e.g., Seminole Road MSW Landfill in DeKalb County, and Macon Bibb Walker Road MSW Landfill in Bibb County). There are EPA data available for landfills in Georgia, including potential for future landfill gas-to-energy

		retrofits. The EPA defines a candidate landfill as "one that is accepting waste or has been closed for five years or less, has at least one million tons of waste, and does not have an operational, under-construction, or planned project; candidate landfills can also be designated based on actual interest by the site[2].
Technically Achievable GHG Reduction Potential (3)	**Yes**	The GHG reduction potential is high. Based on data from EPA's Landfill Methane Outreach Program[2,] there are 25 landfills categorized as "Future Potential" or "Candidate" for landfill gas-to-energy retrofitting in Georgia. Preliminary analysis based on this data indicates that a typical 5 MW retrofit at each facility could abate approximately 0.25 Mt CO_2-e annually per facility. Retrofitting just 4 of the 25 landfills could abate 1 Mt CO_2-e annually.
Cost Competitiveness (4)	**TBD**	This is a potentially cost-effective solution, based on global Project Drawdown® estimates and EPA data (EPA, 2013; Harmsen et al. 2019). Review of other literature indicates mixed results on cost-effectiveness, especially in the absence of a carbon tax.[5] Preliminary analysis suggests that the 6.3 MW Georgia Landfill Gas Oak Grove Plant produces electricity at a LCOE of 9.6 cents per kWh. We will explore Georgia-specific cost effectiveness during the next phase of research.
Beyond Carbon Attributes (5)		Social benefits of this solution include improvement of air quality by reducing GHG (mainly methane) and toxic gas emissions. Additionally, the utilization of landfill gases (LFG) for electricity generation can offer an offset to the use of non-renewable sources.[4,5,6] Moreover, the capture and use of LFG to generate electricity mitigates the possible health risks associated with the release of non-methane organic compounds (including hazardous air pollutants and volatile organic compounds (VOCs)) that are present at low concentrations in uncontrolled LFG. An added economic benefit, LFG energy projects provide a source of revenue from the sale of captured gas and can create local jobs associated with the design, construction, and operation of energy recovery systems.[7] The Landcaster Landfill in Pennsylvania, for example, created over 100 temporary construction jobs, while an LFG project in Virginia resulted in 22,000 hotel stays for project workers.[8] Additionally, waste management and landfill businesses stand to benefit from the expansion of this solution by reducing their environmental compliance costs that is mandated by the Clean Air Act.[9] Potential concerns center around high upfront costs for installation of the landfill gas-to-electricity system. Also, decreasing landfill waste can be considered a challenge for the adoption rates of this solution.
Down-select Decision	**Yes**	Retain for further analysis

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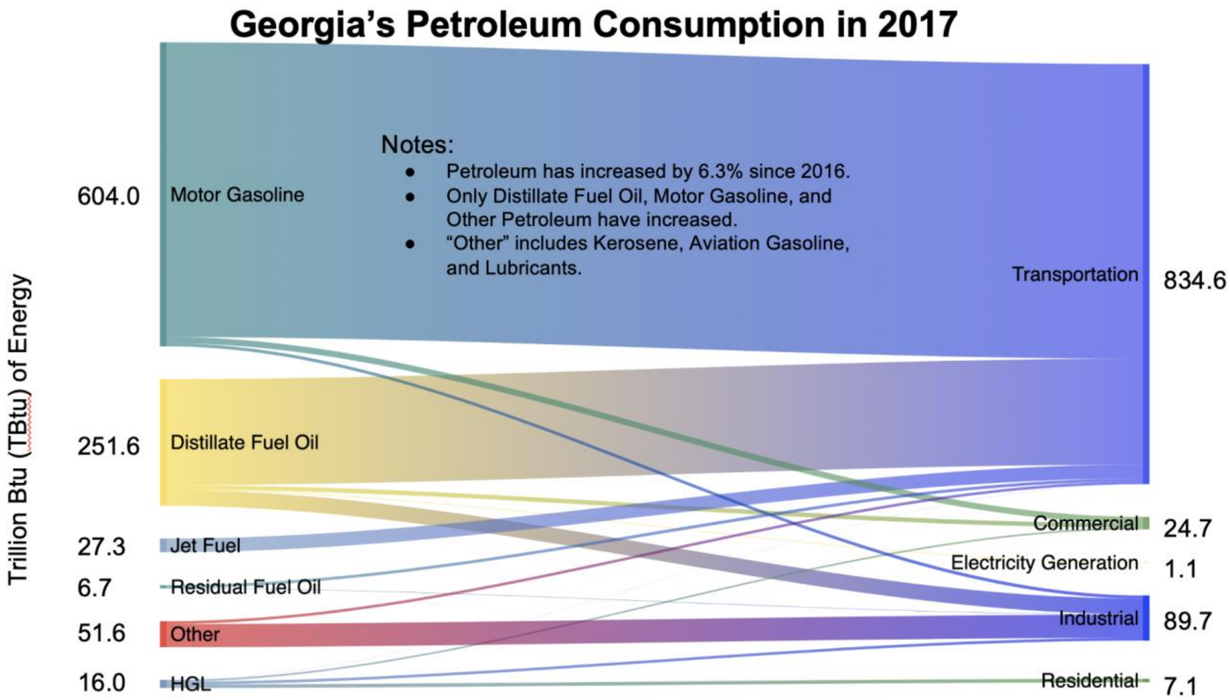
B Appendix B. Transportation

B.1 Solution List

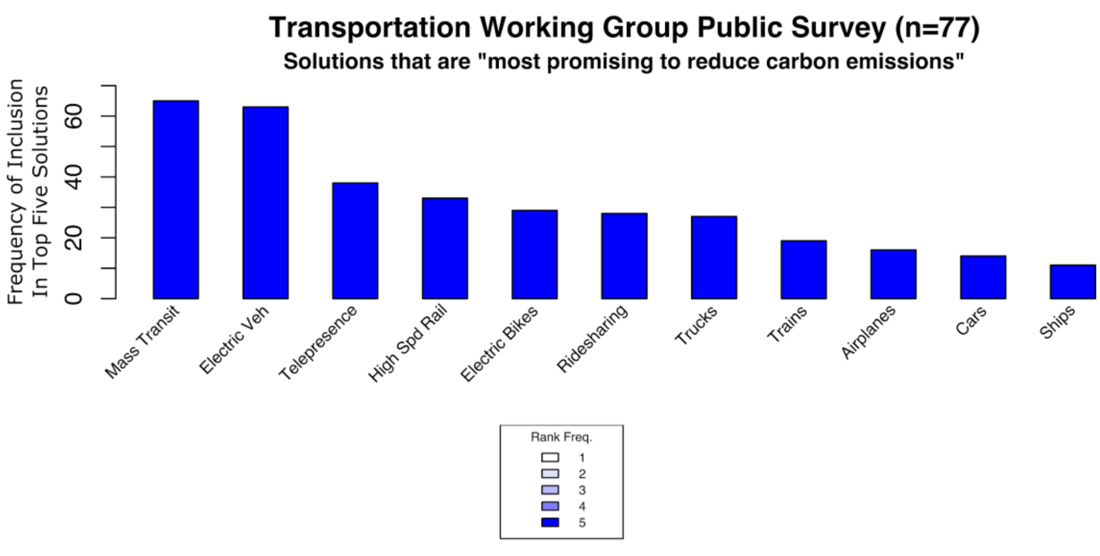
- Energy-Efficient Cars
- Energy-Efficient Trucks
- Mass Transit
- Electric Vehicles
- Aviation Groundworks
- Shipping (Port Groundworks)
- Trains
- Autonomous Vehicles
- High-Speed Rail
- Alternative Mobility
- Electric Bikes
- Telepresence
- Walkable Cities

B.2 Down-Select Criteria for Transportation Solutions

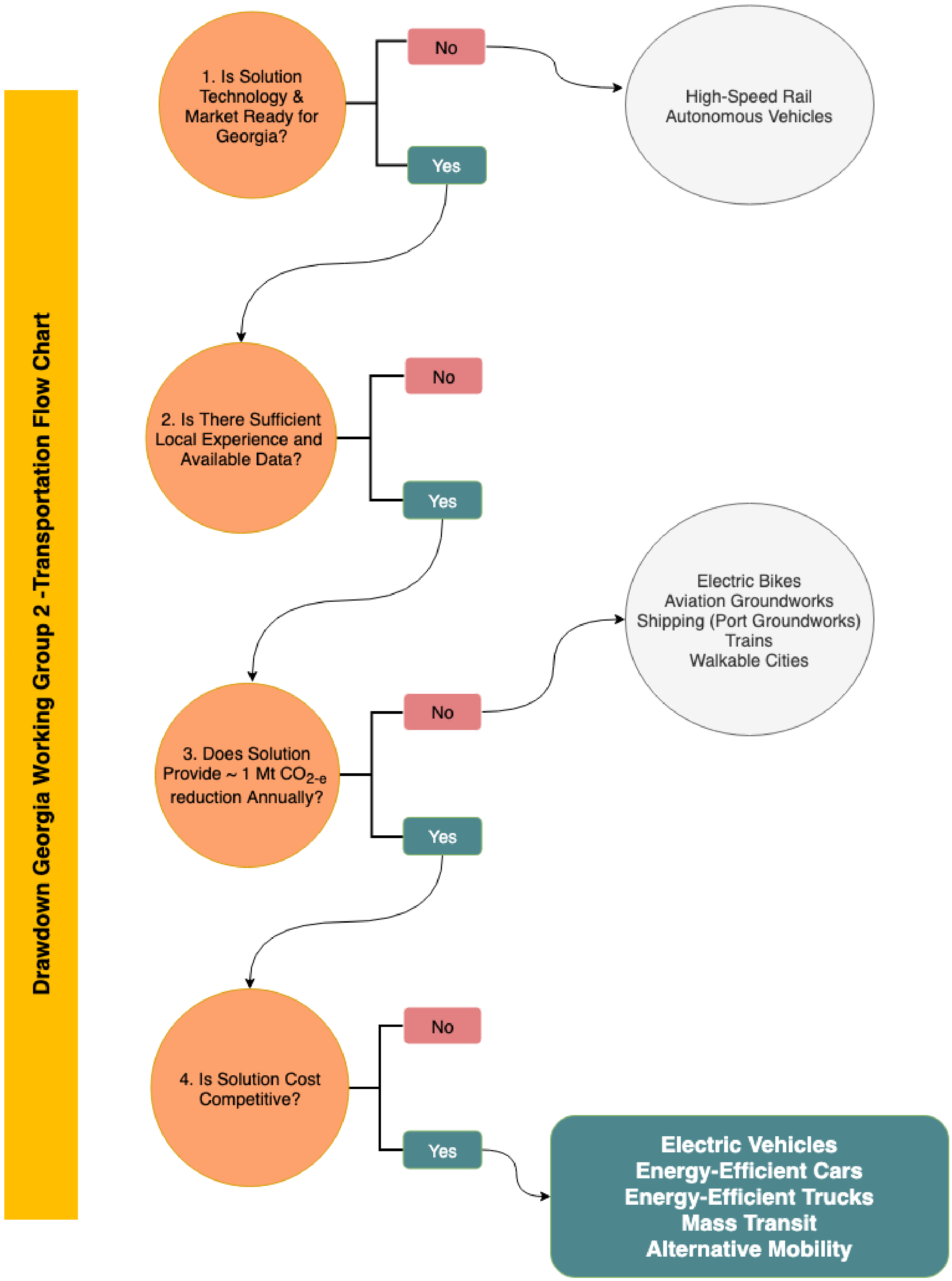
1. **Technology & Market Readiness** - Are the components of the Solution ready enough to be launched at significant scale over the next decade? (Can innovation, technology, and policy developments make the Solution workable by 2030, if it is not already?)
2. **Local Experience & Data Availability** - Are there sufficient data or qualitative analysis to adequately consider the Solution in a Georgia context? Is there local familiarity with the technology? Are there any local pilot or demonstrations to study? Is the level of complexity of the Solution manageable so that it can be credibly assessed? If state-level data and experience are limited or non-existent, can national level data be used to scale and perform a reasonable assessment of Solution's potential for Georgia?
3. **Technically Achievable CO_2e Reduction Potential** - Could the Solution achieve significant carbon equivalent reductions, especially in the 2030 timeframe, as compared to other Solutions available to this sector? (a minimum threshold of 1 Mt CO_2e annually was considered -- about 1% of 2017 Georgia CO_2 emissions). If a Solution cannot meet the 1 Mt CO_2e annually threshold alone, could multiple Solutions be combined / bundled in a rational and strategic manner to achieve the targets? The preliminary CO_2e reduction estimates were obtained via "back-of-the-envelope" type calculations using data from existing literature.
4. **Cost competitiveness** - Is the Solution cost competitive relative to other Solutions available to the sector? Are the up-front capital costs affordable? Is the payback period competitive with other Solutions? Both the global Project Drawdown® estimates, as well as abatement curves based on engineering estimates were considered, while bearing in mind that these should be treated with care given the large uncertainties typically associated with these estimates. Expert feedback on cost effectiveness was also considered. Viable market-ready technological solutions exist for all down-selected solution categories, although greater penetration and impact are possible.
5. **Other ("Beyond Carbon") Attributes** - Should any of the Solutions be retained for further analysis based on major co-benefits or co-costs beyond carbon (e.g., environment, economic development, public health, equity, etc.)?



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



(Each 1st place rank earns 5 points, 2nd place 4 points, 3rd place 3 points, 4th pace 2 points, 5th place 1 point)



Note: Several transportation-sector solutions are considered with the Alternative Mobility Solution in the Built Environment & Materials sector. This includes: Electric Bikes, Telepresence and Walkable Cities.

Down-Select Steps to Identify High-Impact 2030 Solutions[2]

B.3 Down-Select Results for Transportation Solutions

B.3.1 Energy-Efficient Cars | Down-Select

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.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Hybrid cars and fuel-efficient light duty vehicles (LDVs: cars, SUVs, pickups) are readily available and have secured a strong presence in the market (EPA, 2019). All vehicle manufacturers are currently developing technologies to improve fuel economy.[1] CO_2 emissions from cars and light duty trucks have been steadily declining, reaching record lows nearly every year since 2004. Fuel economy has likewise improved drastically over the same time period and is projected to continue to increase into the future. The U.S. Environmental Protection Agency's (EPA) GHG regulations and corporate average fuel economy (CAFE) standards have encouraged innovation and continue to stimulate the market for increased efficiency.[2] Many advanced technologies are now standard equipment on new LDVs (EPA, 2019).
Local Experience & Data Availability (2)	**Yes**	Currently, approximately 3.6% of all vehicles in the United States are registered in Georgia.[3] About 6,225,000 passenger vehicles are registered in the state. There is readily available data on fuel efficiency and emissions for light-duty and energy efficient hybrids.[4] The Georgia dealer network and marketplace are very familiar with fuel saving and alternate vehicle technologies.
Technically Achievable CO2 Reduction Potential (3)	**Yes**	Given the high number of single-occupancy trips, potential reductions in car emissions derived from efficiency improvements will prove significant. Aggressive GHG regulations such as CAFE standards have reduced the amount of CO_2 emitted per mile by the average light duty vehicle by about 14% from 395 grams per mile in 2009 to 348 grams per mile in 2018.[2] (EPA, 2019). Assuming the next decade of GHG regulations are only half as effective, then the average light duty vehicle in 2030 would emit around 323 grams per mile. It is estimated that there will be

[2] 18118

		approximately 556,000 new light duty vehicle sales in Georgia in 2030.[5] The average vehicle travels 13,000 miles per year,[6] thus new vehicles sold in 2030 that follow this trend in compliance with efficiency standards will avoid CO_2 emissions by 180,700 metric tons in 2030 alone compared to 2018 levels. If it is assumed that the impacts of new vehicle sales in model years that precede 2030 are also added, then the cumulative CO_2 reductions of these new technologies in the fleet will exceed 1 $MMTCO_2$/year.
Cost Competitivene-ss (4)	**Yes**	Many fuel saving technologies are available at attractive paybacks. Since a vast majority of Georgia's fleet operates on the traditional internal combustion engine (ICE), a focus on steady increases in average fuel economy from ICEs and hybrids (as quantitatively described above) will make significant contributions to drawdown goals and demonstrate economic viability. Depending on miles travelled and fuel prices, the cost of fuel economy technologies can be offset by operational cost savings on a net present value basis (Simmons, et al., 2015). Compared to other means of mitigating CO_2 in transportation, cars and the suite of fuel efficiency technologies pose a relatively low-cost solution for a significant impact.
Beyond Carbon Attributes (5)		Co-benefits: This solution offers benefits to the environment and public health from the improvement in air quality[7]. Additional benefits include the creation of jobs associated with selling, installing, and maintaining hybrid vehicles and improved fuel economy[8]. Co-costs: In terms of potential adverse impacts, there are some concerns regarding the disposition of end-of-life of batteries (Ai, et al., 2019). There are also concerns regarding upward pressure on electricity rates to fund the investment in infrastructure required to charge hybrid batteries, because some (not all) hybrids require electric charging. Also, there are some accessibility challenges as lower income drivers are often not able to afford the latest or most energy efficient vehicle options[9].
Down-select Decision	**Yes**	Retain for further analysis

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Ai, Ning, Junjun Zheng, and Wei-Qiang Chen. 2019. “U.S. End-of-Life Electric Vehicle Batteries: Dynamic Inventory Modeling and Spatial Analysis for Regional Solutions.” Resources, Conservation & Recycling 145 (June): 208–19. doi:10.1016/j.resconrec.2019.01.021.

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B.3.2 Energy-Efficient Trucks | Down-Select

U.S. trucks consume about 50 billion gallons of diesel fuel each year. Trucks consume a disproportionate quantity of fuel relative distances travelled. Increasing fuel efficiency for both new and existing trucks can lead to significant emission reductions. Numerous fuel-saving technologies are available at compelling paybacks.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Fuel efficient medium duty (MD) and heavy duty (HD) trucks are available and already a strong presence in the market. Vehicle technologies and improved connectivity and routing can all be subsets that contribute to reductions within this solution category. Because of the compelling economics and prevalence of a range of truck applications within the economy, market forces encourage technological innovation.
Local Experience & Data Availability (2)	**Yes**	There are around 4 million registered MD and HD trucks in Georgia.[1] Logistics account for 18% of the state's gross state product (GSP), supporting 5,000 companies, employing 110,000 Georgians and generating over $50 billion in sales annually.[2] The National Highway Traffic Safety Administration (NHTSA) and the EPA periodically publish information on fuel efficiency and emissions for MD and HD vehicles, as well as draft regulatory policy setting efficiency and emission standards.[3]
Technically Achievable CO2 Reduction Potential (3)	**Yes**	Improving freight movement efficiency and reducing congestion, particularly in bottleneck congestion sites, will yield significant fuel savings and emissions reductions. According to the Georgia Department of Transportation (GDOT), long-haul trucks emit around 1,345.4 gCO2/mile.[3] By reducing idle time and increasing route and operating efficiency via infrastructure and technological improvements, this number can be reduced substantially. Significant opportunities exist in converting MD vehicles to alternative fuels such as compressed natural gas (CNG) and hybrid-electric powertrains (Quiros et al., 2017) showing emissions reductions in excess of 20%. Additional opportunities exist to substitute MD diesel trucks with electric or hybrid-electric vehicles, as many are centrally garaged, rarely require operation outside of a defined area, and have routes (i.e., predictable, start-stop, urban) that can exploit the CO_2 reducing benefits of hybridized or electrified powertrains.
Cost Competitiveness (4)	**Yes**	Fuel efficient vehicles can incur higher upfront costs, but paybacks can be attractive (Gelmini and Savaresi, 2018). MD applications may exploit technologies that have been developed for LDVs and are now competitive at scale for selected use cases. Relative to the price tag of other emissions reductions solutions, the cost is relatively minimal and fuel-saving technologies in freight result in concurrent economic benefits and emissions reductions.

Beyond Carbon Attributes (5)		Co-benefits: The solution offers benefits to the environment and public health from improvements in air quality[5]. Other benefits include the creation of jobs for the manufacturing and engineering of fuel-efficient trucks (One study estimated that widespread national deployment of more-efficient trucks would create 63,000 additional jobs by 2020, and 124,000 jobs by 2030)[6]. Additionally, there are benefits for truck drivers and owners from reduced spending on fuel from improved fuel efficiency[7]. Co-costs: These include higher initial upfront investments, early depreciation and sunk costs associated with incumbent assets, and other market barriers for adoption.
Down-select Decision	**Yes**	Retain for further analysis

References:

Quiros, D. C., Smith, J., Thiruvengadam, A., Huai, T., & Hu, S. (2017). Greenhouse gas emissions from heavy-duty natural gas, hybrid, and conventional diesel on-road trucks during freight transport. *Atmospheric Environment*, *168*, 36-45.

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   https://www.ucsusa.org/resources/delivering-jobs
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B.3.3 Mass Transit | Down-Select

Public mass transit include modes such as buses, trains and streetcars. When people rely on mass transit instead of cars, it reduces GHG emissions.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	The technology for mass transit options is readily available and there are well-established markets for it in Georgia. Behavioral shifts, however, will be required to achieve maximum GHG reduction potential.[1] More specifically, the trend in public transit ridership has not followed a favorable trajectory as compared with competing travel options (e.g., ride-hailing). If ridership can be sustained or increased, it could open the door to large emissions reductions from this solution, driven by more advanced vehicle technology and routing intelligence.
Local Experience & Data Availability (2)	**Yes**	Georgia has MARTA, GRTA and Cobb County Transit in Atlanta metro area and Chatham in Savannah. As a result, significant data is available on ridership demand and vehicle and system efficiency. While large deployments of electric vehicles have not been undertaken in Atlanta, a growing dataset is available from other urban transit systems which would be relatively translatable.
Technically Achievable CO2 Reduction Potential (3)	**Yes**	For a rough order of magnitude comparison, it is estimated that mass transit options in Georgia (MARTA in Atlanta in particular) releases .245lbs CO_2/passenger mile, compared to .891lbs CO_2/passenger mile for a single occupancy vehicle personal vehicle.[2] While a true trip comparison and consideration of ridership would be required to complete the analysis, this notional difference suggests that CO_2 potentials are technologically achievable. This figure decreases further as ridership percentages rise, since the system increases in efficiency. There is potential for significant avoided emissions for most trips so long as ridership is sufficiently high. Beyond directly replacing existing trips, the availability of transit alters land use patterns that result in fewer or shorter vehicular trips, which in turn helps to reduce tailpipe emissions. In reviewing the literature, one comprehensive study found that CO_2 emissions can be on the order of 70% lower than diesel emissions for an EV bus applications in a simulation of European and California contexts (Lajunen and Lipman, 2016).
Cost Competitiveness (4)	**Yes**	Government subsidies for transit can reduce the cost per trip. For passengers, mass transit can frequently be the cheapest mode of travel (and the lowest CO_2 option), replacing the financing, operating, and maintenance costs associated with owning personal vehicles with a small fare or a monthly pass. While this option may incur longer commutes, the direct cost savings can be considerable. In a given benefit cost comparison, an EV bus was found to have a capital cost of 2 to 3x that of a diesel bus in an identical application, but a net operating cost of less than 1.5x, due to

		reduced energy, maintenance and operating expenses (Lajunen and Lipman, 2016). Finally, the EV-Diesel transit bus cost gap is expected to approach parity by about 2030.
Beyond Carbon Attributes (5)		Co-Benefits. These include improved air quality from reduction in higher emission vehicles[3], potential for increased business and property values in areas around mass transit stations (Stjernborg and Matisson, 2016), improved quality of life and reduced obesity (She, et al., 2017), and reduced vehicle traffic and congestion in cities (Stjernborg and Matisson, 2016). Potential equity benefits incude low-cost access to transportation in low-income communities and for those who cannot drive or do not have a driver's license[4]. Co-Costs: In terms of potential adverse impacts, there will likely be concerns resulting from the acquisition of new corridors and consequential segmenting of land and neighborhoods. Other concerns include the potential for an increase in crime related activities in neighborhoods around stations (Di, 2017).
Down-select Decision	**Yes**	Retain for further analysis

References:

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Stjernborg, V., Mattisson, O. (2016). The Role of Public Transport in Society—A Case Study of General Public Policy Documents in Sweden, *Sustainability*, 8, 1120, doi:10.3390/su8111120

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B.3.4 Electric Vehicles | Down-Select

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

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Electric vehicles are available in the marketplace in LDV applications (Note: there are electric vehicles for other transportation solutions that are not included under this solution). Over the last decade, Georgia provided state subsidies (in the form of a tax credit on new EVs) that led to significant new EV sales, yet allowed those subsidies to expire in 2016. Adoption rates during the subsidy period demonstrate a huge potential for EVs in the Georgia market. In 2018, about 14,000 electric vehicles were registered in Georgia.[1] The projected percentage share of new vehicle sales for EVs range from anywhere from around 20%[2] to nearly 50%[3] of total LDV sales in 2030. We assume that Georgia's adoption will fall within this national range, depending on future technology and policy scenarios.
Local Experience & Data Availability (2)	**Yes**	From 2017-2018, Georgia had 122.64% year-on-year share percentage increase and was a leader in EV adoption.[4] Consequently data is readily available and local markets have experienced high rates of adoption.
Technically Achievable CO2 Reduction Potential (3)	**Yes**	EVs are readily capable of achieving significant CO_2 reductions when the electricity generated comes from renewable or net-neutral carbon energy sources (Cox, et al., 2018). CO_2 reductions are still possible compared to conventional internal combustion vehicles when the electricity derives from natural gas generation. Reduction potential is heavily contingent on grid portfolio and emissions associated with manufacturing and resource extraction. Large potential reductions are possible in the 2050 timeframe, in particular under high renewable penetration scenarios (Cox, 2018). Current EV technology can reduce CO_2 emissions (including upstream) by 50gCO_2e/km for a small, light duty passenger vehicle using weighted average for the CO_2 emissions intensity of the Georgia grid.[5] As technology and efficiency continues to improve, these CO_2 reductions are expected to be even greater (by up to 50% more) by 2030.[6] Even with modest penetration, electrification of Georgia's light duty personal & commercial vehicles shows significant potential for reduction. Additional carbon emissions associated with increased electricity demand warrants further study.
Cost Competitiveness (4)	**Yes**	As reflected by sales projections, the cost of a new EV is expected to be comparable to that of internation combustion engine vehicles (ICEVs) over the next decade. Cost competitiveness will increase as manufacturing

		economies of scale are realized and adoption rates grow. Costs and benefits vary with regard to usage patterns, but are broadly positive as technology becomes cheaper and more commonplace (Simmons, 2015). Reduced operation and maintenance costs should offer significant savings to consumers over vehicle lifetimes.[7] More study is likely needed to determine the impact of charging infrastructure costs and electricity generation/rates and how these should be allocated to users or society as a whole.
Beyond Carbon Attributes (5)		Co-beneifts: The solution offers benefits to environmental and public health from localized air quality improvements (Smit, et al., 2018), recognizing that such benefits may not exist or may be limited in energy generation/producing locations. Other benefits include the creation of jobs associated with selling, installing, and maintaining batteries for electric vehicles[8]. Another positive consideration emerges from research that highlights the storage locations of commercial trucks in low income communities – with electrification and movement in/out of these facilities offering localized public health/air quality benefits (versus emission vehicles). Co-costs: Potential adverse impacts include disposition of end-of-life of batteries (Ai, et al., 2019). Also, large scale EV adoption will necessitate charging/related infrastructure investments that have the potential to increase electricity rates. As with other solutions such as solar, the higher costs of EV vehicles may make access to this solution challenging for low-income communities[9].
Down-select Decision	**Yes**	Retain for further analysis

References:

Ai, Ning, Junjun Zheng, and Wei-Qiang Chen. (2019). “U.S. End-of-Life Electric Vehicle Batteries: Dynamic Inventory Modeling and Spatial Analysis for Regional Solutions.” Resources, Conservation & Recycling 145: 208–19.

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B.3.5 Aviation Groundworks | Down-Select

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.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	Electrification of a variety of ground transportation has already been tested in several locations. The Delta Hub in Atlanta is already incorporating various solutions to improve aviation fuel efficiency and groundworks. Currently they have invested $2 million in biofuel research, offer a carbon offset program, and have a company-wide fuel savings initiative out of their hub in Atlanta.[1]
Local Experience & Data Availability (2)	**Yes**	Georgia has extensive aviation experience and data availability, as Hartsfield Jackson (ATL) is the world's largest passenger airport and provides a testing ground for new research and initiatives. ATL has conducted surveys of baggage tractors and other ground support equipment with the goal of substituting conventional fuels with advanced/renewable fuels and electricity[2]. Delta airlines has performed pilot demonstrations of electric tugs at ATL to determine their technological and economic viability, confirming favorable results from a year-long field trial. Ground service and ground transportation vehicles have limited emissions control systems and electrification offers significant co-benefits. Ground vehicles are centrally garaged and follow predictable routes, making them strong candidates to exploit the benefits of electrified technology.
Technically Achievable CO2 Reduction Potential (3)	**TBD**	Focusing on airport groundworks (in lieu of airplanes) enables the Drawdown Georgia team to study the achievable emissions reductions associated with an aviation-related solution that is appropriate for the given regional jurisdiction. Scope refinement is required to determine what should be included versus excluded in improving the efficiency of logistics (reduced idling time and fuel loss moving to and from gates), improving recyclability of airplanes, seats, and systems, reducing drag on planes in flight, etc.[3] Ground movements may be a smaller share of total emissions reductions relative to in-flight efficiency improvements, but are more attainable from a Drawdown Georgia perspective. According to a recent sustainability plan, Delta's overall objective is to reduce emissions by half between 2005 and 2050, and they explicitly mention the introduction of electric-ground vehicles as one several activities to help achieve this goal[4].

Cost Competitiveness (4)	**Yes**	Reduced operation and maintenance costs. Carbon offsets, air quality improvements, new technologies, etc. will require validation, research and development, and scale up before achieving significant reductions.
Beyond Carbon Attributes (5)		Co-benefits: The solution offers benefits to the environment and public health from improvements in air quality (Smit, et al., 2018). These environmental and public health benefits would be seen directly in the adjacent communities in which they are implemented. Co-costs: Upfront capital costs and investments in charging infrastructure, if passed on, may result in higher costs. As with other EV solutions, there are also end of life battery disposal issues that will need to be managed (Ai, et al., 2019).
Down-select Decision	**Yes**	Retain for further analysis, with focus on ground operations

References:

Ai, Ning, Junjun Zheng, and Wei-Qiang Chen. (2019). "U.S. End-of-Life Electric Vehicle Batteries: Dynamic Inventory Modeling and Spatial Analysis for Regional Solutions." Resources, Conservation & Recycling 145: 208–19. doi:10.1016/j.resconrec.2019.01.021.

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B.3.6 Shipping (Port Groundworks) | Down-Select

Shipping produces 3% of global GHG emissions. While ship design and onboard technologies are beyond the scope of Drawdown Georgia, on-shore practices could have an important impact on regional CO_2 emissions because of huge shipping volumes in Georgia.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology is readily available and improvements are similar to those witnessed with airports in terms of efficiency increases and fuel savings.
Local Experience & Data Availability (2)	**Yes**	Georgia Ports Authority has extensive experience with electrication of port groundworks, largely through the Ports of Savannah and Brunswick.
Technically Achievable CO2 Reduction Potential (3)	**No**	While ships are responsible for around 3% of global GHG emissions, the most significant reductions from the shipping industry will focus on on-board fuel switching and efficiency improvements, which are beyond the scope of Drawdown Georgia. In addition, ground works in major Georgia Ports have already benefited from recent investments, and are unlikely to reduce emissions much more.[1] All 27 ship-to-shore cranes at Savannah and Brunswick have already been electrified from diesel fuel.[2] Other electrification of ground movements at the ports are possible, but possibly beyond scope.
Cost Competitiveness (4)	**No**	Although there are structural changes that can be made to ships to improve efficiency (reducing drag for hulls and propellers), more intensive solutions can cost up to $25k per ship and are beyond scope.[1] Groundwork efficiency enhancements made possible by shore-side electrification are generally less costly compared to vessel-powered services and compared to major design-related energy modifications to ship systems depending on the local energy sources (MariTerm, 2004). However, overall cost competitiveness is complicated to estimate. It should be noted that studies (Kerl, et al., 2015; MariTerm, 2004) suggest port-side electrification can contribute to substantial improvements in air quality, health impacts, and other beyond carbon benefits.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

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1. https://www.economist.com/science-and-technology/2018/11/03/shipping-regulators-plan-to-cut-greenhouse-gas-emissions
2. https://gaports.com/our-port/community-sustainability/

B.3.7 Trains | Down-Select

In general, heavy-rail trains are powered by diesel-burning engines and primarily transport freight, whereas light-rail trains are commonly used for urban transit and use multiple sources of energy, including electricity. Technology and operations can improve fuel and energy efficiency, depending upon the primary energy source and application. Rail electrification also has the potential to provide nearly emissions-free transport, but may be more suitable for applications near urban centers, which could be more easily equipped with the supporting infrastructure. For the Drawdown Georgia context, this solution refers exclusively to heavy-rail trains, whereas light-rail trains are addressed within the context of Public Mass Transit.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	The market in Georgia is prepared for trains and there is a demand for increased efficiency measures.
Local Experience & Data Availability (2)	**Yes**	With nearly 5,000 miles of active rail lines, Georgia has the largest rail network in the Southeast. Georgia's location provides direct rail access to the Mid-Atlantic, Northeast and Midwest regions of the United States.[1]
Technically Achievable CO2 Reduction Potential (3)	**No**	Some research has demonstrated that rail can work in conjunction with freight and multi-modal transport of goods to deliver reductions in net system emissions (Lin, et al., 2017). Other publications cite compelling technological benefits of hybrid drive architectures for trains (Lorenz, et al., 2014). However, rail is by default an interstate industry. Any meaningful carbon reduction would need to take place on a regional or national level, which would place this solution largely outside of the Drawdown Georgia scope. In addition, due to the high efficiency of diesel engines at cruising speeds over long distances, a more immediate concern in urban regions with train emissions involve particulate matter rather than CO_2 (Jaffe, et al., 2014). Thus, due to limitations on scope and technical potential for the Drawdown Georgia project, there is limited opportunity for substantial CO_2 reduction in the 2030 timeframe.
Cost Competitiveness (4)	**No**	Retrofitting thousands of miles of active rail lines in Georgia would be cost-prohibitive. Disruption to critical economic activity during construction could be significant enough to deter electrification. Further, electrification for any segment of rail would require national coordination in order to deploy locomotive technologies that can run solely on electricity without sacrificing power.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Jaffe, D. A., Hof, G., Malashanka, S., Putz, J., Thayer, J., Fry, J. L., ... & Pierce, J. R. (2014). Diesel particulate matter emission factors and air quality implications from in–service rail in Washington State, USA. Atmospheric Pollution Research, 5(2), 344-351.

Lin, B., Liu, C., Wang, H., & Lin, R. (2017). Modeling the railway network design problem: A novel approach to considering carbon emissions reduction. Transportation Research Part D: Transport and Environment, 56, 95-109.

Lorenz, L., Seitz, A., Kuhn, H., & Sizmann, A. (2014). Hybrid power trains for future mobility. Deutsche Gesellschaft für Luft-und Raumfahrt-Lilienthal-Oberth eV.

Endnotes:

1. http://www.dot.ga.gov/IS/Rail

B.3.8 Autonomous Vehicles | Down-Select

Autonomous Vehicles (AVs) are being actively researched and increasingly demonstrated in selected cities and applications. While many believe AVs have the potential to improve safety, relieve congestion, shrink the auto fleet, and accelerate ridesharing, the energy implications of broad AV deployment is less certain (Wadud, 2016; Cox, 2018). Initial AV demonstrations are using a variety of energy sources (e.g., EV, HEV, FCV, ICEV). Furthermore, the long term powertrain architectures and on board energy needs of AVs are highly sensitive to application, and thus, yet to be determined. For these reasons, insufficient data are currently available about energy signatures, sources and needs that preclude conclusive, near-term assessments of the CO_2 impacts for future AV deployment scenarios in a Georgia context.

Criteria		**Comments**
Technology and Market Readiness (1)	**No**	The technology is in its very early stages. Limited programs have been implemented in other states, but none in Georgia. For AVs, the CO_2 benefits, energy consumption (Wadud, et al., 2016), use cases, and ability to deliver on safer trips are largely unknown today.
Local Experience & Data Availability (2)	**No**	There is no experience with AVs in Georgia, but the technology is developing. There are pilot programs for the technology are being developed elsewhere (Moorthy, et al., 2017; Stocker and Shaheen, 2019). It is unclear what energy and emissions savings will result, and how various pilots may be applicable in a Georgia context, due to insufficient data.
Technically Achievable CO2 Reduction Potential (3)	**No**	Many questions remain regarding emissions reductions. There could be a net increase, neutral or net decrease in emissions associated with AV adoption (Wadud, 2019, et al., Cox, 2018, et al.). While much early-stage research is considering Battery Electric Powertrains, until range and recharging challenges are resolved, on-board energy sources for AVs is uncertain. Whether AVs employ electrified powertrains, liquid fuel, fuel cells, or some other form of energy approach, is an open question that may not be resolved during the period of interest.
Cost Competitiveness (4)	**No**	Assuming current market conditions hold, there are estimates that using an automated taxi will cost consumers nearly three times more on a per mile basis than owning an older vehicle.[1] The per-mile or per-trip cost of AV travel is similarly unknown.
Beyond Carbon Attributes (5)	**TBD**	Co-benefits: increased quality of life Co-costs: without full penetration, there are some potential risks during the transition to new technologies (Wadud, et al., 2016; Cox, et al., 2018). AV technologies are also expected to be costlier than current vehicles, and their

		benefit-cost value proposition is uncertain.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Cox, Brian, Christopher L Mutel, Christian Bauer, Angelica Mendoza Beltran, and Detlef P. van Vuuren. *Environmental Science & Technology* **2018** *52* (8), 4989-4995

Moorthy, A., De Kleine, R., Keoleian, G., Good, J. et al., "Shared Autonomous Vehicles as a Sustainable Solution to the Last Mile Problem: A Case Study of Ann Arbor-Detroit Area," SAE Int. J. Passeng. Cars – Electron. Electr. Syst. 10(2):328-336, 2017.

Stocker, A., & Shaheen, S. (2019). Shared automated vehicle (SAV) pilots and automated vehicle policy in the US: Current and future developments. In *Road Vehicle Automation 5* (pp. 131-147). Springer, Cham.

Wadud, Zia, Don MacKenzie, and Paul Leiby. "Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles." *Transportation Research Part A: Policy and Practice* 86 (2016): 1-18.

Endnotes:

1. https://hbr.org/2019/01/the-cost-of-self-driving-cars-will-be-the-biggest-barrier-to-their-adoption

B.3.9 High-speed Rail | Down-Select

High-speed rail lines are powered almost exclusively by electricity, instead of diesel, and provide the fastest way to travel distances between 100 to 700 miles. Emissions are significantly lower than driving, conventional heavy rail or flying. The infrastructure needs and capital investments for such technologies can be significant, suggesting that great attention to market demands and projected ridership will be a critical factor in selecting where and when this technology can be a viable solution.

Criteria		Comments
Technology and Market Readiness (1)	**No**	Although the technology is available for high-speed rail, the market is limited for it at this time in Georgia. While there is some discussion of a high-speed rail line linking Atlanta and Charlotte, North Carolina, this is likely to be outside of the 2030 time frame.[1]
Local Experience & Data Availability (2)	**No**	There is no experience in high-speed rail in Georgia at this time. Data on the most contemporary technology would likely have to come from foreign sources.
Technically Achievable CO2 Reduction Potential (3)	**No**	The potential for high-speed rail in Georgia is limited both geographically and in the potential it has to curb emissions within the state. It is unclear which current modes of transportation (for goods and people) would be displaced by high-speed rail. Other technical parameters associated with energy sources and conversion efficiencies are similarly uncertain for high-speed rail, making it complicated to estimate the use-phase or LCA equivalents for the present analysis (Chester, et al., 2017).
Cost Competitiveness (4)	**No**	High-speed rail projects in the United States are incredibly expensive, capable of costing up to $100 billion based on experience in California.[2]
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Chester, M., Ryerson, M. S., & Horvath, A. (2017). Uncertainties in the life cycle assessment of high-speed rail's energy and environmental impacts. *High-Speed Rail and Sustainability*, 278-298.

Endnotes:

1. https://atlanta.curbed.com/2019/10/24/20930180/atlanta-charlotte-high-speed-rail-proposal
2. https://www.citylab.com/transportation/2011/11/how-green-high-speed-rail/492/

B.3.10 Alternative Mobility | Down-Select Scores

For the purposes of this project, we define, “Alternate Mobility,” to include a combination of bike infrastructure, approaches and technologies that support walkable cities, including, but not limited to telecommuting, e-bikes and scooters. Note: See also: C.3.3 Alternative Mobility in Built Environment & Materials.

Criteria	Score	Comments
Technology and Market Readiness (1)	Yes	Many of the technologies are mature and market ready.
Local Experience & Data Availability (2)	Yes	There is data available for vehicle miles traveled (VMT) at the state level; this can be used to estimate reduction in VMT resulting from more widespread use of alternate mobility measures. Adoption rates (current and projected) will need to be determined with greater accuracy.
Technically Achievable CO2 Reduction Potential (3)	Yes	The GHG reduction potential is high, assuming that VMT for urban local trips can be substituted by biking, walking and/or telepresence or use of e-bikes/e-scooters. For example, preliminary analysis using data from Federal Highway Administration’s National Household Transportation Survey (NHTS, 2017) indicates that for bike infrastructure alone, a substitution of 1 out of 10 of urban local car trips (under 3 miles) by bikes could abate over 1 MT CO_2-e annually. Additional substitution of vehicle trips by walking, telepresence, and/or e-bikes/e-scooters is expected to contribute to further abatement, even when considering the interactions between these solutions (e.g., e-scooters might be a substitute for walking, as well as vehicle trips).
Cost Competitiveness (4)	Yes	Review of literature and expert survey feedback indicate that this bundle can be cost competitive, especially when considering the fact that new bike infrastructure will negate the need for new motorized vehicle infrastructure. We will explore Georgia-specific cost effectiveness during the next phase of research.
Down-select Decision		Retain for further analysis with focus on built environment Alternate Mobility solution under the jurisdiction of Built Environment and Materials.

References:

Atlanta Regional Commission (2015). The Atlanta Region’s Plan – Transportation Assessment.
FHWA National Household Transportation Survey (2017). Available online at: https://nhts.ornl.gov/
The League of American Bicyclists (2017). Where We Ride – Analysis of bicycle commuting in American cities. Report on 2017 American Community Survey Data by the League of American Bicyclists.

B.3.11 Electric Bikes | Down-Select Scores

Electric bikes are equipped with both pedals and a small battery-powered motor. They can provide significant emission reductions when they replace other motorized travel, including car rides.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Electric bikes exist in primarily urban areas within Georgia and appear to be increasingly used. One use case that has grown is the rented service of an e-bike for very short urban distances.
Local Experience & Data Availability (2)	**Yes**	Georgia has experience with electric bikes, largely in urban areas
Technically Achievable CO2 Reduction Potential (3)	**No**	For electric bikes to have significant emissions reduction potential, it would require 15% e-bike mode share for them to achieve an 11.4% emissions reduction of around 921 tons CO_2 per day or 350 MT/year.[1] It should be noted that only a very small fraction of bicycles today in Georgia are equipped with an electric motor. While the emissions reduction potential of conventional (non-electric) bicycles as a solution within the alternate mobility bundle has greater potential (NHTS, 2017), it is unclear what portion of the market share can be gained by electric bicycles, and the CO_2 intensity of the trips being replaced is similarly unclear, complicating a complete analysis.
Cost Competitiveness (4)	**Yes**	Electric bikes can be cost-competitive. However, in leased/rented business models, their lifespan may be greatly reduced, suggesting greater attention to a total lifecycle CO_2 emissions analysis.
Down-select Decision		Retain for further analysis with focus on built environment. The Alternate Mobility solution is examined under the jurisdiction of Built Environment and Materials.

References:

FHWA National Household Transportation Survey (2017). Available online at: https://nhts.ornl.gov/

Endnotes:

1. https://peopleforbikes.org/wp-content/uploads/2019/05/E-bike-Potential-Paper-05_15_19-Final.pdf

B.3.12 Telepresence | Down-Select

Telepresence in various forms, such teleconferencing, videoconferencing, virtual meetings, and the like, integrates high-performance visual, audio, and network technologies to enable people who are geographically separated to interact. Telepresence substitutes physical processes with virtual ones, thus reducing travel and subsequently, emissions.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Technology for telepresence has penetrated the market and workplace and has become common practice in many Fortune 500 companies. It seems likely that market forces will undergird this continuing trend. It should be noted that this preliminary assessment of the readiness of telepresence for the Drawdown Georgia project was prepared in late 2019 and early 2020, prior to the outbreak of the COVID-19 pandemic. Early indications from the global response to COVID-19 are that telepresence could play a more prominent role than it might have before the virus outbreak. Nonetheless, based on limited data as of March 2020, it remains somewhat unclear how our research might assess the extent to which this approach can be expanded previously known business-as-usual trajectories. Additional uptake will not focus on technology readiness as much as it will behavioral decisions and simple cost analyses.
Local Experience & Data Availability (2)	**Yes**	Telepresence is widely used, but rarely exclusively used *(Note: notwithstanding the recent COVID-19 situation, as mentioned above). Data do however exist and there is local experience in Georgia.
Technically Achievable CO2 Reduction Potential (3)	**TBD**	One source suggests that, if a company with an annual revenue of $1 billion or more deployed four telepresence conference rooms, 900 business trips could be prevented in a single year and, subsequently, 2,271 metric tons of CO_2 emissions – the GHG equivalent of removing 434 cars from the road for one year – would be eliminated.[1] One study estimates that a videoconference can avoid up to 93% of the emissions of an in-person meeting[2] (though results are highly variable, with certain usage scenarios offering no net benefits over an in-person meeting) (Ong, et al., 2014). However, telepresence is a growing trend that is expected to justify itself without proactive support and is therefore considered in the "business as usual" forecast.
Cost Competitiveness (4)	**Yes**	Telepresence can provide a return on investment (ROI) for investing companies within 15 months. U.S. firms can save over $15 billion over 10 years; annual net financial benefits rising from $315 million in 2010 to over $3.5 billion in 2020.[1] Other anecdotal corporate studies and experiments reveal that considerable direct cost savings (from avoided travel expense, personnel transit time) can result, as well as direct reductions in energy and emissions (which also have favorable indirect cost implications).

		Unfortunately, it is complicated to assess the productivity or value of a virtual meeting as compared to an in-person one.
Down-select Decision		Retain for further analysis in the “Alternate Mobility” solution considered in the Built Environment and Materials sector.

References:

F. Guerin, T. (2017). A demonstration of how virtual meetings can enhance sustainability in a corporate context: Quantified benefits of virtual meetings through video conferencing. *Environmental Quality Management*, *27*(1), 75-81.

Ong, Dennis, Tim Moors, and Vijay Sivaraman.(2014). "Comparison of the energy, carbon and time costs of videoconferencing and in-person meetings." Computer communications 50: 86-94.

Endnotes:

1. https://www.att.com/Common/about_us/files/pdf/Telepresence/CDP_Telepresence_Report_Final.pdf
2. https://www.mnn.com/green-tech/gadgets-electronics/sponsorstory/study-telepresence-can-reduce-corporate-co2-emissions-by

B.3.13 Walkable Cities | Down-Select

Walkable cities is generally defined to include technological solutions that facilitate more pedestrian travel in lieu of other, more carbon-intensive modes of travel within urban areas. In many cases, the type, convenience, time-efficiency, energy and emissions impacts of first and last mile connections can play a significant role in modal transit shift. Walkable cities effectively prioritize "two feet over four wheels" through careful planning and design. As people opt to drive less and walk more, emissions decrease. Walkable cities have other important implications about urban planning/zoning, infrastructure, congestion, convenience, quality of life and other socio-economic factors.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Several studies have assessed the co-benefits of "compact development," which includes a bundle of attributes, including increased pedestrian travel in lieu of more energy/emissions-intensive forms (NRC, 2010). Many tangible examples of walkable cities exist worldwide but will require major infrastructure investments for most American cities including those in Georgia.
Local Experience & Data Availability (2)	**Yes**	Expansive construction on Atlanta's Beltline is ongoing. By Fall 2020, paving of two-thirds of a mile on the Northeast Trail will be finished, complete with irrigation and retaining walls. Lighting and security retrofits are to follow.[1] The Beltline is widely used and has had largely positive impacts.
Technically Achievable CO2 Reduction Potential (3)	**No**	Investing in walkable cities in Georgia will not reduce emissions enough by 2030 on its own. Reduction potential is greatly enhanced when bundled with other Alternate Mobility solutions.
Cost Competitiveness (4)	**Yes**	We expect modestly higher cost than existing approaches initially due to infrastructure and planning retrofits. Benefits would accrue over longer periods. Also, it is difficult to allocate the capital costs for such an infrastructure enhancement, since it would have other substantial benefits to economic development, real estate value, tax base, etc. Finally, some studies note the potential co-benefits afforded by walking as related to public health (Milner, et al., 2012), though establishing a clear baseline and developing a full accounting of this would be complicated.
Down-select Decision		Retain for further analysis with focus on built environment Alternate Mobility solution under the jurisdiction of Built Environment and Materials.

References:

Milner, James, Michael Davies, and Paul Wilkinson. "Urban energy, carbon management (low carbon cities) and co-benefits for human health." *Current Opinion in Environmental Sustainability* 4, no. 4 (2012): 398-404.

National Research Council. (2010). *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO2 Emissions--Special Report 298*. National academies press.

Endnotes:

1. https://www.ajc.com/news/local/construction-atlanta-beltline-northeast-trail-underway/gFFMOjbB1ubq8sOoMzKqiO/

C Appendix C. Built Environment and Materials

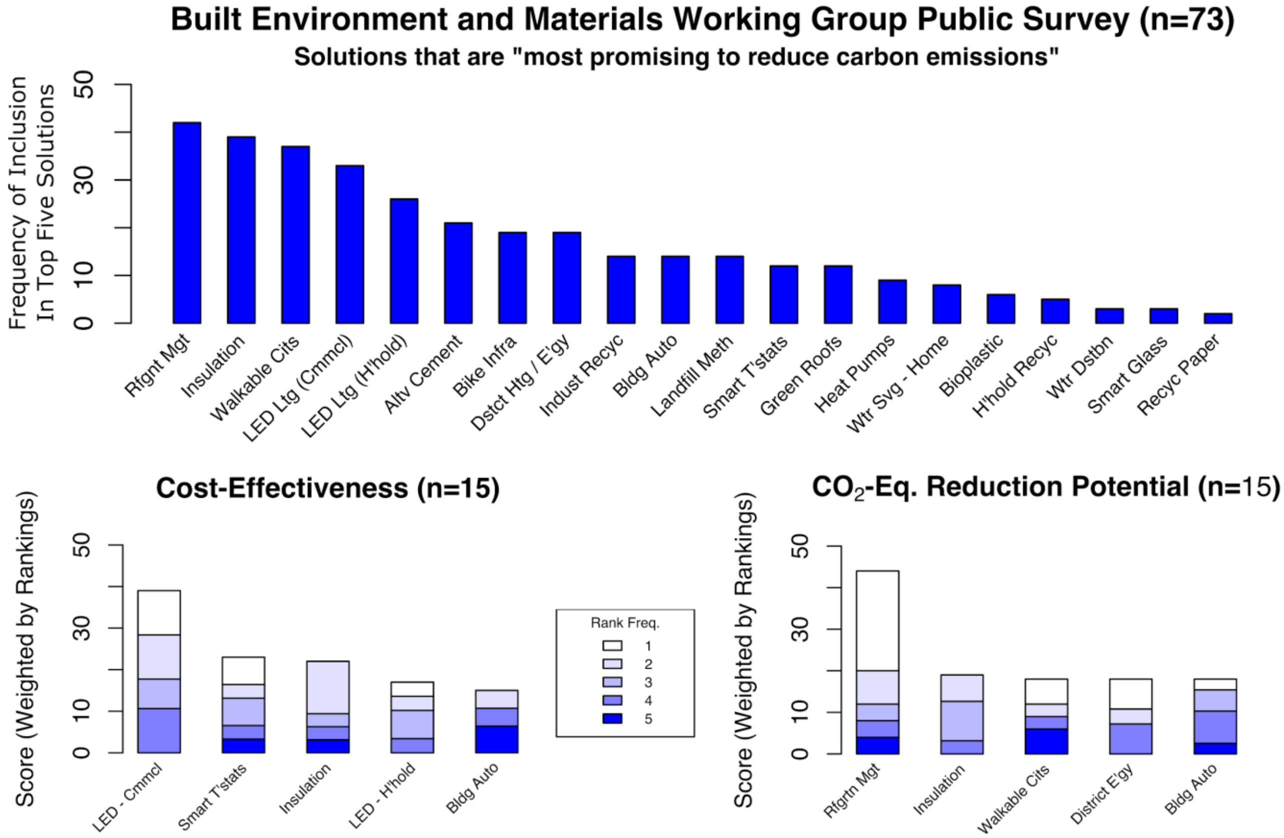
C.1 Solution List

Refrigerant Management
Retrofitting
Recycling [1]
Retrofitting [2]
Alternative Mobility [3]
Net Zero Buildings
Building with Wood
District Heating/District Energy
Smart Glass
Water Distribution
Alternative Cement
Bioplastic
Industrial Hemp
Enhanced Weathering of Minerals

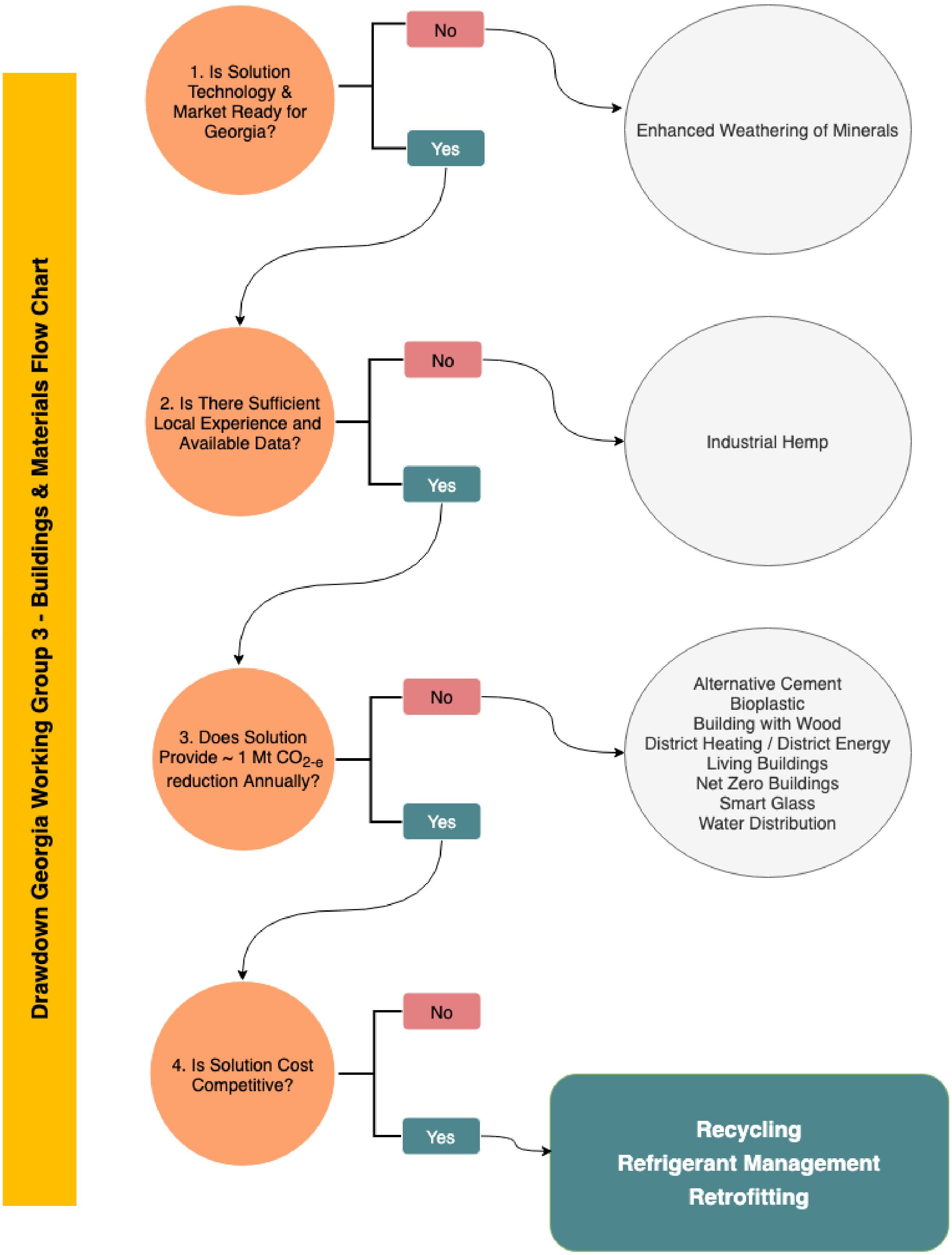
(1) Includes insulation, LED lighting, heat pumps, building automation, smart thermostats, water saving, green roofs, as well as additional solutions for Drawdown Georgia, such as windows, water heating, recommissioning of existing commercial buildings, and dead-band range expansion
(2) Includes household recycling, industrial recycling and recycled paper
(3) Includes bike infrastructure, walkable cities, e-bikes, and telepresence, as well as additional solutions for Drawdown Georgia, such as e-scooters and urban design/zoning

C.2 Down-Select Criteria for Buildings & Materials Solutions

1. **Technology & Market Readiness** - Are the components of the Solution ready enough to be launched at significant scale over the next decade (supply chain and policies largely in place, sufficient market size and market penetration potential, etc.)? If not, can innovation, technology, and policy developments make the Solution workable by 2030?
2. **Local Experience & Data Availability** - Is there sufficient data or qualitative analysis to adequately consider the Solution in a Georgia context? Is there local familiarity with the technology? Are there any local pilot or demonstrations to study? Is the level of complexity of the Solution manageable so that it can be credibly assessed? If state-level data and experience are limited or non-existent, can national-level data be used to scale and perform a reasonable assessment of Solution's potential for Georgia?
3. **Technically Achievable CO_2e Reduction Potential** - Could the Solution achieve significant carbon (or to be more precise, carbon equivalent) reductions, especially in the 2030 timeframe, as compared to other Solutions available to this sector? (a minimum threshold of 1 Mt CO_2e annually was considered -- about 1% of 2017 Georgia CO_2e emissions). If a Solution cannot meet the 1 Mt CO_2e annually threshold alone, could multiple Solutions be combined / bundled in a rational and strategic manner to achieve the targets? The preliminary CO_2e reduction estimates were obtained via "back-of-the-envelope" type calculations using data from literature.
4. **Cost competitiveness** - Is the Solution cost competitive relative to other Solutions available to the sector? Are the up-front capital costs affordable? Is the payback period competitive with other Solutions? Both the global Project Drawdown® estimates, as well as abatement curves based on engineering estimates were considered (e.g., McKinsey abatement curves), while bearing in mind that these should be treated with care given the large uncertainties typically associated with these estimates. Expert feedback on cost effectiveness was also considered.



(Each 1st place rank earns 5 points, 2nd place 4 points, 3rd place 3 points, 4th place 2 points, 5th place 1 point)



Note: Recycling/Waste Management and Retrofitting solutions are bundles of several solutions. Each of these bundles is described in the summaries below.

C.3 Down-Select Results for Buildings & Materials Solutions

C.3.1 Refrigerant Management | Down-Select

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.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology is mature and market ready. The high global warming potential of refrigerants (as much as 22,800 CO_{2}-e) means that there are large opportunities available for reducing the emissions of refrigerants. Evidence from the EPA's Green Chill program and evidence from other corporate programs that improve refrigerant management or implement alternative refrigerants suggests that substantial reductions of refrigerant emissions are possible at relatively low cost[1]. Project Drawdown® calculates that globally, only 2.7% of refrigerants are destroyed or recycled at end of life.[2] Their technical potential assumptions suggest that nearly all refrigerants can be eliminated from developed countries. Further, the Kigali Accord of 2016 aims to phase out many synthetic refrigerants and move towards less harmful alternatives, suggesting significant political momentum aimed at reducing refrigerants.
Local Experience & Data Availability (2)	**Yes**	There is state level data available from EPA on emissions resulting from ozone depleting substance (ODS) substitutes, and leak rates for refrigerants can be approximated based on EPA guidelines. Local experience is also available; for example, Atlanta-based Coca-Cola Company has been switching to HFC-free natural refrigerants in their new cold-drink equipment, with stated plans to be 100% HFC-free by 2020. That said, there is little information about specific initiatives and strategies in Georgia to address refrigerants. It is assumed that technological and managerial strategies that exist globally are also available in Georgia.
Technically Achievable GHG Reduction Potential (3)	**Yes**	The GHG reduction potential is high. According to EPA's 2016 Revised Section 608 - Refrigerant Management Regulations, the allowable leak rates of refrigeration and air-conditioning equipment containing 50 or more pounds of refrigerant was lowered from 35% to 30% for industrial process refrigeration, 35% to 20% for commercial refrigeration and 15% to 10% for comfort cooling equipment, effective January 2019.[3] Preliminary analysis using these leak rates as a current baseline and EPA's ODS substitutes emissions data for Georgia[4]

		indicates that reducing the leak rates slightly below the new EPA guidelines by 2030, and to 5% or less by 2050 (similar to the targets specified by EPA's GreenChill program), can result in a reduction significantly greater than the 1 Mt CO_2-e annual reduction threshold.
Cost Competitiveness (4)	**TBD**	While there are ambitious national and international goals for improving refrigerant management, there are unclear economic incentives in place to accomplish these reductions. Refrigerants are highly distributed through a wide range of industrial, commercial and residential applications. Further, the strategies for reducing refrigerant leakage are highly distributed as well, with strategies relating to the reduction of usage of appliances that use refrigerants; the improved efficiency of these appliances; replacement of refrigerants; the improved management and operation of refrigerants; and improved collection and destruction of refrigerants at end of life. One challenge of estimating costs is that Project Drawdown® notes a lack of information on the costs of improving refrigerant management – and in particular any increases in operational costs in order to reduce leakage, switch to natural refrigerants, or improved efficiency of appliances.[2] Project Drawdown® relies solely on estimated costs of the safe disposal of existing refrigerants. Without clear economic incentives to improve refrigerant management, the cost-effectiveness of solutions is uncertain, and there are mixed results on cost-effectiveness of this solution based on global Project Drawdown® estimates and abatement curve data (e.g., McKinsey abatement curve). We will explore Georgia-specific cost effectiveness during the next phase of research.
Beyond Carbon Attributes (5)		Reducing refrigerant leakage and replacing HFCs with HFC-free alternatives have beyond carbon benefits mainly in the form of improved air quality, which consequently leads to improved public health in the surrounding areas.[5] Improved cooling systems for residential communities would also help to reduce energy bills as HVAC costs account for a large portion of utility bills. A cost of the solution is retraining programs for HVAC professionals to promote HCF free refrigerants[6], and the development of proper installation and disposal procedure as these alternative refrigerants are still chemical agents.[7]
Down-select Decision	**Yes**	Retain for further analysis

References:

EPA National Emissions Source: 1990-2016 US Inventory, "ODS Substitutes BY16.xls"

EPA Revised Section 608 Refrigerant Management Regulations. Available online at https://www.epa.gov/section608/revised-section-608-refrigerant-management-regulations

McKinsey & Company (2007). Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost? Executive Report, December 2007.

Purohit, P. Höglund-Isaksson, L. (2016). Global emissions of fluorinated greenhouse gases 2005-2050 with abatement potentials and costs. Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-727, 2016.

Refrigerants Naturally (2016). Coca-Cola Targets 100% Natural Refrigerants for Vending Equipment. Available online at: http://www.refrigerantsnaturally.com/data/user_upload/20161114_AccAU_NZ_Nov_TCCC.pdf

Endnotes:

1. Purohit, P. Höglund-Isaksson, L. (2016). Global emissions of fluorinated greenhouse gases 2005-2050 with abatement potentials and costs. Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-727, 2016.
2. https://www.drawdown.org/solutions/materials/refrigerant-management
3. EPA Revised Section 608 Refrigerant Management Regulations. Available online at https://www.epa.gov/section608/revised-section-608-refrigerant-management-regulations
4. EPA National Emissions Source: 1990-2016 US Inventory, "ODS Substitutes BY16.xls"
5. United States Environmental Protection Agency. (2020, March 8). Managing Refrigerant Emissions . Retrieved from United States Environmental Protection Agency Website: https://www.epa.gov/ozone-layer-protection/managing-refrigerant-emissions
6. Garry, M. (2019, June 14). California allocates $1 million in incentives for green refrigeration. Retrieved from Hydrocarbons21 Website: http://hydrocarbons21.com/articles/9034/california_allocates_1_million_in_incentives_for_green_refrigeration
7. New Hampshire Department of Environmental Services. (2010). Environmental Fact Sheet: Chlorofluorocarbons: Health Information Summary. Retrieved from New Hampshire Department of Environmental Services Web Site: https://www.des.nh.gov/organization/commissioner/pip/factsheets/ard/documents/ard-ehp-34.pdf

C.3.2 Alternative Mobility | Down-Select

Replacing emissions-intensive vehicle miles traveled (VMTs) with zero- or low-carbon alternatives such as bicycling, walking, or tele-working can reduce GHG emissions. This bundle includes the following Drawdown Georgia solutions: bike infrastructure, walkable cities, telepresence, and e-bikes, with a specific focus on replacing short-distance vehicle trips with these alternatives.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	These technologies are mature and market ready. Telecommuting and alternative mobility solutions such as bicycles are already widely used around the world and have some presence in Georgia. Given the minimal current presence of biking and alternative mobility, there is significant potential to reduce CO_2 emissions by replacing CO_2-intensive car trips with low-carbon alternatives. Telecommuting has even greater potential. With advances in video-conferencing and teleworking solutions, there is significant potential to reduce VMT by implementing teleworking policies, and many businesses and organizations already employ teleworking as a strategy to improve employee satisfaction and reduce operation costs.
Local Experience & Data Availability (2)	**Yes**	The Federal Highway Administration's National Transportation Survey has detailed data for VMT at the state level, which can be used to estimate reduction in VMT resulting from more widespread use of alternative mobility measures. Several cities around the state are planning or have already started implementing improvements to bicycling and walking infrastructure, such as the Transportation Alternative Program (TAP), Georgia Commute Options (GCO), and the Atlanta Regional Commission (ARC). Challenges include a lack of data relating to existing biking and telecommuting data as well as historical trends of these data.
Technically Achievable GHG Reduction Potential (3)	**Yes**	The GHG reduction potential is high, assuming that VMT for urban local trips can be substituted by biking, walking and/or telepresence. For example, preliminary analysis using data from the Federal Highway Administration's National Household Transportation Survey indicates that for <u>bike infrastructure alone</u>, a substitution of 1 out of 10 of urban local car trips (under 3 miles) by bikes could abate over 1 Mt CO_2 annually.[1] Additional substitution of vehicle trips by walking, telepresence, and/or e-bikes is expected to contribute to further abatement. In particular, telecommuting has high CO_2 reduction potential because telepresence has the ability to offset longer trips and thus more VMT. Average market penetration of telepresence one day per week could reduce VMT by nearly 20 percent. Combined with other market trends such as co-working and synergies with biking and walking,

		there is ample achievable CO_2 reduction potential.
Cost Competitiveness (4)	**Yes**	Review of literature and expert survey feedback indicates that this bundle is cost competitive, especially when considering the fact that new bike infrastructure will negate the need for new motorized vehicle infrastructure. Biking & bike infrastructure, telepresence, and walking are all cheaper solutions than building new automobile infrastructure. Alternative transportation and telepresence also reduce private expenditures on transportation and if managed properly, telepresence can reduce the need for physical office space. Further, reduced commuting can provide significant positive externalities related to congestion reduction and air quality.
Beyond Carbon Attributes (5)		Co-benefits: Benefits include improved air quality from reduced emissions and improved water quality from reduced particulates and debris from cars that end up in stormwater runoff (Grabow et al., 2012). A drop in traditional commuting would also reduce wear & tear on local infrastructure, thereby lowering roadway construction and maintenance costs. Social co-benefits include improved public health due to increased physical activity and improved mental health, increased social interaction that could benefit local businesses, reduction in noise pollution caused by traffic, and overall reduction in local traffic & parking challenges (Grabow et al., 2012). Telecommuting would also reduce the productivity loss attributed to time lost in traffic jams, which was estimated to be $87 billion in the United States in 2018.[2] Moreover, a co-benefit of improved health of workers would lead to a decrease in workplace accidents due to fatigue and total sick days. Co-costs: An equity related concern is that adoption rates for this solution would vary between urban versus rural communities, which may lead to possible gentrification impacts. On the other hand, insufficient dispersion of infrastructure for alternative mobility routes may discourage communities (i.e. gender, age) from adopting these options and cause social disparity in the degree of access (Bushell et al., 2013). An additional concern involves an increased number of bikes (or other mobility devices) and car accidents if the resources and infrastructure upgrades are not made available (Bacchieri et al., 2010).
Down-select Decision	**Yes**	Retain for further analysis

References:

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Endnotes:

1. https://www.drawdown.org/solutions
2. https://www.weforum.org/agenda/2019/03/traffic-congestion-cost-the-us-economy-nearly-87-billion-in-2018/

C.3.3 Recycling | Down-Select

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.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technologies used in Recycling / Waste Management are mature and market ready. According to Project Drawdown®, Europe achieves paper recycling rates as high as 75% and the United States currently achieves paper recycling rates of 66%. Other recyclable materials have commercial and market presence in the United States including plastics (8%), glass (27%), and aluminum (50%)[1].
Local Experience & Data Availability (2)	**Yes**	There are state-level data available (Beck, 2005) on the amount of recyclable waste (paper, plastics and metals), though the data are somewhat dated. There are also more recent U.S.-level data available through the EPA[2]. The City of Atlanta and many other cities in Georgia have active recycling programs. Other organizations, such as the Center for Hard to Recycle Materials (CHARM) highlight innovative partnerships to improve recycling rates by using information provision programs and facilitating the procurement of high-quality recyclable materials. Plastic recycling start-ups such as Nexus LLC demonstrate opportunities for commercialization of plastic recycling in Georgia.
Technically Achievable GHG Reduction Potential (3)	**Yes**	The GHG reduction potential is high. According to a 2005 municipal solid waste (MSW) composition study by the Georgia Department of Community Affairs (Beck, 2005), Georgians annually throw away approximately 1.9 million tons of paper, 1 million tons of plastics, 0.36 million tons of metal and 0.24 million tons of glass. This study also indicated that Georgia generally lags behind the United States in terms of recycling rates, especially in paper recycling. Significant energy savings can be achieved by more widespread recycling. For example, one ton of recycled plastic saves approximately 5,800 kWh or energy[2]. Preliminary analysis using assumed current recycling rates equal to the U.S. averages for different recyclable materials and increasing to 65% for plastics, glass and metals and 90% for paperboard by 2030, indicates carbon reduction potential greater than the 1 Mt CO_2 threshold.

Cost Competitiveness (4)	**TBD**	This bundle may not be a highly cost-competitive solution, based on global Project Drawdown® estimates. In addition, current market conditions are not necessarily favorable for increased recycling (e.g., abundance of cheap natural gas in the United States has formed an economic barrier against increased plastics recycling). We will explore Georgia-specific cost effectiveness during the next phase of research.
Beyond Carbon Attributes (5)		Co-benefits: Benefits from this solution relate to environmental and public health from the improvement in air quality and water quality associated with waste diversion from landfills. Additional benefits would likely emerge from the creation of jobs associated with expanded/upgraded recycling services.[4,5] Moreover, establishing alternative waste management and recycling programs could create a steady supply of recycled materials that could be used in promoting new business and construction startups, products, and services (for example, the use of recyclable plastics in house insulation or reclaimed fibers in new textiles and clothes). This could foster the creation of new local economies for recycled/reclaimed products, that would promote jobs and local economic development.[6] Co-costs: There are concerns relating to the siting of additional recycling facilities which may be disproportionately located in low-income communities, negatively impacting air quality and in turn would negatively impact property values in those areas.[7]
Down-select Decision	**Yes**	Retain for further analysis

References:

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Endnotes:

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2. Stanford University – Land, Buildings & Real Estate. Frequently Asked Questions: Benefits of Recycling. Available online at: https://lbre.stanford.edu/pssistanford-recycling/frequently-asked-questions/frequently-asked-questions-benefits-recycling
3. https://www.drawdown.org/solutions
4. Renewable Resources Co. (2016, December 19). *Advantages & Disadvantages of Recycling*. Retrieved from Renewable Resources Coalition: https://www.renewableresourcescoalition.org/recycling-advantages-disadvantages/

5. Boulder County. (2020). *Reduce, Reuse, Recycle*. Retrieved from Boulder County Website: https://www.bouldercounty.org/environment/recycle/reduce-reuse-recycle/
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C.3.4 Retrofitting | Down-Select

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. This solution considers several key retrofitting options:

- Improving insulation/air sealing 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®, including replacing conventional windows and water heaters with high-efficiency units, recommissioning / retro-commissioning of existing commercial buildings, and deadband range expansion / human factors will also be considered under the Retrofitting bundle for the Drawdown Georgia project.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	The technologies are mature and market ready, innovations continue to improve efficiency of retrofitting technologies. Historically in Georgia, retrofitting rates have been relatively low due to market barriers including high upfront costs, information asymmetry, transaction and administrative costs, and split/misplaced incentives and subsidies. However, policy improvements could make the solution workable by 2030.
Local Experience & Data Availability (2)	**Yes**	There is state-level data available for some solutions, and nationwide data available for many of the solutions that can be projected down to the state level. There is ample local experience available with retrofitting projects (both commercial and residential) in the state. There are also several state-level studies (including one performed by Nexant for Georgia Power) highlighting the cost-effective energy savings potential of retrofitting in Georgia.

Technically Achievable GHG Reduction Potential (3)	**Yes**	Preliminary analysis based on NEMS data as obtained from EIA's Annual Energy Outlook 2018 (reference case vs. new-efficiency case, with U.S. level results proportioned for Georgia), suggests that many of the individual solutions do not necessarily meet the threshold of 1 Mt CO_2 annual reduction. However, strategic combination of technologies (for both residential and commercial sectors) as part of a retrofit bundle can provide CO_2 reduction potential well beyond the 1 Mt threshold. The CO_2 reduction potential can be further increased by promoting replacement strategies that favor more efficient solutions relative to the baseline alternatives for technologies that have reached end-of-life and are in need to replacement.
Cost Competitiveness (4)	**Yes**	Review of literature and expert survey feedback indicate that the individual solutions that make up a retrofit are typically cost-effective, with heat pumps being potentially not cost effective depending on the type of retrofit (Nadel & Ungar, 2019). However, the bundles can be selected with emphasis on cost-effective solutions, and highly cost-effective solutions like smart thermostats and LED lighting can be used to offset less cost-effective solutions like heat pumps. We will explore Georgia-specific cost effectiveness during the next phase of research.
Beyond Carbon Attributes (5)		According to the 2017 American Housing Survey, Georgia has an estimated 4.2 million homes, with 2.8 million of these being single-family detached residential units.[4] The greatest social benefits from the implementation of retrofitting can be seen through air quality improvements.[5] These improvements are a result of an increase in energy efficiency and reduction in energy demand from residential and commercial buildings.[6,7,8] Improved building health can lead to increased productivity and lower absenteeism particularly in commercial buildings and office environments. However, Atlanta ranks fourth highest in median energy burden levels and third highest among low income household populations compared to other major cities in the United States.[3] This indicates that there is a "beyond energy" benefit to retrofitting residential homes to decrease economic hardship of families.[4] However, access to retrofits is often cost-prohibitive for low income communities without external financing and support. Without inclusion of lower income residents, retrofitted home value increases can contribute to neighborhood gentrification and a reduction in affordable housing.[9]
Down-select Decision	**Yes**	Retain for further analysis

References:

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Nadel, S. and Ungar, L. (2019). Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050. American Council for an Energy-Efficient Economy.

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C.3.5 Net Zero Buildings | Down-Select

Net Zero Buildings are new buildings that utilize high-efficiency building solutions and on-site renewable energy systems to achieve zero net energy consumption. Over the course of a year, these buildings produce as much energy as they consume. This could include some months when the building produces more energy than it needs and other months when the building relies on the larger electric grid for energy.

Criteria		**Comments**
Technology and Market Readiness (1)	**Uncertain**	While the technologies that go into a typical Net Zero Building (NZB) are mature and market-ready, it is not clear that supply chain and policies can be put in place in time to achieve large-scale adoption of NZBs in Georgia to meet the 1 Mt annual CO_2 reduction threshold by 2030, especially in the absence of policies promoting and/or mandating NZBs (which currently do not exist). Another barrier is that due to the high energy needs of buildings in Georgia, the building footprint required for a NZB likely limits construction to several stories without additional technological advances. However, there are significant Beyond Carbon benefits which could make this solution attractive based on other dimensions.
Local Experience & Data Availability (2)	**Uncertain**	There is limited local experience with NZBs in Georgia (one example is the Carbon-Neutral Energy Solutions Laboratory building on Georgia Tech's campus). It is possible to project national data to the state level for modeling purposes.
Technically Achievable GHG Reduction Potential (3)	**Uncertain**	NZBs are applicable to new construction, which is a small market in comparison to the existing building stock. Preliminary analysis using projected new building stock data from EIA's Annual Energy Outlook 2019[1] (proportioned for Georgia) suggests that starting by 2021, about 10% of new building construction would need to consist of NZBs to meet the 1 Mt annual CO_2reduction threshold by 2030. It is much more likely to meet the threshold for the 2050 timeframe.
Cost Competitiveness (4)	**Uncertain**	The customization of solutions typically involved in a NZB (unlike typical bundles for LEED certification, for example) makes estimating cost-competitiveness challenging without detailed analysis. However, according to DOE, there is mounting evidence that NZBs can be constructed within typical construction budgets (NREL, 2014).
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

National Renewable Energy Laboratory (2014). Cost Control Strategies for Zero Energy Buildings – High Performance Design and Construction on a Budget.

Endnotes:

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2. https://www.drawdown.org/solutions/buildings-and-cities/net-zero-buildings

C.3.6 Living Buildings | Down-Select

Living Buildings are designed to meet a number of environmental and societal priorities including GHG emission management. These buildings use onsite renewable energy sources, such as solar panels, to produce more energy than they consume. They also offset all embodied carbon.

Criteria		Comments
Technology and Market Readiness (1)	**Uncertain**	While the technologies that go into a typical Living Building are mature and market-ready, it is not clear that supply chain and policies can be put in place in time to achieve large-scale adoption of Living Buildings in Georgia to meet the 1 Mt annual CO_2 reduction threshold by 2030, especially in the absence of policies promoting and/or mandating these buildings (which currently do not exist). In addition, due to the energy footprint needs (and the need to generate net positive energy and water) it remains unclear whether this is a scalable solution or which building types might be feasible in Georgia. However, there are significant Beyond Carbon benefits which could make this solution attractive based on other dimensions.
Local Experience & Data Availability (2)	**Uncertain**	There is very limited local experience with Living Buildings in Georgia (as of 2019, there is only one Living Building in Georgia – The Kendeda Building on the campus of Georgia Tech which was built in 2019 as a pilot project). There are also very few Living Buildings nationally (the International Living Future Institute lists three Certified Living buildings in the United States on their website); hence there is limited data available for detailed modeling.
Technically Achievable GHG Reduction Potential (3)	**Uncertain**	Living Buildings are applicable to new construction which is a small market in comparison to the existing building stock. Further, the specs of such a building – due to the need for particular energy footprints – likely limit the solution to certain types of buildings with certain uses and specific dimensions. The Living Building demonstration project on Georgia Tech's campus, for example, has a large solar canopy to provide net positive energy. Similar to NZBs, a significant percentage of new building construction would need to consist of Living Buildings to meet the 1 Mt annual CO_2 reduction threshold by 2030. In addition, Living Buildings could displace a percentage of new NZB construction (and vice versa), as a Living Building is also technically a NZB.

Cost Competitiveness (4)	**Uncertain**	The customization of solutions typically involved in a Living Building (unlike typical bundles for LEED certification, for example) tends to drive costs up, and makes estimating cost-competitiveness challenging without detailed analysis. While it is plausible that developing the market for Living Buildings can drive down costs, costs of the Kendeda Living building were over $600/sq. ft., making this solution unlikely to be competitive in the short run.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

Endnotes:

1. Living Building at Georgia Tech – The Kendeda Building. Available online at: https://livingbuilding.gatech.edu
2. International Living Future Institute. Available online at: https://living-future.org
3. https://www.drawdown.org/solutions/coming-attractions/living-buildings

C.3.7 Building with Wood | Down-Select

Using wood instead of cement or steel as a building material has two primary climate benefits. First, wood contains carbon sequestered by trees. The carbon is locked in as long as the wood is in use. Second, wood production creates fewer emissions than cement or steel production. New high-strength wood technologies are expanding opportunities for safe, strong wood-based buildings.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	The technology is mature and market ready, and appears to be gaining momentum both across North America and in Georgia. While timber has historically been used primarily in residential construction in the United States, recent technological advances (such as cross-laminated timber, or CLT) have increased structural strength as well as fire safety and have allowed timber to be used in medium- to high-rise construction as well. Recent examples in North America include the 18-story tall Brock Commons building in British Columbia, Canada, as well as the 8-story tall Carbon12 Building in Portland, Oregon.
Local Experience & Data Availability (2)	**Yes**	There are limited projects and data at the state level; however, it is possible to project national data to the state level. Georgia is emerging as a leader in mass timber production. There are some market barriers and challenges including state and/or local building codes which preclude the use of mass timber for medium- to high-rise projects. However, Georgia House Bill 777, working its way through the state legislature aims to reduce barriers and develop standards for mass timber as a widespread construction technology [2]. Some recent mass timber construction projects have been completed in the state including the Kendeda Building at Georgia Tech and the T3 Atlanta Office building, which is touted as the largest (by square footage) mass timber building in the United States. (StructureCraft, 2019).
Technically Achievable GHG Reduction Potential (3)	**No**	This technology is applicable to new construction, which is a small market in comparison to the existing building stock. Preliminary analysis using new commercial building stock data from NEMS obtained from EIA's Energy Outlook 2019 and proportioned for Georgia, and using published emissions factors for timber construction as compared to building with concrete (Lipke et al., 2010), indicates that the potential carbon reduction is significantly less than the threshold of 1 Mt CO_2 annually. However, there are significant Beyond Carbon benefits which could make this solution attractive based on other dimensions, especially related to economic development and jobs since Georgia is a leader in mass timber.
Cost	**Yes**	Building with wood can be cost effective (Schneider, 2017), especially in

Competitiveness (4)		Georgia where the material can be locally sourced. Costs would be expected to come down as designers become more familiar with mass timber construction and more widespread adoption occurs.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Lipke et al. (2010). Life Cycle Environmental Performance of Renewable Building Materials in the Context of Residential Construction, Phase II Research Report: an Extension to the 2005 Phase I Research Report.

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StructureCraft (2019). T3 Atlanta Office. Available online at: https://structurecraft.com/projects/t3-atlanta

Endnotes:

1. https://www.drawdown.org/solutions/coming-attractions/building-wood
2. http://www.legis.ga.gov/legislation/en-US/Display/20192020/HB/777

C.3.8 District Heating / District Energy | Down-Select

District heating and cooling systems provide centralized heating and cooling for a group of buildings and replace the need for each building to have its own units. Buildings are connected via a network of underground pipes and can maintain their own thermostats. These larger and centralized heating and cooling systems allow for increased efficiency.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology is mature and market ready. District energy is a proven solution that has been deployed for many years in a large number of cities throughout the world, and has many benefits including energy efficiency and affordable energy provision, and reduced CO_2 emissions and local air quality improvements (UNEP, 2015). It should be noted that district energy is much more widespread outside of the United States, in particular in the more densely populated city centers of Europe, though there are examples in the Unoted States as well including Arlington County, Virginia, and the City of Seattle.
Local Experience & Data Availability (2)	**Yes**	There are several district energy installations in Georgia (including several on university campuses, large industrial facilities, office buildings and military bases), though performance data are not readily available. One example is a recent project at Georgia Tech, which resulted in an energy savings of about 30%, a savings of 31 million pounds of CO_2 emissions per year, and annual savings of approximately \$1.5 million in utility costs[2]. It is also possible to obtain estimates of energy savings and cost-effectiveness from the literature.
Technically Achievable GHG Reduction Potential (3)	**No**	The CO_2 reduction potential is estimated to be relatively low, especially given the density and development patterns in Georgia (this solution works best in urban, densely populated areas). For example, preliminary analysis suggests that if the entire City of Atlanta (including Hartfield-Jackson airport) were to be retrofitted using District Energy with 30% energy savings (UNEP, 2015), it would still offset less than 1 Mt CO_2 annually based on the reported annual energy use for the City (City of Atlanta, 2019). Fossil fuels (mainly natural gas) remain as the choice of energy input for district energy installations in the United State. (EIA, 2018). A switch to more renewable energy sources as energy input could further reduce GHG emissions.

Cost Competitiveness (4)	**Yes**	This can be a cost-effective solution according to global Project Drawdown® estimates, as well as McKinsey abatement curve data. For example, the aforementioned example at Georgia Tech had an estimated payback period of 5 years.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:
City of Atlanta (2019). Clean Energy Atlanta – A Vision for a 100% Clean Energy Future.
U.S. Energy Information Administration – EIA (2018). U.S. District Energy Services Market Characterization.
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Endnotes:
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2. Optimum Energy (2018). Higher Education Case Study - Georgia Institute of Technology, HVAC optimization reaps savings and insights into daily plant operations.

C.3.9 Smart Glass | Down-Select

Smart glass technologies dynamically change opacity to reduce or increase the amount of light and heat that is able to pass through. This real-time response can improve a building's energy efficiency and reduce its energy load. Smart glass replaces conventional, non-dynamic glass.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	Smart glass was originally developed in the 1970s and 1980s and is currently in use on many buildings throughout the world. Although the technology is mature and market ready, more widespread adoption of this technology is currently challenged by high upfront costs.
Local Experience & Data Availability (2)	**Yes**	There is limited data at the state level; however, it is possible to project national data to the state level. There have been recent projects in the Metro Atlanta area using smart glass (e.g., the CODA building, and the new NCR headquarters) although local performance data do not appear to be available at this time.
Technically Achievable GHG Reduction Potential (3)	**No**	The CO_2 reduction potential is estimated to be low. According to a 2004 LBNL study (Lee et al., 2004), smart glass could save ~0.1 quad energy annually by year 2030 at a nationwide level. Proportioning for Georgia (at 3.5%) would abate about 0.3 Mt CO_2 annually, significantly below the 1 Mt threshold. A similar analysis using a more recent study (Wong & Chan, 2014) indicates slightly lower CO_2 reduction potential. The energy savings potential is hindered by limited market penetration, potentially due to the high upfront costs, despite the relatively high potential for energy savings (on the order of 20% to 30% in heating and cooling costs).
Cost Competitiveness (4)	**No**	This is not a cost-effective solution according to global Project Drawdown® estimates and review of other literature. Cost competitiveness of smart glass has lagged behind (Wong & Chan, 2014), with costs an order of magnitude higher than conventional glass (Verrengia, 2010).
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Lee et al. (2004). The Energy Savings Potential of Electrochromic Windows in the US Commercial Buildings Sector. Lawrence-Berkeley National Laboratory, Report No. LBNL-54966.

Verrengia, J. (2010). "Smart Windows: Energy Efficiency with a View," National Renewable Energy Laboratory, available online at: https://www.nrel.gov/news/features/2010/1555.html

Wong, K.V. and Chan, R. (2014). Smart Glass and Its Potential in Energy Savings. Journal of Energy Resources Technology, 136, 012002-1 - 012002-6.

Endnotes:

1. https://www.drawdown.org/solutions/buildings-and-cities/smart-glass

C.3.10 Water Distribution | Down-Select

Reducing water leakage within a water distribution system can 1) save water and 2) lower emissions by reducing the electricity needed to pump water through a system. Leak detection programs can address major water leaks as well as smaller, persistent leaks that often go undetected.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technologies for leak detection and repairs in water distribution systems are mature and market ready. The Georgia Environmental Protection Division (EPD) has published a guidance document for water leak detection and repairs in Georgia resulting from old or poorly constructed pipelines, inadequate corrosion protection, poorly maintained valves and mechanical damage to infrastructure.
Local Experience & Data Availability (2)	**Yes**	There is data available for nationwide leak quantities associated with water distribution systems from the EPA (EPA, 2016); however, there is limited data available at the state level as it relates to leak rates / quantities in Georgia's water distribution system. The aforementioned guidance document by EPD does not provide state-specific leak rates; however, it recommends that unaccounted-for-water for industrial / commercial systems should not be more than 10% of the total water produced.
Technically Achievable GHG Reduction Potential (3)	**No**	The CO_2 reduction potential is estimated to be low. Preliminary analysis based on historic water use data in Georgia,[1] as well as leaked water quantities as a proportion of the United States and embodied energy of water (Mo, 2012) suggests this solution can reduce emissions by about 0.1 - 0.2 Mt CO_2 annually, which is significantly below the 1 Mt threshold.
Cost Competitiveness (4)	**Yes**	This can be a cost-effective solution according to global Project Drawdown® estimates, as well as EPA analysis.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Georgia Environmental Protection Division (2007). Water Leak Detection and Repair Program, EPD Guidance Document, August 2007.

Mo, Weiwei (2012). Water's Dependence on Energy: Analysis of Embodied Energy in Water and Wastewater Systems. PhD Dissertation, University of South Florida.

U.S. Environmental Protection Agency – EPA (2010). Control and Mitigation of Drinking Water Losses in Distribution Systems.

U.S. Environmental Protection Agency – EPA (2016). Best Practices to Consider When Evaluating Water Conservation and Efficiency as an Alternative for Water Supply Expansion. Report No. EPA-810-B-16-005.

Endnotes:

1. United States Geological Survey – USGS. Water Use in Georgia. Available online at: https://www.usgs.gov/centers/sa-water/science/water-use-georgia?qt-science_center_objects=0#qt-science_center_objects
2. https://www.drawdown.org/solutions/buildings-and-cities/water-distribution

C.3.11 Alternative Cement | Down-Select

Alternative cements utilize fly ash (and other alternative materials) as clinker substitute, reducing the use of limestone (the typical primary raw material for clinker-making) and decreasing GHG emissions (decarbonizing limestone reduces roughly 60% of cement's emissions).

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	The technology is mature and market ready. Clinker can be blended / substituted with a range of alternative materials including coal fly ash. The use of alternative constituents in cement can mean lower energy use and lower CO_2 emissions (ECRA, 2017; IEA, 2018). Local availability of materials for use in clinker substitution is a major challenge.
Local Experience & Data Availability (2)	**Yes**	There is clinker capacity and cement production data available at the national and state level. As of 2013, the five leading cement-producing states in the United States, in descending order, were: Texas, California, Missouri, Florida, and Alabama[1]. Together, the five accounted for almost half of U.S. cement production. The concentration of cement production in these states is due to local abundance, availability and suitability of calcium-bearing rock formations (mainly, limestone). While there is significant cement end-use in Georgia, there is very little cement production in Georgia: clinker capacity is 0.8 million metric tonnes out of 101.3 million metric tonnes for the United States, or less than 1%[2], mainly due to a relative lack of limestone resources. In addition, based on conversations with Georgia Power personnel, Georgia already faces seasonal fly ash shortages due to its existing beneficial reuse in other sectors.
Technically Achievable GHG Reduction Potential (3)	**No**	There is significant energy and CO_2 savings potential via clinker substitution using fly ash. According to CEMBUREAU, clinker substitution has the third highest CO_2 reduction potential, behind new breakthrough technologies and increased kiln efficiency and fuel mix. According to a study by the WWF International, new alternatives to Portland Cement would lead to a 10% decrease in CO_2 emissions from the sector by 2030, assuming these alternatives can account for 20% of the market by then. However, given the very small amount of clinker and cement production capacity in Georgia, as well as existing fly ash shortages, the CO_2 reduction potential in the state is deemed very low. Additionally, while Georgia is a large consumer of cement, this solution impacts primarily new construction, meaning that it only

		impacts a small percentage of the total market. Looking beyond Georgia's production footprint, and looking beyond 2030, this solution may be worthy of further consideration.
Cost Competitiveness (4)	**Uncertain**	According to global Project Drawdown®, this can be a cost-competitive solution when considering the cost to produce fly ash as compared to Portland cement. For Georgia, given the lack of limestone resources and seasonal fly ash shortages that already exist, it is not certain whether this solution would be cost-competitive.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

CEMBUREAU (2013) – The role of Cement in the 2050 Low Carbon Economy. The European Cement Association.

European Cement Research Academy – ECRA (2017). Development of State of the Art Techniques in Cement Manufacturing: Trying to Look Ahead. CSI/ECRA-Technology Papers 2017.

Imbabi, M.S., Carrigan, C. and McKenna, S. (2013). Trends and developments in green cement and concrete technology. International Journal of Sustainable Built Environment, 1, 194-216.

International Energy Agency – IEA (2018). Technology Roadmap – Low Carbon Transition in the Cement Industry.

Muller, N. and Harnisch, J. (2008). How to Turn Around the Trend of Cement Related Emissions in the Developing World. A report prepared for the WWF – Lafarge Conservation Partnership On behalf of: WWF International.

Endnotes:

1. https://www.drawdown.org/solutions/materials/alternative-cement
2. United States Geological Survey (2018). USGS 2015 Minerals Yearbook – Cement.
3. Portland Cement Association (2017). Georgia Cement Industry. Available online at: https://www.cement.org/docs/default-source/market-economics-pdfs/cement-industry-by-state/ga-statefacsht-17-d2.pdf?sfvrsn=cb7fe6bf_2

C.3.12 Bioplastic | Down-Select

Today, most plastic is created using fossil fuels. Bioplastic uses plant-based feedstocks instead.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology is mature and largely market-ready. According to the U.S. Department of Agriculture, while bioplastics currently make up less than one percent of the plastics market, the opportunity for future growth is high, with an expected annual growth pace of about 20%[2]. Currently, most bioplastics are produced from agricultural crop-based feedstocks. This method does not ideally conform to UN's sustainable development goals because of their competition for arable land, fresh water and food production (Karan et al., 2019). These challenges can be addressed by switching to algae-based bioplastics production or other alternatives. There are also challenges related to substituting proven incumbent oil-based plastics with new, relatively untried bioplastics, as well as supply-chain and other issues related to scaling relatively small-scale biotechnologies to industrial levels (SBI, 2010; Iles and Martin, 2013), though policy improvements could alleviate some of these challenges.
Local Experience & Data Availability (2)	**Yes**	Georgia ranks No. 8 in plastics industry shipments in the United States, though the state is only responsible for 3.5% of national shipments[3]. There is one bioplastics facility in Bainbridge, Georgia, operated by Danimer Scientific. This facility produces polyhydroxyalkanoate (PHA) based bioplastics (starting with canola)[4]. There is also national-level data available through the EPA for plastics production at a national level[5].
Technically Achievable GHG Reduction Potential (3)	**No**	Using U.S. level data proportioned for Georgia, and assuming bioplastics emit 40% less emissions than conventional plastics (as per Project Drawdown®), preliminary analysis indicates that essentially all the plastics production in Georgia would need to be shifted to bioplastics to meet the 1 Mt CO_2 annual reduction threshold. An immediate and complete shift to bioplastics is deemed very unlikely in the 2030 timeframe.
Cost Competitiveness (4)	**No**	Global Project Drawdown® estimates a small net cost for switching to bioplastics. On the other hand, the abundance of natural gas in the United States as a result of the shale gas boom has driven the price of conventional plastics down significantly[6]. According to a study by the Freedonia Group, the success of the bioplastics industry will ultimately depend on price and performance considerations, and large-scale conversion to bioplastics will not occur until price parity with conventional plastic resins is achieved.
Down-select	**No**	Do not retain for further screening in the 2020-2030 timeframe.

Decision		

References:

Cushman-Roisin, B. and Cremonini, B.T. (2019). Useful Numbers for Environmental Studies and Meaningful Comparisons. Chapter 1 – Materials.

Iles, A. and Martin, A. (2013). Expanding bioplastics production: sustainable business innovation in the chemical industry. Journal of Cleaner Production, 45, 38-49.

Karan, H., Funk, C., Grabert, M., Oey, M. and Hankamer, B. (2019). Green Bioplastics as Part of a Circular Bioeconomy. Trends in Plant Science, 24(3), 237-249.

SBI Energy, December 2010. Biorenewable Chemicals: World Market. Maryland, Rockville.

The Freedonia Group (2013). World Bioplastics. Industry Study No. 3089.

Endnotes:

1. https://www.drawdown.org/solutions/materials/bioplastic
2. U.S. Department of Agriculture. A New Industrial Revolution for Plastics. Available online at: https://www.usda.gov/media/blog/2018/09/19/new-industrial-revolution-plastics
3. Plastics Industry Association. Facts and Figures of Georgia. Available online at: https://www.plasticsindustry.org/factsheet/georgia
4. Danimer Scientific. PHA Comes from Nature and Returns to Nature. Available online at: https://danimerscientific.com/pha-the-future-of-biopolymers/
5. U.S. Environmental Protection Agency – EPA. Plastics: Material-Specific Data. Online at: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data
6. Bloomberg News (2019). America's Shale Boom is a Threat to Recycled Plastic Bottles. Available online at: https://www.bloomberg.com/opinion/articles/2019-10-06/america-s-shale-boom-is-a-threat-to-recycled-plastic-bottles

C.3.13 Industrial Hemp | Down-Select

Hemp outproduces cotton or trees by factors of 10 to 100 times in terms of yielding usable fiber, and is a GHG reduction solution because it can replace cotton.

Criteria		Comments
Technology and Market Readiness (1)	**Uncertain**	Under the 2014 Farm bill, U.S. growers are able to grow industrial hemp, as long as they comply with state rules. Most states require a licensing process. In 2019, U.S. farmers were licensed to grow 511,442 acres of industrial hemp, a more than 400% increase over 2018 levels[1].
Local Experience & Data Availability (2)	**No**	While hemp is a mature crop, only growers licensed by the Georgia Department of Agriculture (GDA) are permitted to grow and process industrial hemp in the state of Georgia. The GDA is currently working to develop regulations for hemp production in the state of Georgia, and licenses will not be issued until rules and regulations are in place[2]. While it is plausible that the hemp industry will grow rapidly over the next 10 years, there are not enough data to evaluate the carbon reduction potential of this strategy. It is also likely that regulatory barriers will continue to hamper this industry over the next decade.
Technically Achievable GHG Reduction Potential (3)	**Uncertain**	No analysis was conducted, given that the solution is not market-ready and lack of local experience and data.
Cost Competitiveness (4)	**Uncertain**	No analysis was conducted, given that the solution is not market-ready and lack of local experience and data.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

Endnotes:

1. Georgia Department of Agriculture. FAQ's: Industrial Hemp Production in Georgia Agriculture. Available online at: http://www.agr.georgia.gov/industrial-hemp-production.aspx
2. https://www.drawdown.org/solutions/coming-attractions/industrial-hemp

C.3.14 Enhanced Weathering of Minerals | Down-Select

Enhanced weathering is a geoengineering solution that would involve mining and milling olivine, and then applying the resulting rock powder to land and water, so that the soil, oceans, and biota can act as "reactors" for accelerated weathering. The weathering of minerals absorbs CO_2 being mainly stored as bicarbonate in the oceans.

Criteria		**Comments**
Technology and Market Readiness (1)	**No**	While enhanced weathering has been discussed as a potential geoengineering solution for a number of years, the technology is not yet market ready (and was listed under "Coming Attractions" by Project Drawdown®).
Local Experience & Data Availability (2)	**No**	There is no local experience or data availability in Georgia. In addition, while there are olivine deposits available in Georgia (Hunter, 1941), this solution works best in warm and humid areas where soils are warmer and wetter and have fewer minerals that would inhibit dissolution, in particular in India, Brazil, Southeast Asia, and China (Strefler et al. 2018).
Technically Achievable GHG Reduction Potential (3)	**Uncertain**	No analysis was conducted, given that the solution is not market ready and lack of local experience and data.
Cost Competitiveness (4)	**Uncertain**	No analysis was conducted, given that the solution is not market ready and lack of local experience and data.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Hunter, Charles (1941). Forsterite Olivine Deposits of North Carolina and Georgia. Georgia Department of Natural Resources, Division of Mining and Geology, Bulletin No. 47.

Strefler et al. (2018). Potential and costs of carbon dioxide removal by enhanced weathering of rocks, Environmental Research Letters, 13 (2018) 034010.

Endnotes:

1. https://www.drawdown.org/solutions/coming-attractions/enhanced-weathering-minerals

D Appendix D. Food & Agriculture

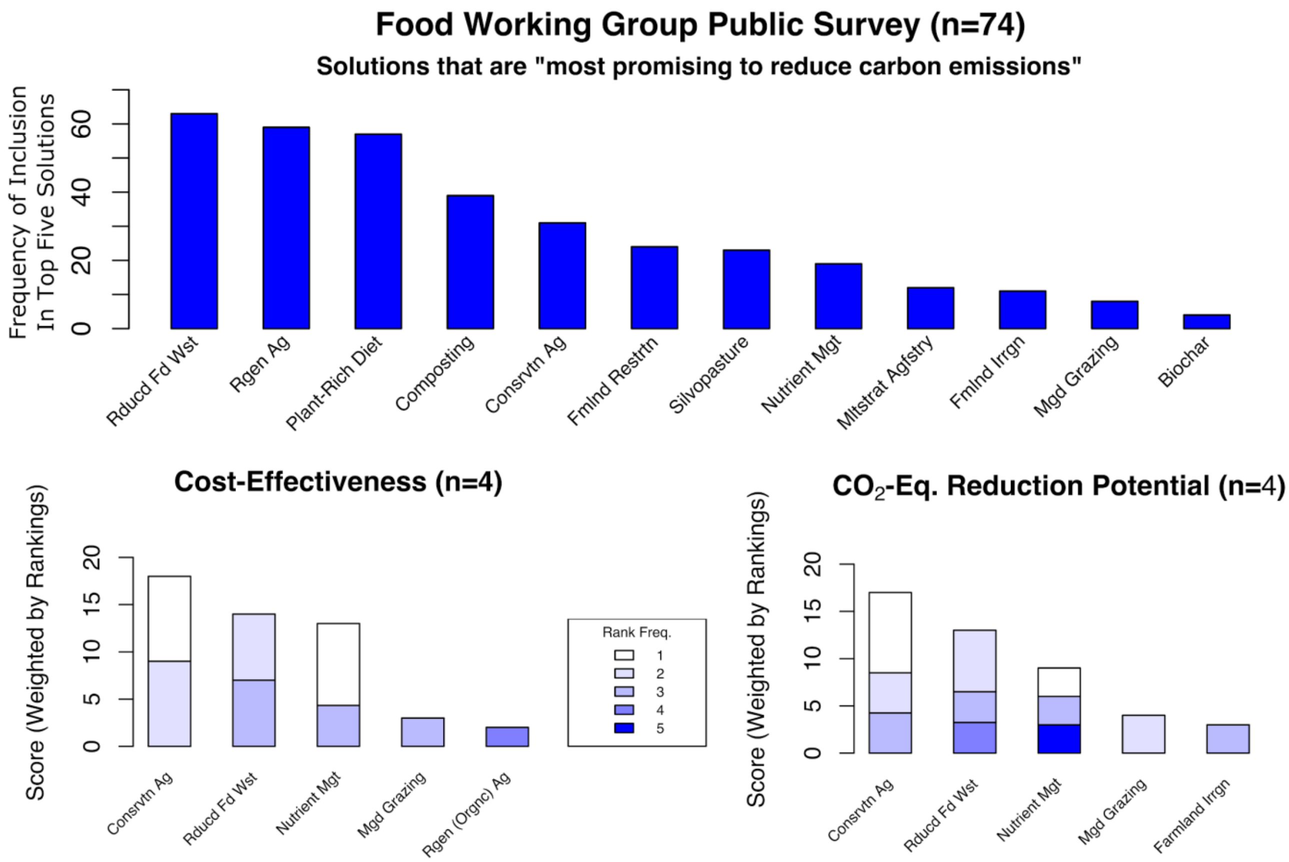
D.1 Solution List

- Reduced Food Waste
- Plant-Rich Diet
- Regenerative Agriculture
- Conservation Agriculture
- Managed Grazing
- Composting
- Nutrient Management
- Tree Intercropping
- Farmland Restoration
- Farmland Irrigation
- Biochar

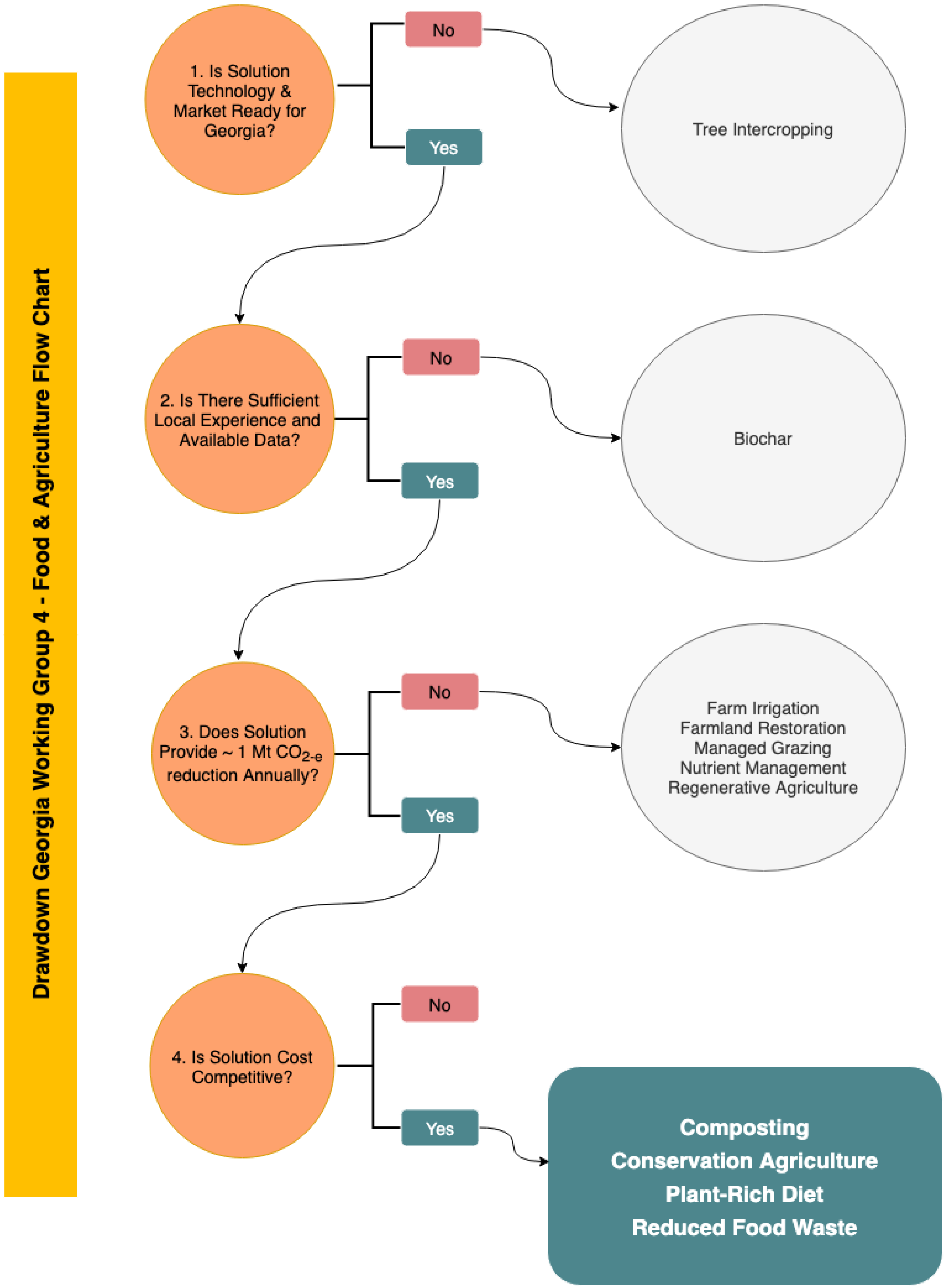
Note: Silvopasture is included as a solution under Land Sinks

D.2 Down-Select Criteria for Food & Agriculture Solutions:

1. **Technology, Applicability & Market Readiness** - Are the components of the Solution applicable to Georgia ready enough to be launched at significant scale over the next decade? (Can innovation, technology, and policy developments make the Solution workable by 2030, if it is not already?)
2. **Local Experience & Data Availability** - Are there sufficient data or qualitative analysis to adequately consider the Solution in a Georgia context? Is there local familiarity with the technology? Are there any local pilot or demonstrations to study? Is the level of complexity of the Solution manageable so that it can be credibly assessed? If state-level data and experience are limited or non-existent, can national level data be used to scale and perform a reasonable assessment of Solution's potential for Georgia?
3. **Technically Achievable CO_2e Reduction Potential** - Could the Solution achieve significant carbon equivalent reductions, especially in the 2030 timeframe, as compared to other Solutions available to this sector? (a minimum threshold of 1 Mt CO_2e annually was considered -- about 1% of 2017 Georgia CO_2e emissions). If a Solution cannot meet the 1 Mt CO_2e annually threshold alone, could multiple Solutions be combined / bundled in a rational and strategic manner to achieve the targets? The preliminary CO_2e reduction estimates were obtained via "back-of-the-envelope" type calculations using data from literature.
4. **Cost competitiveness** - Is the Solution cost competitive relative to other Solutions available to the sector? Are the up-front capital costs affordable? Is the payback period competitive with other Solutions? Both the global Project Drawdown® estimates, as well as abatement curves based on engineering estimates were considered, while bearing in mind that these should be treated with care given the large uncertainties typically associated with these estimates. Expert feedback on cost effectiveness was also considered. Viable market-ready technological solutions exist for all down-selected solution categories, although greater penetration and impact are possible.
5. **Other ("Beyond Carbon") Attributes** - Should any of the Solutions be retained for further analysis based on major co-benefits or co-costs beyond carbon (e.g., environment, economic development, public health, equity, etc.)?



(Each 1st place rank earns 5 points, 2nd place 4 points, 3rd place 3 points, 4th place 2 points, 5th place 1 point)



Down-Select Steps to Identify High-Impact 2030 Solutions

D.3 Down-Select Results for Food & Agriculture Solutions:

D.3.1 Reduced Food Waste | Down-Select

Food waste refers to food that is produced but not eaten. This can occur for a variety reasons such as people purchasing more food than they need or customers rejecting bruised or mis-shaped 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.

Criteria		Comments
Technology and Market Readiness?	**Yes**	Multiple interventions are required both at the consumer and retail levels to reduce food waste. Major interventions have already been identified – Prevention; Recovery & Recycling (ReFED, 2016). Recent case studies by restaurants and hotels indicated that simple interventions would not only reduce food wastes, but also cut costs. A coordinated effort along the supply chain and policy changes are required to mitigate food wastes.
Local Experience & Data Availability?	**Yes**	According to USDA-ERS, about 67-63 million tons of food is wasted annually in the United States. Although no state-specific food loss data is available, several estimates are available at the national and global levels and also in specific sectors. USDA-ERS has national-level data on food wastes and the state-specific data can be obtained. However, the potential food waste from the State of Georgia can be estimated from the population data.
Technically Achievable CO2 Reduction Potential	**Yes**	For the state of Georgia with a total population of 10.52 million (2018), the estimated food waste is about 2.03 million tons. We assumed that for every one ton of food waste diverted, about 1.35 tons of CO_2 could be reduced depending on the interventions based on the study by ReFED (2016). If Georgia could reduce 50% of the food waste by 2030, it could reduce about 1.38 Mt $CO_{2\text{-}e}$ each year.
Cost Competitiveness (4)	**Yes**	According to ReFED organization, about $18 billion investment is required to reduce 13 million tons of food waste that would yield $100 billion net economic value (ReFED, 2016). However, costs depend on the potential food waste reduction solutions – Prevention, Recovery and Recycling.
Beyond Carbon Attributes (5)	**Yes**	By reducing food waste, land use and landfill use decreases, aiding in environmental health. Around 56.7 million tonnes of food is wasted from farms to consumers in the United States, which entails using 16 million hectares of land, 3.9 million tonnes of fertilizers, and 17 billion cubic meters of irrigation (CAST, 2018). Water quality and air quality can be improved from less pesticide use (Tilman & Clark, 2014). Public health is

		improved from increased food security and safety, especially through donating food that would otherwise be wasted to those in need (Snyder et al., 2018). Some potentially adverse effects include lower profits for farmers, since they may be encouraged to produce and sell smaller quantities of food. Overall, education needs to be spread to encourage changes in consumer and producer habits to lower food waste across all sectors (FAO, 2011).
Down select Decision	**Yes**	Retain for further analysis

References:

Buzby, J. C. and J. Hyman. (2012). Total and per capita value of food loss in the United States. Food Policy 37(5): 561–570.

Council for Agricultural Science and Technology (CAST). (2018). Food Loss and Waste—A paper in the series on The Need for Agricultural Innovation to Sustainably Feed the World by 2050. Issue Paper 62. CAST, Ames, Iowa.

FAO. (2011). Global food losses and food waste –Extent, causes and prevention. Rome.

Heller, M.C., Keoleian, G.A. (2014). Greenhouse Gas Emission Estimates of U.S. Dietary Choices and Food Loss: GHG Emissions of U.S. Dietary Choices and Food Loss. J. Ind. Ecol. n/a-n/a. doi:10.1111/jiec.12174.

Hoover, D and L. Moreno. (2017). Estimating quantities and types of food waste at the city level. NRDC report – R-17-09-B. Natural Resources Defense Council (NRDC), U.S.

ReFED. (2016). A roadmap to reduce U.S. food waste by 20 percent. Available online at: https://www.refed.com/downloads/ReFED_Report_2016.pdf.

Snyder, A., Shumaker, K., and Nelsen, N. (2018). Ensuring Food Safety as Demand for Improved Food System Efficiency Increases. Journal of Extension, 56(7).

Tilman, D., Clark, M. Global diets link environmental sustainability and human health. Nature 515, 518–522 (2014). https://doi.org/10.1038/nature13959

Endnotes:

1. https://www.drawdown.org/solutions/food/reduced-food-waste
2. https://www.usda.gov/oce/foodwaste/faqs.htm
3. www.refed.com

D.3.2 Plant-Rich Diet | Down-Select

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.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Meat-rich diets are one of the major sources of GHG emissions in the United States. An alternative to meat, plant-rich diets have significant potential to reduce GHG emissions. The technology is becoming mature by brands such as "Beyond Meat" and "Impossible Foods", but the market readiness depends on the shift of consumer choices and affordability. The National Academies of Sciences, Engineering and Medicine (2019) convened a workshop in 2019 to review and discuss the Sustainable Diets, Food and Nutrition for Americans.
Local Experience & Data Availability (2)	**Yes**	A good number of companies in the United States are promoting plant-rich diets and grass-fed meats that produce less CO_2 emissions. There is a wide range of environmental impacts data for the production of animal-based proteins, which widely various based on the production practices.
Technically Achievable CO2 Reduction Potential (3)	**Yes**	The solution has significant potential to reduce CO_2 emissions by displacing meat with plant-based diet or low-carbon meats. According to the USDA-ERS, the per capita disappearance of meat was about 100 kg of red meat and poultry in 2018. Based on the Life Cycle Analysis (LCA) data from Heller et al., (2013), the average GHG emissions rate is 12.05 kg of CO_2 per kg of meat. If 10% of the Georgia population shifts to plant-based diet, the shift would reduce about 1.4 Mt $CO_{2\text{-}e}$ per year.
Cost Competitiveness (4)	**Yes**	It depends on the consumer choices, accessibility, availability and preferences.
Beyond Carbon Attributes (5)	**Yes**	This solution results in improved water quality and less extensive farming practices. The farming efficiency of plant-based foods increases with the concentration of higher proteins, while higher animal protein foods decreases the efficiency of energy inputs (Sabaté & Soret, 2014). It promotes an increased quality of life due to the health benefits associated with a plant-rich diet, and it encourages a reduction in obesity.[2] There is statistically significant protection from cancer associated with switching to a non-animal-based diet and a reduced risk of developing diabetes (Tonstad et al., 2013;Tantamango-Bartley et al., 2013). Plant-rich diets are less expensive, especially in healthcare costs from lowering chronic diseases (Tilman & Clark, 2014). An example from New Zealand found healthcare

		savings to be from $14-$20 billion over the lifetime of their population (Drew et al., 2020). A negative impact can result from the possibility of increased water usage for plant-based crops, which could amount to 16% increase in freshwater usage (Springmann, et al., 2018). There could also be adverse monetary effects for producers of meat-based products and loss of money on livestock. A major difficulty for this solution will be overcoming opposition in specific regions to a non-meat diet, although smaller steps towards the new diet will be more effective in achieving success.
Down-select Decision	**Yes**	Retain for further analysis

References:

Drew, J., Cleghorn, C., Macmillan, A., and Mizdrak, A. (2020). Healthy and Climate-Friendly Eating Patterns in the New Zealand Context. Environmental Health Perspectives, 128(1).

Eshel, G., P.Sttainier, A. Shepon and A. Swaminathan. (2019). Environmentally optimal, nutritionally sound, protein and energy conserving plant based alternatives to U.S. meat. Scientific Reports, 9:10345

Eshel, G., Shepon, A., Noor, E. & Milo, (2016). R. Environmentally Optimal, Nutritionally Aware Beef Replacement Plant-Based Diets. Environ. Sci. Technol. 50, 8164–8168.

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National Academies of Sciences, Engineering, and Medicine. (2019). Sustainable Diets, Food, and Nutrition: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/25192.

Sabaté, J., and Soret, S. (2014). Sustainability of plant-based diets: back to the future. American Journal of Clinical Nutrition, 100(1), 476S-82S.

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Springmann, M., Wiebe, K., Mason-D'Croz, D., Suler, T.B., Rayner, M., and Scarborough, P. (2018). Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Plant Health, 2.

Tantamango-Bartley, Y., Jaceldo-Siegl, K., Fan, J., and Fraser, G. (2013). Vegetarian Diets and the Incidence of Cancer in a Low-risk Population. Cancer Epidemiology, Biomarkers & Prevention, 22(2).

Tilman, D. & Clark, M. 2014. Global diets link environmental sustainability and human health. Nature 515, 518–522.

Tonstad, S., Stewart, K., Oda, K., Batech, M., Herring, R.P., and Fraser, G.E. (2013). Vegetarian diets and incidence of diabetes in the Adventist Health Study-2. Nutrition, Metabolism & Cardiovascular Diseases, 23, 292-299.

Endnotes:

1. https://www.drawdown.org/solutions/food/plant-rich-diet

https://www.health.harvard.edu/blog/what-is-a-plant-based-diet-and-why-should-you-try-it-2018092614760

D.3.3 Regenerative Agriculture | Down-Select

Regenerative agricultural practices improve soil health and sequester carbon in the soil. Practices include: compost application, cover crops, crop rotation, green manures, no-till or reduced tillage, and/or organic production.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Cover crops and reduced tillage practices are already widely used in the United States and Georgia. There are cost-share programs by USDA-Natural Resources Conservation Services (NRCS) already established to incentivize their adoption.
Local Experience & Data Availability (2)	**Yes**	There is widespread adoption of reduced tillage and cover crops. Many empirical studies have been conducted analyzing the costs of these practices and the yield effects for a variety of crops. More data is available on small-scale studies. Large-scale agricultural practices by row crops such as peanut is yet to be adopted.
Technically Achievable CO2 Reduction Potential (3)	**No**	There is an issue of additivity here – namely, many farmers already use reduced tillage practices and cover crops. While many farmers use reduced tillage practices, they often alternate them with conventional tillage. Beyond that, use of natural fertilizers and adoption to large-scale organic agriculture is still underdeveloped in Georgia. However, there is a growing interest in organic farming of fruits and vegetables and some row crops such as peanuts. According to the USDA-NASS data, about 5,347 acres of organic farms in 2016, which is about less than 0.2% of total cropland in the state. A recent study by Smith et al. (2019) in UK reported that the positive GHG emission reduction is still minimal for a number of food crops in UK.
Cost Competitiveness (4)	**No**	It depends on the types of crops grown and require organic certification and demands from local market.
Beyond Carbon Attributes (5)	**Yes**	Clean air and water quality, no pesticides or chemical use, improved human health, improved soil health.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Smith, L.G., Kirk, G.J.D., Jones, P.J. et al. The greenhouse gas impacts of converting food production in England and Wales to organic methods. Nat Commun 10, 4641 (2019) doi:10.1038/s41467-019-12622-7

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1. https://agecon.uga.edu/extension/budgets.html

2. https://www.ers.usda.gov/amber-waves/2019/march/no-till-and-strip-till-are-widely-adopted-but-often-used-in-rotation-with-other-tillage-practices/
3. https://www.ers.usda.gov/webdocs/publications/90201/eib-197.pdf?v=1783.8
4. USDA-NASS. 2016. Certified organic survey-Georgia. Available at www.nass.usda.gov/ga
5. https://www.drawdown.org/solutions/food/regenerative-agriculture
6. www.GeorgiaOrganics.org
7. https://www.nrcs.usda.gov

D.3.4 Conservation Agriculture | Down-Select

Conservation agriculture refers to a set of agricultural practices that supports biosequestration via crop rotation, managing soil organic matter, and reduced tillage.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Cover crops and reduced tillage practices are already widely used in the United States and Georgia. Natural Resources Conservation Serices (NRCS) cost-share programs already established to incentivize their adoption.
Local Experience & Data Availability (2)	**Yes**	There is widespread adoption of reduced tillage and cover crops. Many empirical studies have been conducted analyzing the costs of these practices and the yield effects for a variety of crops.
Technically Achievable CO2 Reduction Potential (3)	**Yes**	There is an issue of additivity here – namely, many farmers already use reduced tillage practices and cover crops. While many farmers use reduced tillage practices, they often alternate them with conventional tillage. According to Project Drawdown®, conservation agriculture practices increases the carbon sequestration rate at an average of 0.2 tons of C/ac/y. Georgia has about 3.8 million acre of croplands about 47% of the croplands are under conservation tillage practices. If another 40% of the land would be converted into conservation tillage, the CO_2 sequestration potential could be about 1.1 Mt $CO_{2\text{-}e}$ per year.
Cost Competitiveness (4)	**Yes**	Cost depends on the types of crops and yield potentials. In the literature, there were limited data related to conservation tillage practices for specific crop types. The farm specific practiced conservation measures and the associated costs can be estimated by the procedures from Gordon (2013). In general, conservation agriculture practices saves cost to farmers.
Beyond Carbon Attributes (5)	**Yes**	This solution improves water quality and quantity, while also lowering soil erosion and improving soil health. Excess water runoff is minimized from better soil protection, reducing water use and the carrying of fertilizer contaminating water (Derpsh et al., 2010). Soil quality is improved though reducing the loss of organic material and improving/maintaining the original soil porosity, resulting in higher resistance to drought (Derpsh et al., 2010). Farmers may experience increases in crop/agricultural yield and thus increases in income and wages (Knowler & Bradshaw, 2007; Pretty et al, 2006). When plants have a better opportunity to healthily grow from the extension of water and plant nutrients, yields have been reported to increase anywhere between 20%-120% with lower energy and production costs (Derpsh et al., 2010). Water quality improvements can increase public health and raise the quality of life for farmers/rural communities, and upfront costs for farmers would be low if agricultural systems are already in place (Lal, 2015).

		A negative impact of this solution is the difficulty in changing farmers' perceptions that conservation agriculture lowers yield and income. Interventions such as subsidies and interest groups continue to discourage farmers from adopting no-tillage practices, stagnating the preference for conservation agriculture (Derpsh et al., 2010).
Down-select Decision	**Yes**	Retain for further analysis

References:

Derpsh, R., Friedrich, T., Kassam, A., and Hongwen, L. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. Int J Agric & Biol Eng, 3(1), 1-25.

Gordon, H. (2013). Basic economic analysis using T-Charts. Economics Technical Note No.: TN 200-ECN-1. Natural Resources Conservation Service (NRCS), United States Department of Agriculture (USDA).

Knowler, D., & Bradshaw, B. (2017). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy, 32(1), 25–48. https://doi.org/10.1016/j.foodpol.2006.01.003

Lal, R. (2015). Sequestering carbon and increasing productivity by conservation agriculture. Journal of Soil and Water Conservation, 70(3), 55A–62A.

Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine,R. E., Penning de Vries, F. W.& Morison, J. I. (2006). Resource-conserving agriculture increases yields in developing countries.Environmental science & technology,40(4), 1114-1119.Retrieved from http://www.julespretty.com/wp-content/uploads/2013/09/7.-Pretty-et-al-EST-2006-Vol-40-4-pp-1114-19.pdf

Endnotes:

1. https://agecon.uga.edu/extension/budgets.html
2. https://www.ers.usda.gov/amber-waves/2019/march/no-till-and-strip-till-are-widely-adopted-but-often-used-in-rotation-with-other-tillage-practices/;
3. https://www.ers.usda.gov/webdocs/publications/90201/eib-197.pdf?v=1783.8;
4. https://gaswcc.georgia.gov/agricultural-conservation-programs
5. https://www.drawdown.org/solutions/food/conservation-agriculture

D.3.5 Managed Grazing | Down-Select

Managed grazing is a set of practices that can increase carbon sequestration on land used for livestock grazing. Practices include adjusting the stocking rates, timing, and intensity of grazing.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	In recent times, a number of farmers across the state of Georgia are practicing managed grazing approaches.
Local Experience & Data Availability (2)	**Yes**	In Georgia, the solution offers both the benefits and challenges related to cost and water demand for animals.
Technically Achievable CO2 Reduction Potential (3)	**No**	Depends on the short- and long-term management practices. The recent LCA study of White Oak Farm is very promising with a long-term commitment from the farmers to produce organic certified products with managed grazing practices. The 1250 acre farm is managed for more than half a century to retain about 10 times more carbon than other conventional farms.
Cost Competitiveness (4)	**No**	It can be expensive to manage, although further study is required. More incentives are required for potential adoption.
Beyond Carbon Attributes (5)	**Yes**	Improved soil health, improved air and water quality, improved humane health.
Down-select Decision	**No**	Do not retain

References:

Thorbecke, M and J. Dettling. (2019). Carbon footprints of evaluation of regenerative grazing at White Oak Farm. Available at https://blog.whiteoakpastures.com/hubfs/WOP-LCA-Quantis-2019.pdf

Endnotes:

1. https://sustainagga.caes.uga.edu/systems/management-intensive-grazing.html
2. https://www.drawdown.org/solutions/food/managed-grazing

D.3.6 Composting | Down-Select

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.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology is currently practiced and readily available in many counties in Georgia
Local Experience & Data Availability (2)	**Yes**	Data is available in major cities and metro areas.
Technically Achievable CO2 Reduction Potential (3)	**Yes**	Composting could reduce a number of landfills in Georgia and would potentially reduce methane emissions. According to the 2005 study by the Georgia Department of Community Affairs, about 3 million tons/y of organic fractions of municipal solid waste is available for composting. The organic fractions does not include food waste, but include mainly green wastes such as papers, wood and yard trimmings. Although some counties in Georgia operate composting facility (e.g. Clarke county), a majority of green wastes are landfilled, which may be diverted to composting facility. It was estimated by the EPA that about 0.16 t $CO_{2\text{-}e}$ is reduced for every short ton of mixed organic waste (EPA, 1998). If 50% of organic waste generated in Georgia is composted every year, composting could reduce about 2.4 Mt $CO_{2\text{-}e}$ by 2030.
Cost Competitiveness (4)	**Yes**	Usually economical. Operating expenses are often high.
Beyond Carbon Attributes (5)	**Yes**	This solution can enrich soil health, reduce methane emissions and reduce the need for chemical fertilizers [4]. Microbial activity degrades raw food wastes resulting in end-products rich in microbial populations, creating extremely fertile soils (EPA, 1998). In addition, landfills will have reduced waste and land use demands will correspondngly decrease. Approximately 27 million tons of municipal solid waste was recovered in 2017 through composting, allowing for that waste to be diverted from landfills[6]. Composting can also provide increased food security and is affordable if composting at home[5]. If compost is used to return nutrients back into exhausted soils on farmlands, the food waste loop can narrow aiding in food security[7]. Negative beyond carbon impacts could result if operating costs for composting services become higher than those associated with landfills. An example from Colorado found backlash to mandatory composting when it added $4.45 to household's monthly expenses[8]. Additionally, there are costs

		associated with interventions and education required for households and businesses to change disposal practices.
Down-select Decision	**Yes**	Retain for further analysis.

References:

Beck, R. W. (2005). Georgia Statewide waste characterization study. Final Report. Georgia Department of Community Affairs.

EPA. (1998). An Analysis of Composting As an Environmental Remediation Technology. EPA530-R-98-008. https://www.epa.gov/sites/production/files/2015-09/documents/analpt_all.pdf

Platt, B and N. Goldstein. (2014). State of composting in the U.S. BioCycle, July 2014: 19-27. Available online at: https://ilsr.org/wp-content/uploads/2014/07/biocycle-stateofcomposting-us-article-july-2014.pdf

Endnotes:

1. https://www.drawdown.org/solutions/food/composting
2. Waste Reduction Model - https://www.epa.gov/warm
3. http://lessismore.org/materials/72-benefits-of-composting/
4. https://www.epa.gov/recycle/composting-home
5. https://ilsr.org/benefits-composting-compost/
6. https://www.epa.gov/sustainable-management-food/reducing-impact-wasted-food-feeding-soil-and-composting
7. https://extension.uga.edu/publications/detail.html?number=B1189&title=Food%20Waste%20Composting:%20Institutional%20and%20Industrial%20Application
8. https://smartasset.com/mortgage/the-economics-of-composting

D.3.7 Nutrient Management | Down-Select

Nitrogen fertilizers are used to increase crop yields. However, excess fertilizer that is not absorbed has environmental impacts. This includes releasing nitrous oxide emissions, a GHG. Better managing fertilizer usage and reducing fertilizer waste can reduce these emissions.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	In Georgia, some fractions of poultry letters, rich in nutrients are spread in crop lands. However, leaching of nutrients and odor emissions are major issues.
Local Experience & Data Availability (2)	**Yes**	Some field-level data are available to reduce synthetic fertilizers with poultry litter.
Technically Achievable CO2 Reduction Potential (3)	**No**	The potential CO_2 reduction is expected due to reduced fertilizer used and the possible use of organic source fertilizers. If the use of excess fertilizer may be reduced by 10% from the conventional farming operation, the practice could reduce the CO_2 reduction. Assuming the carbon footprint of nitrogen fertilizers is about 5 kg of CO_2/kg of fertilizer. For example, if 20% of cotton land can be diverted to 10% reduced nutrient management with an average fertilization rate of 50 kg N/ac, it would reduce the CO_2 emission by only 0.007 Mt $CO_{2\text{-}e}$ per year. In addition, reduced nutrient management require smart agricultural practices to selectively reduce field requirements without compromising on the crop yield.
Cost Competitiveness (4)	**No**	Cost depends on the yield compromise and the types of crops.
Beyond Carbon Attributes (5)	**Yes**	Improved air and water quality due to reduced fertilization rate. Improved human health and cost savings.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

References:

Gaskin, J. and G. Harris. (2012). Nutrient Management. Georgia Farm Assessment System, UGA Cooperative Extension Bullentin 1152-16.

GSWCC (2013). Best management practices (BMP) for Georgia Agriculture – Conservation Practices to protect surface water quality. Georgia Soil & Water Conservation Commission (GSWCC), Athens, GA.

Endnotes:

1. Recommended fertilization rate for different crops. Available at: http://aesl.ces.uga.edu/publications/soil/CropSheets.pdf
2. https://www.yara.com/crop-nutrition/why-fertilizer/environment/fertilizer-life-cycle/
3. https://www.drawdown.org/solutions/food/nutrient-management

D.3.8 Tree Intercropping | Down-Select

Tree intercropping is a suite of practices where trees and annual crops are both grown in a given area at the same time. The mixing of trees and annual crops can increase the carbon content of the soil.

Criteria		Comments
Technology and Market Readiness (1)	**No**	The solution has been tested in sparsely in the United States by NRCS, USDA. The solution does improve the soil health, water quality and biodiversity. The impacts of intercropping on GHG emission reductions are mainly expected from indirect routes such as reduced fertilizer use.
Local Experience & Data Availability (2)	**No**	Only research-plot level data are available in Georgia. It is not yet commercially practiced in Georgia.
Technically Achievable CO2 Reduction Potential (3)	**No**	Depends on the harvesting and silvoculture practices.
Cost Competitiveness (4)	**No**	It can be expensive and have a varying results if practiced. Incentives are critical for adoption.
Beyond Carbon Attributes (5)	**No**	It preserves the natural diversity while sustaining our land resources.
Down-select Decision	**No**	Do not retain

Endnotes:

1. https://www.drawdown.org/solutions/food/multistrata-agroforestry
2. Intercropping Principles and Production Practices https://www.iatp.org/sites/default/files/Intercropping_Principles_and_Production_Practi.htm
3. Strip Intercropping http://www.extension.iastate.edu/Publications/PM1763.pdf
4. Potential economic, environmental benefits of narrow strip intercropping http://www.p2pays.org/ref/49/48354.pdf

D.3.9 Farmland Restoration | Down-Select

Farmland restoration is a set of practices for restoring degraded, abandoned farmland and returning it to productivity. Farmland restoration offers a range of potential benefits including opportunities to sequester carbon in healthy soils.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	Tools and technology are available for restoring soils, including soil amendments and introduction of carbon sequestering cover crops.
Local Experience & Data Availability (2)	**Yes**	The NRCS and state extension service have considerable experience with improving soil conditions as well as multiple programs aimed at encouraging adoption of soil-improving practices.
Technically Achievable CO2 Reduction Potential (3)	**No**	Georgia has very limited abandoned farmland.
Cost Competitiveness (4)	**No**	Not applicable to the State of Georgia
Beyond Carbon Attributes (5)		
Down-select Decision	**No**	Do not retain

Endnotes:

1. https://www.drawdown.org/solutions/food/farmland-restoration

D.3.10 Farmland Irrigation | Down-Select

The energy used to process, pump, and distribute water for farmland irrigation can release GHG emissions. Therefore, practices that increase irrigation efficiency and reduce water demand can help avoid emissions.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Efficient irrigation practices for row crops are still limited due to high cost. However, drip irrigation systems are used for perennial fruit trees. Current pivot irrigation systems achieve a fairly high degree of irrigation efficiency (0.85-0.95) but require more energy than fixed systems such as drip or micro-sprinklers. The fixed systems, however, are not compatible with large-scale row crop production. Switching from diesel powered pumps to electric powered pumps is technically feasible and would lead to a near tripling in irrigation energy efficiency (Mullen et al., 2009). Electric pumps are widely available.
Local Experience & Data Availability (2)	**Yes**	The USDA Farm and Ranch Irrigation Survey has pretty good data on irrigation pump fuel types, but not good data on the types of crops grown by fuel type. Precision monitoring and smart irrigation tools are currently tested in Georgia for cotton, corn and peanuts using Irrigation Pro software tool. Their effect on water withdrawals is uncertain.
Technically Achievable CO2 Reduction Potential (3)	**No**	CO_2 reductions generated by switching irrigation systems from center pivot to micro sprinklers or drop irrigation would come from reduced water use. However, in 2015, there were fewer than 100,000 acres of irrigated vegetables grown in Georgia (USDA-NASS), and many center pivot systems already have fairly high irrigation efficiency, so promoting the adoption of drip or sprinkler irrigation will have limited CO_2 reduction potential. In 2018, about 200,000 acres were irrigated using diesel pumps. Converting these to electric pumps could lead to a reduction of about 12 gallons of diesel fuel per acre per year, for a total of 2.4 million gallons of diesel (average price of diesel in South Atlantic states in 2018 was $3.06/gallon). At 22.4 lb CO_2 / gallon diesel, that would save 53.76 million pounds of CO_2 per year or 0.0244 Mt $CO_{2\text{-}e}$/y *. That diesel fuel would be replaced by about 337 kWh/acre of electricity, for an additional 67.5 million kWh of electricity per year (average price of electricity in Georgia in 2017 was $0.98/kWh, and average $/acre spent on electric pumps is $34/acre (USDA-NASS, 2018). At about 0.95 lb CO_2 / kWh in Georgia (EIA, 2018), converting to electric pumps would likely lead to a net increase in CO_2. This is despite the fact that electric pumps are more energy efficient. The discrepancy likely comes from the fact that available data do not differentiate crops grown by pump type. If we assume electric pumps are 3 times as efficient as diesel, and a gallon of

		diesel is equivalent to about 38 kWh of electricity, then converting the 12 gallons of diesel to an electric pump would use 152 kWh/acre (12*38/3) – equal to about 145 lb CO_2/acre (0.95*152). So, this would lead to 53.76 million pounds less carbon avoided through diesel, but additional 29 million pounds of CO_2 from the electricity generation, netting 24.76 million pounds of CO_2 reduction (or 0.011 Mt $CO_{2\text{-}e}$ per year).
Cost Competitiveness (4)	**Yes**	Due to lower operating and maintenance costs, electric pumps are more cost-effective than diesel pumps (Curley and Knutson, 1992). The cost competitiveness varies depending on fuel costs. In 2018, farmers using diesel pumps spent about $35/acre on irrigation, while those using electric pumps spent about $33.75/acre. (USDA-NASS, 2018)
Beyond Carbon Attributes (5)	**Yes**	Improving irrigation efficiency can reduce water withdrawals, leading to significant improvements in ecosystem services, bio-diversity, ecological health and water quality.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe..

References:

Curley, R. G. & G. D. Knutson. (1992). Cost Comparison: engines vs. electric motors for irrigation pumping. California Agriculture, 48(5): 24-26.

Mullen, J. D., Y. Yu and G. Hoogenboom. (2009). Estimating the demand for irrigation water in a humid climate; A case study from the Southeastern United States. Agricultural Water Management, 96(10): 1421-1428.

USDA-NASS (2018). Energy expenses for all well pumps and other irrigation pumps by the type of energy used. 2017 Census of Agriculture. Available at: https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris_1_0013_0013.pdf

Endnotes:

1. https://gaswcc.georgia.gov/intelligent-irrigation-scheduling
2. https://www.sciencedirect.com/science/article/pii/S0378377409001012
3. https://www.nass.usda.gov/Quick_Stats/
4. https://www.pumpsandsystems.com/topics/motors/powering-pump-diesel-versus-electric-motors
5. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris_1_0013_0013.pdf
6. https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_r1z_a.htm
7. https://www.eia.gov/electricity/state/
8. https://www.drawdown.org/solutions/food/farmland-irrigation

D.3.11 Biochar | Down-Select

Biosequestration process for converting biomass to long-lived charcoal (and energy) which can be used as a soil amendment. This solution provides an alternative to disposing of unused biomass through burning or decomposition.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The technology is ready, but there is a limited market for agriculture due to high cost of production. The use of biochar for other environmental remediation applications are under development to prevent leaching of heavy metals and nutrients from soils.
Local Experience & Data Availability (2)	**No**	There are a number of studies conducted on assessing the impacts on soil health, biodiversity and water quality. Limited field-level data is available for Georgia. There is a Wakefield Bio Char facility in Valdosta, Georgia, that sells bio-based ash to enhance soil. The Biochar Soil Conditioner is USDA Certified Biobased made from a wood feedstock (Lehmann et al., 2006). However, other states and universities within the United States have more information (e.g. California, Cornell University, etc.).
Technically Achievable CO2 Reduction Potential (3)	**No**	Application of biochar to crop lands is expected to increase soil carbon as a carbon sink, while improving soil health and crop growth (Lehmann et al., 2006). However, the long-term stability of biochar on soil as carbon sink is not fully understood due to diverse quality of biochar, soil types and environmental conditions. There has been significant effort devoted to standardization of biochar by International Biochar Initiative (IBI). The GHG emission reduction depends on how biochar is produced, the biomass sources and the carbon sequestration potential (Roberts et al., 2010).
Cost Competitiveness (4)	**No**	Cost depends on the technology and the biomass types. A recent study by Sahoo et al. (2019) on the cost of biochar production has demonstrated that the biochar cost ranged from \$1,044 to \$467 per metric tonne. Roberts et al., (2010) estimated that the potential to cost to reduce GHG emissions was about \$80 per t CO_{2e}, if biochar is produced from yard waste with about 60% of carbon sequestration on soil.
Beyond Carbon Attributes (5)	**Yes**	Modest improvement in water quality and biodiversity; some economic benefits due to new biochar production facilities; some improvement in air quality; marginal improvement in food security.
Down-select Decision	**No**	Do not select for further analysis

References:

Jeffery, S., F. G. A. Verheijen, M. van der Velde, and A.C. Bastos. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agriculture Ecosystems & Environment 144: 175-187

Lehmann, J.; Gaunt, J.; Rondon, M. (2006). Bio-Char Sequestration in Terrestrial Ecosystems—A Review. Mitigation and Adaption Strategies for Global Change, 11, 395-419.

Roberts, K. G., B. A. Gloy, S. Joseph, N. R. Scott and J. Lehmann. (2010). Life cycle assessment of biochar systems: Estimating the energetic, economic and climate change potential. Environmental Science & Technology, 44(2): 827-833.

Sahoo, K.K., E.M. (Ted) Bilek, R. Bergman, S. Mani. (2019). Techno-economic analysis of producing solid biofuel and biochar from forest residues using portable systems. Applied Energy, 235: 578-590.

Endnotes:

1. https://www.wakefieldbiochar.com in Valdosta, Georgia
2. https://biochar-international.org
3. https://biochar-us.org/organizations-and-resources
4. https://www.drawdown.org/solutions/food/biochar

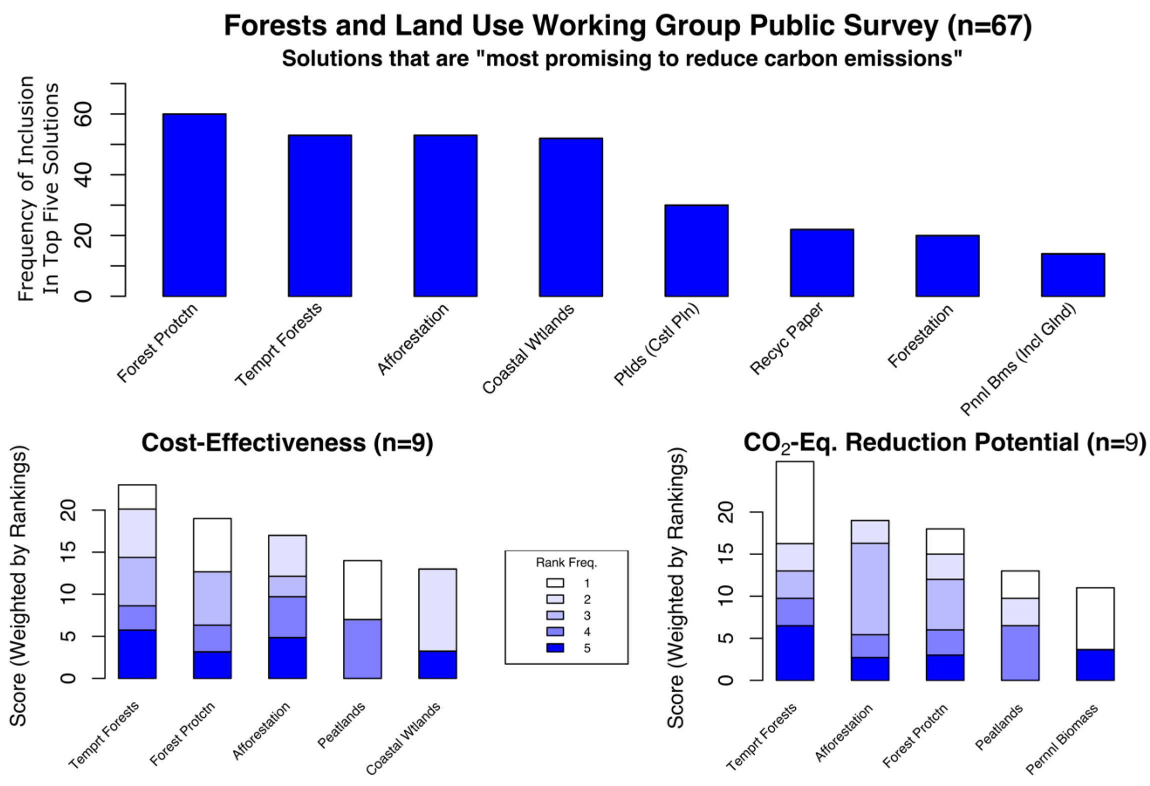
E Appendix E. Land Sinks

E.1 Land Sinks Solution List

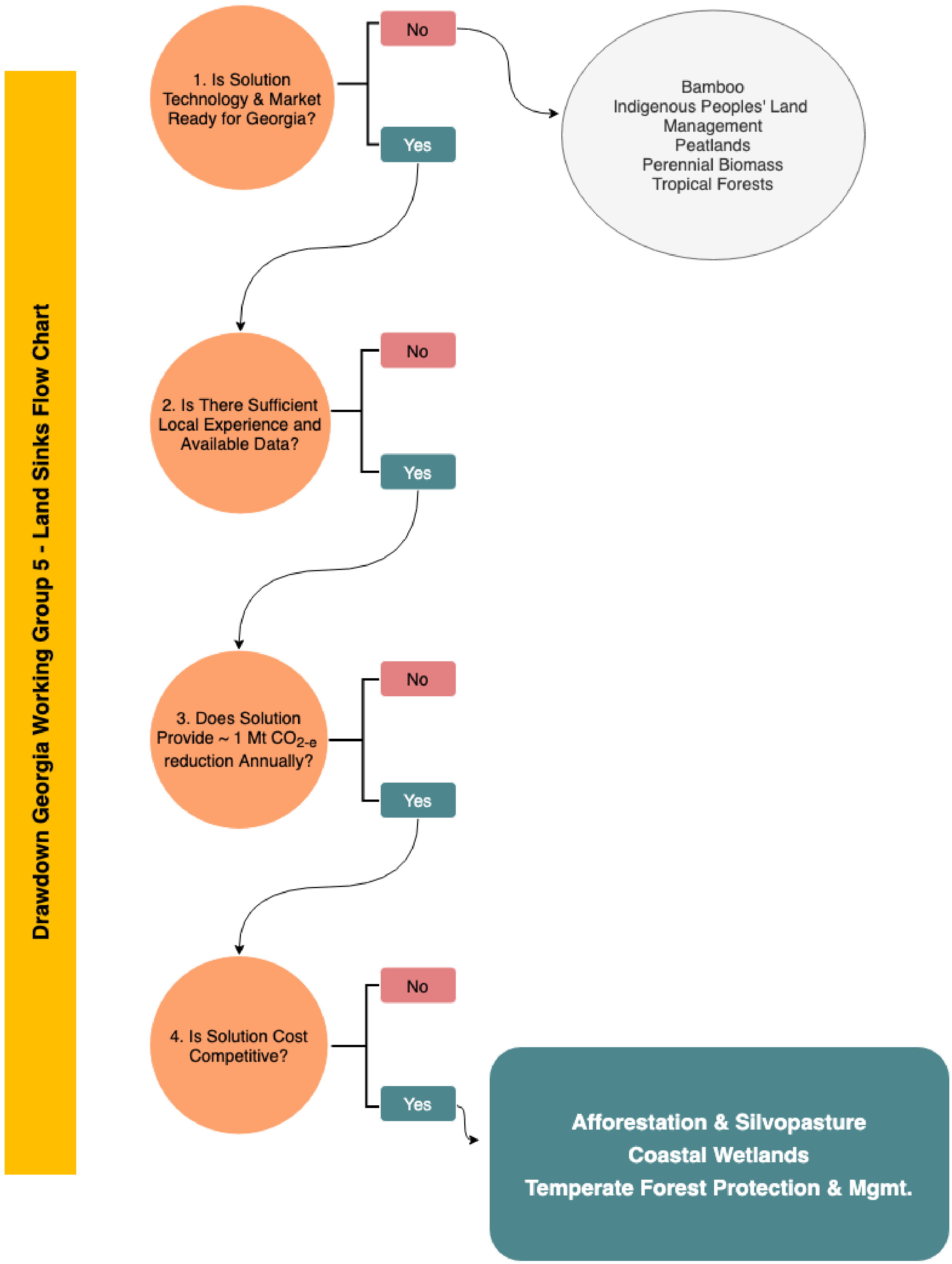
Temperate Forests
Peatlands
Afforestation
Bamboo
Forest Protection
Indigenous Peoples' Land Management
Perennial Biomass
Coastal Wetlands
Silvopasture
Tropical Forest
Temperate Forest Protection & Management

E.2 Down-Select Criteria for Land Sinks Solutions:

1. **Technology & Market Readiness** - Whether this Solution was already feasible on a current land use basis or whether this Solution would become feasible in time for the 2030 timeframe.
2. **Local Experience & Data Availability** - Whether we have a high level of local (within Georgia) expertise and data available to implement this Solution.
3. **Technically Achievable CO2 Reduction Potential** - Whether CO2 drawdown potential for this solution is realistic in the 2030 timeframe based on current and near-future land use.
4. **Cost competitiveness** - The cost relative to other Solutions of acquiring appropriate land, if necessary, and managing this land use type.
5. **Other ("Beyond Carbon") Attributes** - The importance of this Solution for achieving Beyond Carbon benefits including biodiversity conservation, providing jobs and other economic opportunities, and promoting education particularly of girls.



(Each 1st place rank earns 5 points, 2nd place 4 points, 3rd place 3 points, 4th place 2 points, 5th place 1 point)



Down-Select Steps to Identify High-Impact 2030 Solutions

E.3 Down-Select Results for Land Sinks Solutions:

E.3.1 Temperate Forests | Down-Select

Restoring and protecting temperate-climate forests has many benefits including carbon sequestration from trees, soil and other vegetation.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Almost 60% of land in Georgia is comprised of naturally-recruited and planted temperate forests, and Georgia is the number one forestry state in the nation, so this is definitely a market-ready solution (Edwards et al. 2013). For example, about 150,000 acres are planted in Georgia with pine seedlings each year (GFC, 2019).
Local Experience & Data Availability (2)	**Yes**	With our large extent of temperate forests and the importance of forestry for the state's economy, we have abundant local experience and data availability on Georgia's temperate forests from universities; county, state and federal agencies; NGO's and businesses.
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**Yes**	Almost 60% of land in Georgia is comprised of native and planted temperate forests, and Georgia is the number one forestry state in the nation. Georgia's forests offset approximately 8% of the state's CO_2 emissions, and can sequester one to four tons of carbon per acre, per year (GFC, 2019). Based on Forest Inventory and Analysis (FIA) data, between 2007 and 2017 forests of Georgia accumulated an average of 27 Mt CO_2 annually in living tree biomass above and below ground[1]. A preliminary estimate of annual carbon uptake in state soils is 3 Mt CO_2 (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 30 Mt CO_2. An increase in this annual carbon sequestration by 1 Mt CO_2 by 2030 could be achieved by expanding Georgia's forest acreage by 2.9%. To put this in perspective, a 15% increase of forest acreage would be achieved if Georgia's forests in 2030 covered the same acreage as it did in 1974.
Cost Competitiveness (4)	**Yes**	Almost 60% of the current State of Georgia is comprised of native and planted temperate forests so little cost would be associated with maintaining these forests and this solution relative to other solutions. For planted pines with management, the cost of aboveground carbon storage is about \$11 per ton C. The cost for unmanaged forests is essentially \$0 per ton C in Georgia (Fuller and Dwivedi, unpublished data).
Beyond Carbon Attributes (5)	**Yes**	Positive environmental impacts from this solution include improved air quality from trees' natural ability to provide oxygen, as well as increasing wildlife habitats and biodiversity (Bonan, 2008). Estimates suggest that trees and forests removed 17.4 million tonnes (t) of U.S. air pollution in

		2010 (Nowak, et al., 2014). Increased air quality greatly improves public health of communities in the surrounding areas, which was valued at $6.8 billion in annual health effects in 2010, avoiding over 850 deaths and 670,000 acute respiratory symptoms. Forests offer improved water quality through soil protection, reduced water runoff and evapotranspiration (Trabucco, et al., 2008). Forests create jobs in the areas of forest protection and management, corresponding to the areas with the highest forest coverage,[2] but temperate forests may also need to be legally managed (Guariguata, et al., 2010). Another positive benefit is improved quality of life forests provide by offering recreational opportunities for people in the local community and/or tourists.[3] Since there is little to no cost for these recreational opportunities, this solution is highly accessible to low-income families. A potential barrier is that the temperate forest land use may restrict rural land available for farming/food, and could potentially lead to a reduction in timber-related jobs (Chazdon, 2008).
Down-select Decision	**Yes**	Retain for further screening in the 2020-2030 timeframe.

References:

Bonan, G. B. (2008). Forests and climate change:Forcings, feedbacks, and the climate benefits of forests. *Science* 320(5882): 1444-1449.

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Endnotes:

1. https://www.fia.fs.fed.us/
2. https://www.drawdown.org/solutions/land-use/temperate-forests
3. https://www.bls.gov/careeroutlook/2016/article/forestry-careers.htm
4. https://discovertheforest.org/partners

E.3.2 Peatlands | Down-Select

Peatlands, also known as bogs or mires, are carbon-rich environments formed over many years as wetland vegetation slowly breaks down. Protecting peatlands safeguards these carbon sinks and prevents emissions being released.

Criteria		Comments
Technology and Market Readiness (1)	**No**	Native peatlands were once common in Coastal Plain wetland ecosystems before European settlement (Edwards et al. 2013, Bartram 1791). A few rare Mountain Bog ecosystems with rare species still exist in the southern Appalachians (Edwards et al. 2013). However, only some of these peatlands persist under federal, state, or NGO protection. Many Coastal Plain privately owned peatlands have long been converted to agriculture or golf courses. Further, carbon accumulation in Georgia peatlands is less than in cooler northern Peatlands (Craft, et al., 2008, Schlesinger and Bernhardt 2013). Retaining Georgia native Peatlands will contribute to "Coastal Wetland," "Forest Protection," and "Temperate Forest" solutions (Edwards et al. 2013). Here we are considering only the re-establishment of peatlands on unprotected, private lands.
Local Experience & Data Availability (2)	**No**	Peatlands on protected, non-private federal, state and NGO lands are considered under the "Temperate Forests," "Forest Protection," and "Coastal Wetlands" solutions.
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**No**	Peatlands on protected federal, state and NGO lands are considered under the "Temperate Forests," "Forest Protection," and "Coastal Wetlands" solutions. Here we are considering only the re-establishment of peatlands on unprotected, private lands.
Cost Competitiveness (4)	**No**	Restoring native peatlands on private lands would be cost prohibitive in the 2020-2030 timeframe relative to other solutions. Peatlands on protected federal, state and NGO lands are considered under the "Temperate Forests," "Forest Protection," and "Coastal Wetlands" solutions.
Beyond Carbon Attributes (5)		Restoration of private, largely agricultural lands to native peatlands would provide biodiversity benefits and promote local jobs via restoration and monitoring efforts. Restoration would also provide educational and local ecotourism job opportunities. Currently the fields of Biology and Ecology are strongly comprised of females, so this solution would also provide opportunities for aspirational women and girls.
Down-select Decision	**No**	Do not retain this solution for stand-alone analysis in the 2020-2030 time frame but do consider undisturbed peatlands under the

		"Temperate Forest," "Forest Protection," and "Coastal Wetlands" solutions.

References:

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Endnotes:

1. https://www.drawdown.org/solutions/land-use/peatlands

E.3.3 Afforestation | Down-Select

Afforestation is the process of creating forests in places that are no longer forested. This could include planting trees on degraded agricultural or pasture lands and planting in urban areas. Forests sequester carbon in trees, soil, and other vegetation.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Planting trees on formerly forested lands that are now developed (urban, suburban) or used for agricultural pastures would benefit both the carbon sequestration potential and protect humans and livestock from intense summer heat via shade (Karl et al. 2009, Bastin et al. 2019). Georgia is the number one forestry state in the nation and has urban tree planting programs such as Trees Atlanta[1], so the Technical and Market Readiness benefits of Afforestation are present.
Local Experience & Data Availability (2)	**Yes**	Georgia is the top forestry state in the United States, and agriculture as a whole is the most important business in the state. We also have established tree planting programs in Atlanta and other cities, so we have much local experience, expertise, and data for afforestation. Afforestation data can be easily estimated using National Land Cover Database available free of cost to users (NLCD, 2016).
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**Yes**	Forests are the main natural terrestrial carbon sink on the planet (Crowther et al., 2016, Carey et al., 2016). According to the USDA (2016), 11.1% of the state of Georgia was in croplands in 2012 for a total of about 4.19 million acres. Conservatively, if 10% of Georgia's current croplands are afforested with mixed tree species, equivalent to 0.42 million acres, this would increase CO_2 uptake and storage in living tree biomass by 0.46 Mt CO_2 per year. However, if instead these lands were planted as loblolly pine (*Pinus taeda*) plantations, this CO_2 uptake rate in living biomass would increase to over 1.8 Mt CO_2 per year by 2030. When CO_2 storage in soils is also considered, the CO_2 sequestration would increase further (see "Silvopasture" solution). For each Mixed Species versus Loblolly scenario, the estimated CO_2 sequestration refers to CO_2 stored in both trees and in soils. The mixed tree species scenario at a 10% crop+pasture planting level would sequester 5.3 Mt CO_2 in 2030. The Loblolly Pine scenario with a 10% crop+pasture planting level would sequester 7.8 Mt CO_2 in 2030. Also see the discussion of "Silvopasture" which overlaps with this solution's estimated carbon sequestration.
Cost Competitiveness (4)	**Yes**	Forestry is one of the state's biggest economic sectors. For planted pines with forestry management the cost of aboveground carbon storage is about \$3.5 per ton of CO_2. The cost for unmanaged forests is essentially \$0 per ton of CO_2 (Fuller and Dwivedi, unpublished data).

Beyond Carbon Attributes (5)	**Yes**	Reforesting formerly forested lands would provide biodiversity conservation, jobs, and freshwater quality benefits. Environmental benefits of afforestation include improved air quality through a reduction in particulate matter (Nowak, 2002). Afforestation provides habitats for wildlife further benefiting local ecosystems and may provide social-economic opportunities through timber production, and recreation, and tourism. Since these solutions are often concentrated in rural areas, the environmental and social benefits are often accessible to lower income groups, providing increased mental/physical health from outdoor recreational opportunities (Karjalainen, et al., 2009). The rural land use available for farming may be reduced, but may be supplemented by farming tree products, which can lead to economic benefits for landowners, increasing sustainable income (Hardy, et al., 2018). Afforestation also has the potential to cut farmer's costs by reducing the need for feed, fertilizer and herbicides, and can improve the fertility of soil with clay content. However, costs to establish and maintain the solution, for example increased water usage to plant trees, pruning, and root damage to infrastructure, should be considered. Additionally, trees can be a source of seasonal pollen allergies. Afforestation is positively linked to infant health; increasing fresh plant-based food supply in food deserts lowers prematurity and low birth weight rates in these areas (Zhang, et al., 2018). Economic barriers to implement and maintain afforestation may be an issue for low-income farmers (Current, et al., 1995). Shifting traditional farming routines is a potential issue for new solutions that are not typically custom for farmers, and therefore may not be easily adopted (Calle, et al. 2009). See also "Silvopasture."
Down-select Decision	**Yes**	Retain for further screening in the 2020-2030 timeframe.

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Endnotes:

1. https://www.treesatlanta.org/
2. https://www.drawdown.org/solutions/land-use/afforestation
3. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2793342/

E.3.4 Bamboo | Down-Select

Bamboo can rapidly take carbon out of the air and sequester it in its biomass. As a result, large-scale cultivation of bamboo has significant climate benefits.

Criteria		Comments
Technology and Market Readiness (1)	**No**	Native bamboo (*Arundinaria gigantea*; Edwards et al. 2013, Goble 2013. Barone et al. 2008) still occurs in floodplains of the Southeast including Georgia and extensive "canebrakes" were historically important for Native Americans in pre-European settlement time (Bartram 1791). However, canebrakes are currently rare enough to be considered an endangered ecosystem (Barone et al. 2008) so are not considered a viable solution. Akin to kudzu (*Pueraria montana*), exotic bamboo species are invasive to the point of suppressing native tree recruitment thus interfering with forest carbon sequestration so are also not considered as a viable solution (Georgia Invasive Species Task Force 2018, Georgia Exotic Pest Plant Council 2006). While Lieurance et al. (2018) found some exotic bamboo species to be less invasive than others, even these less invasive species still inhibit tree recruitment and thus over time will result in less carbon sequestration relative to other forest solutions. Thus, Bamboo is not a viable solution. In addition, in 2010 bamboo in all North and Central America represented little more than ~0.1% of the worldwide distribution of bamboo (Buckingham et al. 2014).
Local Experience & Data Availability (2)	**No**	Local experience with bamboo in Georgia consists mainly of eradicating invasive, non-native bamboo.
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**No**	No
Cost Competitiveness (4)	**No**	Bamboo is not a cost competitive solution compared with other solutions.
Beyond Carbon Attributes (5)	**Yes**	The establishment of the native bamboo would have environmental benefits including biodiversity.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe.

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Endnotes:

1. https://www.drawdown.org/solutions/land-use/bamboo

E.3.5 Forest Protection | Down-Select

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.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The majority of Georgia is forested, and of these lands about 72% are not intensively managed, so the Technical and Market Readiness of Forest Protection benefits are important. Forests serve as natural conduits of carbon from the atmosphere to the trees and then to the soil and form the largest terrestrial carbon sink for both the globe and for Georgia (Schlesinger and Bernhardt 2013, Machmuller et al. 2018, Crowther et al. 2016). Thus, Forest Protection is an essential solution for drawing down carbon in Georgia.
Local Experience & Data Availability (2)	**Yes**	We have abundant local experts in forest ecology and protection at local to federal government agencies, universities, and NGO's with much experience and data, so the Local Experience and Data Availability benefits are large.
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**Yes**	Protected forests in Georgia are already present and functioning as an important carbon sequestration solution (Edwards et al. 2013, Crowther et al. 2016, Machmuller et al. 2018, Carey et al. 2016). According to the U.S. Forest Service's Forest Inventory and Analysis (FIA) data, the forests in Georgia not managed for timber averaged 19.8 Mt CO_2 per year of carbon storage in living biomass from years 2007-2017[1]. This is a subset of the annual 27 Mt CO_2 of storage in living biomass estimated for the "Temperate Forests" solution. Thus, a small enhancement in Forest Protection could offer a technically achievable means for increasing CO_2 sequestration in Georgia by 1 Mt CO_2.
Cost Competitiveness (4)	**Yes**	About 43% of the current State of Georgia is comprised of forests not managed for timber so little cost would be associated with continued Forest Protection. The cost of carbon storage for unmanaged forests is essentially $0 per ton CO_2 (Fuller and Dwivedi, unpublished data). As these protected forests are already present, with many on public lands and private lands with conservation easements requiring little to no management efforts, so costs are estimated to be low.
Beyond Carbon Attributes (5)	**Yes**	Keeping much of Georgia in forested ecosystems would continue to provide Beyond Carbon benefits to biodiversity conservation, provisioning of water quantity and quality, ecotourism, recreation and associated job opportunities especially in rural areas. Also see "Temperate forest Protection and Management".
Down-select Decision	**Yes**	Retain for further screening in the 2020-2030 timeframe.

References:

Carey, J. C., Tang, J., Templer, P. H., Kroeger, K. D., Crowther, T. W., Burton, A. J., Dukes, J.S., Emmett, B,, Frey, S.D., , Heskel, M.A., Jiang, L., Machmuller, M.B., Mohan, J., Panetta, A.M., Reich, P.B., Reinsch, S., Wang, X., Allison, S.T., Bamminger, C., Bridgham, S., Collins, S.L., de Dato, G., Eddy, W.C., Enquist, B.J.,Estiarte, M., Harte, J., Henderson, A., Johnson, B.R., Larsen, K.S., Luo, Y., Marhan, S., Melillo, J.M., Peñuelas, J., Pfeifer-Meister, L., Poll, C., Rastetter, E., Reinmann, A.B., Reynolds, L.L., Schmidt, I.K., Shaver, G.R., Strong, A.L., Suseela, V., and Tietema, A. (2016). Temperature response of soil respiration largely unaltered with experimental warming. *Proceedings of the National Academy of Sciences* 113(48): 13797-13802.

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Endnotes:

1. https://www.fia.fs.fed.us/
2. https://www.drawdown.org/solutions/land-use/forest-protection

E.3.6 Indigenous Peoples' Land Management | Down-Select

Efforts by indigenous communities to resist deforestation, extractive industries, and monocrop plantations have prevented GHG emissions. This solution considers the impact of increasing indigenous peoples' secure legal tenure rights to their traditional lands.

Criteria		**Comments**
Technology and Market Readiness (1)	**No**	Pre-European settlement Georgia had many Native American societies including the Cherokee, Creek, Hitchiti, Oconee, Miccosukee, Guale, Yamassee, Timucua and Apalachee (American Library Association, nd). However, forced removal of these people diminished populations and land rights, and the state of Georgia does not currently have federally recognized Indigenous People's Lands. The state of Georgia currently recognizes three tribes (Cherokee of Georgia Tribal Council, Georgia Tribe of Eastern Cherokee, and Lower Muskogee) in Georgia.
Local Experience & Data Availability (2)	**No**	The state of Georgia does not have federally recognized Indigenous Peoples' Lands. However, there are many southeastern forest ecology and management experts who could provide assistance if such lands were recognized and protected for indigenous people.
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**No**	Georgia does not have federally recognized Indigenous People' Lands so managing lands for CO_2 sequestration would likely not store 1 $MtCO_2$ by 2030.
Cost Competitiveness (4)	**No**	The state of Georgia does not have federally recognized Indigenous Peoples' Lands.
Beyond Carbon Attributes (5)	**Yes**	The state of Georgia does not have federally recognized Indigenous Peoples' Lands, but if this were achieved the Beyond Carbon Benefits would benefit the environment, economic development, and equity.
Down-select Decision	**No**	Do not retain for further screening in the 2020-2030 time frame but do consider over the longer term if state or federal agencies set aside indigenous peoples' land.

Endnotes:

1. American Library Association, nd. http://www.ala.org/aboutala/offices/muscogee-and-cherokee-tribes-georgia

2. National Conference of State Legislatures (NCSL). 2019. https://www.ncsl.org/research/state-tribal-institute/list-of-federal-and-state-recognized-tribes.aspx#State
3. https://www.drawdown.org/solutions/land-use/indigenous-peoples%E2%80%99-land-management

E.3.7 Perennial Biomass | Down-Select

Bioenergy can be sourced from annual crops, such as corn, or perennial crops, such as switchgrass and fountain grasses. Using perennial crops instead of annual crops to create products such as ethanol and biodiesel can cut carbon emissions.

Criteria		Comments
Technology and Market Readiness (1)	**No**	Treeless grasslands and prairies were historically rare in the state of Georgia which historically and currently is dominated by forest and woodland savanna cover (Edwards et al. 2013, Barbour and Billings 2000). Almost 60% of Georgia lands are forested and those managed for pine production (GFC 2019) include bioenergy production, but are considered under the "Temperate Forest" solution for Georgia.
Local Experience & Data Availability (2)	**No**	We have some local research experience with switchgrass in Georgia where it is not viewed as an effective pasture grass or hay for forage as it is outcompeted by non-native grass species (Hancock 2017). Further, switchgrass and other warm-season perennial grasses are likely not sustainable low-input sources of bioenergy production in Georgia due to site nutrient depletion (Knoll et al. 2012). Bioenergy production in Georgia is being accomplished using forests and trees (GFC 2019).
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**No**	This is not a technically achievable solution for increasing CO_2 sequestration, particularly in comparison with the effectiveness of reducing carbon via the Temperate Forest, Forest Protection, and Afforestation Drawdown solutions.
Cost Competitiveness (4)	**No**	Switchgrass and other grass seeds are relatively inexpensive but they are not viewed as a sustainable bioenergy solution as they deplete site nutrients (Knoll et al. 2012). Further, globally carbon sequestration is much higher in forest ecosystems (Crowther et al. 2016, Schlesinger and Bernhardt 2013) so converting Georgia lands already supporting forests to non-woody perennial biomass is not cost effective.
Beyond Carbon Attributes (5)	**Yes**	Switchgrass and some other warm-season perennial grass species are native to Georgia.
Down-select Decision	**No**	Do not retain this solution for stand-alone analysis in the 2020-2030 time frame.

References:

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Endnotes:

1. **https://www.drawdown.org/solutions/land-use/perennial-biomass**

E.3.8 Coastal Wetlands| Down-Select

Coastal wetlands, including mangroves, seagrasses, tidal salt marshes and freshwater marshes, are powerful carbon sinks. These ecosystems sequester carbon in plants and soils.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	The state of Georgia has ~100 miles of coast and the coastal wetlands. Further, with a few small exceptions these wetlands are owned by federal, state and conservation agencies (the exceptions being Jekyll Island, Tybee Island, and St. Simons). Georgia's Department of Natural Resources reports 420,324 acres of tidal salt and freshwater marshes in Georgia comprising the largest amount of tidal wetlands of any state in the U.S. Atlantic seaboard (Seabrook 2006, Edwards et al. 2013)[1]. Further, Georgia's tidal marshes are among the most productive ecosystems in the world on a per unit area basis (NASEM 2019, EPA 2019, Edwards et al. 2013, Schlesinger and Bernhardt 2013, Ouyang and Lee, 2014, Schubauer and Hopkinson 1984, E. Odum 1961). Thus, maintaining Georgia's Coastal Wetlands is an important Drawdown Georgia solution.
Local Experience & Data Availability (2)	**Yes**	We have many local coastal wetland experts at universities, state and federal agencies, and NGO's and much data from Georgia.
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**Yes**	Globally tidal marshes sequester 7.98 t CO_2 ha^{-1} each year (NASEM 2019, EPA 2019). Georgia has 420,374 acres of tidal marshes[1] so has an annual CO_2 sequestration rate of 1.4 Mt CO_2 mainly in sediments. In comparison, estimates for the entire continental U.S. coastal wetlands including the mangrove forests of Florida is 8 Mt CO_2e per year (NASEM 2019, EPA 2019).
Cost Competitiveness (4)	**Yes**	The vast majority of Georgia's coastal wetlands are already protected by government and conservation agencies making this solution very cost competitive in terms of initial land acquisition. However, sea level rise will make the management and conservation of coastal wetlands more expensive due to management efforts such as acquiring buffers for future marsh migration.
Beyond Carbon Attributes (5)	**Yes**	Coastal wetlands, including salt marshes in estuaries and freshwater wetlands, provide positive social-economic benefits by acting as the first line of defense from storm surges and floods. A study on flood damage reduction in the Northeastern United States found that wetlands avoided $625 million in flood damage during Hurricane Sandy, and on average, coastal wetlands reduced annual flood losses by 16% (Narayan, et al., 2017). Coastal wetlands enhance water quality and provide crucial habitat, nurseries, and shelter for fish, migratory birds, and other wildlife. Over 35% of endangered species live only in wetlands, with additional species requiring wetland habitats to reproduce (Kusler, 1983).

		Other benefits include the potential increase in fishery and coastal tourism. Since over one third of all U.S. adults participate in wetland tourism activities, wetlands are a huge economic opportunity for their respective communities[3]. These factors can lead to increased quality of life, jobs, and safety for the residents living within coastal communities. A potential beyond carbon concern relates to development and construction firms' inability to develop coastal floodplain areas.
Down-select Decision	**Yes**	Retain for further screening in the 2020-2030 timeframe.

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2. https://www.drawdown.org/solutions/land-use/coastal-wetlands
3. National Oceanic and Atmospheric Administration. (2020). Coastal Wetlands: Too Valuable to Lose. https://www.fisheries.noaa.gov/national/habitat-conservation/coastal-wetlands-too-valuable-lose

E.3.9 Silvopasture | Down-Select

Silvopasture is the practice of adding trees to pastureland. Silvopastures can sequester carbon in the trees and soil and help counteract the methane emissions associated with raising cattle on pasture lands.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	Silvopasture is an ancient practice, integrating trees and pasture into a single system for raising livestock. It can help sequester carbon, reduce soil erosion, improve water quality by shading streams (Franzluebbers et al., 2000) and provide shade for livestock which improves animal health and productivity (Swift and Messers 1971, Clinton 2011, Baas et al. 2017, NRDC 2017, USDA n.d.). Shade-tolerant and semi-tolerant crops such as blueberries and blackberries can also be incorporated into Silvopastures. In combination with the "Afforestation" solution, Silvopasture is a technological and market ready solution.
Local Experience & Data Availability (2)	**Yes**	Georgia has limited experience and operational data at large scale to assess its potential. However, the state of Georgia has about 2.8 million acres of pastureland, which could be converted into silvopasture practices (USDA 2016, USDA-NASS). (Also, see "Afforestation.)"
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**Yes**	The solution has the potential to sequester more carbon in the soil (Morgan et al. 2010). According to the USDS (2016) 7.3% of the state of Georgia was in pastures in 2012 for a total of about 2.8 million acres. Conservatively, we consider the option of planting trees in 10% of Georgia's current pastures. Two approaches are considered: (1) planting with mixed tree species (which is preferable for biodiversity and wildlife, but sequesters a bit less CO_2) and (2) planting entirely as loblolly pine (*Pinus taeda*) (which sequesters more CO_2 but could cost more if actively planted and managed, and is not as beneficial for biodiversity). For each scenario the estimated CO_2 sequestration refers to CO_2 stored in both trees and in soils. The mixed tree species scenario at a 10% crop+pasture planting level would annually sequester **5.3 Mt CO_2** in 2030. The Loblolly Pine scenario with a 10% crop+pasture planting level would annually sequester **7.8 Mt CO_2** in 2030. Also see the discussion of "Afforestation" which overlaps with this solution's estimated carbon sequestration.
Cost Competitiveness (4)	**Yes**	Cost depends on the adoption rate of farmers in Georgia and the potential incentives provided to the farmers. Economic analysis suggests that silvopasture systems are more profitable over time than monoculture system (Stainback and Alavalapati, 2004). Also see "Afforestation."

Beyond Carbon Attributes (5)	**Yes**	The beyond carbon benefits of silvopasture include improved air quality and water quality (Bonan, 2008 and Trabucco, et al., 2008). A University of Florida study found that the presence of trees in pastures contributed to significant nutrient retention benefits including lower water-soluble phosphorus, and higher soil phosphorus storage capacity. The resulting environmental quality improvements of this solution have the potential to improve human and ecosystem health of the surrounding areas. Economic barriers to implement and maintain silvopasture systems may be an issue for low-income farmers (Current, et al., 1995). Shifting traditional farming routines is a potential issue, as silvopasture is not a typical custom for farmers, and therefore may not be easily adopted (Calle, et al. 2009). However, farmers that do adopt this solution see higher livestock yields, which leads to increased calve and milk yield, as well as more diversely productive land, protecting farmers from financial and weather-related risk (Yamamoto, et al., 2007). Silvopasture also has the potential to cut farmer's costs by reducing the need for feed, fertilizer and herbicides. Also see "Afforestation."
Down-select Decision	**Yes**	Retain for further screening in the 2020-2030 time frame combined with the "Afforestation" solution.

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1. Silvopasture studies in the U.S. https://www.fs.usda.gov/nac/practices/silvopasture.php
2. https://www.drawdown.org/solutions/food/silvopasture
3. USDA, n.d. Silvopasture studies in the U.S. https://www.fs.usda.gov/nac/practices/silvopasture.php

E.3.10 Tropical Forests | Down-Select

Restoring and protecting tropical forests has many benefits including carbon sequestration from trees, soil, and other vegetation.

Criteria		Comments
Technology and Market Readiness (1)	No	The tropics are defined as an equatorial region delineated to the north by the Tropic of Cancer (23°26’14’’N) and to the south by the Tropic of Capricorn (23°26’14’’S) (Wood et al. 2019, Holdridge 1967). The southernmost latitude in Georgia is 30°21’21’’N. Thus, Tropical Forests and associated species are not native to the state of Georgia and not possible to be successful here in the 2020-2030 time frame due to current winter climate being too cool for species defined by their intolerance of frost (Holdridge 1967, Coen 1983, Hartshorn 1988, Markgraf 1993, Archibold 1995, McGregor and Nieuwolt 1998, Edwards et al. 2013, Wood et al. 2019).
Local Experience & Data Availability (2)	No	While the state of Georgia has many scientists familiar with and data from tropical forests at equatorial latitudes, this forest biome type does not exist in Georgia and will not exist here in the 2020-2030 timeframe. There are forecasts of tropical mangrove species migrating to southern Georgia by year 2060, but it is not clear this will also occur with upland tropical species.
Technically Achievable Potential for Increased CO_2 Sequestration (3)	No	No
Cost Competitiveness (4)	No	Tropical Forests and associated species are not native to the state of Georgia and not possible to be successful here in the 2020-2030 time frame due to current winter climate being too cool for species defined by their intolerance of frost (Holdridge 1967, Coen 1983, Hartshorn 1988, Markgraf 1993, Archibold 1995, McGregor and Nieuwolt 1998, Edwards et l. 2013, Wood et al. 2019).
Beyond Carbon Attributes (5)		Tropical Forests and associated species are not native to the state of Georgia and not possible to be successful here in the 2020-2030 time frame due to current winter climate being too cool for species defined by their intolerance of frost (Holdridge 1967, Coen 1983, Hartshorn 1988, Archibold 1995, Markgraf 1993, McGregor and Nieuwolt 1998, Edwards et l. 2013, Wood et al. 2019).
Down-select Decision	No	Do not retain for further screening in the 2020-2030 timeframe.

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Endnotes:

1. https://www.drawdown.org/solutions/land-use/tropical-forests

E.3.11 Temperate Forest Protection & Management | Down-Select

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.

Criteria		**Comments**
Technology and Market Readiness (1)	**Yes**	Almost 60% (about 25 million acres) of land in Georgia is comprised of naturally recruited and planted temperate forests. Of these lands, about 72% are not intensively managed. Georgia is the number one forestry state in the nation, so "Temperate Forest Protection & Management" is a market-ready solution (Edwards et al., 2013). For example, about 150,000 acres are planted in Georgia each year mostly with pine seedlings (Georgia Forestry Commission Report, 2019). Forests serve as natural conduits of carbon from the atmosphere to the trees and then to the soil and form the largest terrestrial carbon sink for both the globe and for Georgia (Schlesinger and Bernhardt 2013, Machmuller et al. 2018, Crowther et al. 2016). Thus, Forest Protection is an essential Solution for drawing down carbon in Georgia.
Local Experience & Data Availability (2)	**Yes**	With our large extent of temperate forests and the importance of forestry for the state's economy, we have abundant local experience and data availability on Georgia's temperate forests from universities; county, state and federal agencies; NGO's, and businesses. We also have abundant local experts in forest ecology and protection.
Technically Achievable Potential for Increased CO_2 Sequestration (3)	**Yes**	Georgia's managed forests offset a significant proportion of the state's CO_2 emissions and can sequester one to four tons of carbon per acre, per year (GFC, 2019). Based on Forest Inventory and Analysis (FIA) data, between 2007 and 2017 forests of Georgia accumulated an average of 27 Mt CO_2 annually in living tree biomass above and below ground.[1] Using a conservative estimate of annual soil CO_2 accumulation rate of 0 Mt CO_2 for mixed and hardwood forests results in an estimated temperate forest sequestration rate of 27 Mt CO_2 per year in the state of Georgia. If we assume a slight accumulation of soil CO_2 in the forests of Georgia calculated as 10% of the rate of CO_2 sequestration in organic and top 0-15 cm of mineral soils for a South Carolina loblolly pine plantation (Richter et al. 1999) we have a rate of CO_2 storage in Georgia forests of 30 Mt CO_2 per year. Further state soil carbon analyses are underway (Carey et al. 2016, Crowther et al. 2016, Reinmann and Hutyra 2016, Machmuller et al. 2018). Protected forests in Georgia are already present and functioning as an important carbon sequestration solution (Edwards et al. 2013, Crowther

		et al. 2016, Machmuller et al. 2018, Carey et al. 2016). According to the U.S. Forest Service's Forest Inventory and Analysis (FIA) data, the forests in Georgia not managed for timber (GFC, 2019) averaged 19.4 Mt CO_2 per year of carbon storage in living biomass from years 2007-2017,[1] thus Forest Protection is a technically achievable carbon reduction solution.
Cost Competitiveness (4)	**Yes**	Almost 60% of the current State of Georgia is comprised of native and planted temperate forests, so little cost would be associated with maintaining these forests and this solution relative to other solutions. For planted pines with management, the cost of aboveground C storage is about \$3.5 per ton of CO_2 (Fuller and Dwivedi, unpublished data). About 43% of the current State of Georgia is comprised of forests not managed for timber so little cost would be associated with continued Forest Protection. The cost of carbon storage for unmanaged forests is essentially \$0 per ton CO_2 (Fuller and Dwivedi, unpublished data). As these protected forests are already present, many on public lands and private lands with conservation easements and require little to no management efforts so costs are low.
Beyond Carbon Attributes (5)	**Yes**	Temperate forest protection and forest management result in positive environmental impacts related to improved air quality from trees' natural ability to provide oxygen, as well as increasing wildlife habitats and biodiversity (Bonan, 2008). Estimates suggest that trees and forests removed 17.4 million tonnes (t) of U.S. air pollution in 2010 (Nowak, 2014). Increased air quality greatly improves public health of communities in the surrounding areas, which was valued at \$6.8 billion in annual health effects in 2010, avoiding over 850 deaths and 670,000 acute respiratory symptoms. As a result, this solution also has the potential to increase nearby property values. Forests offer improved water quality through soil protection, reduced water runoff and evapotranspiration (Trabucco, et al., 2008) and restored forests offer more resilience to pests/disease. Forests create jobs in the areas of forest protection and management, corresponding to the areas with the highest forest coverage[2], but temperate forests may also need to be legally protected against hunting and forest products thefts (Guariguata, et al., 2010). Another positive benefit is improved quality of life forests provide by offering recreational opportunities for people in the local community and/or tourists.[3] Since there is little to no cost for these recreational opportunities, this solution is highly accessible to low-income families. A potential barrier is that the temperate forest land use may restrict rural land available for farming/food, and could potentially lead to a reduction in timber-related jobs (Chazdon, 2008). This solution can also lead to increased potential for human/animal conflict.

Down-select Decision	**Yes**	Retain for further screening in the 2020-2030 timeframe.

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1. https://www.fia.fs.fed.us/
2. https://www.drawdown.org/solutions/land-use/temperate-forests
3. https://www.bls.gov/careeroutlook/2016/article/forestry-careers.htm
4. https://discovertheforest.org/partners

F Appendix F. Beyond Carbon

F.1 Beyond Carbon Solution List

Educating Girls
Family Planning
Women Smallholders

F.2 Down-Select Criteria for Drawdown Solutions:

The overall impact of the solutions “Educating Women and Girls”, “Family Planning”, and “Women Smallholders” in global Project Drawdown® are drawn from developing country contexts where very large-scale gaps in these areas and high fertility rates offer material opportunities for achieving carbon reduction objectives.

According to Project Drawdown®, “Advancing key areas of gender equity can reduce emissions—that is what defines the Women and Girls Sector. Access to education and voluntary family planning are basic human rights and should be secured simply because they are, yet significant gaps remain around the world today.” It is well-documented that access to education, increased educational attainment levels, and access to family planning education and resources are correlated with a lower number of children. Consequently, global Project Drawdown® classifies women’s access to education and family planning as drawdown solutions.

We note that – in contrast to developing countries – population growth in the United States seems to be slowing overall: two of three measures of fertility, the general fertility rate (GFR) and the total fertility rate (TFR), both point to the fact that fertility in the United States is at its lowest level in decades (Livingston 2019). According to Passel et al. (2012), black and brown communities account for over 90% of U.S. population growth from 2000 to 2010. Therefore, viewing choices about number of children through the lens of “carbon” impact can create a disproportionate and negative focus on families of color and reinforce a dynamic that problematizes reproductive decisions by women in general, and by women of color in particular. In addition, it must be recognized that communities of color face different realities when it comes to reproductive health. For example, pregnancy-related maternal deaths are three times larger for black women compared white women; and mortality for black infants is twice that of white infants (Taylor et al. 2019). Consequently, women and girls drawdown solutions may provide an opportunity to pivot to an equity-centered approach to develop solutions at the intersection of reproductive health and climate change.

The above-mentioned concerns notwithstanding, to parallel the Drawdown analysis, we carry out a Drawdown Georgia analysis of these solutions. We conclude that the carbon benefits would in any case not reach the 1MMT threshold for retention for further study. Also considering the key reservations noted above, we eliminate these solutions from consideration. Yet, there is much overall societal benefit generally, and environmental benefit specifically, to women and individuals from underserved populations fulfilling their highest educational aspirations, being more represented in STEM fields, and taking leadership at higher levels of government and industry. Therefore, we recommend that any U.S.-centric implementation of Drawdown be very intentional about representation, equity, and inclusion. In particular, to avoid paternalistic approaches/policies driven by the carbon lens and not by families and communities, we recommend developing new analyses that are informed, co-designed/co-created, and implemented by women who are most directly affected by climate change. It is often the case that the families/communities directly affected by issues related to climate change are not at decision making tables and, as a result, could be adversely impacted by policies aimed at addressing one problem (i.e. carbon) at the expense of reproductive health outcomes and overall human rights. Ensuring women who are directly affected are at the decision-making tables will be of paramount importance in designing and implementing Drawdown Georgia.

References:

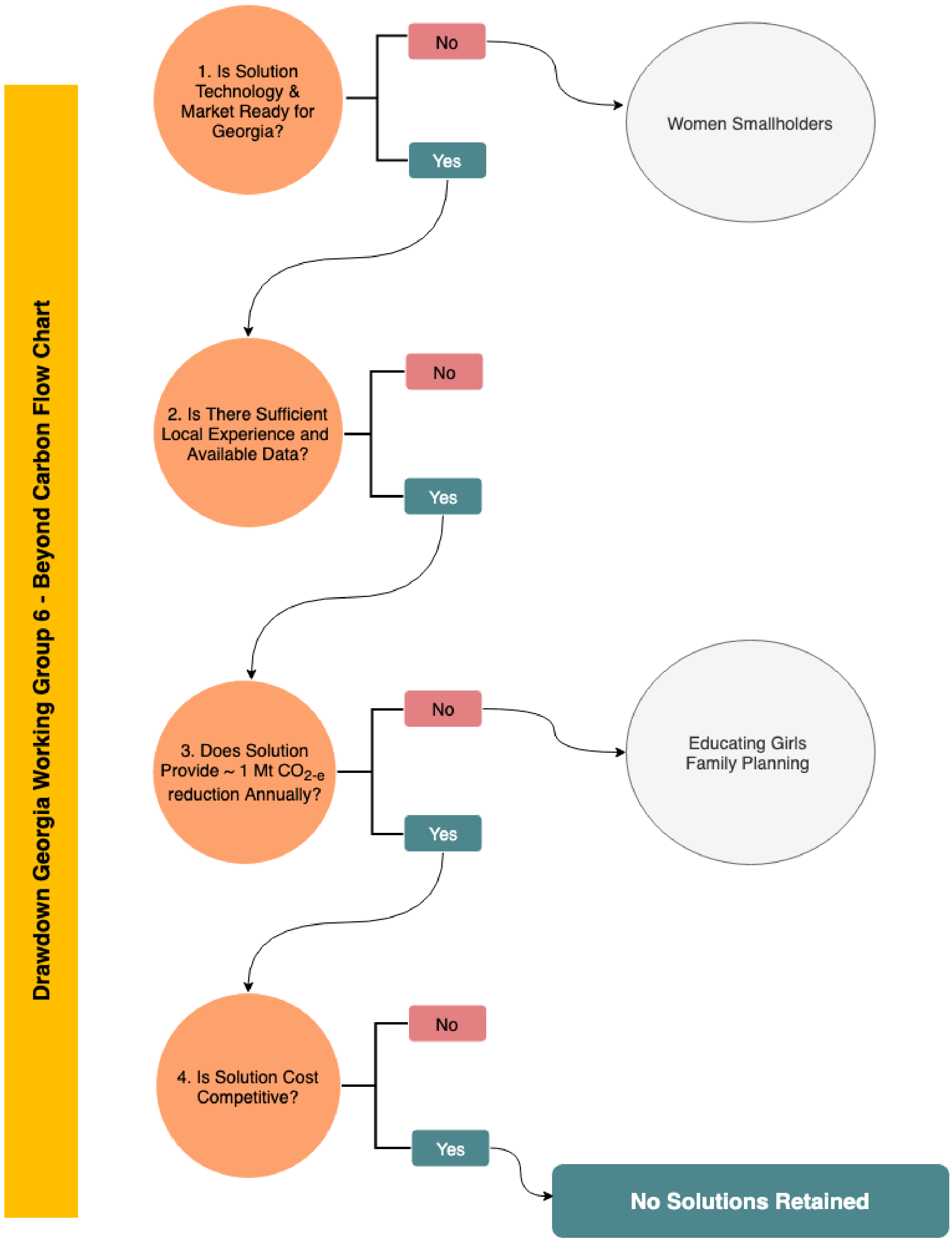
Gretchen Livingston, “U.S. fertility at an all-time low? Two of three measures point to yes,” May 22, 2019.

https://www.pewresearch.org/fact-tank/2019/05/22/u-s-fertility-rate-explained/

https://www.pewsocialtrends.org/2012/05/17/explaining-why-minority-births-now-outnumber-white-births/

Jamila Taylor, Cristina Novoa, Katie Hamm, and Shilpa Phadke, “Eliminating Racial Disparities in Maternal and Infant Mortality: A Comprehensive Policy Blueprint, May 2, 2019. https://www.americanprogress.org/issues/women/reports/2019/05/02/469186/eliminating-racial-disparities-maternal-infant-mortality/

Jeffrey S. Passel, Gretchen Livingston, and D’Vera Cohn, “Explaining Why Minority Births Now Outnumber White Births,” May 17, 2012.



Down-Select Steps to Identify High-Impact 2030 Solutions

F.3 Down-Select Results for Beyond Carbon

F.3.1 Educating Girls | Down-Select Scores

Providing equal quality of and access to education to girls/young women currently being denied access, leading to improved livelihoods, delayed onset of marriage, delayed childbearing, and fewer children than peers with less education.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	This solution in Project Drawdown® focused largely on the developing world where gaps in education for girls are much greater than developed country counterparts.[1] The elements of the solution are available in Georgia both in terms of enhancing educational parity (where gaps exist) and regarding linkages between girls' education and propensity to have fewer children (as the primary focus of the Project Drawdown® solution).
Local Experience & Data Availability (2)	**Yes**	Per Project Drawdown® and other studies/data internationally and locally, there is certainly a linkage between improving girls' education (by providing equal quality of and access to education to girls) and having fewer children (as noted in Project Drawdown®: "women with more years of education have fewer, healthier children and actively manage their reproductive health").[2] According to the enrollment records of Georgia Department of Education (March 2019)[3], the educational gaps between boys and girls in Georgia (and the United States) are quite limited in terms of school enrollment[4] (especially as compared to developing country indicators provided by Project Drawdown®); therefore, the impact of closing the gap in access to primary education is not as significant in Georgia as it is in some developing countries. There are nevertheless opportunities to address other gaps in education (such as girls/women in science, technology, engineering, arts, and mathematics – STEAM), though these are not likely to have a primary impact on having less children. However, they may offer other carbon-reducing opportunities as some research (Cordero, et al., 2020; not specific to Georgia or the SE) is available to show that targeted climate education can contribute to reduced individual carbon footprints. In addition, there is an opportunity to increase educational attainment levels in Georgia, which is shown to be correlated with the choice to have fewer children. Research based on the Carbon Disclosure Project (Ben-Amar, et al., 2017) also points to women in decision making roles at organizations who tend to make more sustainable choices than their male counterparts, which speaks to a major role for leadership opportunities for women.
Technically Achievable CO2	**No**	In terms of the Project Drawdown® variation of this solution and contribution to reducing population growth, Georgia's population growth is less than 1% annually with migration contributing a portion of this growth.[4]

Reduction Potential (3)		Under the family planning solution, we estimated an upper bound based on eliminating all unwanted births (through a combination of educating girls and access to family planning) in line with the definition at the publication of Guttmatcher Institute. The result was approximately 0.3 Mt CO_2 per year in total. Splitting this between the two solutions (as was done in Project Drawdown), this results in 0.15 Mt per year. This estimate is based on existing educational attainment levels. As noted above, increasing educational attainment will likely lead to fewer children, which will increase the carbon reduction potential relative to this benchmark.
Cost Competitiveness (4)	**N/A**	Difficult to quantify in terms of a carbon solution for Georgia.
Beyond Carbon Attributes (5)	**N/A**	Educating girls has innumerable beyond carbon benefits and we believe the gaps that exist in Georgia should be closed for a variety of reasons. We will be assessing some of the items listed here as key enabling tactics of other solutions.
Preliminary Downselect Decision	**No**	Considering the above data and concerns noted in the introduction, do not retain for further screening as a stand-alone carbon mitigation solution but consider how some of the education themes that are noted may advance other solutions or otherwise be advanced through Drawdown.

References:

Ben-Amar, Walid, Millicent Chang, and Philip McIlkenny. "Board Gender Diversity and Corporate Response to Sustainability Initiatives: Evidence from the Carbon Disclosure Project." Journal of Business Ethics 142.2 (2017): 369-83. Web.

Cordero EC, Centeno D, Todd AM (2020) The role of climate change education on individual lifetime carbon emissions. PLoS ONE 15(2): e0206266. https://doi.org/10.1371/journal.pone.0206266

Georgia Department of Education, Data Reports, Graduation Rates
https://www.gadoe.org/External-Affairs-and-Policy/Policy/Pages/Equity.aspx
https://www.gadoe.org/Pages/Home.aspx

Endnotes:

1. UNICEF Data, Gender and Education: https://data.unicef.org/topic/gender/gender-disparities-in-education/
2. https://drawdown.org/solutions/health-and-education
3. Georgia Department of Education, Enrollment by Ethnicity/Race and Gender: https://oraapp.doe.k12.ga.us/ows-bin/owa/fte_pack_ethnicsex_pub.entry_form
4. Georgia Governor's Office of Planning and Budget, Population Projections: https://opb.georgia.gov/census-data/population-projections

F.3.2 Family Planning | Down-Select Scores

Scaling-up voluntary family planning efforts, including access to contraception and reproductive health resources, especially in countries where the unmet need for contraception is high or current demand is low, can lead to the decline in total fertility rates.

Criteria		Comments
Technology and Market Readiness (1)	**Yes**	This solution in Project Drawdown® focused largely on the developing world where gaps in access to family planning are much greater and in locations with higher population growth than developed country counterparts such as the United States. Having said this, 45% of pregnancies in the United States are unintended, with the number even higher for Georgia (58% in 2010)[1]. The Georgia Department of Public Health's Family Planning program[2] refers to availability in all 18 health districts and 159 counties, offering health care services designed to provide women support with planning when to have children, reduce unintended pregnancies, determine effective birth control methods and improve the wellbeing of families. There is of course concern that more is needed and that current/emerging policies are curtailing access and/or quality of services.
Local Experience & Data Availability (2)	**Yes**	Despite the availability of the solution in the United States and its importance in relationship to health care needs, the literature reviewed under this assessment (Lopoo and Raissan, 2012 and Kearney, et al., 2015) has demonstrated different views on the effectiveness of specific/existing family planning interventions on birth rates in the United States, necessitating additional research.
Technically Achievable CO2 Reduction Potential (3)	**No**	In terms of the Project Drawdown® variation of this solution and contribution to reducing population growth, Georgia's population growth is less than 1% annually with migration contributing a portion of this growth[3]. Under the family planning solution, we estimated an upper bound based on eliminating all unwanted births (through a combination of educating girls and access to family planning) in line with the definition at the publication of Guttmatcher Institute. The result was approximately 0.3 MT per year in total. Splitting this between the two solutions (as was done in Project Drawdown®), this results in 0.15 MT CO_2 per year.
Cost Competitiveness (4)	**N/A**	Difficult to quantify in terms of a carbon solution for Georgia.
Beyond Carbon Attributes (5)	**N/A**	Affordable and available family planning services have important societal benefits in Georgia and therefore strong beyond carbon drivers.

Preliminary Downselect Decision	**No**	Considering the above data and concerns noted in the introduction, do not retain for further screening as a stand-alone solution but consider how education and related themes may advance other solutions or otherwise be advanced through Drawdown.

References:

Lopoo, L.M., Raissian, K.M., 2012. Policy retrospective: natalist policies in the United States. *Journal of Policy Analysis and Management* 31 (4), 905–946.

Melissa S. Kearney, Phillip B. Levine, Investigating recent trends in the U.S. teen birth rate, *Journal of Health Economics*, Volume 41, 2015, Pages 15-29, ISSN 0167-6296.

Endnotes:

1. Guttmatcher Institute, Unintended Pregnancy Rates as States Levels : https://www.guttmacher.org/report/unintended-pregnancy-rates-state-level-estimates-2010-and-trends-2002
2. Georgia Department of Public Health, Family Planning: https://dph.georgia.gov/georgia-family-planning
3. Georgia Governor’s Office of Planning and Budget, Population Projections: https://opb.georgia.gov/census-data/population-projections

F.3.3 Women Smallholders | Down-Select Scores

Providing resources, financing, and training to women smallholder farmers around the world, leading to improved agricultural yields and therefore reduced deforestation rates

Criteria		Comments
Technology and Market Readiness (1)	**No**	While U.S. Census of Agriculture Report (2017) shows that there are gender gaps in Georgia agriculture particularly among large-scale farm operations/ownership, the principal research provided by Project Drawdown® regarding the larger yields by women versus men has come under question and there is little research outside of developing economies with linkage to carbon mitigation. Doss (2018) highlights the challenges in distinguishing women's agricultural productivity from that of men.
Local Experience & Data Availability (2)	**No**	There has not been sufficient research of this topic to establish a strong connection broadly nor in the state of Georgia.
Technically Achievable CO2 Reduction Potential (3)	**No**	Due to lack of available evidence and the time it would take to achieve greater parity even with attention to this solution, we rate the carbon reduction potential by 2030 as fairly low.
Cost Competitiveness (4)	**N/A**	Difficult to quantify in terms of a carbon solution for Georgia.
Beyond Carbon Attributes (5)	**N/A**	Eliminating gender gaps in farming have important societal benefits in Georgia and therefore strong beyond carbon drivers.
Preliminary Downselect Decision	**No**	Do not retain for further screening in the 2020-2030 timeframe, but consider how gender/race/other parity themes may advance other solutions or otherwise be advanced through Drawdown.

References:

Doss, Cheryl R. "Women and Agricultural Productivity: Reframing the Issues." Development Policy Review 36.1 (2018): 35-50. Web.

https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/Georgia/

U.S. Department of Agriculture's National Agricultural Statistics Service (NASS), (2017). Census of Agriculture Report.