



# Florida Alternative Transportation Fuel Resilience Plan

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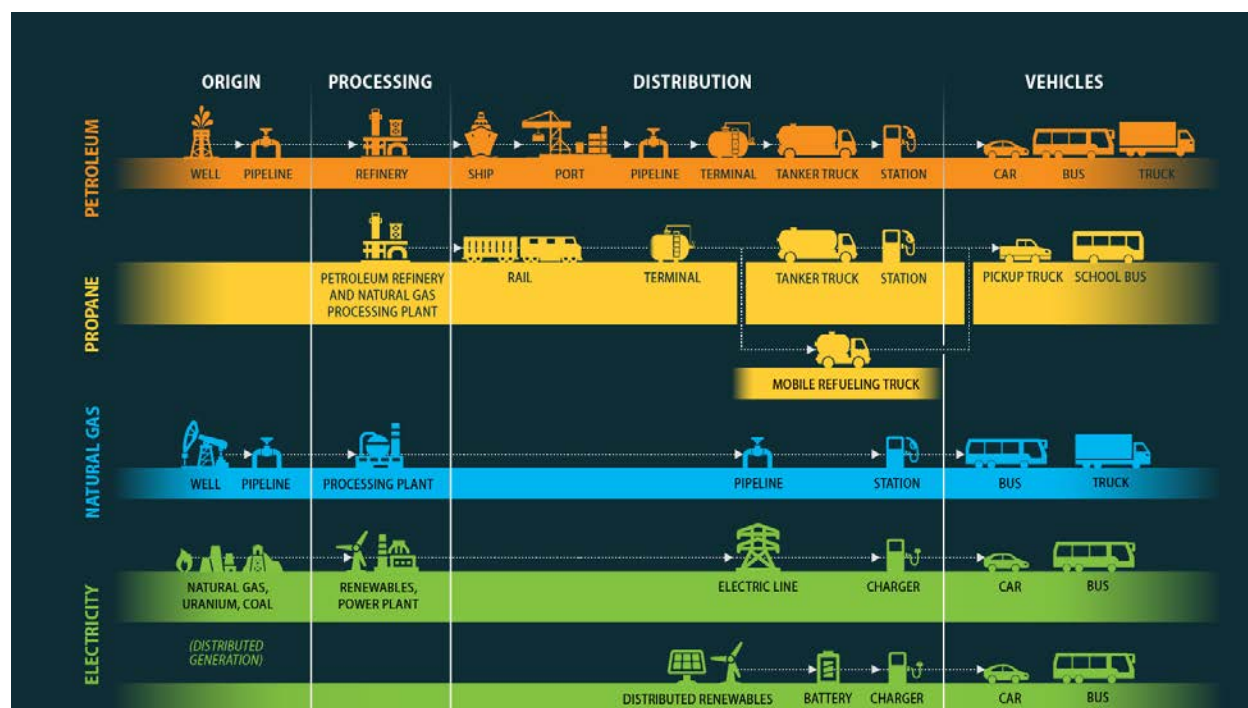
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## List of Acronyms

AFV	alternative fuel vehicle
BCT	Broward County Transit
BEB	battery-electric bus
BRT	bus rapid transit
CNG	compressed natural gas
CUTR	Center for Urban Transportation Research
DCFC	DC fast charger
DEMP	Diesel Emissions Mitigation Program
DOE	U.S. Department of Energy
EOC	emergency operations center
ESF-12	Emergency Support Function 12
EV	electric vehicle
EVI-Pro	Electric Vehicle Infrastructure – Projection
EVSE	electric vehicle supply equipment
FDACS	Florida Department of Agriculture and Consumer Services
FDEM	Florida Division of Emergency Management
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GIS	geographic information system
iREV	Initiative for Resiliency in Energy through Vehicles
JTA	Jacksonville Transportation Authority
L1	Level 1
L2	Level 2
LMTV	Light Medium Tactical Vehicle
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MCDA	multi-criteria decision analysis
MUSC	Medical University of South Carolina
NHTS	National Household Travel Survey
NREL	National Renewable Energy Laboratory
SAIDI	System Average Interruption Duration Index
VBFD	Virginia Beach Fire and Rescue Department

## Executive Summary

Many counties and cities in Florida are developing resilience plans to help them minimize damage from hurricanes and accelerate recovery.<sup>1</sup> An Achilles' heel of these plans is their dependence on diesel fuel, which is particularly vulnerable to hurricane-related disruptions because 90% of petroleum in Florida is imported via maritime tanker (EIA 2014). Fuel diversification can add to Florida's transportation resilience because if the supply of one fuel gets disrupted during a hurricane, there is a good chance that the supplies of other fuels are still available. As Figure ES-1 shows, the four main transportation fuels in Florida have different means of distribution. If one means of transport (e.g., marine port) is removed, then other means (e.g., pipeline, rail, cable) could then be relied upon to deliver transportation fuel. The *Florida Alternative Transportation Fuel Resilience Plan* aims to address these factors and create a strategy for how three alternative fuels (natural gas, propane, and electricity) can best be employed to improve transportation resilience in Florida. It does this through a combination of literature review and stakeholder engagement for best practices, vehicle technology recommendations, the creation of three tools (with descriptions and brief guides included), and charting how stakeholders coordinate to overcome these hurdles.



**Figure ES-1. Origin, processing, and distribution of four transportation fuels in Florida.**

Source: National Renewable Energy Laboratory

In Florida, various stakeholders share responsibility for emergency preparedness and resilience, and actions and decisions are made at multiple levels, including government, the private sector, and communities. These stakeholders receive direction from the State of Florida Comprehensive Emergency Management Plan (CEMP), which is administered by the Florida Division of

<sup>1</sup> County and city resilience resources and plans listed in the Florida Resilience Tool, <https://widgets-stage.tada-stage.nrel.gov/tada/fl-resiliency/>.



Emergency Management (FDEM). Stakeholders convened via webinar at the beginning of this project and revisited numerous times so their wide variety of perspectives could help inform the plan. Fleet partners helped develop a list of best practices for fleets, including vehicle recommendations, fueling prioritization strategies, redundancies in fuel supply networks, and fuel tanker logistics. Site visits also provided input that was incorporated into the plan. None of the visited alternative fuel fleets experienced interruptions in fuel supply to their alternative fuel vehicles (AFVs) during recent hurricanes (in the past ~7 years), even when diesel and gasoline supplies were interrupted due to port closures. Fleets increased the resilience of their natural gas and propane supplies by using mobile fueling units.

The supply chain of alternative fuels, as shown in Figure ES-1, is diverse in Florida. Natural gas comes via four interstate pipelines. Propane is a byproduct of both natural gas and petroleum processing facilities and is imported to the state via rail. Electricity in Florida is generated largely from natural gas (with fuel oil as backup), two nuclear power plants, coal, solar, and biofuels. Alternative fuels are then sold to vehicles through 28 electricity, 15 natural gas, 11 propane, 10 biofuel, and 3 hydrogen vendors.

Hurricanes can limit communication by knocking out cellphone towers and other communications infrastructure while simultaneously increasing the need for fleet and vehicle communications to facilitate evacuation and recovery operations. Surveyed fleets reported communicating via radio, cellphones, and landlines during disaster situations. However, some of the fleets that could be most beneficial during evacuation, such as propane school buses or natural gas-fueled power line repair vehicles, are prioritized below first responders and might not have access to their radio channels. Electric vehicle supply equipment (EVSE) normally communicates with drivers through its network and mobile applications. EVSE is built to withstand 18 inches of standing water (per the National Electrical Code), but if this threshold is surpassed and the hardware is damaged, it cannot be brought back online until a technician physically inspects it. ChargePoint (the largest EVSE network company in Florida) has mobile fast chargers on skids/trucks with 4 feet of clearance that can be moved to strategic locations and connected quickly to the grid.

To facilitate the use of alternative fuels before and during a hurricane, the National Renewable Energy Laboratory (NREL) developed a Florida Resiliency Tool website to help facilitate planning and communications. Available at <https://widgets-stage.tada-stage.nrel.gov/tada/fl-resiliency/>, this website uses state-of-the-art technologies to provide useful maps, information, connections, and other resources. A second tool developed as part of this plan is an electric vehicle evacuation planning prototype web tool to prepare the state for using electric vehicles (EVs) before and during an emergency event. This tool, developed by the University of South Florida (USF), uses a novel algorithm to coordinate reservations for EVs to charge along evacuation routes.

Resilience should be considered when planning and building out the nascent EVSE network in Florida. Therefore, NREL projected the number of EVs in each Florida county in 2030 and 2050 and used the Electric Vehicle Infrastructure – Projection (EVI-Pro) tool to estimate how much public EVSE will be needed to charge those vehicles. Florida is estimated to have 74,000 EVs in 2030, with 17% of them being plug-in hybrid EVs and 83% battery-electric vehicles. These EVs will need 45,485 nonresidential EVSE chargers by 2030. To be specific, 54% are workplace

Level 2 chargers, 34% are public Level 2 chargers, and 12% are fast chargers. By 2030, Broward County will have the most significant need for EVSE, whereas Lafayette County will require the least EVSE.

NREL also developed a geographic information system (GIS) model for two purposes: (1) to identify potential locations for new AFV stations to increase the connectivity of the road network for AFVs evacuating or performing emergency response duties, and (2) to address future needs for EVSE by comparing counts of current EVSE ports against future EVSE needs forecast by EVI-Pro. This analysis considered flood zones, emergency shelters, evacuation routes, AFV refueling infrastructure, garage locations of AFV fleets, and the EV and EVSE projections from EVI-Pro. After removing stations that are at risk of flooding, the percentage of evacuation routes covered by each AFV service area averaged 87.6%. However, after integrating proposed new stations at emergency shelters, the coverage increased to an average of 99.0%. The tool was also used to track progress toward meeting the required number of DC fast-charging ports in 2030. Several of the more populated counties need more than 200 stations to meet their goals, and other counties were already at or near their 2030 targets. The GIS-based Alternative Fuel Resilience tool was made available to planners and analysts at <https://nrel.maps.arcgis.com/apps/mapviewer/index.html?webmap=70d980d59f39453387d8286fcb505ae1>, and a case study was developed for instruction using the tool. Finally, the methodologies and findings of this analysis were compared to relevant portions of the *Florida Electric Vehicle Roadmap* (Burk et al. 2020) and the *EV Infrastructure Master Plan* (FDOT 2021).

This plan must interact with other aspects of resilience planning in Florida, so relevant laws, regulations, and organizations were described. The state's 10 regional planning councils and the Florida Division of Emergency Management were identified as particularly important to work with.

A vehicle's ability to drive through standing water can be crucial during a hurricane, so NREL and USF conducted a literature review and held multiple interviews on this topic. Fleet managers should try to purchase vehicles with high air intake or modify the air intake system to raise the height. Fleet managers must ensure that electrical components are water-resistant or move them to higher locations on the vehicle. It is also important to remotely mount vent tubes to the transmission and differential at the highest points possible. Vehicle buoyancy is a key consideration, and liftoff occurs later (deeper) in vehicles with higher clearance, greater mass, smaller footprint, and better tire traction. Vehicles powered by propane or natural gas have completely sealed fuel systems, reducing the likelihood of water infiltration. EVs do not need oxygen to operate, and key components are often waterproofed (Evarts 2018). This has enabled the EV company Rivian to claim in the specifications of their R1S and R1T that these vehicles can drive through 43 inches of standing water.<sup>2</sup> Likewise, DD DANNAR claims that its electric off-road work vehicles can operate in up to 4 feet of water.<sup>3</sup> However, 11 EVs from other manufacturers auto-ignited after Hurricane Ian (Weise 2022), accelerating research into the impact that extended periods of saltwater submersion has on EVs.

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<sup>2</sup> <https://rivian.com/support/article/what-is-the-water-fording-height>

<sup>3</sup> <https://www.dannar.us.com/>



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# 1 Introduction

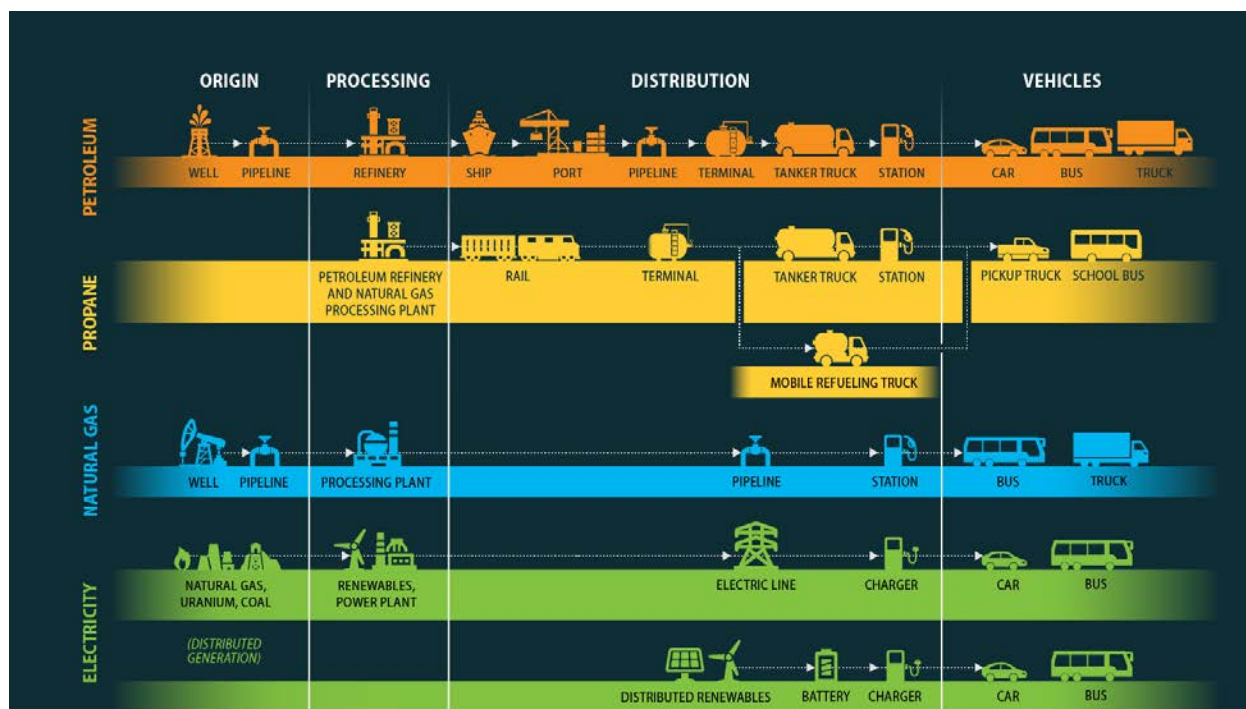
Hurricanes are increasing in frequency, intensity, and duration and are projected to continue increasing (Knutson 2022; Kossin 2018). Many counties and cities in Florida are developing resilience plans to help them minimize damage from hurricanes and accelerate recovery.<sup>4</sup> The transportation portions of these plans tend to focus on bolstering road infrastructure, stockpiling diesel for strategic fleets, purchasing high-water vehicles, and placing evacuation shelters in safe areas. An Achilles' heel of these plans is their dependence on diesel fuel, which is particularly vulnerable to hurricane-related disruptions because 90% of petroleum in Florida needs to be imported via maritime tanker (EIA 2014). These tankers are restricted from accessing Florida ports before and during hurricanes because the risks of damage to the port facilities and tanker are too high. Therefore, transportation resilience can be fortified by diversifying the transportation fuels utilized in a hurricane.

Fuel diversification can add to the transportation resilience of Florida because if the supply of one fuel gets disrupted during a hurricane, there is a good chance that the supplies of other fuels have not. As Figure 1 shows, the four main transportation fuels in Florida have very different means of distribution, and if one means (e.g., marine port) is removed, then other means (e.g., pipeline, rail, cable) could then be relied upon to deliver transportation fuel.

Fuel diversification is complicated by a few factors. First, there must be vehicles available that can use an alternative fuel, be useful for hurricane evacuation or recovery purposes, and also be useful outside of hurricane operations. These vehicles are discussed in Section 4. Second, alternative fuels have fewer and less standardized refueling stations, so fleets must be able to communicate with the stations to know their operating status and compatibility with their vehicles (Section 5), and new stations need to be added strategically (Sections 6 and 7). Third, alternative fuel vehicles (AFVs) and conventional vehicles need to be assessed for their capabilities in driving through standing water, which would likely be required during hurricane recovery operations (Section 9). The *Florida Alternative Transportation Fuel Resilience Plan* aims to address these factors and create a plan for how alternative fuels can best be used to improve transportation resilience in Florida. It does this through a combination of literature review and stakeholder engagement for best practices, vehicle technology recommendations, the creation of three tools (with descriptions and brief guides included), and charting how stakeholders coordinate to best overcome these hurdles.

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<sup>4</sup> County and city resilience resources and plans listed in the Florida Resilience Tool, <https://widgets-stage.tada-stage.nrel.gov/tada/fl-resiliency/>.



**Figure 1. Origin, processing, and distribution of four transportation fuels in Florida.**

Source: National Renewable Energy Laboratory

This plan follows a framework used for numerous supplies during natural disasters, including water, food, and medical supplies. The first step is to add redundancy to the supply. This is done through fuel diversification, as mentioned previously and discussed throughout the majority of this report. The second step is to have adequate storage. State and local resilience plans address this for petroleum used by essential fleets, and this plan addresses this for alternative fuels. The third step is to ensure access to supplies. This plan does this for alternative fuels through a geographic information system (GIS) analysis that estimates which fueling locations are likely to remain accessible and by setting up a communication system so alternative fuel fleets can ensure that a station can accommodate them during a hurricane. It goes further for electric vehicles (EVs), where a reservation system and coordinating algorithms is proposed to coordinate the charging of numerous evacuating EVs. The fourth step is to resupply as quickly as possible; the plan discusses the rates at which various fuels are likely to be resupplied after a hurricane. The fifth step is to improve the efficiency with which a given amount of fuel is used, so that a maximum amount of transportation services might be rendered per a given amount of fuel. The plan discusses the relative efficiency of evacuation and emergency vehicles and compares efficiency between fuels.



## 2 Background

State departments of transportation have a long history of supporting transportation resilience, but they are mainly focused on infrastructure rather than fuel supplies.<sup>5</sup> Likewise, local resilience planning agencies have a history of focusing on transportation infrastructure and storing diesel reserves for strategic yet conventional vehicles. The U.S. Department of Energy (DOE) assessed the resilience of various fuels in their seminal 2014 three-part report *United States Fuel Resilience: U.S. Fuels Supply Infrastructure* (DOE 2014). These reports set a useful definition of resilience as “the ability to withstand small to moderate disturbances without loss of service, to maintain minimum service during severe disturbances, and to quickly return to normal service after a disturbance.” This is the definition that we use in this plan. The DOE report highlighted numerous chokepoints in the petroleum supply, transportation, storage, and distribution infrastructure and the relative resilience of the natural gas and propane infrastructure. In doing so, they discussed the relative fragility of the electric grid (largely due to lack of storage capacity), but their focus was on the interactions between the electric grid and the supply of other fuels rather than electricity as an end-use fuel. For example, electricity is needed to pump diesel out of underground storage tanks or to compress natural gas. In general, the focus of the 2014 report was upstream of the fuel dispensers and vehicles.

The first initiative to assess and utilize alternative fuels to improve transportation resilience was the Initiative for Resiliency in Energy through Vehicles (iREV) program. This was a joint project with DOE’s Clean Cities program and the National Association of State Energy Officials (NASEO). iREV began by documenting the role of natural gas minibuses helping New Jersey recover from Hurricane Sandy when diesel was in short supply.<sup>6</sup> Throughout 2015 and 2016, iREV published a series of case studies of using alternative fuels in emergency response vehicles.<sup>7</sup> In 2017, a GIS-based iREV-Tracking tool was created to help coordinate alternative fuel stations and national-level critical infrastructure when planning for emergencies.<sup>8</sup>

In addition to iREV case studies, the utilization of alternative fuels during natural disasters has also been documented. During Japan’s 2011 tsunami, oil refineries were destroyed but electricity was still available in some areas. Therefore, EVs were an asset in transporting small items like medicines and transporting doctors and building inspectors so that buildings could be safely reopened (Belson 2011). This event inspired Nissan’s “Leaf to Home” power exporter. Wildfires in California proved another value for EVs when the Pacific Gas and Electric Company began using their Class 5 plug-in hybrid electric vehicle utility trucks with exportable power modules to provide power to evacuation shelters (Morris 2015). Compressed natural gas (CNG) was documented fueling buses in the face of diesel shortages during Hurricane Sandy (Atlantic City<sup>9</sup>) and Hurricane Harvey (Houston<sup>10</sup>). Propane-fueled school buses transported medical personnel to hospitals during Hurricane Sandy (New York) and evacuated residents of Tampa during

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<sup>5</sup> As reflected by the agendas of the Transportation Research Board’s Transportation Resilience Innovations Summit and Exchange annual meetings, [www.trb.org](http://www.trb.org).

<sup>6</sup> <https://www.naseo.org/irev>

<sup>7</sup> <https://www.naseo.org/irev>

<sup>8</sup> <https://irev.ctc.com/Account/Login>

<sup>9</sup> <https://afdc.energy.gov/case/1323>

<sup>10</sup> <https://afdc.energy.gov/case/3078>

Hurricane Irma (Thompson 2017). These disasters were the proving grounds for the potential of alternative fuels during natural disasters.

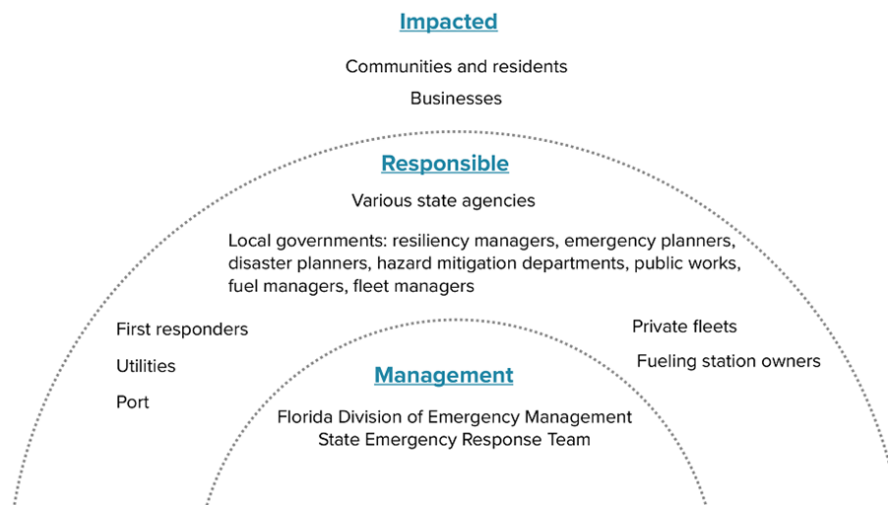
Of the three alternative fuels utilized by this resilience plan, electric vehicle stock is projected to grow the most (EIA 2021). Therefore, Florida has published two documents outlining the state's strategy for building out infrastructure. These are the *Florida Electric Vehicle Roadmap* (Burk et al. 2020) and *EV Infrastructure Master Plan* (Florida Department of Transportation [FDOT], 2021). Both of these plans focus on electric vehicle supply equipment (EVSE) needs during nonemergency times, briefly addressing hurricane evacuation routes. Comparisons between these EV infrastructure development plans and this plan are included in our GIS analysis in Section 7.

### 3 Stakeholders and Involvement

The researchers integrated input from a wide variety of stakeholders from various geographic areas of the state representing organizations that are involved in resilience planning or providing critical transportation functions during emergencies. Over 240 stakeholders were identified for this study from which to potentially seek input, including representatives from airports, ports, local governments, county school districts, conventional and alternative fuel suppliers, transit agencies, local and regional planning agencies, state agencies, vehicle manufacturers, and utilities, as well as universities, research institutions, Clean Cities coalitions, advocacy groups, and other stakeholders.

#### Fuel Resilience Stakeholders

Responsibility for emergency preparedness, response, and resilience is shared among various stakeholders, and actions and decisions are made at multiple levels, including government, private sector, and communities. See Figure 2 for responsible stakeholders, which include emergency managers, planners, and public agencies responsible for decision-making during emergency conditions. To plan and implement fuel resilience strategies, there is a need for cross-collaboration among both public and private entities and to engage both responsible and impacted stakeholders. Fuel resilience involves stakeholders across jurisdictions and requires intergovernmental coordination, collaboration, and planning given that vulnerabilities are embedded across stakeholder groups and government jurisdictions.



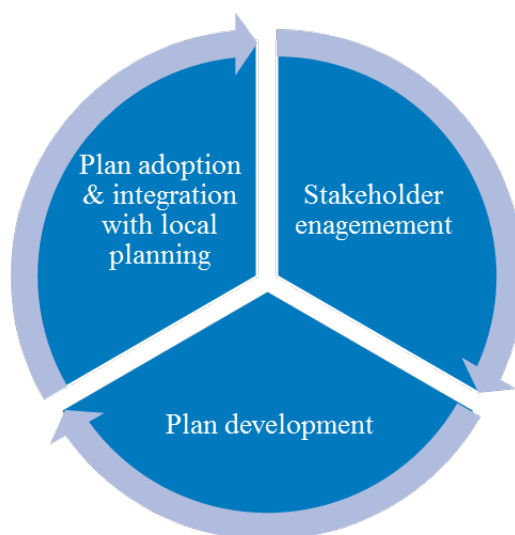
**Figure 2. Categories of fuel resilience stakeholders**

In the state of Florida, emergency response is dictated by the State of Florida Comprehensive Emergency Management Plan (CEMP), which is administered by the Florida Division of Emergency Management (FDEM). The plan provides a unified framework for all levels of government within the state to respond to emergencies that is in accordance with federal guidelines (FDEM 2020). It contains strategies, objectives, and means of mobilizing resources and guidance for local governments to coordinate all stages of emergency management, including emergency preparedness, response, recovery, and mitigation.

Within the State of Florida Comprehensive Emergency Management Plan, the state has designated the Emergency Support Function 12 (ESF-12) as the function responsible for ensuring that policies and procedures that are used by the Public Service Commission, and others engaged in responding to and recovering from power disruptions. Recently, Florida has split the roles of ESF 12, creating ESF 19 – Fuels to assist with all transportation fuel and propane response in the state. ESF 19 is housed at FDEM in the Infrastructure Branch, and FDEM is the primary agency tasked with coordinating with fuel suppliers to ensure adequate supplies of fuel are available. Response actions are coordinated and communicated with the public and governmental agencies with support from additional agencies and organizations, such as the Florida Department of Agriculture and Consumer Services, Florida Department of Environmental Protection, Florida Department of Health, Florida Department of Transportation, Florida National Guard, Florida Petroleum Council, American Petroleum Institute, Florida Trucking Association, Florida Petroleum Marketers Association, and Florida Propane Gas Association, as well as various industry trade groups and associations. ESF-12 is responsible for coordinating agencies and organizations with identifying response and recovery needs, maintaining communications with fuel and energy providers, supporting the State Emergency Response Team and local emergency operations centers to determine emergency fuel needs, aiding local government agencies with identifying fuel providers, and maintaining communications with electric utilities and support agencies responsible for recovery and response of electric generating capacities and outages (FDEM 2020).

## Stakeholder Kickoff Meeting

A stakeholder webinar—held in September 2020 by the Florida Energy Office in partnership with the Tampa Bay Clean Cities Coalition, University of South Florida, National Renewable Energy Laboratory (NREL), and Florida Solar Energy Center—informed stakeholders on the state resilience initiative work plan and solicited stakeholder input. The goal of the workshop was to gain insight from stakeholders to inform the development of the Alternative Transportation Fuel Resilience Plan following the implementation model (see Figure 3).



**Figure 3. Alternative Transportation Fuel Resilience Plan design and implementation model**

Over 80 people attended the stakeholder workshop, representing local governments, state governments, EVSE suppliers, airports/ports, nonprofit organizations, utilities, and other organizations. A poll of the attendees revealed that the majority of participating fleets have emergency fueling plans for hurricanes and other emergency events. The majority of participants indicated that their fleets play a critical role for transporting people and/or goods before, during, and after hurricanes, while a few others can also use their vehicles for critical roles if needed. Participants noted that a lack of fueling infrastructure and costs of AFVs and infrastructure remain the biggest obstacles for using alternative fuels. Following the stakeholder webinar, the Florida Solar Energy Center published a “Resilient Florida Buildings” brochure (FSEC 2021).

## Fuel Resilience Best Practices for Fleets

In addition to the workshop, researchers also reached out to individual fleets to seek input regarding best practices in resilience initiatives. Finally, some of the preliminary findings from the Tampa Resilience study (Kolpakov et al. 2021) also informed the development of this plan. Lessons learned from previous hurricane events in Florida include:

- Asset staging prior to hurricane landfall is a key step for public fleets to preserve critical transportation assets by moving them from low-lying areas to higher elevations.
- Navigating flooded streets and performing recovery operations after a hurricane may require high-water-capable vehicles. The capability of the vehicle to operate in standing

water conditions is typically determined by the vehicle clearance and the position of air intake at the highest possible point aboveground.

- Off-road equipment (e.g., loaders, dump trucks, claw trucks) is often required to remove debris from roadways after a hurricane to restore critical transportation functions.
- Fuel strategy is critical to fleet preparation during an emergency event. Critical public fleets are encouraged to maintain adequate fuel storage on-site (underground or aboveground) that can sustain fleet operation for at least a week in case of fuel shortage. Fueling prioritization strategies can be implemented to determine which vehicles fuel first during a shortage.
- Accurately predicting fuel burn rate under emergency conditions is challenging but an essential calculation for estimating fuel supply needs, particularly for public agencies responsible for fueling generators. It is not uncommon for fleets to consume 2–3 times more fuel under emergency conditions than during normal operations.
- Fuel diversification is an important resilience strategy, which may include diversifying fuel supply channels (e.g., receiving fuel from different geographic areas, by different delivery methods) and diversifying types of fuel used (e.g., use AFVs, flex-fuel vehicles, and solar-powered EV charging stations).
- It is necessary to plan for redundancies in fuel supply networks to ensure the resilience of fuel supply.
- Investing in backup electricity generators, including generators powered by alternative fuels, is a wise strategy for fleets and facilities responsible for providing critical services before, during, or after natural disasters.
- Sharing fuel resources between critical public fleets is a resilience strategy already employed through the use of formal and informal agreements between local governments. This practice can also be expanded to include better collaboration between public and private fleets.
- Police escorts for fuel tankers may be needed to ensure timely delivery on congested roads impacted by evacuation efforts.
- Electricity outages can contribute to fuel shortages caused by the disruption of fuel supply channels resulting from natural disasters. Even if fuel is available, electricity is often required to dispense it. Therefore, quick restoration of power to fueling sites after a hurricane is crucial for ensuring that critical services will be provided.

A variety of different vehicles can be used for emergency response and recovery operations. Transit vehicles (including large and small buses) and school buses are often used for evacuating people and/or transporting work crews to impacted sites. Despite relatively high clearance, transit and school buses do have limitations regarding the level of standing water in which they can safely operate. Usually, the safe water level for a transit or school bus is just a few inches (5–8 inches of water). Operating in higher water levels can be harmful for the bus undercarriage components, including the rear differential, air brake system, and many grease-lubricated parts that can be damaged if submerged in water. See section 9 for more details. Both transit and school buses can be powered by various alternative fuels, including propane, CNG, and electricity.

Fleets can employ high-water-capable tactical vehicles (often former military vehicles), including Humvees and 5-ton trucks with high clearance, to transport equipment and personnel

during flooding events. Such vehicles are rarely designed to run on alternative fuels but can be converted to run on propane or CNG.

Finally, there is a variety of off-road equipment that can be used for recovery operation and can withstand high-water conditions, at least for some time. While most off-road equipment brands/models are currently powered by conventional petroleum fuels, some of those vehicles can operate on alternative fuels. For example, available models/brands currently on the market include battery-electric mobile power stations that can use changeable attachments for performing various tasks, have high clearance, are rated to operate in 3–4 feet of standing water, and can be operated by a remote control from a significant distance. The ability to withstand standing water and remote-control capability provide great potential for using such vehicles for recovery operations after hurricanes/floods without placing the operator in danger.

The capability of such vehicles to remain operational while being submerged in standing water for a prolonged period of time is questionable. Furthermore, saltwater presents additional challenges since it is significantly more corrosive than fresh water. Even completely sealed vehicle components can get damaged by being submerged in salt water for a prolonged period of time, so even high-water-capable vehicles may need evaluation and repairs after encountering salt water.

## Site Visits

This plan incorporates best practices and lessons learned from site visits to five alternative fuel fleets throughout Florida, including both public and private fleets. The site visits that informed the development of the current plan include the following fleets: WastePro (Samford), Seminole County Schools (Winter Springs), City Furniture (Tamarac), Broward County Transit (Plantation), and Jacksonville Transportation Authority (Jacksonville). Reviewed technologies included CNG, propane, and battery-electric.

Despite differences in visited fleets and types of reviewed alternative fuel technologies, some similarities in resilience practices were noted. The common takeaways from these site visits included:

- None of the visited alternative fuel fleets experienced interruptions in fuel supply to their AFVs (natural gas, propane, or EVs) during recent hurricanes (in the past ~7 years). Even when diesel and gasoline supply were interrupted due to port closures during past hurricanes, alternative fuel remained available to the reviewed fleets.
- None of the visited fleets encountered standing water conditions during previous hurricane events. At the same time, some of the vehicles in the visited properties are capable of handling high standing water (e.g., refuse trucks).
- Fleets that use CNG and propane have access to mobile fueling systems that can be used to deliver fuel in case of interruptions during natural disasters. This includes both their own mobile fueling vehicles and vehicles owned by fuel suppliers.
- Most visited fleets rely on diesel-powered generators to provide emergency power in case of power outages. Fleets typically maintain adequate supply of diesel for diesel-powered generators. Few fleets also employ alternative fuel-powered generators to provide backup power (e.g., CNG).



- Several visited fleets (both public and private) received and accommodated requests in the past to share fuel with other essential fleets (mainly government fleets) in the aftermath of hurricanes. Such requests were typically coordinated through the emergency operations center (EOC).
- During the times of fuel shortage, such as during or after a hurricane, it is common practice for fleets to ration fuel depending on the routes and ranges required for vehicles to perform essential tasks.
- Fueling all vehicles (including AFVs) prior to a hurricane is a common strategy used by fleets to prepare for the upcoming impact.
- Several visited fleets experienced severe accidents involving AFVs (including rollover accidents and vehicle fire), none of which caused fuel tank rupture, demonstrating the safety of AFVs.

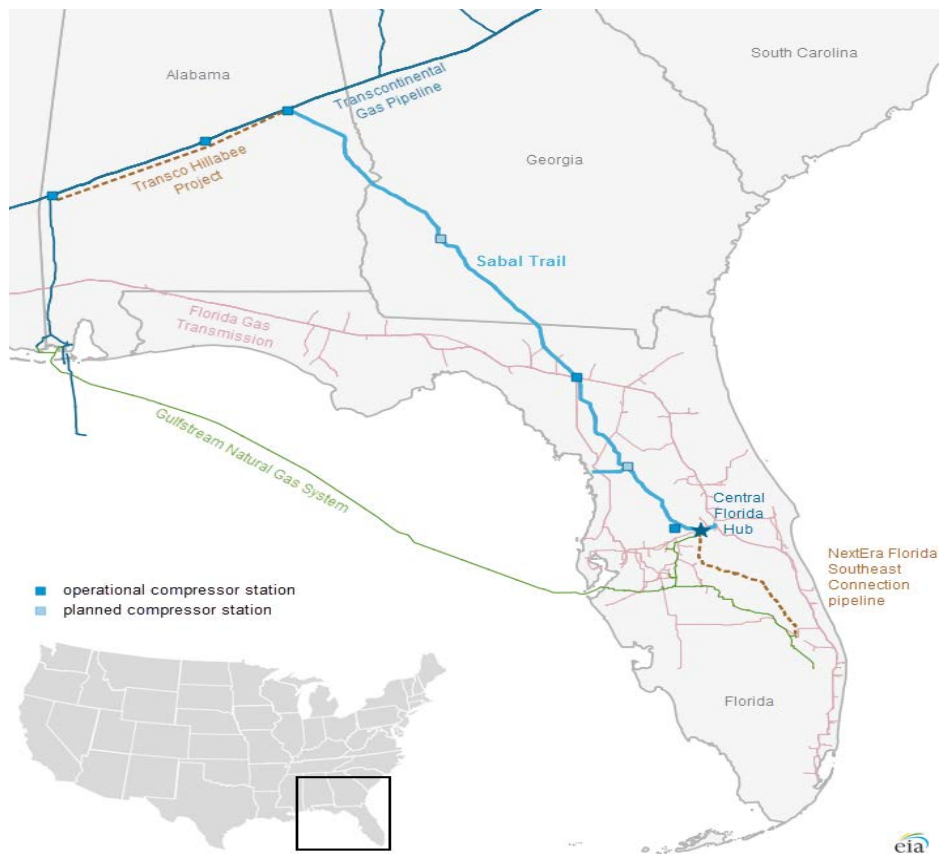
Summaries of all the site visits are provided in Appendix B.

## 4 Supply Chain of Natural Gas, Propane, and Electricity in Florida

The diversity of supply chains for alternative fuels is a large part of why they add to the resilience of transportation systems in Florida. This section assesses the upstream supply chains of alternative fuels and lists vendors of alternative fuels to enable fleets and refueling stations to access the fuels.

### Upstream Sources of Alternative Fuels

This subsection tracks the source and upstream pathways of alternative fuels in Florida in order to assessing their resilience. Florida receives its natural gas supplies from four interstate pipelines, as shown in Figure 4 and described below:



**Figure 4. Florida's Four Interstate Natural Gas Pipelines**

Source: EIA

- The Florida Gas Transmission line runs from Texas through the Florida Panhandle to Miami;
- The Gulfstream Gas System is an underwater pipeline running under the Gulf of Mexico from Mississippi and Alabama to Central Florida;
- The Sabal Trail pipeline runs from Alabama to Orange County; and
- The Cypress Pipeline supplies liquefied natural gas to the Jacksonville area from Elba Island, Georgia.

Propane stocks are abundant nationally, with nearly 78 million barrels of supply available as of September 9, 2022 (EIA 2022). As a byproduct of domestic natural gas processing and petroleum refining, they come from similar locations as natural gas and petroleum. However, they are generally delivered via rail to Florida instead of pipeline. Florida belongs to the Petroleum Administration for Defense Districts (PADD) Subdistrict 1C, which includes the Lower Atlantic States. The PADD is the Federal classification used for organizing the allocation of fuels derived from petroleum products.

Florida is one of the largest generators of electricity in the nation, second only to Texas. Florida's primary fuel source (fueling  $\frac{3}{4}$  of all electricity) is natural gas, but  $\frac{2}{3}$  of these power plants can use fuel oil as a backup fuel source. The remaining  $\frac{1}{4}$  of Florida's electricity is fueled by a diverse set of two nuclear power plants, coal-fired power plants, solar and biofuels, listed from largest to smallest contributors (EIA 2021).

## Alternative Fuel Vendors

All Clean Cities coalitions in the state of Florida, including Tampa Bay Clean Cities, Southeast Florida Clean Cities, Central Florida Clean Cities, and North Florida Clean Fuels, collaborated to compile a list of alternative fuel vendors in Florida. Identified organizations include vendors of various alternative fuels (CNG, propane, ethanol, biodiesel), utilities, infrastructure providers, stationary and mobile generator suppliers, and other types of organizations that may be useful for providing redundancy in service during emergency events.

Table 1 provides an inventory of 62 alternative fuel vendors. These include 28 electricity, 15 natural gas, 11 propane, 10 biofuel, and 3 hydrogen vendors (some vendors offer more than one fuel). While most listed vendors are headquartered in Florida, some are not. Instead, they have a presence in Florida or provide their products/services in the state.

**Table 1. Alternative Fuel Vendors in the State of Florida**

Organization Name	Fuel/Infrastructure Type	Location
All in One Propane	Propane	Leesburg, FL
American Homegrown Fuel Corporation	Hydrogen, biofuels	
American Natural Gas	CNG	
Amerigas	Propane	Jacksonville, FL
AmeriGas Propane	Propane	Tampa, FL
ampCNG	Natural gas	Chicago, IL
Be-Ev.Com	EVSE infrastructure	
BioDiesel Las Americas (BDLA)	Biodiesel production	Miami, FL
Blink	EVSE infrastructure	Miami, FL
Blossman Gas	Propane	Jacksonville, FL
Brickell Energy	EVSE infrastructure	Miami, FL
ChargePoint, Inc.	EVSE infrastructure	
City of Orlando	Electric	Orlando, FL
Clean Energy CNG Station Orlando Airport	CNG	Orlando, FL
Clean Energy Fuels	Natural gas	Dallas, TX
Clearwater Gas System	Natural gas	Clearwater, FL
Commercial Aviation AF Initiative (CAAFI)	Aviation fuel	
Dannar	Offroad EV/mobile power station	Muncie, IN
Duke Energy	Electric	Charlotte, NC
Efacec USA	EVSE infrastructure	
Endera	EVSE infrastructure	

<b>Organization Name</b>	<b>Fuel/Infrastructure Type</b>	<b>Location</b>
Ferrell Gas - Pinellas Park Service Center	Propane	Pinellas Park, FL
Fleetwing Corporation	Biodiesel, ethanol	Lakeland, FL
Florida City Gas	CNG	Doral, FL
Florida Power & Light Company	Electric	Juno Beach, FL
Florida Public Utilities	Natural gas, propane, electric	West Palm Beach, FL
Florida Public Utilities	Electric, CNG	Fernandina Beach, FL
GAIN Clean Fuel	CNG	Kissimmee, FL
Gate Petroleum	Ethanol, CNG, electric	Jacksonville, FL
Glover Oil	Biodiesel 20	Melbourne, FL
GoSpace	EVSE infrastructure	
Heritage Propane	Propane	Tampa, FL
Jacksonville Transportation Authority	CNG	Jacksonville, FL
JEA	Electric	Jacksonville, FL
NASA/KSC	Electric/B20/E85/hydrogen	Kennedy Space Center, FL
Nopetro	Natural gas	Coral Gables, FL
NoPetro CNG (LYNX)	CNG	Orlando, FL
Northside Propane Inc.	Propane	Lutz, FL
NovaCharge	EVSE infrastructure	Oldsmar, FL
OBE Power Networks	EVSE infrastructure	Miami, FL
Orlando Utilities Commission	Electric	Orlando, FL
Palatka Gas	CNG	
Pioneer Critical Power	Generators/mobile	Miami, FL
Pioneer Power Mobility	Mobile EVSE/propane	Champlin, MN
Pivotal LNG	Liquefied natural gas (LNG)	
Port Canaveral	Electric/LNG	Cape Canaveral, FL
Protec Fuel Management LLC	Ethanol	Boca Raton, FL
Rack Electric	EVSE infrastructure	Boca Raton, FL
Ross Plumbing	CNG	Leesburg, FL
St. Johns County	CNG	
Suburban Propane	Propane	Tampa, FL
Superior Energy Systems	Propane infrastructure	Columbia Station, OH
Targray	Biodiesel, ethanol	Kirkland, Quebec
TECO Energy	Electric	Tampa, FL
TECO Peoples Gas	CNG	Tampa, FL
Tesla	Electric	Palo Alto, CA

Organization Name	Fuel/Infrastructure Type	Location
Thorntons Inc.	Ethanol	Louisville, KY
TruStar Energy	Natural gas	Rancho Cucamonga, CA
University of Central Florida	Electric/propane	Orlando, FL
VISTRA	Electric, natural gas	Tampa, FL
Waste Pro	CNG	Bunnell, FL
Withlacoochee Electric Cooperative	Electric	Dade City, FL

Appendix C provides a more detailed list of alternative fuel vendors that includes company names and contact information.

## 5 Communications Practices and Protocols

Hurricanes limit communication by knocking out cellphone towers and other communications infrastructure. At the same time, they increase the need for fleet and vehicle communications to facilitate evacuation and recovery operations. This section assesses the current fleet communication strategies during hurricanes, with a focus on areas in need of improvement. It then introduces two solutions to some of the communications problems that currently limit the usefulness of alternative fuels before, during, and after a hurricane. The first solution is a website and GIS mapping tool that NREL created to facilitate emergency planning and ensure that fleets have the right contacts and information beforehand to minimize the last-minute communication needs during a hurricane. This website also ensures that fleet managers know the likelihood of their home station being shut down and the best areas to refuel if their station is no longer operable. The second solution is a series of algorithms developed by the University of South Florida's Center for Urban Transportation Research (CUTR) that maximizes the evacuation potential of EVSE in a given area by directing vehicles to available EVSE and charging them the appropriate amount to make it to safety.

### Current Status and Shortcomings of Communications During Hurricanes

At a September 2020 webinar hosted by the FDACS Office of Energy and project partners Tampa Bay Clean Cities Coalition, University of South Florida, NREL, and the Florida Solar Energy Center, stakeholders from Florida municipalities were asked about how fleets communicate with dispatch during hurricanes and other disaster situations.

In preparation for hurricanes, EOC communications are tested, and radios are staged at accessible locations, including in high-clearance vehicles. Local governments are primarily responsible for developing and managing local communications plans in coordination with the state. EOCs have a designated list of where fleet vehicles can refuel, which does not currently include alternative fuels.

Participants reported that their fleets communicate via radio, cellphones, and landlines during actual disaster situations. Cell phone outages have not been a problem in recent events, and communication that occurs from EOCs and backup EOCs also includes email correspondence, which has remained largely intact in recent events.

During or after a hurricane, public safety is the priority, and first responders have exclusive access to public emergency radio channels. According to interviews with the Florida Division of Emergency Management, many school districts have their own designated channels and dispatchers, and utilities often have their own systems. School bus channels are not prioritized during emergencies, despite the fact that these high-clearance, high-capacity, often propane-fueled vehicles could serve as a means of getting people without their own vehicles to emergency shelters (which are often located in elementary schools) prior to hurricane impacts. Utilities and telecommunications services have their own radio channels and are given second priority by the Division of Emergency Management after first responders. This covers many of the utility-owned, CNG-fueled vehicles used to repair power lines.

Along with the commercial-grade radio, amateur radio network (ham), satellite phones, business band radio, and mobile cellular towers are sometimes used by fleets to communicate. Private companies are responsible for their own communication redundancies, and some choose to pay a retainer to third parties for access to equipment (e.g., mobile cellular towers) during hurricanes or other emergency events.

Most of the emergency planning and coordination is handled at the county level, although some cities have dedicated emergency coordinators. When overwhelmed, these local governments request “missions” from the state, who can subsequently request a mission to the Federal Emergency Management Agency (FEMA). When possible, FDEM sets up camps and mobile fueling depots for first responders. These fueling depots typically provide diesel and unleaded fuel but no alternative fuels.

### ***EVSE Communications Systems***

To assess the communications capabilities and needs of EV charging infrastructure, NREL interviewed a variety of researchers and managers at ChargePoint. ChargePoint was chosen because it is the largest charging network provider in Florida. All of ChargePoint’s public EVSE are networked (i.e., connected to the internet), and therefore allow for communication between the EV charging infrastructure and the ChargePoint mobile app. This allows drivers to see in real time the available ChargePoint networked EV chargers in their area. In addition, the app shows the availability of “roaming partners” outside the ChargePoint network that ChargePoint members could use. If connectivity were to go down, ChargePoint members could still charge on ChargePoint equipment, but nonmembers would no longer be able to.

Individual EVSE are built to withstand 18 inches of standing water (per the National Electrical Code), but if this threshold is surpassed and the hardware is damaged, it cannot be brought back online until it is physically inspected by a technician. ChargePoint also has mobile DC fast chargers (DCFCs) on skids/trucks (with 4 feet of clearance) that can be brought to appropriate locations and connected quickly to the grid, which could be critical to deploy along major evacuation routes before a hurricane. It should be noted that there are skids with DCFCs and propane-powered generators available on the market (Pioneer Power Solutions, Inc. 2022). Some features of ChargePoint’s communication system that could help coordinate charging during an emergency include reservations and waitlists, but they fear that using these features in an emergency situation could lead to the chargers going unused for valuable minutes. Another feature that could help encourage people not to idle at an EV charger is the capability for hosts to raise their prices quickly in response to demand. However, the raises need to be limited so as to

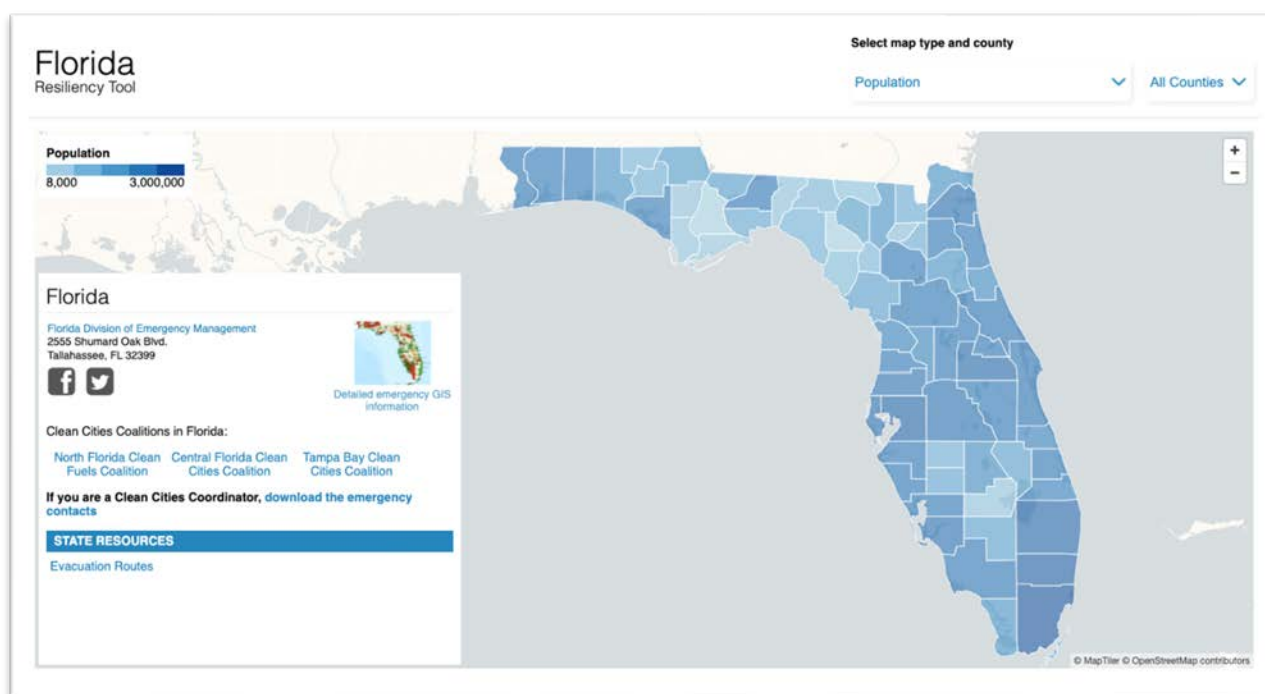


not be considered “price gouging,” which is illegal. The limitations to the network’s communications systems and remote features are addressed in Solution 2.

## Solution 1: New Website to Facilitate Planning

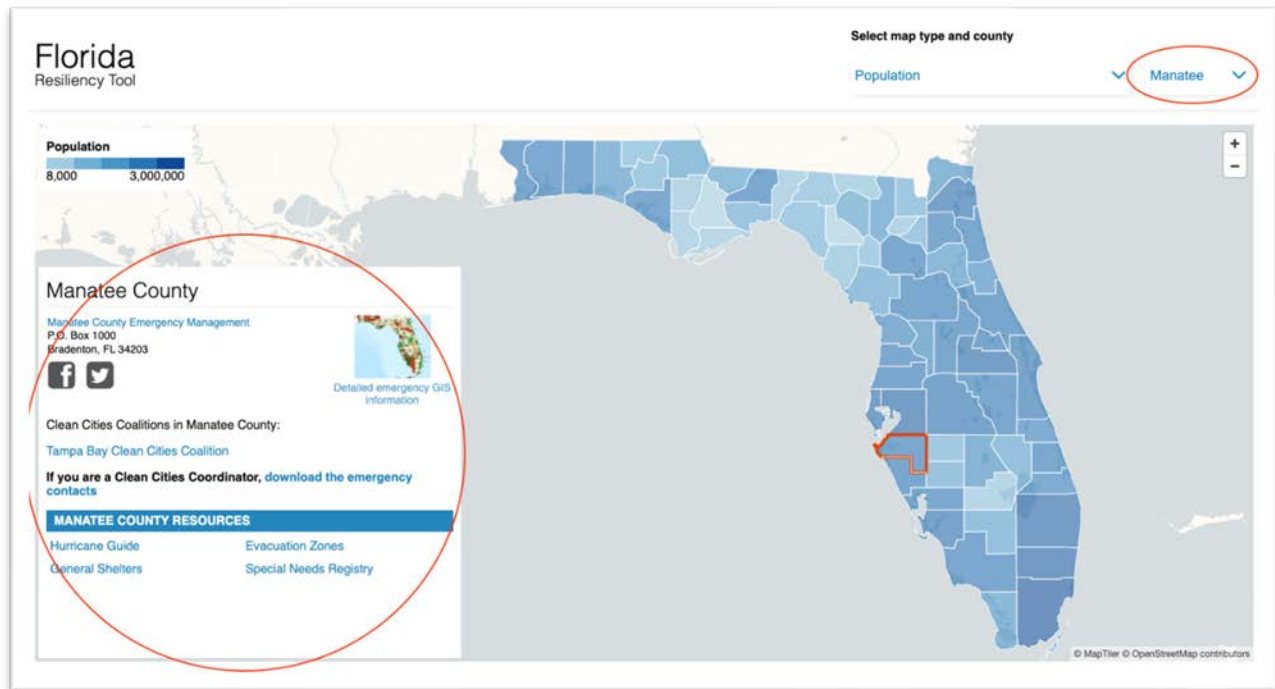
To facilitate the use of alternative fuels before and during a hurricane, NREL developed a Florida Resiliency Tool website to help facilitate planning and communications. Available at <https://widgets-stage.tada-stage.nrel.gov/tada/fl-resiliency/>, this website uses state-of-the-art technologies to provide useful maps, information, connections, and other resources. Here, users are presented with state-level information, including links to Clean Cities coalitions and the FDEM’s website, Facebook, and Twitter pages. It is intended for use by resilience planners, fleet managers, individuals planning their evacuation, and alternative fuel station operators.

Dropdown menus provided at the top of the page allow users to adjust information displayed by choosing from various map layers and counties. When changed, the website automatically refreshes to present the information selected.



**Figure 5. Florida Resiliency Tool homepage**

To obtain local information, users can select a county from a drop-down menu at the top right-hand side of the page or click the appropriate county on the map.



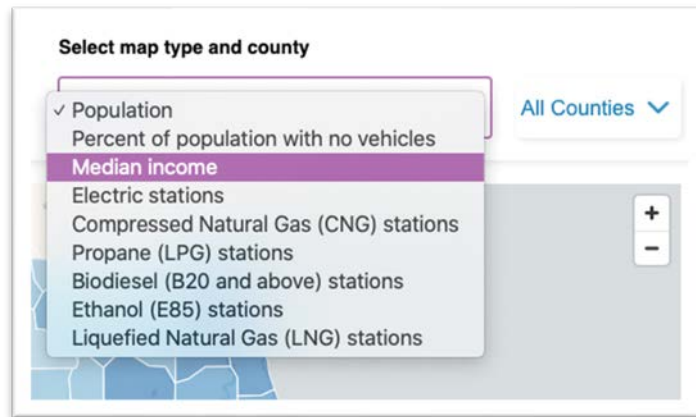
**Figure 6. County-specific resources appear when a county is selected.**

Where available, the following information is presented:

- Emergency management department name.
- Link to emergency management website.
- Link to emergency management Twitter.
- Link to emergency management Facebook.
- Emergency management department address.
- Link to county hurricane guide.
- Link to county evacuation zone information.
- Link to county evacuation route information.
- Shelter location information.
- Special needs shelter location information.
- County special needs registry.
- Link to county notification system.
- Link to county emergency management app.
- Community Emergency Response Team (CERT) information.
- Link to county YouTube station.
- County 311 app.
- Links to partner organizations.
- County population.
- Clean City coalition information.

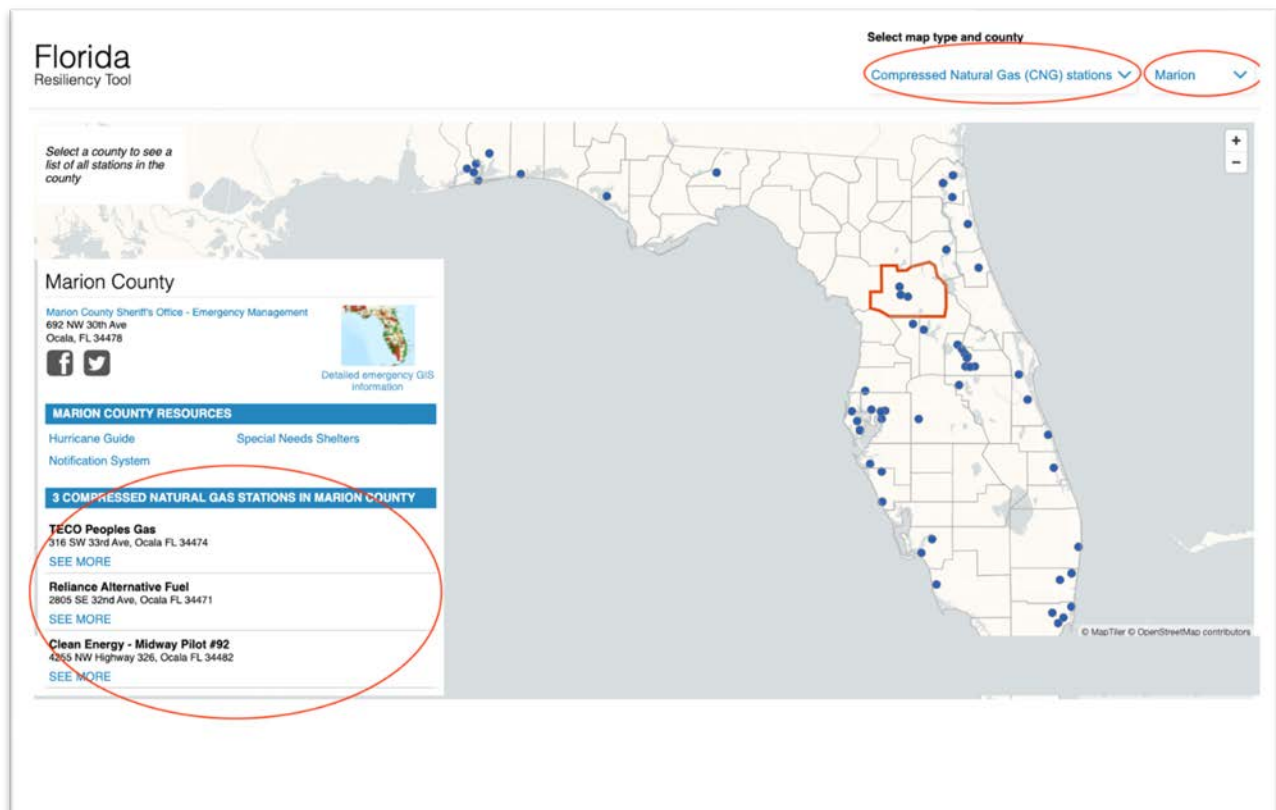
A second drop-down menu allows users to select a map layer with the following options:

- Population (default).
- Percent of population with no vehicles.
- Median income (to ensure equitable preparation).
- Electric station locations.
- CNG station locations.
- Propane (liquefied petroleum gas [LPG]) station locations.
- Biodiesel (B20 and above) station locations.
- Ethanol (E85) station locations.
- LNG station locations.



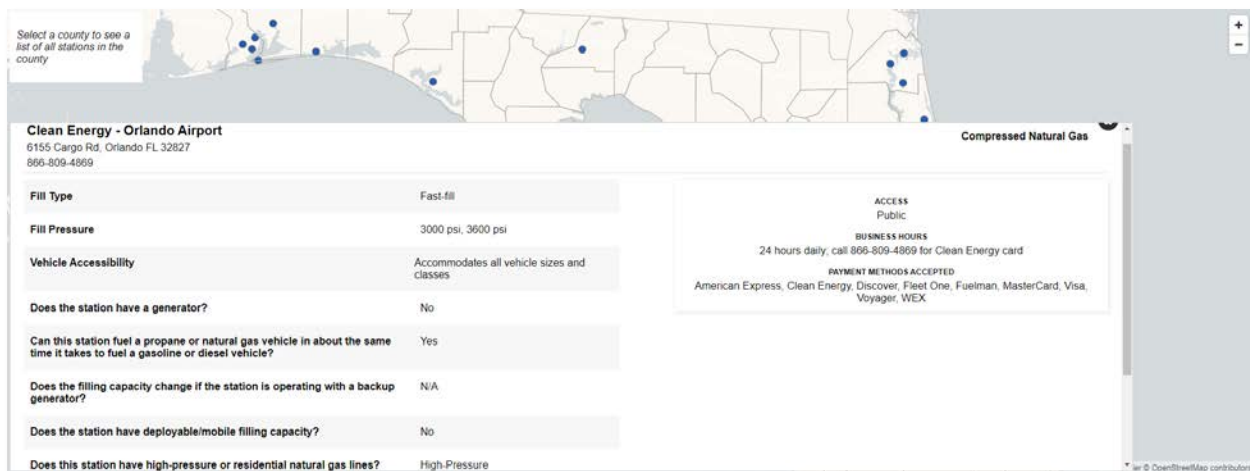
**Figure 7. Florida Resiliency Tool map layers**

Users may select from one or both drop-down menus to view detailed information. Clicking on a county on the map also selects that county and updates the information displayed.



**Figure 8. Accessing fuel-specific station location by county**

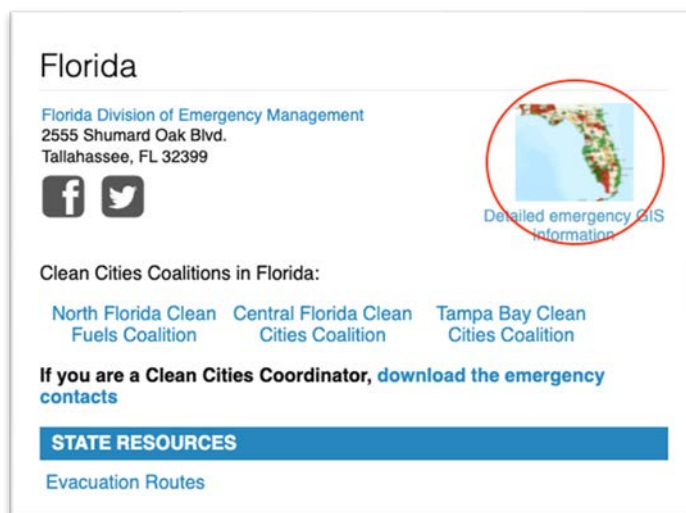
When both a fuel type and county are selected, users can see fuel station details in the info box that help fleet managers determine if the station would be compatible with their vehicles and the likelihood that the station could remain in operation during a power outage. Clicking “SEE MORE” displays more detailed station location information such as fill type, fill pressure, fill rate, vehicle accessibility, electric generator existence, and fuel, as well as change to station capacity with a generator, if applicable.



**Figure 9. Station-specific information provides detail**

A link to download emergency contact information for fueling stations is provided, but this information is considered private and therefore only accessible by Clean Cities coordinators. Please contact your local coordinator via the Clean Cities link in order for them to download this information from the coordinator toolbox (via the state-level link showed in Figure 9).

From any view of the Florida Resilience Tool, users can click the small map image to see detailed emergency GIS information. This information is elaborated in the GIS analysis in Section 7.



**Figure 10. Detailed emergency GIS information accessible from any view in the Florida Resilience Tool**

## Solution 2: EVSE Communications Algorithms and Web Tool

In addition to the web-based Florida Resilience Tool, an electric vehicle evacuation planning prototype web tool was also developed to better prepare the state for the use of electric vehicles before and during an emergency event.

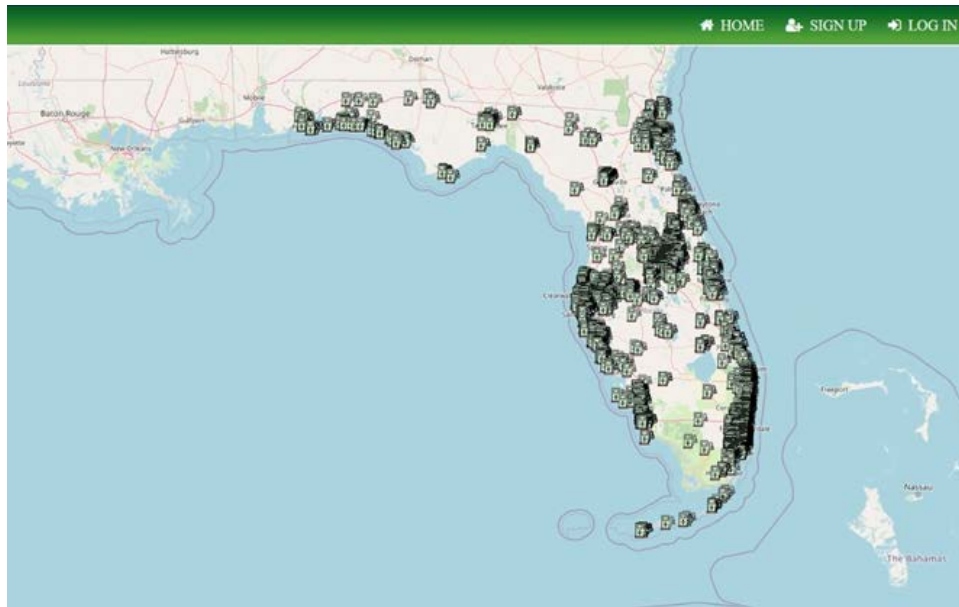
A long-distance evacuation is expected when an emergency event affects a wide range of areas (Adderly et al. 2018). In the United States, private vehicles are usually the first evacuation mode choice, given high automobile ownership (Phiophuead and Kunsuwan 2019). During Hurricane Irma in 2018, it was reported that about 90% of people evacuated with private vehicles (Wong, Shaheen, and Walker 2018). As an alternative to internal combustion engine vehicles, the popularity of EVs has rapidly developed in the past years because of lower maintenance costs, lower operating costs, performance advantages, lower carbon footprints, and government support (Bushnell, Muehlegger, and Rapson 2022).

It was predicted that the global EV market would grow from 4.1 million in EVs in 2021 to nearly 35 million EVs in 2030 (MarketsandMarkets 2021). Some households may only possess EVs and need to use them for long-distance travel in the case of an emergency (Feng et al. 2020). Li et al. (2022a) state that “Long-distance travel with EVs in regular circumstances is already challenging because of limited charging facilities, long charging time, and short driving ranges (Rajaeifar et al., 2022; Zhang et al., 2021), not to mention in the case of an emergency where the travel demand (or charging demand) is significantly high. Without proper management, serious congestion could happen at charging stations. This results in a long network clearance time, thus putting human lives at risk”. Efficient mass evacuation planning for EVs is demanded. Therefore, the electric vehicle evacuation planning web tool has been developed.

After registration with the tool, people evacuating in EVs can make charging reservations before the predicted landfall of the hurricane. The web tool collects evacuation demand and ends the reservation portal as needed (e.g., when a hurricane is close at hand). Then the back-end algorithm will optimize the evacuation route for each user, considering the limited charging facilities. Users can log back on the web tool and check the detailed evacuation route, including when to start evacuating and where to charge. As a preliminary user guide, the detailed user interface and back-end algorithm of this web tool are introduced in the following subsections.

### ***EV Evacuation Tool Homepage***

Before registration, users will see the homepage of the web tool, as shown in Figure 11. On the homepage, publicly available EV charging stations are shown on the map of Florida. The data source is the Alternative Fuels Data Center (<https://afdc.energy.gov/>).



**Figure 11. EV Evacuation Tool homepage**

### ***Signup and Login to the EV Evacuation Tool***

To make an evacuation reservation, users must first register. As shown in Figure 12, a user should create an account with their email and set a password. After signing up, the user will be able to log in to the web tool.

**Figure 12. Signup and login to the EV Evacuation Tool**

### ***Evacuation Reservation***

After logging in, users can make evacuation reservations. It should be noted that one user can only make one evacuation reservation considering the limited resources, especially in the case of an emergency. As shown in Figure 13, users need to indicate the evacuation origin and destination. Instead of typing the detailed address, they are asked to select from two drop-down lists with cities and regions in Florida. Specifically, the origin and destination options include Pensacola, Panama City, Youngstown, Port St. Joe, Tallahassee, Perry, Gainesville, Jacksonville, Lake City, Daytona Beach, Ocala, Cedar Key, Wildwood, Titusville, Orlando, Vero Beach, Lake



Placid, Cleveland, Sarasota, Tampa, South Bay, West Palm Beach, Dania Beach, Miami, Islamorada, and Key West. These cities/regions are selected in a way such that more origin/destination options are available at places with denser populations. At the same time, for places with very light populations, necessary origin/destination options are also available such that all users can use this web tool to plan their evacuation. Users will select the cities/regions (provided in the list) in the vicinity of their actual origins and destinations when making reservations. The limited number of origins/destinations significantly helps with the solution efficiency of the back-end optimization algorithm. More city/region options can be incorporated as long as the supporting computation resources can handle them.

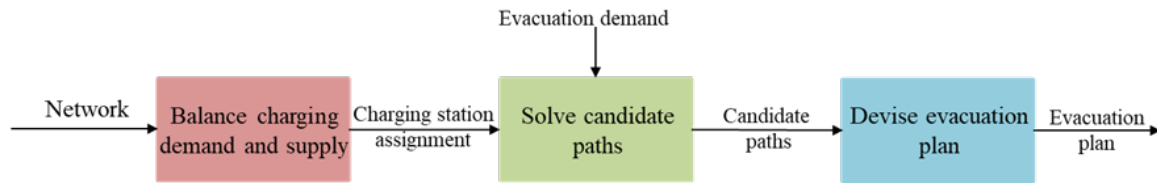
Besides the origin and destination, users also need to input the departure time window (a range for the preferred evacuation starting time) and the initial electricity level of their EVs in percentage (a rough estimation is enough). Users will never be suggested to evacuate earlier than their intended time window but may be delayed for system-level optimality. After all the information is filled out, users should hit reserve, and their reservation will immediately enter the database, where all evacuation demand is saved.

**Figure 13. Evacuation reservation in the EV Evacuation Tool**

### ***Back-End Planning Algorithm***

After receiving all the evacuation reservations, the back-end planning algorithm designs the optimal evacuation plan for EVs considering limited charging facilities. This problem is complex, involving EV charging, routing, and scheduling. An intuitive approach is to construct a time-space-energy extended network to solve it. However, such a network for a practical application instance is likely too huge to solve. To circumvent this computational challenge, a three-stage method (Figure 14) is proposed to efficiently solve this problem based on the following premises. First, vehicles tend to charge in the vicinity of the evacuation path. Charging stations far away from the evacuation path will not be visited because of the considerable energy and time costs. Second, only a few candidate paths are selected by each origin-destination EV flow (OD flow) during the evacuation. Paths that are too long can be trimmed from consideration. The inputs to the proposed method are a set of evacuation demands (specifying the origin, destination, initial EV energy level, and intended departure time window) submitted

by web tool users and a network (consisting of a set of critical locations without charging facilities, a link matrix between locations, a distance matrix between locations, and a set of charging stations). The output is the evacuation plan, including the evacuation routes considering charging and the departure schedule for each OD flow.

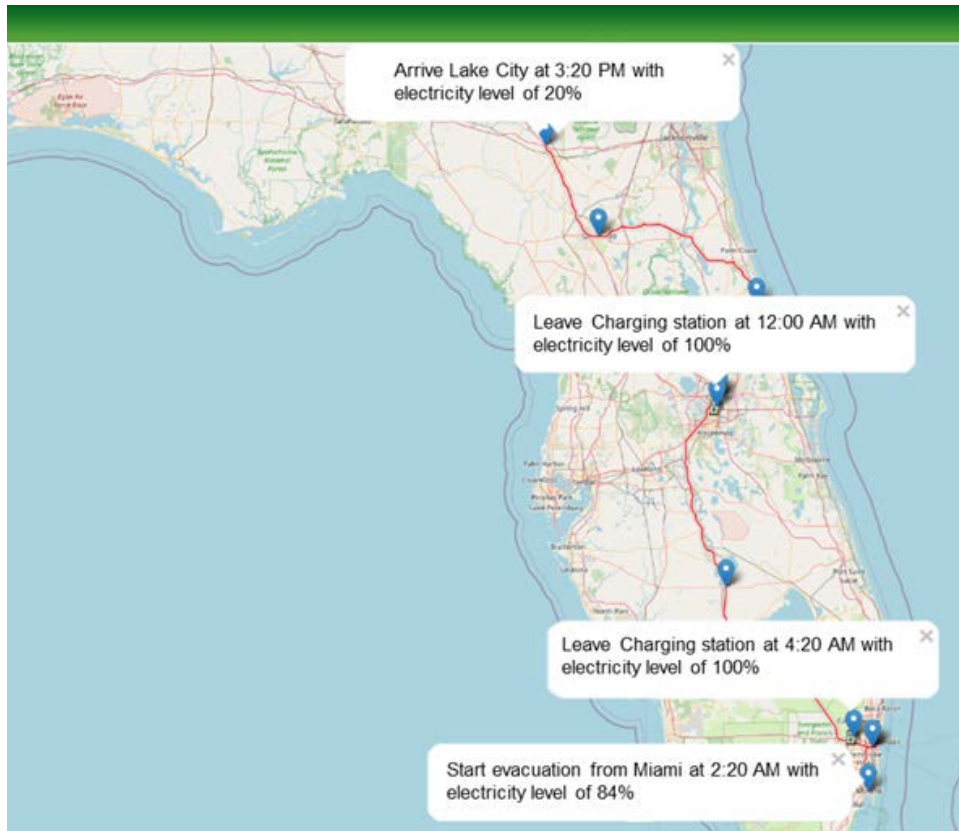


**Figure 14. Back-end evacuation planning algorithm structure**

Stage 1 is conducted to reduce the network size and mimic realistic evacuation behavior that vehicles usually charge in the vicinity of the evacuation path, and only a small number of short paths are selected by each OD flow during the evacuation. Stage 1 first consolidates the network by pre-assigning charging stations to the closest critical locations and then aggregating a group of charging stations in the same vicinity into a mega charging facility. Next, a customized shortest path algorithm is proposed to trim excessively long evacuation paths and only consider a small set of short paths between each OD pair. Given this, sparsely distributed charging stations in the network should be allocated wisely to path locations to balance the EV charging demand and supply. To do this, Stage 2 computes the location significance based on the path set solved in Stage 1 and the evacuation demand. With the location significance, charging stations are reassigned and reaggregated such that locations visited by more EVs are assigned with more charging facilities. Finally, in Stage 3, a set of candidate evacuation paths is solved based on the evacuation demand and the network after balancing the charging demand and supply using the same algorithm as in Stage 1. An evacuation planning model is then formulated to devise the optimal mass evacuation plan for EVs. This model optimally selects evacuation paths and schedules departure for EVs of each OD pair. Charging facility capacity is considered to avoid congestion at charging stations. This model is macroscopic because aggregated EV flows are considered to handle the mass evacuation demand efficiently rather than tracking each EV movement. An optimization objective of minimizing the network clearance time and the delayed departure time is used to evacuate as soon as possible.

### **Evacuation Route**

After the back-end algorithm optimizes the evacuation routes, users can check the results by logging in to the web tool. An evacuation route for a user is provided in Figure 15. This user is suggested to start evacuation at 2:20 a.m. from Miami. The initial electricity level is 84%. By 4:20 a.m., this user will leave a charging station with a full battery. This user will continue the evacuation and leave another charging station with a full battery at 12:00 p.m. Finally, by 3:20 p.m., this user arrives at the destination (i.e., Lake City) with an electricity level of 20%. The evacuation ends.



**Figure 15. Evacuation route**

It should be noted that the electric vehicle evacuation planning web tool described here is a prototype to demonstrate the feasibility of optimally scheduling long-distance EV evacuations in the case of an emergency. The web tool operating stakeholders are suggested to conduct the following additional efforts before the actual deployment of the web tool:

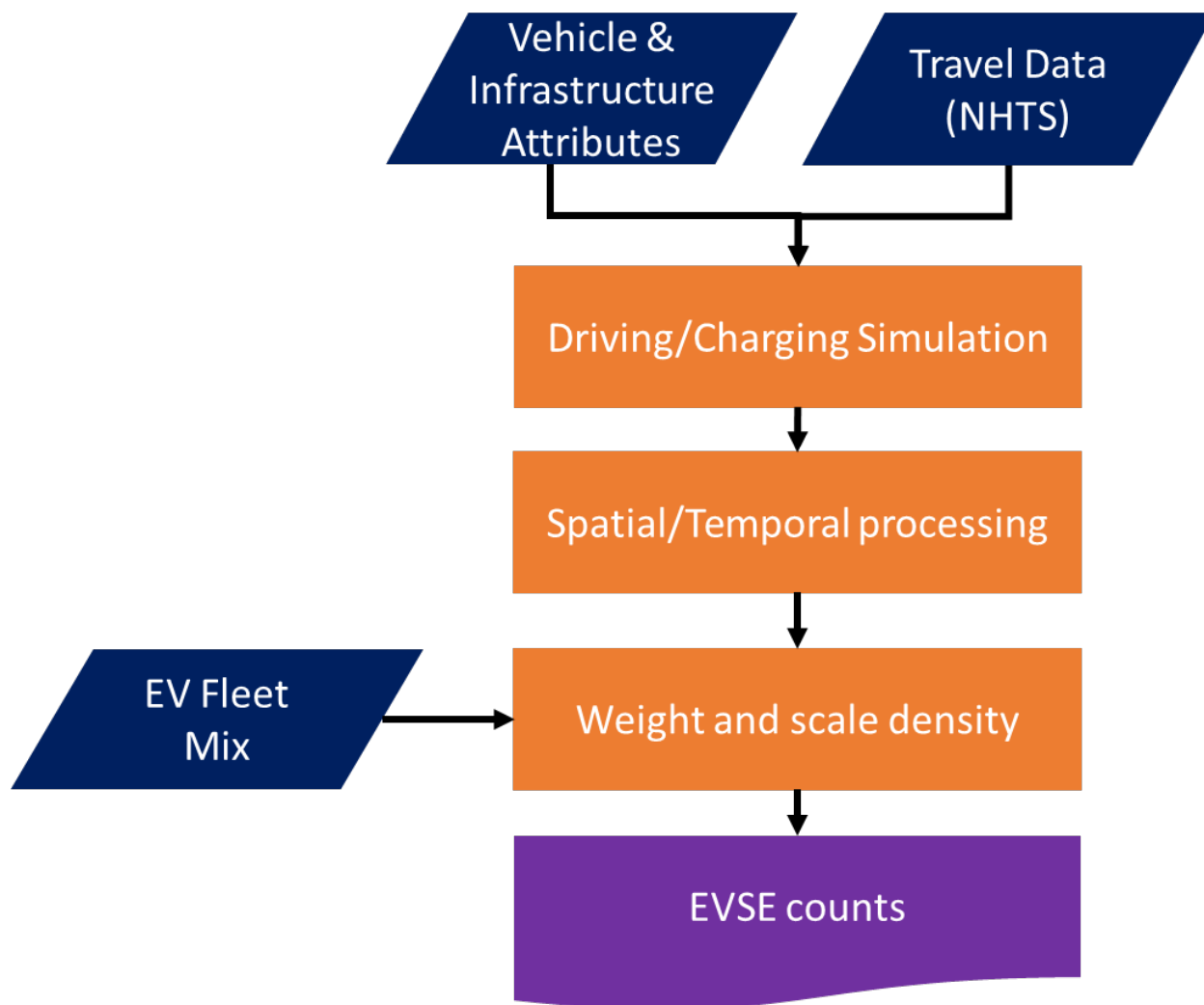
- Connect this prototype with the Alternative Fuels Data Center ([https://afdc.energy.gov/fuels/electricity\\_locations.html#/find/nearest?fuel=ELEC](https://afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC)) to incorporate the changes in charging stations (e.g., newly added stations and the number of charging ports at each station).
- Connect this prototype with the National Highway System maps (<https://www.fdot.gov/statistics/hwydata/nhsmaps.shtm>) to incorporate the changes in the physical roadway network (e.g., new link).
- Switch to a commercial map application programming interface (e.g., Google Maps) to guarantee a robust and efficient illustration of the evacuation route.

## 6 Long-Term Planning for Electric Vehicle Infrastructure Expansion

Electric vehicles are projected to increase their market share more than any other alternative fuel in the history of automobiles. Therefore, Florida needs to forecast their infrastructure needs well into the future and consider the resilience implications. NREL did this with their Electric Vehicle Infrastructure – Projection (EVI-Pro) tool. This section analyzes the EV charging infrastructure needs in Florida from 2030 to 2050 to meet the charging demand of EVs—primarily light-duty vehicles. The statewide charging infrastructure need is quantified using the EVI-Pro tool, incorporating the spatial travel patterns, vehicles, and charger attributes in a bottom-up simulation framework. The analysis is performed at the county level for 2030 and 2050, considering the EV adoption rate increase in Florida. The results indicate that in public and workplace charging, the needs for chargers are 46,487 and 170,471 in 2030 and 2050, respectively, including 5,561 and 26,901 DCFCs. Conversely, the home charging infrastructure needs are 159,103 and 464,709 in 2030 and 2050, respectively.

### Electric Vehicle Infrastructure Projections Method Overview

EVI-Pro is a simulation tool that identifies the electric vehicle charging infrastructure and predicts the power demand for the EVSE based on the anticipated electric vehicle fleet composition and their corresponding driving behaviors (Wood, Raghavan, et al. 2017). EVI-Pro employs the real-world travel data and the EV projections to estimate the charging requirements in work, home, and public places. The model’s anticipated output is the spatial/temporal consumer power demand for charging and the corresponding charging infrastructure projection at the targeted area. The general EVI-Pro model structure and input/output data flows are presented in Figure 16.



**Figure 16. EVI-Pro model structure and data flow**

The two fundamental assumptions in EVI-Pro are the vehicle and EV charging infrastructure attributes that enable the model to identify the energy consumption and power supply for the EV travel demand. To simulate mainstream drivers' travel behavior, National Household Travel Survey (NHTS) travel data are analyzed and categorized based on population density to represent the travel behavior at the county level in Florida (FHWA 2017). The projected EV fleet size in 2030 and 2050 are derived from the Annual Energy Outlook to reflect the increased adoption rate of EVs (EIA 2020).

### Vehicle and Infrastructure Attribute Assumptions

The vehicle and charging infrastructure attributes are the two major assumptions in EVI-Pro to complete the charging simulations. An EV's attributes are highly related to its electric range. Thus, the vehicle attributes required in the EVI-Pro simulation are electric range, vehicle drive efficiency, minimum range tolerance, onboard charger efficiency, and maximum AC charging power (Wood, Raghavan, et al. 2017). The EV attribute assumptions are derived from the California Energy Commission report based on the vehicle powertrain type and electric ranges (Crisostomo et al. 2021). On the other hand, the EV charging infrastructure attribute

assumptions are made based on the three major categories defined by the Alternative Fuels Data Center of charging power levels: Level 1 (L1), Level 2 (L2), and DCFC.<sup>11</sup> The selection of charging options within EVI-Pro needs to consider the dwell time available for the vehicle to be charged. Longer dwell times lead to lower-power charging, whereas short dwell times usually lead to higher-power charging options, such as DCFC (Wood, Rames, et al. 2017). Thus, the suitable charging infrastructure type (location and power level) could be simulated by EVI-Pro considering the dwell time and consequent travel need. Different charging infrastructure options available to consumers in EVI-Pro are listed in Table 2.

**Table 2. EV Charging Infrastructure Technology Specifications**

Location	Level	Power	Comment
Home	L1	1.4 kW	
	L2	3.6 kW	Battery-electric vehicles simulated with higher L2 power to enable full overnight charge
Work	L1	1.4 kW	
	L2	6.2 kW	Plug-in hybrid EV onboard charger limits maximum power to 3.6 kW in model
Public	L1	1.4 kW	
	L2	6.2 kW	Plug-in hybrid EV onboard charger limits maximum power to 3.6 kW in model
	L3	50 kW	Battery-electric vehicles only

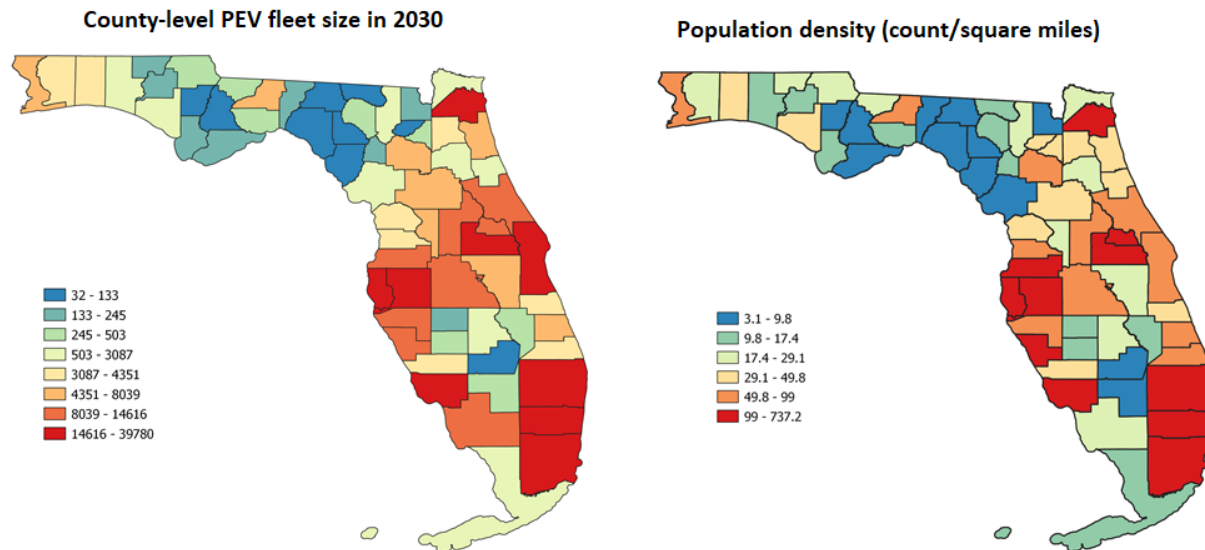
Source: Wood, Rames, et al. 2017

## Florida County-Level Travel Demand Assumptions

To identify EV charging infrastructure needs in Florida, the corresponding spatial travel data representing the travel behavior and EV fleet information are necessary to complete the driving and charging demand simulations. The Florida county-level travel patterns are simulated using the travel information record from the 2017 NHTS, which is the most recent survey collected by the Federal Highway Administration (FHWA) focusing on travel behavior data in the United States (FHWA 2017). This survey provides travel details for the demographic travel behaviors of around 130,000 households, including work and school community, shopping trips, recreational activities, health care visits, and so on. For each trip record, the detailed trip information includes the departure and arrival times, destination type, trip distance, dwell time, and the specific day of travel during the week. The travel data are incorporated into EVI-Pro daily to consider the weekday/weekend travel behavior variation as well. NHTS cannot offer enough travel data sample at the Florida county level. Thus, the travel data from NHTS are categorized by population density derived from the 2018 American Community Survey (U.S. Census Bureau 2020), as illustrated in Figure 17. The subset travel data with the same population density in the specific county are employed to simulate the travel pattern of this county.

<sup>11</sup> [https://afdc.energy.gov/fuels/electricity\\_infrastructure.html](https://afdc.energy.gov/fuels/electricity_infrastructure.html)





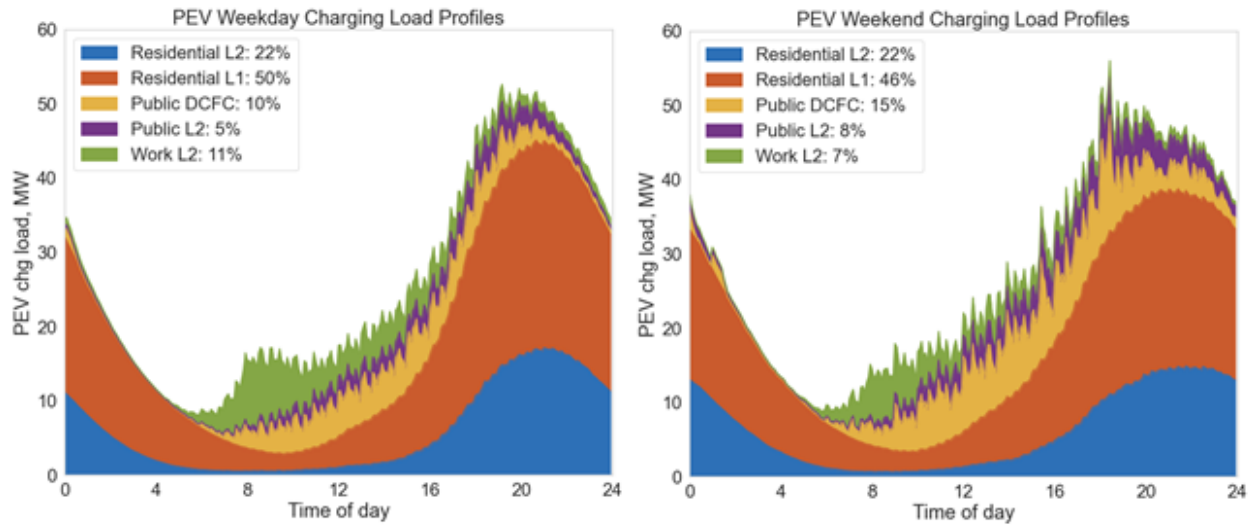
**Figure 17. Florida county-level population density and EV fleets**

The Florida county-level EV fleet projections in 2030 and 2050 are derived from the 2020 Annual Energy Outlook published by the U.S. Energy Information Administration, which forecasts the annual light-duty vehicle fleet size by technology type (EIA 2020). The EV fleet size is distributed throughout the state at the county level based on existing hybrid electric vehicle registration data from R. L. Polk & Co., and their share is compared to the total vehicles (Moniot, Rames, and Wood 2019). One of the important assumptions in charging infrastructure estimation is the residential charger access ratio. Currently, most of the EV charging occurs at residential locations; with the increase of the EV penetration rate, the residential charging ratio decreases due to a higher total charging infrastructure number and density. Thus, considering the different EV penetration rates, the residential charging access ratios are 90% and 80% in 2030 and 2050, respectively (Ge et al. 2021).

## EVI-Pro Simulation Analysis and Results

The EV charger need at the Florida county level is simulated based on the location and time when a charger is necessary to satisfy a driver's travel demand. Home, public, and workplace are the three options for charging locations. Furthermore, to consider the difference in travel behaviors during weekdays and weekends, the corresponding charging events and power demand are simulated and presented in Figure 18. As seen in the figure, residential charging load demands take the largest share—about 70%. The two peaks for daily charging load profiles coincide with the residential charging load and the time range when vehicles arrive at homes. Furthermore, comparing the charging load profiles between weekdays and weekends, the workplace charging load decreases and the public places charging load increases on weekend days. Also, the charging load for DCFCs is more volatile than other charger types due to the high power demand.





**Figure 18. EV charging load profiles in 2030, n = 80,000**

EVI-Pro quantifies the EV charger need by calculating the charging power required by charger type and the corresponding charging power level based on the corresponding charger attributes. Tables 3 and 4 present the nonresidential EV charger needs at the county level in Florida in 2030 and 2050, respectively.

**Table 3. 2030 EV Nonresidential Charging Infrastructure Projection**

County	DCFC	Public L2	Work L2
BROWARD	484	1,454	2,330
PALM BEACH	465	1,359	2,177
MIAMI-DADE	427	1,361	2,170
ORANGE	443	1,244	2,003
HILLSBOROUGH	346	1,010	1,622
PINELLAS	280	838	1,346
DUVAL	207	589	942
LEE	207	575	917
BREVARD	195	542	867
SARASOTA	177	498	792
SEMINOLE	148	421	672
POLK	147	391	625
VOLUSIA	142	389	622
PASCO	133	364	581
MANATEE	123	348	554
COLLIER	123	342	547
LAKE	115	301	481
SAINT JOHNS	108	285	454

<b>County</b>	<b>DCFC</b>	<b>Public L2</b>	<b>Work L2</b>
ALACHUA	102	277	440
MARION	96	245	391
LEON	90	248	398
OSCEOLA	84	226	360
SAINT LUCIE	76	209	334
ESCAMBIA	70	190	303
SUMTER	64	161	256
CHARLOTTE	58	157	252
OKALOOSA	56	156	247
MARTIN	56	153	242
CLAY	51	134	214
INDIAN RIVER	49	133	213
HERNANDO	49	130	207
CITRUS	50	127	203
SANTA ROSA	45	119	191
BAY	42	113	179
FLAGLER	39	103	165
MONROE	31	86	138
NASSAU	26	67	107
WALTON	26	65	103
HIGHLANDS	25	65	103
PUTNAM	12	29	46
COLUMBIA	11	29	45
LEVY	8	19	30
SUWANNEE	7	17	27
JACKSON	7	17	27
WAKULLA	7	16	25
GADSDEN	7	16	25
OKEECHOBEE	5	12	19
HENDRY	4	11	18
DE SOTO	4	10	16
BRADFORD	4	10	15
WASHINGTON	4	9	13
GILCHRIST	3	8	13
JEFFERSON	3	8	13
GULF	3	7	12

County	DCFC	Public L2	Work L2
FRANKLIN	3	7	11
BAKER	3	7	10
HOLMES	2	6	9
HARDEE	2	5	8
TAYLOR	2	5	8
CALHOUN	2	5	7
DIXIE	2	4	6
GLADES	2	4	6
MADISON	2	4	6
UNION	1	3	5
HAMILTON	1	3	5
LIBERTY	1	2	4
LAFAYETTE	1	1	2

Table 3 presents the nonresidential EV charging infrastructure need in 2030. The total Florida state public EVSE need is 45,485. To be specific, 54% are work L2 chargers, 34% are public L2 chargers, and 12% are DCFCs. At the county level, Broward is the county with the largest EV charger need, whereas Lafayette is the county that will need the fewest EVSE.

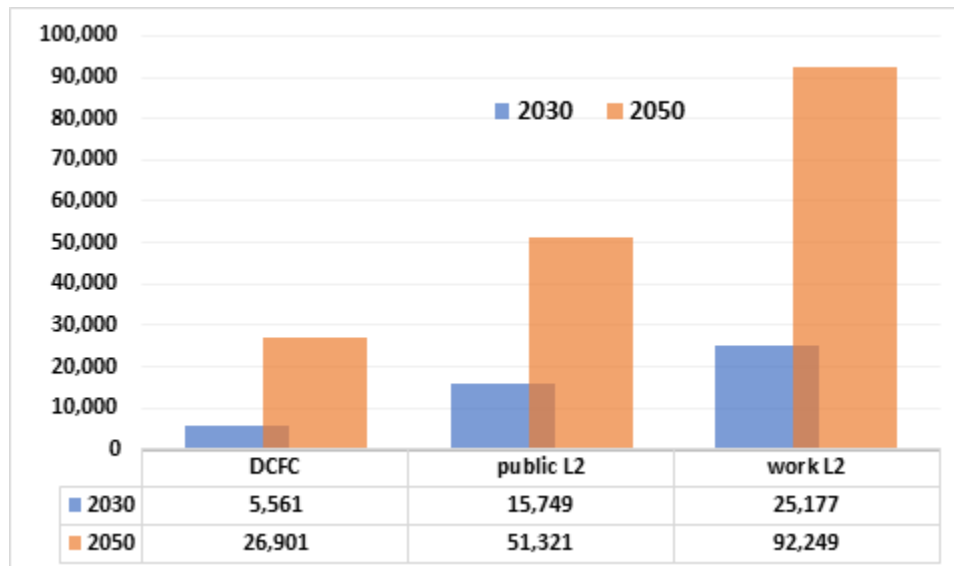
**Table 4. 2050 EV Nonresidential Charging Infrastructure Projection**

County	DCFC	Public L2	Work L2
BROWARD	2,355	4,837	8,547
PALM BEACH	2,262	4,479	7,980
MIAMI-DADE	2,060	4,578	7,951
ORANGE	2,156	4,053	7,356
HILLSBOROUGH	1,680	3,332	5,952
PINELLAS	1,367	2,798	4,941
DUVAL	1,003	1,921	3,451
LEE	998	1,855	3,357
BREVARD	946	1,751	3,181
SARASOTA	854	1,612	2,896
SEMINOLE	716	1,370	2,461
POLK	706	1,248	2,287
VOLUSIA	683	1,255	2,276
PASCO	641	1,169	2,130
MANATEE	596	1,133	2,028
COLLIER	595	1,107	2,002

<b>County</b>	<b>DCFC</b>	<b>Public L2</b>	<b>Work L2</b>
LAKE	551	959	1,760
SAINT JOHNS	519	905	1,658
ALACHUA	487	888	1,607
MARION	458	775	1,431
LEON	434	804	1,457
OSCEOLA	405	726	1,317
SAINT LUCIE	366	674	1,225
ESCAMBIA	337	609	1,110
SUMTER	304	505	933
CHARLOTTE	282	502	925
OKALOOSA	271	502	904
MARTIN	270	488	886
CLAY	244	426	781
INDIAN RIVER	237	425	782
HERNANDO	236	412	759
CITRUS	239	401	740
SANTA ROSA	218	378	698
BAY	200	359	656
FLAGLER	187	327	607
MONROE	151	278	507
NASSAU	126	213	392
WALTON	123	205	375
HIGHLANDS	119	206	378
PUTNAM	55	91	167
COLUMBIA	53	90	163
LEVY	37	59	109
SUWANNEE	33	54	99
JACKSON	32	53	97
WAKULLA	31	50	92
GADSDEN	31	50	91
OKEECHOBEE	22	37	68
HENDRY	21	35	65
DE SOTO	18	32	57
BRADFORD	18	30	55
WASHINGTON	16	27	49
GILCHRIST	16	25	46

County	DCFC	Public L2	Work L2
JEFFERSON	16	25	46
GULF	14	23	42
FRANKLIN	14	22	41
BAKER	13	21	38
HOLMES	11	18	34
HARDEE	10	17	30
TAYLOR	9	15	27
CALHOUN	9	15	27
DIXIE	8	13	23
GLADES	8	13	23
MADISON	7	12	22
UNION	6	10	19
HAMILTON	6	10	19
LIBERTY	4	7	13
LAFAYETTE	2	4	7

Table 4 shows the EV public charging infrastructure prediction for 2050. The total Florida charging infrastructure need is 170,471 in 2050: 54% are work L2 chargers, 30% are public L2 chargers, 16% are DCFCs, and the remainder are home chargers. At the county level, similar to 2030, Broward is the county with the largest EV charger need of 15,739, whereas Lafayette is the county with the least EV charger need of 13.



**Figure 19. Comparison of 2030 and 2050 EV charging infrastructure**

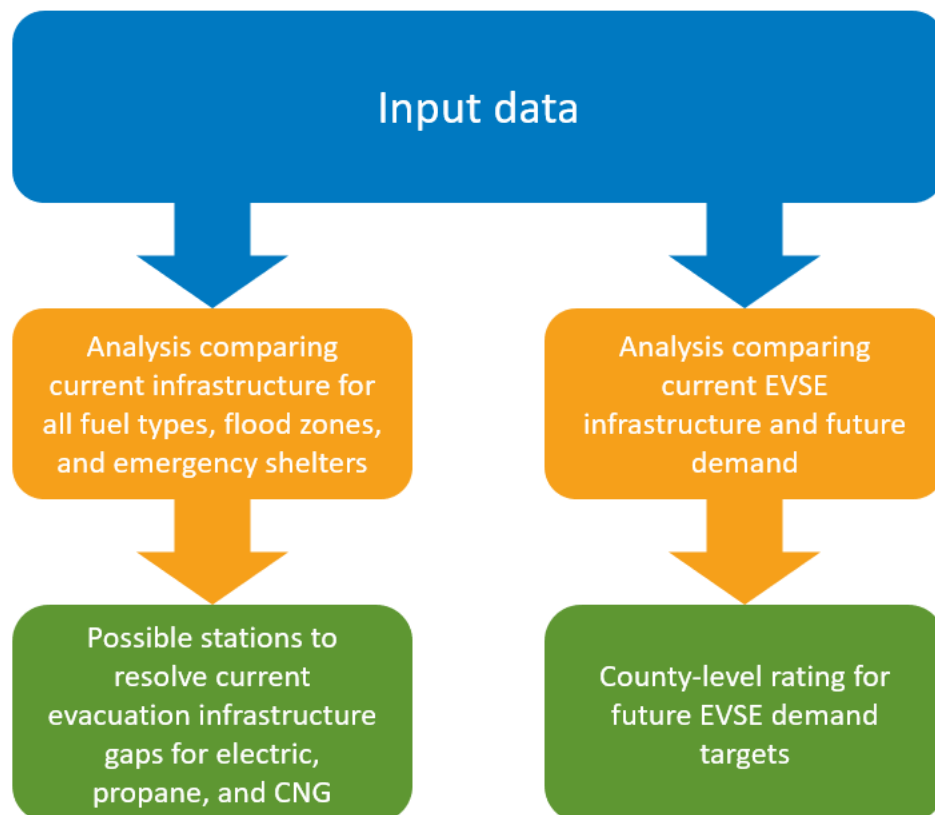
Figure 19 compares the EV charging infrastructure number in 2030 and 2050. With the increase in EV numbers, the charging infrastructure need raises correspondingly. To be specific, public

L2 charger numbers increase about 3 times in 2050 compared to 2030. In contrast, the work L2 charger number increases 3.7 times, and the DCFC number increases around 5 times. The phenomenon could be explained by the increase in vehicle numbers and the decreased residential charging access ratio. Furthermore, DCFCs could offer higher power and shorter charging times. Thus, the rise in DCFC numbers could reduce the burden of other public chargers. Therefore, the increase in public L2 and work L2 chargers is not as large as DCFCs.

The number of EVs in Florida is projected to be 74,154 in 2030, with 17% of them being plug-in hybrid EVs and 83% of them being battery-electric vehicles. In 2050, the total number of EVs is expected to grow to 163,084, with 11% EVs and 89% battery-electric vehicles. The real-world household travel data were analyzed and adopted in EVI-Pro to understand and simulate the travel behavior of these EVs in Florida. 2017 NHTS travel data covering 129,112 households with more than 606,600 trip records have been analyzed and categorized to represent the travel behavior at different Florida counties based on the population density. EVI-Pro simulations estimate that 5,561 DCFCs, 15,749 public L1 chargers, and 25,177 workplace L2 chargers are required to support the EVs in Florida in 2030. The charging infrastructure demand increases to 26,901 DCFCs, 51,321 public L2 chargers, and 92,249 workplace L2 chargers in 2050.

## 7 GIS-Based Preparation for Hurricanes

This section addresses the challenges the state of Florida has for AFV refueling station implementation in the context of flooding resulting from hurricanes, tides, or sea level rise. While alternative fuels can alleviate broad petroleum outages, they currently have fewer refueling/recharging stations in Florida. This, combined with the flooding that accompanies hurricanes, requires logistical preparation before a disaster strikes. The analysis in this section addresses two distinct aspects of AFV infrastructure as it relates to floods in Florida. First, it demonstrates a spatial analysis approach to identify potential locations for new AFV stations to increase the connectivity of the emergency evacuation road network for AFVs, whether for purposes of evacuation or emergency response operations. This would bolster the ability of residents and disaster responders using AFVs to reliably refuel during a flood event. Second, this analysis addresses future needs for EVSE by comparing counts of current EVSE ports against the future EVSE needs forecast in Section 6. Figure 20 outlines the two objectives of this analysis.



**Figure 20. Summary of the two geospatial Florida AFV flood resilience analyses**

The primary outcome of this analysis is a web mapping tool that Florida’s emergency management practitioners can use to incorporate alternative fuels and vehicles into their resilience plans. The tool is not intended to compete with any live web dashboards that provide real-time emergency information, such as GATOR (FDEM 2021). As such, it is not intended for emergency use during any flooding event. The web map does not provide any live data feeds but can be updated annually or quarterly to ensure plans are up to date with the latest state of the alternative fueling infrastructure in Florida. The AFVs of interest in this analysis are propane, CNG, and electric vehicles (charged through both Level 2 EVSE and DCFCs).



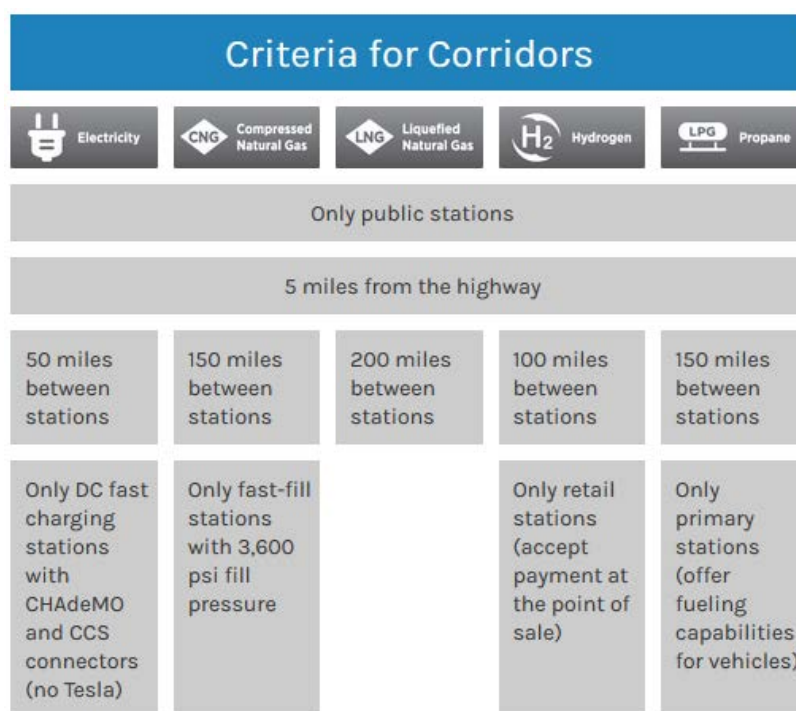
This section is further divided in subsections that address the data used for the analysis, methodology, results, an example case study, and next steps.

## Utilizing Current Infrastructure Data

Florida has AFVs and alternative refueling stations right now that can be utilized during evacuation and recovery operations. This section of the GIS analysis highlights how they might be best used. The descriptions and sources of the data used for this analysis are detailed in the following subsections.

### Current AFV Stations

The core data set for this work is current AFV stations, as downloaded from the Alternative Fuels Data Center Alternative Fuel Station Locator.<sup>12</sup> The Alternative Fuels Data Center provides extensive data for the location and descriptions for both public and private alternative fueling stations. The station data are publicly available and updated daily. The stations used in this analysis are all public stations that meet the criteria for Alternative Fuel Corridors, as well as private propane, CNG, and LNG stations that otherwise meet the Alternative Fuel Corridors criteria. These criteria are used by FHWA’s Alternative Fuel Corridors program to designate sections of highway that AFVs can reliably traverse while having adequate ability to fuel based on baseline range assumptions (FHWA 2021). Figure 21 shows the criteria for each alternative fuel type.



**Figure 21. FHWA alternative fuel corridor requirements.**

Note: The current analysis does not include hydrogen due to lack of vehicles and infrastructure in Florida.

Data Source: FHWA 2021

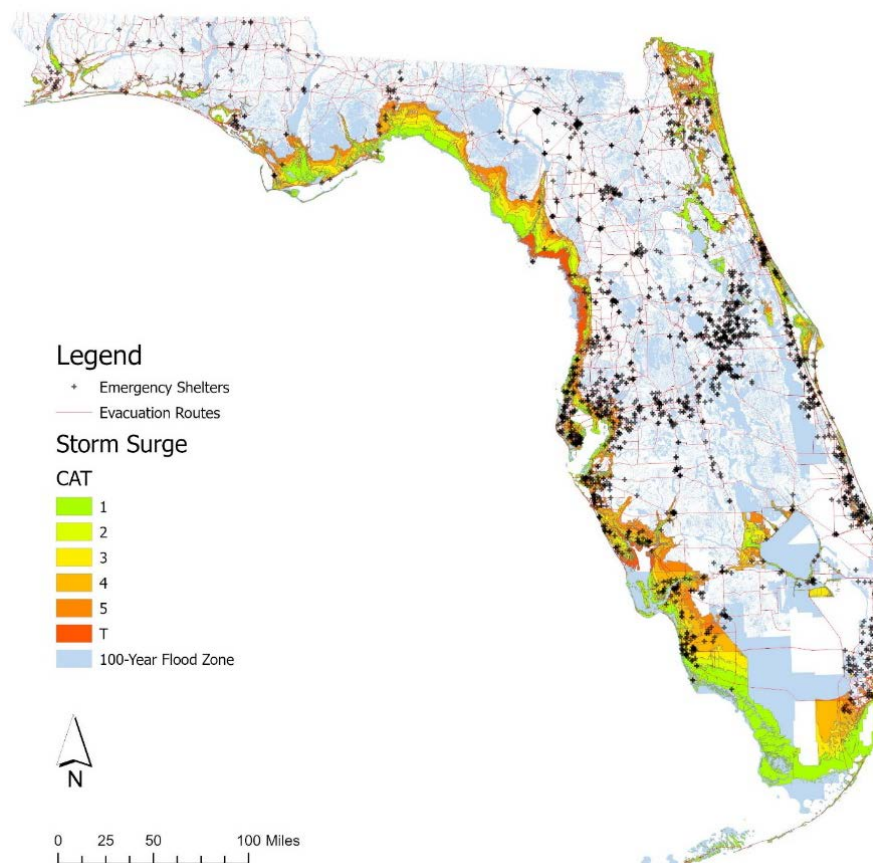
<sup>12</sup> <https://afdc.energy.gov/stations/>

### ***Fleet Locations***

In addition to fueling stations, various private fleet managers provided data for their fleet locations through their local Clean Cities coalition. These data came from numerous fleets in Florida, through all four of the Florida Clean Cities coalitions and other National Clean Fleet Partners (EERE 2014). Data included vehicle type, fuel type, number of vehicles, and location. Fleet names were omitted for privacy reasons.

### ***Flood Zones, Storm Surge Zones, Shelters, and Evacuation Routes***

This analysis uses several data sets that pertain to floods. These data sets were provided by FDEM and University of Florida's GeoPlan Center. The first dataset for this layer is the flood zone data. Flood zones were trimmed to only include 100-year zones because the 500-year zones cover nearly the entire state and were therefore not useful for the scenarios envisioned in this analysis. The second data set was storm surge data, which include zones of storm surge inundation for Category 1–5 hurricanes, as well as storm tides (T). Finally, the flood shelters and evacuation routes data sets were used as the core transportation network for the station connectivity analysis. Figure 22 shows a snapshot of these data sets in Florida.



**Figure 22. Florida flood risk, emergency shelters, and evacuation routes.**

Emergency shelter and evacuation routes obtained from Florida's Division of Emergency Management ([https://geodata.myflorida.com/datasets/7fc21b70ee4942a898ea6dfe5700fcd6\\_0/about](https://geodata.myflorida.com/datasets/7fc21b70ee4942a898ea6dfe5700fcd6_0/about)). Storm surge and flood data obtained from the University of Florida's GeoPlan Center (<https://sls.geoplan.ufl.edu/viewer/>).

## County-Level EVSE Projections

This portion of the analysis is specific to EVs. NREL’s EVI-Pro tool provides projections of the number of EVSE ports needed at the county level for 2030, 2040, and 2050 (per Section 6).

These projections are further broken down into public and private needs, as well as by EV charger type/level. This analysis uses the 2030 EVSE projections for public DCFCs. The details for how these projections are calculated are addressed in the EVI-Pro section (Section 6).

## Other Data Sets Considered

In addition to the data sets previously described, other data sets were considered for the analysis but ultimately not included as part of the methodology. We describe them for the benefit of future analyses. The first is grid reliability data from various Florida utility companies. These data are provided in the form of System Average Interruption Duration Index (SAIDI) values from the five publicly owned utility companies in Florida: Duke Energy, Florida Power and Light, Florida Public Utility Company, Gulf Power Company, and Tampa Electric Company. However, the data from the companies varied dramatically in quality, resolution, and coverage. Not all locations in Florida were covered by these zones, and there is overlap between some zones. Additionally, the siting of new station locations assumed availability of temporary electricity at designated shelters via generator or solar, so the SAIDI value for a shelter’s location was deemed uncritical. For these reasons, these data were not considered consistent enough to factor as part of the EV analysis. Appendix A displays these SAIDI data for reference.

The second data set—the output results from the *Florida Electric Vehicle Roadmap* report (Burk et al. 2020)—were reviewed and considered for this analysis. However, that work was focused predominantly on broader EVSE implementation, without direct focus on such implementation with flood events in mind. As such, the methods from that report were used to inform the analysis, but the data were not a direct input for this work’s methodology.

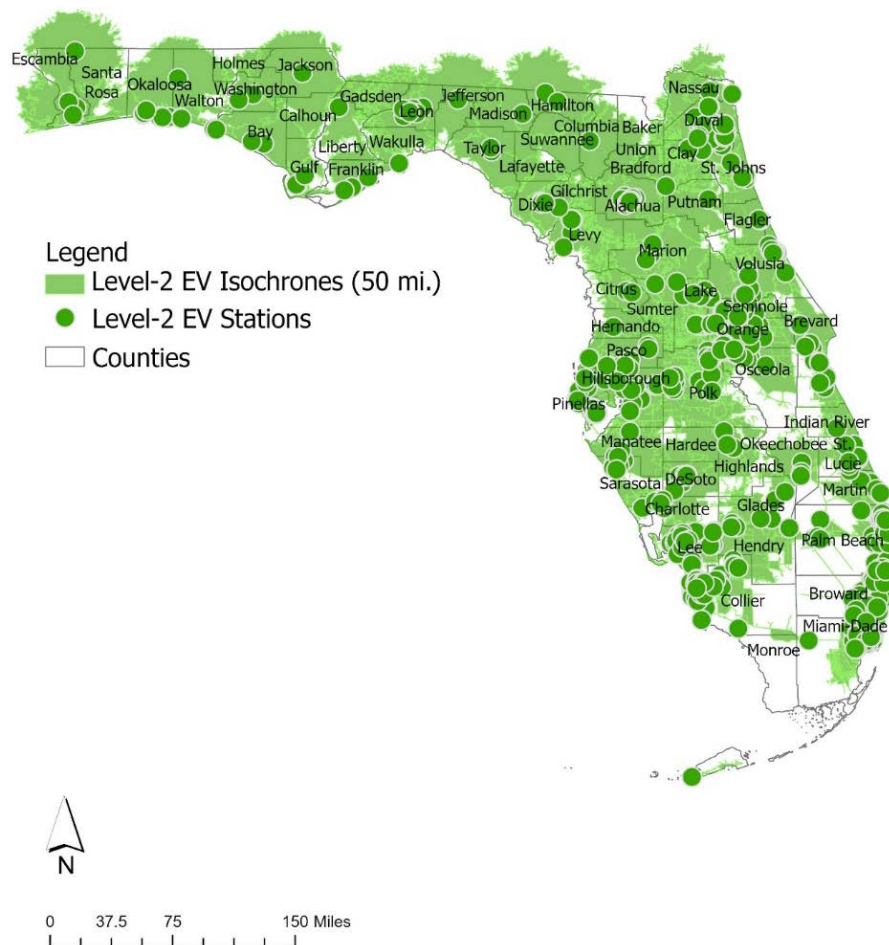
## Future Infrastructure Identification Methods

This analysis has two primary objectives with two corresponding methodologies. The first objective is to identify possible locations for new fueling stations to better build Florida’s AFV fueling network along evacuation routes. The second objective, specific to EVs, is to address how the current EVSE infrastructure compares to the needs shown in EVI-Pro’s model for 2030. A multi-criteria decision analysis (MCDA) pipeline is used to narrow down the input data sets to more discrete spatial locations of possible stations, as well as to limit the current EVSE based on whether a station is within a flood zone, for comparison with 2030 EVSE projection needs from EVI-Pro. The flowchart in Appendix B shows the generalized MCDA algorithm, and the subsequent chart in Appendix C shows the process for EVs with the added steps for calculating the EVSE needs based on the EVI-Pro output. The steps of the MCDA workflow are expanded upon in the following subsections in terms of the data flow of the core inputs.

## Stations and Fleets

Subsets of the station and fleet layers were created for each AFV type. To identify stations that are at risk during a flooding event, these layers were intersected with the flood zone and storm surge zone layers. This resulted in flood-safe and flood-risk station layers that were used in different phases of the model.

Next, driving distance service areas were generated for each fuel type. This was done by using the flood-safe stations and fleets as facilities in a network analysis algorithm to generate service areas for the stations based on driving distance. The service areas for each AFV type were generated using distance thresholds rather than travel time because the model is focused on AFV infrastructure connectivity and is not concerned with traffic volume. The distance thresholds are 150 miles between propane and CNG stations and 50 miles between DCFC and Level 2 EV stations, derived from those used by the FHWA's Alternative Fuel Corridors program. The ranges of modern CNG, propane, and electric vehicles may be considerably longer than these thresholds, but the conservative approach to utilize the distance thresholds established by FHWA was used for this analysis in order to account for the potential for older, lower-range models to operate with auxiliary loads in a variety of temperatures and road grades. The resulting service areas (also called isochrones) from the algorithm represent the places AFV drivers can reliably navigate to flood-safe fueling stations. Figure 23 shows the resulting Level 2 EVSE potential areas as an example.



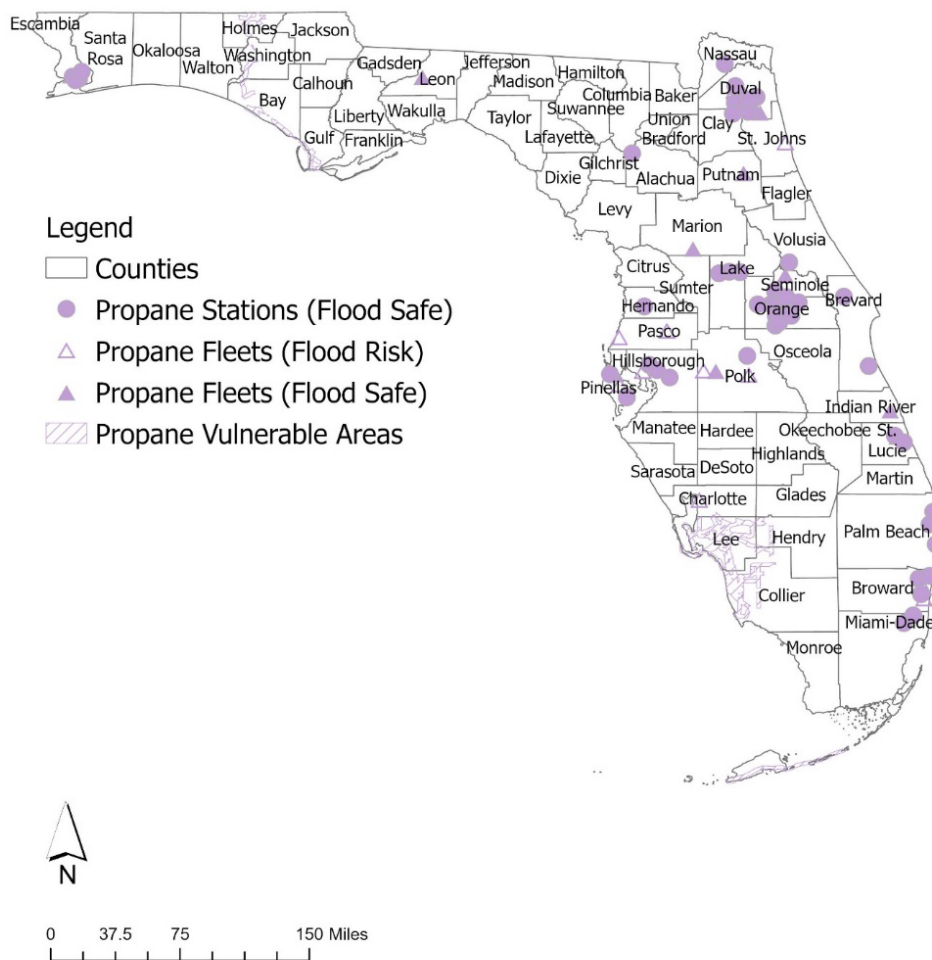
**Figure 23. Level 2 EVSE and related 50-mile radius EV service map**

### **Evacuation Routes**

The designated evacuation routes in Florida were used as the core network for escaping a hurricane or flood in Florida. They are assumed to be structurally secure for utilization during a

flooding event by virtue of their designation as emergency evacuation routes. They also provide adequate coverage in each county. A 1-mile buffer was created around the evacuation routes. This buffer area is assumed to be close enough to the route to be able to fuel a vehicle quickly without going too far from the main road, potentially driving back into inundated areas. Flood-safe AFV stations within these buffers were extracted and used as the stations for the aforementioned service area isochrone generation.

Next, the evacuation route buffers were clipped by the flood-safe service areas for each AFV type based on AFV range. These resulting areas are deemed the potential areas of new AFV station installation due to their proximity to the evacuation routes but exclusion from the service area of current AFV stations. Figure 24 shows an example of this result for propane vehicles.



**Figure 24. Propane vehicle vulnerability map**

### **Evacuation Shelters**

Evacuation shelter locations were used in this analysis as potential locations for new AFV infrastructure installation. This is due to their presumed security from flooding, transportation needs, and grid connectivity or emergency electrical capability. They are also already ingrained in the Florida emergency management system and would therefore likely be easy to track and



monitor by emergency managers. The emergency shelter locations that intersect with the modeled AFV infrastructure potential areas near evacuation routes were extracted and used as the final output map layer for new possible flood-secure AFV station locations.

To determine how the potential locations would strengthen the evacuation route network for AFV travel, the modeled stations were added as new facilities in the original service area process, and then a new service area was generated with the merged stations. This service area and the original service area layer were each used to clip the evacuation routes layer. These two resulting service areas were used to determine the percentage of the evacuation route gaps that can potentially be filled with new stations, as indicated by the cross-hatched areas in Figure 25.

## Key Findings of GIS Analysis

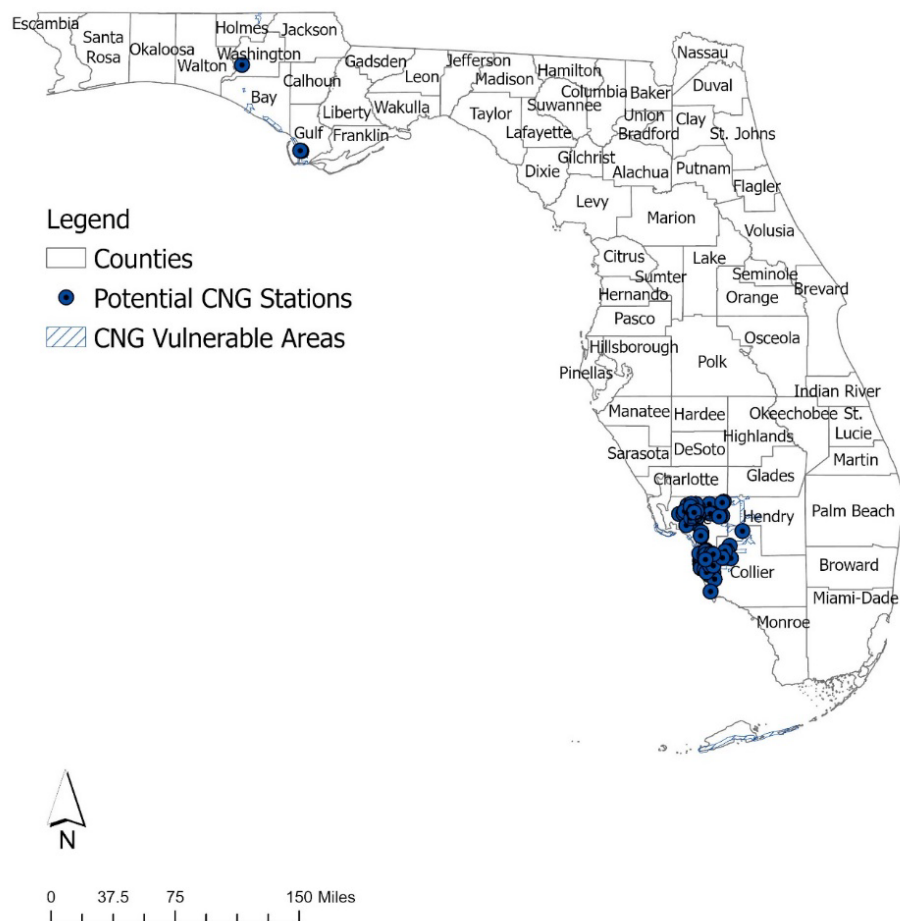
The results from this analysis highlight the state of Florida’s strong potential to build out the AFV refueling networks along evacuation routes. After removing stations that are at risk of flooding, the percentage of the evacuation routes that are covered by each of the AFV service areas averaged to 87.6%. However, after integrating the new station location possibilities, the coverage increased to an average of 99.0%. Table 5 shows the coverage broken down by each alternative fuel type. Figure 25 shows the results of the model for CNG stations.

**Table 5. AFV Corridor Coverage Change with Proposed New Stations**

<b>Fuel Type</b>	<b>Current Evacuation Route Coverage Without Flood-Prone Stations</b>	<b>Evacuation Route Coverage With Proposed New Stations</b>
DC Fast (EV)	85.9%	98.2%
Level 2 (EV)	85.3%	98.7%
Propane	84.2%	99.5%
CNG	95.1%	99.6%

Note: For new station locations, visit the web tool listed at the end of this section.

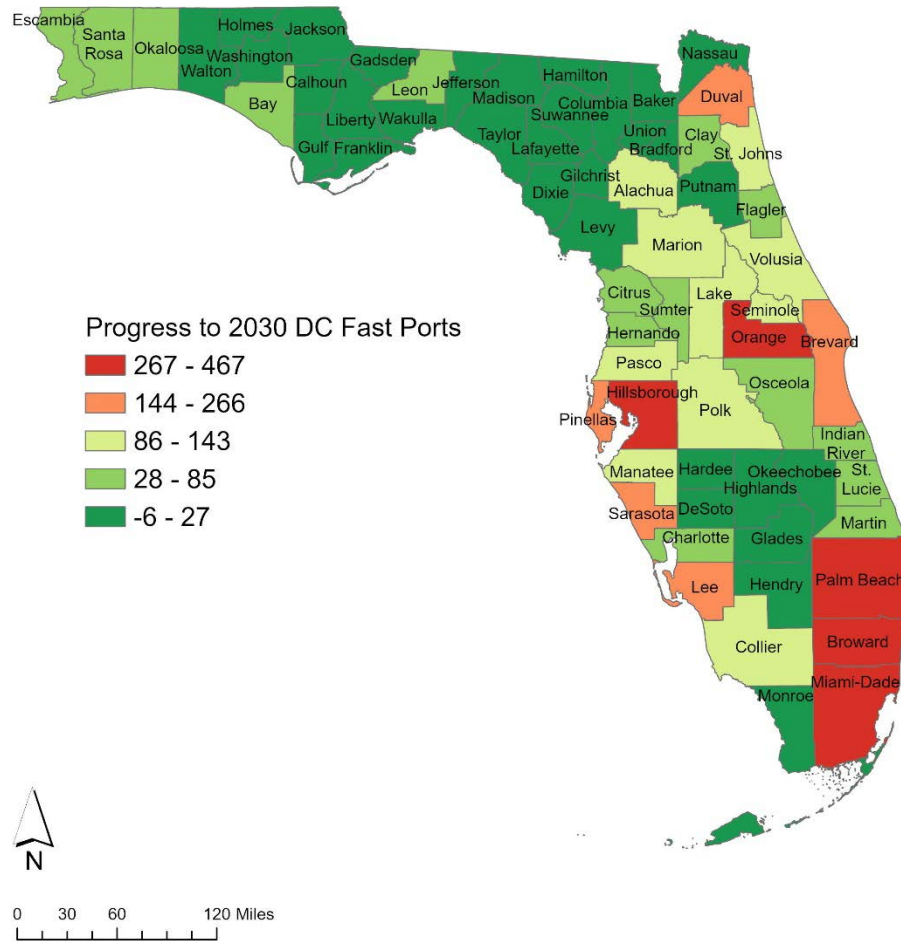
The EVI-Pro projections for needed EVSE were generated and mapped at the county level. From there, the current DCFC stations were spatially joined to the county layer. This spatial join adds a count of stations and a sum of their ports to each county. Calculations were done to determine each county’s progress toward EVI-Pro’s 2030 predictions.



**Figure 25. Best new CNG station locations identified by the analysis**

The other key result from this work is each Florida county's progress toward the 2030 DCFC plug count needs based on the EVI-Pro results. These values are displayed as their total port count toward meeting those goals in Figure 26.





**Figure 26. Number of DCFC Ports Required to Meet 2030 Goals**

The map in Figure 26 highlights varying progress toward meeting the 2030 goals for DCFC ports. Several of the more populated counties needed over 200 stations to meet their goals, and other counties were at or near their 2030 targets. Table 6 provides the values of current and future DCFC plug counts for each county.

**Table 6. Current and Modeled DCFC Port Counts by Florida County**

County	Current DCFC Port Count	2030 Port Count Target
Brevard	7	195
Columbia	2	11
Gadsden	0	7
Jefferson	0	3
Leon	5	90
Orange	16	443
Putnam	1	12
Seminole	5	148

<b>County</b>	<b>Current DCFC Port Count</b>	<b>2030 Port Count Target</b>
Taylor	2	2
Washington	1	3.
Citrus	2	50
Escambia	2	70
Gilchrist	0	3
Hamilton	0	1
Lee	4	207
Liberty	0	1
Miami-Dade	28	427
Okeechobee	11	5
Osceola	9	84
Madison	0	2
Santa Rosa	0	45
Marion	2	96
Gulf	0	3
Suwannee	1	7
Lake	7	115
Pinellas	14	280
Dixie	0	2
Nassau	0	26
Bradford	0	4
Flagler	1	39
Holmes	0	2
Monroe	4	31
St. Johns	5	108
St. Lucie	4	75
Sarasota	3	177
Alachua	2	102
Broward	17	484
Charlotte	4	58
Collier	4	123
Hendry	4	4
Indian River	2	49
Jackson	1	7
Lafayette	0	0
Manatee	1	123

County	Current DCFC Port Count	2030 Port Count Target
Palm Beach	13	465
Clay	0	51
Hardee	0	2
Levy	0	8
Bay	2	42
Okaloosa	1	56
Baker	0	3
Pasco	6	132
Glades	0	2
Martin	1	56
Highlands	5	25
Volusia	11	141
Duval	15	207
Walton	1	26
Hernando	0	49
Sumter	3	64
Union	0	1
Calhoun	0	2
Hillsborough	11	346
Franklin	1	3
Wakulla	0	7
Polk	9	147
DeSoto	0	0

The resulting spatial layers from this analysis were compiled and shared as a web map tool, which was made available for the local emergency managers in Florida to use in their alternative fuel resilience plans.<sup>13</sup> More supplementary information for the web map is available on the homepage.<sup>14</sup> The following section provides an example of how one might use this tool to identify possible locations for a new AFV station.

## Florida Alternative Fuel Resilience Web Map Local Usage Example

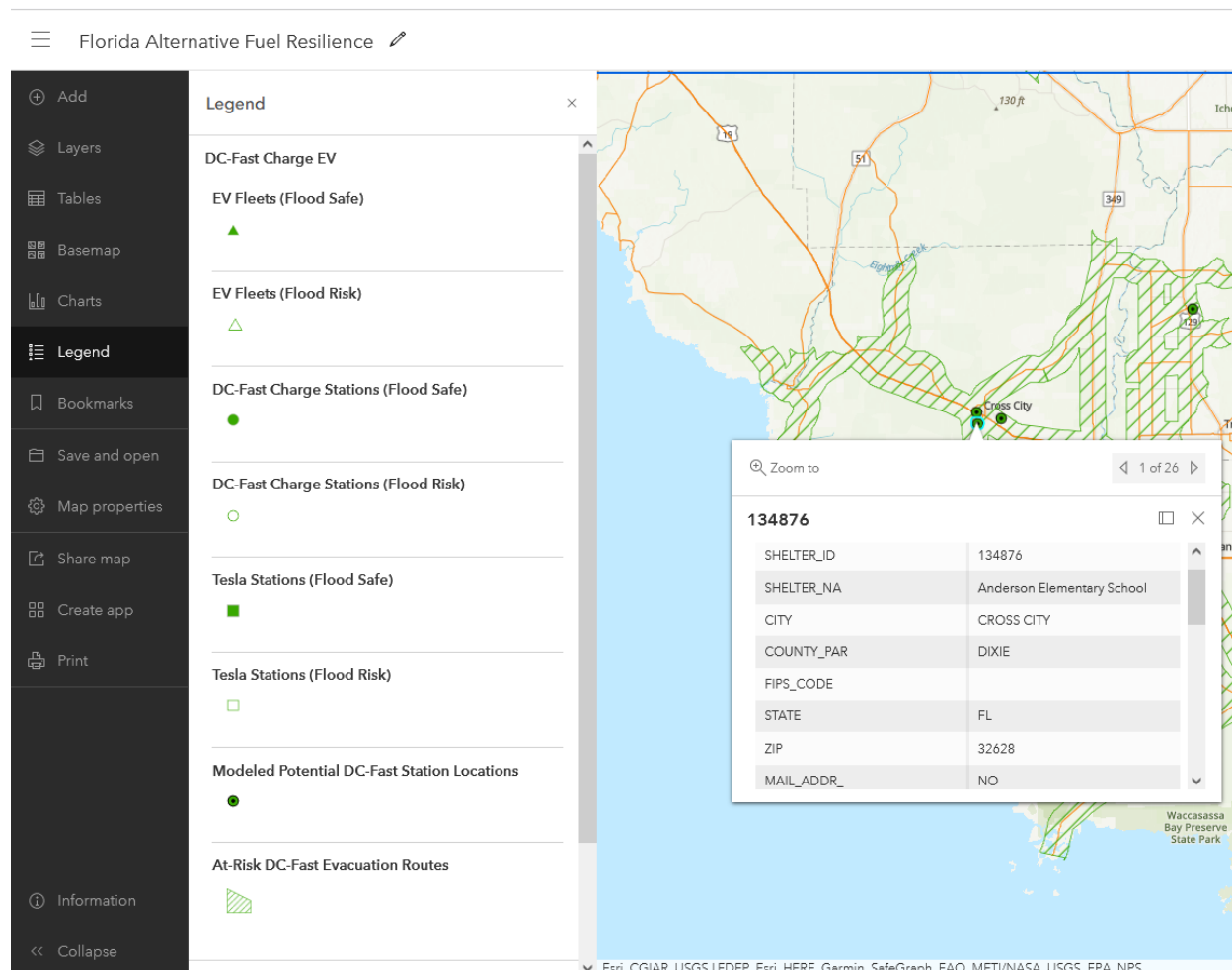
The result of this analysis is the Florida Alternative Fuel Resilience web map on ArcGIS Online: an interactive web map that emergency management practitioners can utilize for making alternative fuel resilience plans in their counties. The results shown in the previous section indicate some counties may be further along in the infrastructure rollout than others. This section

<sup>13</sup> <https://nrel.maps.arcgis.com/apps/mapviewer/index.html?webmap=70d980d59f39453387d8286fcb505ae1>

<sup>14</sup> <https://nrel.maps.arcgis.com/home/item.html?id=70d980d59f39453387d8286fcb505ae1>

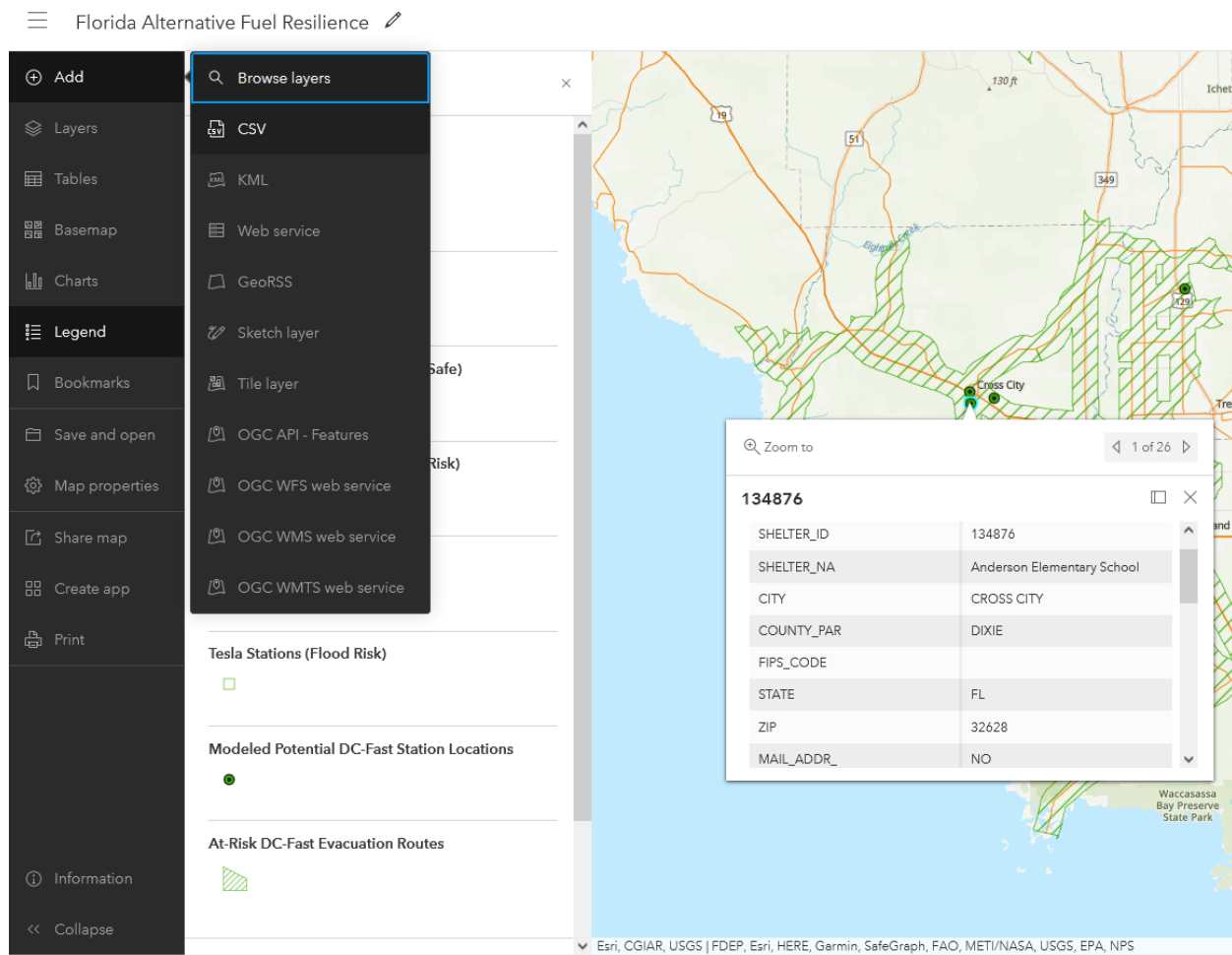
provides an example of how one could utilize the web map tool for DCFC implementation in Dixie County.

When navigating the app, users can interact with the map and sidebar items—as is typical with interactive web maps. Users can click on stations or shelters to gather more information about the location. This can be used to get contact information for a current station or location information about a shelter as a potential installation location, as shown in Figure 27.



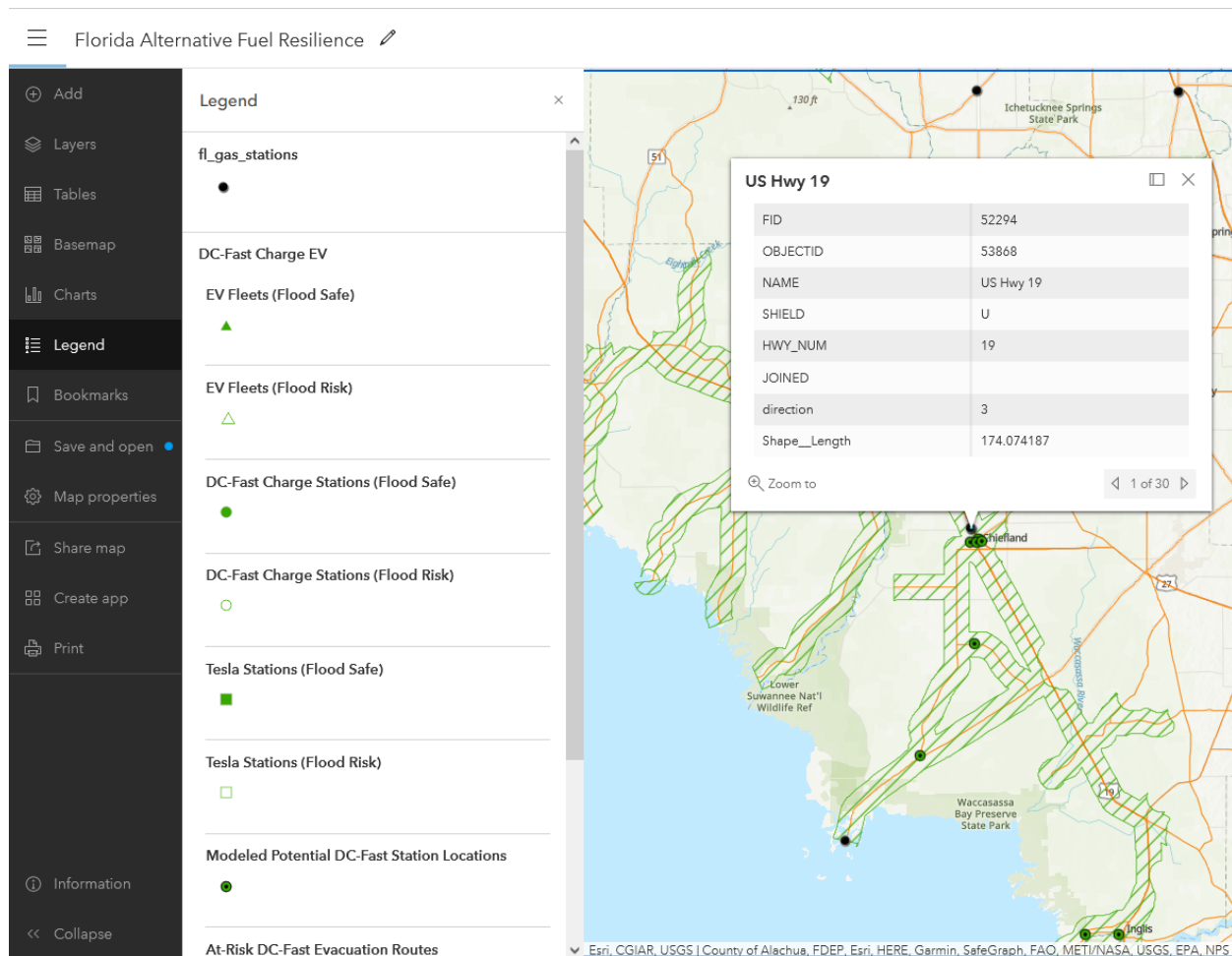
**Figure 27. Resilience web map features while planning EV resilience in Dixie County**

Additionally, the areas of potential EVSE siting based on proximity to the emergency road network were included in the application. In addition to all the data layers outlined above, users have the ability to upload data for other facilities that they are considering for station siting, or if they know the areas for temporary charger placement for further on-site research as part of their plan. By clicking the “Add” button, users can add their own location data from several format options, as shown in Figure 28.



**Figure 28. Example of the ability to add new data to the resilience web map**

The example in Figure 29 shows the addition of a Florida natural gas station data set from ArcGIS Online. The new stations on the map can then be further selected to see the station attributes so that the user may discern further potential in these added stations.



**Figure 29. Example use case after adding gasoline station data to the resilience web map**

The example in this section shows a brief typical usage of the Florida Alternative Fuel Resilience web map. From here, the user can proceed with whatever necessary steps are next (e.g., site evaluation) to determine which of the locations identified in this map can be used for a new alternative fuel station. Additionally, ArcGIS Online has the capability to interface with other web map layers or web tools that the local GIS practitioners in Florida can also utilize as they see fit.

## Comparison to Florida's EV Roadmap and EV Master Plan

Two other Florida-based alternative fuel plans were in development in tandem with NREL's *Florida Alternative Transportation Fuel Resilience Plan*: the *Florida Electric Vehicle Roadmap* from the Florida Department of Agriculture & Consumer Services (Burk et al. 2020) and the *EV Infrastructure Master Plan* from FDOT (FDOT 2021). Each of these three plans addresses fuel resilience to some degree, so it is important to identify the distinguishing factors between them. First, both of the other projects focus exclusively on electric vehicles, whereas this project addresses CNG and propane vehicles in addition to EVs. Secondly, the other plans focused on EV infrastructure broadly for the state of Florida with small subsections regarding resilience, whereas this report focuses centrally on resilience.

When comparing the resilience aspects of each of these three reports, each adds value by approaching the question with different methods and applications of input data, all while adhering to similar MCDA workflows. The *Florida Electric Vehicle Roadmap* approached the problem by incorporating land use and demographic data, such as employment locations, in conjunction with EV adoption projects and current infrastructure. This project also identifies near-term temporary station locations that serve rural areas and bolster key corridors. The *EV Infrastructure Master Plan* has a more demand-focused approach to identify gaps for DCFCs along the state highway system. The key difference in this methodology is the utilization of traffic data and a focus on drive time to identify priority locations for DC fast stations along the state highway system. The distinguishing factor of this project's methodology behind the development of the web mapping tool is a focus on spatial network connectivity of Florida's evacuation routes, and filling gaps within that network regardless of normal traffic demand or local demographics. This methodology was created under the assumption that although the state highway system and the emergency evacuation routes often overlap, travel demand would likely dramatically shift during a flooding event. However, normal demand was considered under the EVI-Pro section as it relates to county-level projections, but this aspect of the project is separate from the specific resilience-related station siting.

## GIS Summary

This section introduces the data, methods, and resulting web map tool of the Florida alternative fuel resilience project. The analysis uses an MCDA spatial analysis approach that identifies areas along Florida's emergency evacuation routes that are vulnerable to flood or storm surge events for each fuel type including propane, CNG, DCFC EV, and Level 2 EV. After using emergency shelter location data to fill in the vulnerable areas, it was found that using just these locations could increase the evacuation route corridor coverage from 87.6% to 99.0% across all alternative fuel types.

The analysis in this section showed strong potential for bolstering Florida's alternative fuel infrastructure along emergency routes by inclusion of emergency shelters alone as possible locations for new AFV stations. These results, however, were based on baseline assumptions about the vulnerability of current stations based on overlap with flood zones and a lack of other data for new station options for each county. Local officials will have a better understanding of local geography, government programs, and other factors that might allow them to identify better locations for new stations. These local officials can then import their own data into the Florida Alternative Fuel Resilience web tool for more refined analyses based on their local expertise.

The objective of this analysis was ultimately to identify a pathway for completing alternative fuel corridors along Florida's emergency evacuation routes for both evacuations and emergency operations. However, it did not factor travel demand or load for the alternative fuel stations. Future iterations of this work might include more of this type of data to determine where stations should be installed from both a spatial and travel demand perspective. Lastly, this analysis was generalized to the entire state of Florida, but storms and flood events impact different parts of the state and affect the emergency management system dynamically. A case study incorporating the results of this analysis using data from a historical flood event could better refine the methodology of this analysis and provide further direction on broadening this analysis to be more impactful.



## 8 Laws, Regulations and Organizations Relevant to Resilience Planning

This Alternative Transportation Fuel Resilience Plan must complement other actions that the state of Florida and local governments have taken to prepare for natural disasters and improve resilience. It must utilize existing laws and regulations, leverage the work of regional planning councils, and build upon work done by the state government.

### Relevant Laws and Regulations

The peninsular geography of Florida requires planning officials to incorporate resilience goals into planning documents for a variety of natural hazard scenarios. The State Comprehensive Plan provides long-range policy guidance for the orderly management of state growth (Section 187.101(1), F.S.), while local governments are required to adopt local comprehensive plans to manage future growth of their localities (Section 163.3167(2), F.S.). Local development must conform to the local Plan's provisions,<sup>15</sup> which may include provisions to better utilize alternative fuel vehicles for hurricane-related evacuation, emergency, and recovery operations.<sup>16</sup>

Local comprehensive plans must include principles, guidelines, standards, and strategies for orderly and balanced future land development, which reflect community commitments to implement these plans (Section 163.3177(1), F.S.) and identify procedures for monitoring, evaluating, and appraising implementation (Section 163.3177(1)(d), F.S.). Mandatory elements of these plans include the following:

- Capital improvements (Section 163.3177(3)(a), F.S.);
- Future land use plan (Section 163.3177(3)(a), F.S.);
- Intergovernmental coordination (Section 163.3177(3)(h), F.S.);
- Conservation (Section 163.3177(3)(d), F.S.);
- Transportation (Section 163.3177(3)(b), F.S.);
- Sanitary sewer, solid waste, drainage, potable water, and aquifer recharge (Section 163.3177(3)(c), F.S.);
- Recreation and open space (Section 163.3177(3)(e), F.S.);
- Housing (Section 163.3177(3)(f), F.S.); and
- Coastal management (Section 163.3177(3)(g), F.S.).

### Regional Planning Councils

In 1980, the Florida Legislature passed the Florida Regional Planning Council Act, finding that “there is a need for regional planning agencies to assist local governments to resolve their common problems, engage in areawide comprehensive and functional planning, administer

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<sup>15</sup> For a discussion of the requirement that Florida localities maintain comprehensive plans informed by an analysis of “relevant and appropriate data,” see David L. Markell, *Emerging Legal and Institutional Responses to Sea-Level Rise in Florida and Beyond*, 42 Colum. J. Envtl. L. 1, 23–26 (2016).

<sup>16</sup> In their local government land development regulations, counties and municipalities must include a provision for “Ensuring safe and convenient onsite traffic flow, considering needed vehicle parking.” Section 163.3202(2)(h), F.S.

certain federal and state grants-in aid, and provide a regional focus in regard to multiple programs undertaken on an areawide basis.” (Section 186.502(1)(b), F.S.)

The state’s 10 regional planning councils (RPCs) have “a duty to assist local governments with activities designed to promote and facilitate economic development in the geographic area covered by the council.” (Section 186.502(5), F.S.). Additionally, RPCs have a duty “to cooperate, in the exercise of its planning functions, with federal and state agencies in planning for emergency management,” (Section 186.505, F.S.) which they have historically fulfilled by conducting regional evacuation studies to assist county emergency management departments as they develop operational evacuation plans.

## **Resilient Florida**

The FDEP Office of Resilience and Coastal Protection offers technical assistance and funding to communities dealing with coastal flooding, erosion, and ecosystem changes through various programs related to coastal issues. The Coastal Construction Control Line Program (<https://floridadep.gov/rcp/fcmp>) and the Florida Resilient Coastlines Program (<https://floridadep.gov/rcp/florida-resilient-coastlines-program>) prepare coastal communities and habitats for the effects of sea level rise.

An additional resource is the Florida Adaptation Planning Guidebook, made available by FDEP for use by local governments to develop and update adaptation plans for sea level rise (FDEP 2018). The adaptation planning process outlined in the guidebook is intended to be used by local government planners in cities and counties of any size, especially as they identify adaptation strategies and prioritize adaptation needs, which may include protection, accommodation, retreat, and avoidance strategies.

## **Functions of the Florida Department of Agriculture and Consumer Services**

The first laws governing the sale of propane (termed “liquefied petroleum gas”) were enacted by Florida’s legislature in 1947 in order to provide the industry with uniform regulation of products in the state. The original law was contained in Chapter 526, Florida Statutes, and entitled “Sale of Liquid Fuels.” In 1961, Chapter 527, Florida Statutes, was created to govern the safe storage, transportation, sale, and use of propane in Florida.

Personnel from FDACS’s Division of Consumer Services perform functions such as weighing and measuring device inspections and motor fuel testing.<sup>17</sup> The Bureau of Compliance is currently responsible for licensing, examinations and training. The Bureau of Standards (bureau) is responsible for the administration and enforcement of Chapter 527 of the Florida Statutes and rules promulgated in accordance with that chapter. These laws and rules, and the national safety codes adopted therein, afford the bureau broad enforcement powers over all propane activities within Florida. The bureau’s public responsibility for propane safety begins when the product enters the state’s borders and continues until the product is safely consumed by the public.

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<sup>17</sup> FDACS, Division of Consumer Services, “Liquefied Petroleum Gas Laws and Rules” (Oct. 2020 Edition), available at: <https://www.fdacs.gov/content/download/73844/file/Florida-Laws-and-Rules-Guide.pdf>

Additionally, FDACS enforces the following rules, standards, and regulations: Rule Chapter 5J-20, Florida Administrative Code, which adopts NFPA 58, Liquefied Petroleum Gas Code; NFPA 54, National Fuel Gas Code; NFPA 110, Standard for Emergency and Standby Power Systems; and Title 49, Parts 191-192 and 199, Code of Federal Regulations. These laws, codes, rules, and regulations require the bureau to inspect any site within Florida where propane is stored (including bulk plants, dispensing units, bulk storage sites, trucks, etc.), and authorize the bureau to perform certain duties. These duties include investigating all propane-related accidents, licensing all propane activities in this state, and training and administer competency examinations to industry personnel. These licensing, inspection, investigation, and training activities enable the department to ensure that only competent persons engage in LP gas business activities and that compliance with acceptable safety codes and standards is achieved statewide.

## 9 Vehicles in Standing Water

To better understand what issues real-world fleets are dealing with when it comes to flooding and high-water conditions, NREL performed a literature review and had multiple discussions with fleets in hurricane- and flooding-prone areas of the country. The goal of these discussions was to learn specifics about any history with vehicles in high-water conditions, including what vehicles they use in these situations (if any) and why they may or may not fare better than other vehicles in the fleet. NREL also wanted to identify if any vehicles were specifically purchased because of their abilities in high water, or if any modifications were made to existing vehicles in the fleet to allow them to operate better in standing water. Finally, we discussed alternative fuel vehicle use in the fleet, including any plans for incorporating alternative fuels in the future and the impact on the fleet's capabilities to drive through standing water.

The following subsections discuss key findings from the literature search and fleet interviews, including components of high-water-capable vehicles, fleet-preferred high-water vehicles, and the feasibility of alternative fuel use in these fleets.

### Important Components of High-Water-Capable Vehicles

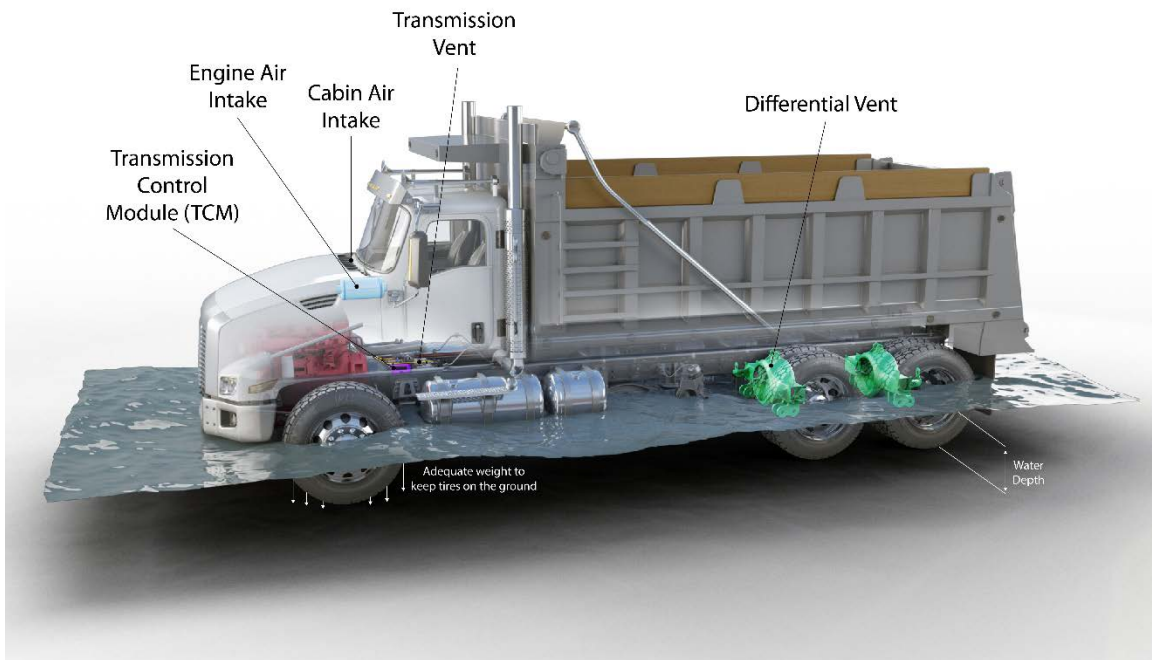
In the literature review (Appendix F), NREL identified common damage to vehicles that have been through high-water conditions, including damage to engines and transmissions, electrical components, and vehicle interiors. Some of these occur immediately, leaving vehicles stranded, and others set in later after the vehicle has performed its emergency mission. Subsequently, NREL's discussions with fleets reinforced many of the findings of the literature review, as discussed here and summarized in Figure 30.

First, fleets with vehicles using any kind of combustion (including diesel, CNG, and propane) must consider how high the vehicles' engine air intake systems are to ensure the engines do not stall. If enough water entered the air intake system, the engine would stall immediately, thus leaving the vehicle inoperable. Second, electrical components are part of the car that can sustain substantial damage from flooding (Scott 2020). Most electrical components are sealed to be water-resistant and can handle water for short periods of time. However, submersion is a potential cause of failure during these situations because wires can short and saltwater will cause corrosion in the longer term. One of the propane school bus fleet managers that was interviewed pointed to transmission control modules as being one of the lowest electronic devices that was not waterproof.

Third, fleets must ensure that other air intakes or vents are prepared to avoid or withstand water intrusion. To do this, it is important to remotely mount the transmission and differential vent tube separate from the components at the highest points possible. This will allow for the vehicle to operate longer while in high-water situations. Another important consideration is the automatic transmission vent; the automatic transmission needs fluid to stay in a viscous state for it to operate properly. If water were to be introduced into this fluid, it would lower its effectiveness and even possibly prevent it from operating. The cabin air system also has air intakes that are a point of vulnerability. This intake is higher than the engine's air intake system or transmission vent and doesn't lead to engine stall or transmission seizure but is still detrimental to the operability of the vehicle.

While air intakes and vents are the most vulnerable to water intrusion, other components are vulnerable to slower seepage. The differential, which is a set of gears that sits beneath the vehicle and transmits engine power to the wheels, is one such component. While water in the differential is not ideal, it could operate for some amount of time if water seeped into the drive axle housing. The differential operates with gears meshing with gears, and its fluid mechanism allows for both lubrication and cooling. Therefore, it can tolerate water intrusion for some period before failure. That said, it is important to ensure that all vehicle components are protected in the case of a high-water situation to safely operate the vehicle.

Another key consideration is vehicle buoyancy. A fleet may have taken all the precautions to prevent water from entering key operating components, but the vehicle may still have the potential of being swept away in high water. Typical passenger vehicles can begin to float in less than 2 feet of water. Buoyancy liftoff occurs later (deeper) in vehicles with higher clearance, greater mass, smaller footprint, and better tire traction. It occurs earlier (shallower) if the water is flowing quickly. However, it should be kept in mind that vehicles with greater mass tend to be less efficient and spend limited fuel reserves more quickly.



**Figure 30. Medium-duty vehicle and its points of vulnerability to standing water.**

Source: Josh Bauer, NREL

## Electric Vehicles and Flooding

Electric vehicles are the only vehicles that do not require oxygen to operate. This has enabled the EV company Rivian to claim in the specifications of their R1S and R1T that these vehicles can drive through 43 inches of standing water.<sup>18</sup> However, this capability has not yet been enshrined in their warranty. Likewise, Danner claims that its electric offroad work vehicles can operate in up to 4 feet of water.<sup>19</sup> According to an article in *Green Car Reports* (Evarts 2018), all-electric vehicles typically have waterproof parts, such as the battery, traction motor, or inverter. In addition, battery cells are generally sealed and watertight. Therefore, the most important parts of the vehicle on an EV are typically less susceptible to water damage. However, the waterproofing generally cannot be trusted if the battery is fully submerged in standing water—particularly salt water. If that is the case, it is more likely that there will be damage done to the battery and possibly fires. Evarts also notes that it is possible for larger battery packs and wiring to become waterlogged and damaged in some EVs during flooding. Other than engines and transmissions, EVs are generally susceptible to the same water damage already discussed.

## High-Water Fleet Experiences

For many of the fleets that NREL spoke with, vehicle ground clearance was one of their main considerations. The best high-water vehicles have good ground clearance. This higher ground clearance raises the height of most of the vulnerable components previously mentioned. It also will allow for the water to pass under the vehicle, allowing the weight of the vehicle to keep it

<sup>18</sup> <https://rivian.com/support/article/what-is-the-water-fording-height>

<sup>19</sup> <https://www.danner.us.com/>

from losing contact with the road surface. Many fleets indicated that they would choose vehicles that were considered 1 ton or more to indicate a ground clearance and weight that would enable the tires to stay on the ground.

For example, the city of Tampa chose several Fords for this purpose. Specifically, they chose F-350 or larger (3500 series or larger in General Motors or Ram). Tampa also installed tires taller than stock. Doing this allows them to go into higher water than they would be able to with a standard pickup truck. Tampa also chose to make some of their heavier equipment, like their Class 6–8 vehicles, capable of multiple uses. For example, vehicles that might be used for street repair or other service applications could be used in high-water situations if need be. These vehicles typically have higher air intake systems, with the transmission and differential vents already relocated when the trucks have their body upfits completed. It is important to note that these vehicles could run on a variety of fuels, but in most cases, they were either diesel or gasoline. There are also options for natural gas in these applications, which have sealed fuel systems without vulnerable vapor recovery systems.

During discussions with multiple fleets, NREL found that many of them, such as Hillsborough County, rely on special equipment ordered for their fire departments for just these types of situations. It was not uncommon to find that they had a few special-purpose vehicles that could help in high-water situations. They also rely on different types of watercrafts that can be deployed when the water surpasses a certain level. The key is to not become part of the problem themselves by requiring rescue. Safety is always paramount.

NREL also spoke with the Medical University of South Carolina (MUSC) and discussed how they handle their fleet when the water rises in their area. MUSC's first building was built in 1829; since then, the university has grown into a much larger campus. The university is built in an area that is prone to flooding, which has forced the staff to investigate creative ways to move its staff between buildings. One of these ways is the use of a simple dinghy, a small boat, that can move staff from building to building during flood conditions. The boats are not powered, so they are typically walked through the water by guides on each side. This can be done if the water is not much more than 2 feet in depth and the undercurrent is what they would consider acceptable to move staff safely.

Another way MUSC moves staff is with a Light Medium Tactical Vehicle (LMTV) truck. These are vehicles originally used by the military for standard operations. They have two of these vehicles. One is an H1 Hummer made by AM General, and the other is a Stevenson M1079 LMTV 4x4 that they acquired when they were ready to be cycled out of the military system. When military vehicles are ready to be cycled out, the military typically gives local jurisdictions an opportunity to receive these vehicles as a donation. MUSC repurposed the vehicles to be able to transport staff from building to building when flooding occurs. These work well when the water is too deep to use safely.

Municipalities and governmental jurisdictions are responsible for the health and safety of their communities. After multiple discussions with various municipalities and governmental jurisdictions, it became clear that the primary focus of these fleets is to move citizens and vehicles away from the possible affected area before the storm surge arrives. This proactive measure is the best way to ensure vehicle and citizen safety in the case where waters rise very

quickly. NREL also found that local governments work with their respective school districts to utilize their school bus fleets to move large numbers of people in a short period of time to safe locations. School buses typically operate on diesel, with the option for propane and electric becoming more common. School uses are ideal with their closed fuel systems, as described in the following section.

## High-Water Vehicle Conclusions and Recommendations

As discussed in this section and in Appendix F, most designated high-water vehicles have good ground clearance to allow for the water to pass under the vehicle, allowing the weight of the vehicle to keep it from losing contact with the road surface. Higher-ground-clearance vehicles also keep the vulnerable components farther off the ground and safer from water damage. Therefore, for fleets looking to incorporate high-water-capable vehicles into their fleets, we recommend identifying vehicles that have good ground clearance and have their components as high off the ground as possible. Some examples discussed here include the Ford F-350 and LMTV trucks.

For fleets looking to incorporate alternative fuels, AFVs may be a good option for use during high-water situations. This is because, for example, vehicles that are powered by propane or natural gas have completely sealed fuel systems. Therefore, at no point would water be allowed to infiltrate the fuel system until it is combined with air in the combustion chamber. In addition, natural gas and propane vehicles do not require a vapor recovery system, which is prone to water damage for conventionally fueled vehicles, and thus would not be a concern for high water.

Not only are alternative-fueled vehicles themselves possibly more reliable during high water, but it is also important to note that alternative fueling stations can be designed with backup generation to provide power during times where the standard power sources are interrupted. For example, natural gas stations can utilize natural gas compressors to power the sites without interruption in the case of a power outage.

As discussed in Appendix F, EVs are the only vehicles that do not require air intake to operate. Therefore, the most important parts on an EV are typically less susceptible to water damage. Some EV manufacturers, such as Rivian and Danner, advertise that their vehicles are capable of crossing high water without damage to the vehicle. Rivian notes a water fording height of up to 43 inches in some of their vehicle models, whereas Danner states that their work vehicles can operate in up to 4 feet of water. However, before taking any EV through standing water, both the vehicle warranty and the owner's manual should be consulted. In some cases, driving a vehicle through standing water may void the vehicle warranty. Furthermore, corrosion from extended periods of submersion in saltwater can result in EV auto-ignition. This resulted in 11 EVs burning after Hurricane Ian (Weise 2022), accelerating research into the impact that extended periods of saltwater submersion has on EVs.



## 10 Conclusions and Recommendations

Diversifying transportation fuels to include natural gas, propane, and electricity can improve transportation resilience in the face of hurricanes in Florida. The FDACS, NREL, and the University of South Florida have come together to develop this *Alternative Transportation Fuel Resilience Plan* so that Florida can take the necessary steps to be ready to utilize their AFVs in evacuation and recovery operations. All three organizations reached out to key stakeholders and convened a workshop to better understand the needs and challenges of transportation during hurricanes.

Communication is a problem for transportation operations during hurricanes—a problem that the reduced number of refueling stations exacerbates. To alleviate this problem, NREL created a web tool that provides fleet managers with key resilience preparation information, including the compatibility of refueling stations to their vehicles and emergency contact information. Since EVs are projected to increase quickly in Florida, NREL ran EVI-Pro to determine the EVSE needs in 2030 and 2050. By 2030, Florida is expected to need 45,485 nonresidential charging stations, with 54% being work L2, 34% public L2, and 12% DCFC. Broward County will need the most charging stations and Lafayette will need the fewest.

Utilizing alternative fuels for evacuation and emergency purposes requires geographical logistics and planning. NREL performed a GIS analysis to determine which corridor (key to connectivity) stations are likely to be inundated during a hurricane and where new stations could be located to improve that connectivity. One strategy the analysis pursued was placing alternative fueling stations at emergency evacuation shelters, since these are in relatively safe areas and they are central to much of the evacuation and essential supply transportation. This analysis found that statewide, placing stations at shelters could increase the evacuation route corridor coverage from 87.6% to 99.0% across all alternative fuel types. The highest value of the GIS tool is using it at the local level with specific fuel types and scenarios. Therefore, NREL made the GIS tool available to the public and used the tool to run a case study of Dixie County to show how to use it.

One of the main vulnerabilities that vehicles have to hurricanes is standing water. Through a literature search and fleet interviews, NREL assessed the vehicle components that are vulnerable to standing water, categorized the severity of this vulnerability, and charted them based on relative height. NREL also highlighted differences between AFVs and preparations that can be taken to enable vehicles to withstand greater depths of standing water.

The *Florida Alternative Transportation Fuel Resilience Plan* lays a pathway for resilience and emergency planners to strategically bolster their alternative fueling infrastructure and fleets so they can be ready to provide evacuation, emergency, and recovery operations during future hurricanes. Many of the preparations outlined in this plan can be transferred to other states or regions of the world, and similar tools can be developed for other regions. Furthermore, many of the general strategies can be adapted to be helpful in the face of other disasters such as floods, forest fires, or freezing stretches due to the polar vortex.

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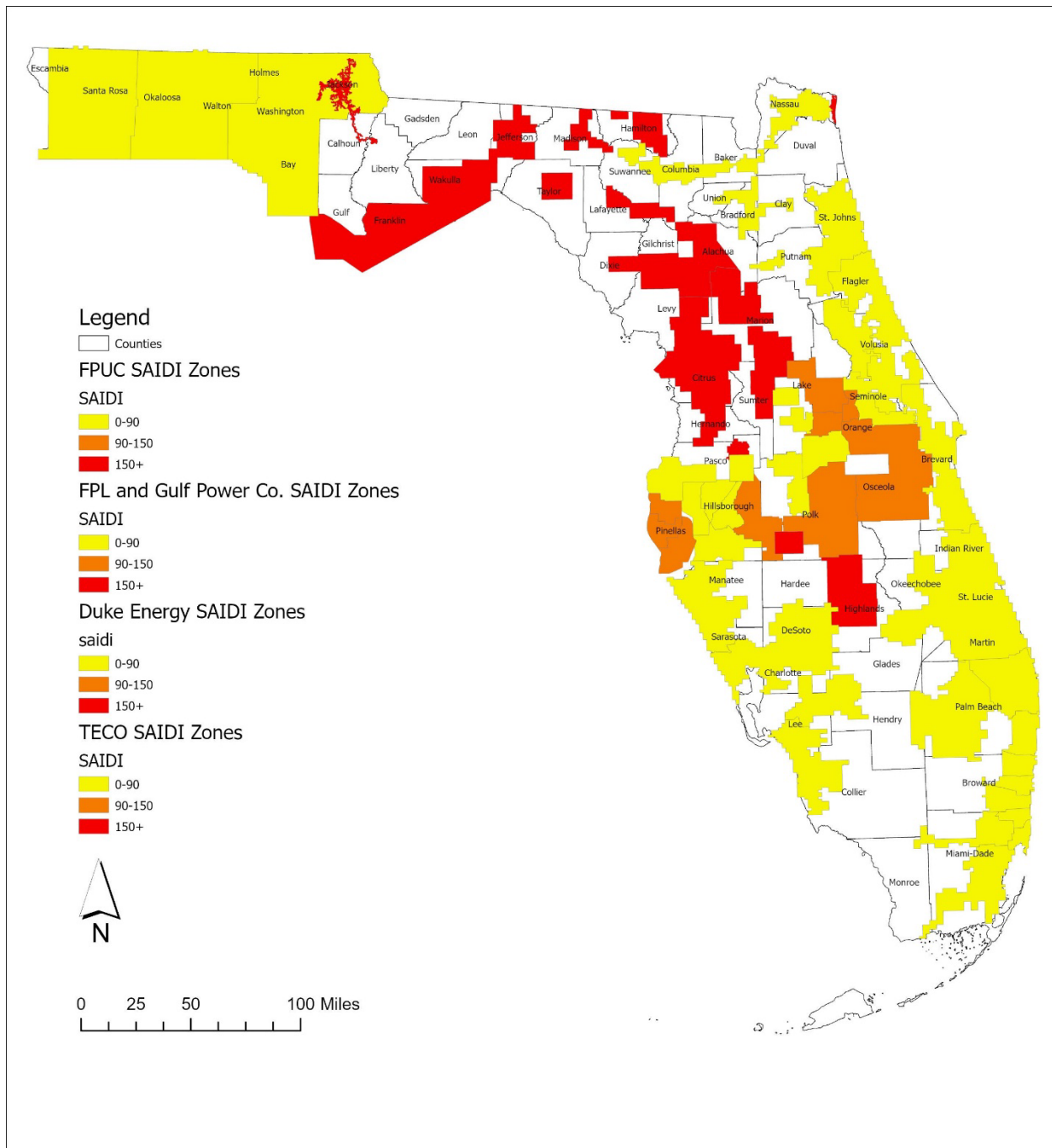
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## Appendix A. SAIDI Zone Data Provided to NREL





## Appendix B. Site Visit Summaries

### Waste Pro Facility and CNG Fueling Site

Waste Pro's conversion to CNG began in 2016 with the construction and installation of CNG stations at the Sanford and Sarasota Waste Pro facilities, and was fully operational by 2017.

The Sanford CNG station can accommodate fueling a maximum of 110 CNG refuse trucks, but as of the writing this report, Waste Pro has a fleet of 48 CNG haulers and 20 diesel refuse trucks (capable of handling 16 tons of garbage). Florida Utility (Infinite Energy) supplies natural gas to support Waste Pro's fueling system, and Waste Pro receives 120,000 gallons of diesel fuel delivered daily from Lynch Oil to fuel the diesel refuse haulers, which are fueled nightly. Although Waste Pro does not store diesel on-site, they do have on-site fueling.

The Waste Pro CNG fueling system has two 250-horsepower Clean Energy compressors that pressurize Waste Pro's CNG at a higher rate compared to rates that similar fleets use, but there are lower-pressure options. Waste Pro receives natural gas at 100 psi from the natural gas service line (Infinite Energy) and compresses it to slightly above 3,800 psi. CNG is delivered at 3,800 psi to the fueling nozzles.

The city of Sanford provided the land for building the CNG station, and Clean Energy built and also maintains the CNG fueling infrastructure. To construct the CNG fueling system, Waste Pro bored under the ground fuel lines. Harland Chadbourne, Director of Purchasing for Waste Pro, noted that Waste Pro prefers the aboveground infrastructure (e.g., pipeline) because it can be cut and reconfigured as needed. The fueling hosts (gas lines fueling the trucks) comprise 20–25-foot hoses. There are 80 dual-fuel fueling hookups to fuel the trucks parked in the lot. The dual-fuel posts can be changed to quad if needed. It was noted that there is a gas line as well as electrical to power the fueling equipment.

For Waste Pro's needs, time-fill was the best option for refueling at the Sanford facility, though Waste Pro does operate fast-fill stations at other locations. Considering the Waste Pro trucks are typically within 30 minutes of the main fueling depot in their service territory, it is not necessary to fuel outside of the Sanford station unless there are extenuating circumstances (e.g., fuel supply is disrupted or the truck travels outside of the service territory). Waste Pro is able to do a quick fuel-up of the trucks if needed. While the Sanford station is time-fill, it is capable of also doing a fast fill (but not all vehicles are able to be fast-filled at the same time). Waste Pro can accommodate a fast fill for 1–2 trucks, but if many trucks are filling at the same time, it will not be able to fill quickly. Fast-fill usually takes 15–20 minutes. Drivers usually look at tank pressure to determine fill status of the tank (and do not have to rely on vehicle gauges, which can be inaccurate). A pressure of 3,800 psi means a full tank, 1,200 psi is 1/4 of a tank, and 600 psi is close to empty engine stall. To obtain access to fueling, each truck has a barcode.



**Figure B-1. Gauge above 400 psi at WastePro.**

Source: Tampa Bay Clean Cities

The CNG rear haulers have dual nozzles, which can accommodate a quick charge of up to 3,800 psi. Waste Pro operates purpose-built Cummins 6-cylinder, 10.7-liter engine refuse haulers, which are the same size as the diesel trucks.

Fuel redundancy is an important strategy for Waste Pro. There needs to be redundancy so one pump is able to rest while the other pump is working. In terms of backup power, the Sanford facility has a diesel generator (140 kW) that can potentially operate for up to a week with its 1,000-gallon diesel storage. In the past, Waste Pro ran the diesel generator for 2 days nonstop. The only natural gas interruption that Waste Pro experienced in the past was when a gas line ruptured in Sanford that disrupted supply to the station for 2 days.

When evaluating the payback period on CNG, Waste Pro determined that there is approximately a 5–6-year payback period on CNG and found that if a fleet has 50 or more trucks and requires 200,000+ gallons of fuel per year, it makes economic sense to have a bulk diesel or CNG station instead of receiving daily fuel deliveries. Waste Pro plans to continue integrating on-site diesel tanks and CNG fueling.



**Figure B-2. Natural gas line service inlet at 100 psi.**

Source: Tampa Bay Clean Cities

Regarding maintenance, Waste Pro is contracted with a third party to conduct inspections of the CNG tanks. There are three different maintenance bays on property. The refuse trucks have methane detectors both in the truck and in the maintenance bays. Waste Pro conducts its own driver training through a 4-day course.

Although Waste Pro has not experienced flooding with past hurricanes, there have been instances when the CNG supply was impacted. Waste Pro has a mobile tank and rescue truck capable of filling a quarter tank of diesel to get the truck back to the yard. The mobile tank is charged at the fueling facility. There are capabilities for sharing fueling. Since the air intake is located high on the refuse trucks, they can handle standing water up to the windows (though this would not be recommended). Waste Pro is considered an essential service and has fueling capabilities.

The overall cost of the Sanford CNG station was \$1.5–\$1.7 million. Waste Pro pays for this in the price of the CNG gallon of gasoline equivalent. The diesel-powered backup generator cost approximately \$70,000–\$150,000. Clean Energy offers finance deals when you pay for station construction in terms of the price of the gallon. Harland also mentioned that cities can have deals in place beforehand to reduce capital costs. The payback is usually 5–7 years. Diesel and CNG refuse haulers can cost anywhere in a range of \$350,000 to \$400,000, whereas electric refuse

trucks are approximately \$700,000–\$750,000. At this price point, electric trucks are hard to justify at this time, and there is barrier to entry because of the capital costs required to invest in electric refuse haulers.

Waste Pro is considering renewable natural gas and will be signing their first such contract.

## **Seminole County Schools**

Seminole County Schools (“Seminole”) began adopting propane (LPG) in 2015. There are two county school-owned facilities: the Midway Transportation Complex and the Winter Springs Transportation Compound. Seminole County Schools run approximately 140 school buses at the Midway Transportation Complex and 310 school buses at the Winter Springs Compound. Approximately 30% of the fleet are propane-powered (the rest are diesel). Seminole’s goal is to have 75% of the fleet transitioned to propane. The Midway facility is the primary fueling station. They have two 1,000-gallon propane tanks (owned by AmeriGas) that includes one dispenser and two hoses with euro nozzles (Strobli nozzles) to perform propane fueling. The LPG school buses are fueled once or twice per day. Seminole County Schools finds they get approximately 4–5 miles per gallon on the propane school buses. They estimate that 1.35 gallons of propane autogas is equivalent to 1 gallon of diesel, but propane fuel costs are lower, and this is where savings are found. There is a secondary fueling site with a 2,000-gallon propane tank at the Winter Springs complex. Seminole County Schools receives 1–2 daily deliveries from AmeriGas, depending on the need. Seminole is currently working on purchasing an 18,000-gallon propane tank to move away from the daily AmeriGas deliveries. Seminole has never experienced issues with AmeriGas LPG deliveries.

Seminole County Schools uses Thomas (LPG), Blue Bird (LPG), and International (diesel) buses, and the buses run approximately 100–200 miles per day. They get slightly lower range with LPG. There are 75- to 100-gallon tanks in each school bus (the LPG buses can store 60 to 70 gallons on board), but these onboard tanks are only filled up to 80%. Seminole also stores diesel on-site. At the Midway Complex, there are two 20,000-gallon diesel tanks. At the Winter Springs Compound, there are three underground 20,000-gallon diesel tanks and one 20,000-gallon unleaded gasoline storage tank.

Seminole has not experienced interruption of their LPG deliveries/supply, even during hurricane and tropical storm events. They rely on historical fuel use data from prior hurricanes to estimate fuel needs for an impending storm, but there is no perfect way to predict fuel needs fully accurately during an emergency. Seminole fuels buses prior to the storm (diesel and propane) and also ensures that the diesel generator located at the Winter Springs Compound is topped off and diesel storage tanks are full.

Seminole County Schools credits good communication with AmeriGas as the reason the district has not experienced fuel shortages or interruptions. They can also modify regularly scheduled delivered with AmeriGas, depending on fueling needs. AmeriGas has a mobile refueling system (Seminole would need to call AmeriGas and arrange to utilize the mobile refueling system). This mobile refueling system can be used if the LPG bus is stranded on the road without fuel. During past hurricane events, Seminole County Schools had loose agreements in place to fill up at Lynx if needed (diesel fuel). School buses are not equipped to deal with standing water. Seminole is tasked with performing evacuations (“Emergency Evacuation Team”), and there is high demand

for wheelchair-capable buses for evacuation (these are diesel-powered school buses). Emergency evacuations are done, but roads are required to be cleared from debris (especially relevant for post-storm activities to resume operation of the school buses on roadways). Seminole uses both LPG and diesel school buses to perform these evacuations and other transport duties.



**Figure B-3. 400-kW genset at Seminole County Schools.**

Source: Tampa Bay Clean Cities



**Figure B-4. Diesel storage at Seminole County Schools (2,877 gallons).**

Source: Tampa Bay Clean Cities



Wind speeds are the determining factor for operating school buses during hurricanes. Once wind speeds reach 35–40 mph, the buses are pulled off the routes. The Midway Complex does not have a diesel generator on-site, but there is a diesel generator located at the Winter Springs Compound. Seminole received a grant for a diesel generator to provide power for emergency fueling. This generator provides enough fuel to supply a week's worth of diesel fuel without refilling. This is a large diesel generator (Generac 3-phase, 400 kW) sitting on top of a storage tank, manufactured by Fidelity in Ocala. The generator is served by a 2,877-gallon diesel storage tank. Since LPG fueling requires electricity, the ability to fuel could be disrupted if power is lost.

Seminole County Schools considered cost-effectiveness when evaluating propane and diesel school buses. Propane infrastructure would have cost the county schools around \$20,000. CNG infrastructure is much more expensive in terms of capital costs. LPG school buses are more cost-effective to maintain because they do not require technologies such as exhaust gas recirculation valves or turbo).

Seminole is exploring other alternative fuel options and is committed to transitioning 75% of their school bus fleet to propane. Seminole applied for 10 new LPG school buses under the Diesel Emissions Reduction Act (DERA), which provides about \$25,000 per bus. The county has also applied to participate in the Electric School Bus Project – Initial Phase through the Florida Diesel Emissions Mitigation Program (DEMP), which utilizes funds from the Volkswagen Settlement and the U.S. Environmental Protection Agency's Diesel Emissions Reduction Act State Grant Program. Seminole has not yet heard results of that application decision. Since our site visit with Seminole County Schools, the Florida Department of Environmental Protection has released funding availability (\$57 million) for the purchase of electric Type C or Type D school buses to replace eligible diesel school buses. It is unknown if Seminole will be pursuing that funding opportunity. Seminole County Schools has explored solar arrays and electric school buses, but there are many issues to address, including concerns over wattage, charging times, and backup power options.

## City Furniture

The City Furniture fleet facility in Tamarac spans over 1 million square feet. The fleet operates 63 electric forklifts and tugs. City Furniture runs Peterbilt CNG trucks and conducts all maintenance in-house. The company has had to make a few changes to the maintenance facility to accommodate CNG vehicles, including lowering lighting and increasing ventilation. The CNG trucks achieve 7 miles per diesel gallon equivalent, versus 4–5 mpg for similar diesel trucks.



**Figure B-5. CNG fleet using time-fill.**

Source: Tampa Bay Clean Cities

City Furniture also operates two electric Kalmar Ottawa yard trucks on-site and has three on order. These battery-electric trucks can operate 12–15 hours before they need to be recharged. It takes approximately 4 hours to recharge them using a 480-V charger. City Furniture has had those yard trucks for 2–3 years now without encountering any operational issues.





**Figure B-6. City Furniture electric Kalmar Ottawa yard truck.**

Source: Tampa Bay Clean Cities

City Furniture started with 150 diesel trucks and began converting its fleet to CNG in 2012–2013. They used several companies in the past to convert vehicles to CNG. Currently, City Furniture uses companies in Texas (Net G and Momentum Fuels) to retrofit trucks to CNG. The company currently operates 207 CNG delivery trucks and has the goal of converting 100% of the fleet to CNG and electric. All trucks are owned by City Furniture. In their conversion, City Furniture took advantage of a Florida Natural Gas Rebate previously offered by the FDACS. CNG vehicles perform better than gasoline and cost less to maintain. Additionally, even with conversion costs, CNG trucks end up costing \$4,000 less than gasoline trucks.

City Furniture has its own employees certified to inspect CNG tanks (required every 36 months and after each accident 5 mph or higher). The Natural Gas Vehicle Institute (NGVI) provides CNG training that City Furniture uses to train its staff. However, 80% of NGVI training is basic. Most CNG training received by City Furniture staff (e.g., drivers, mechanics) comes from on-the-job training.

The company uses private time-fill CNG fueling on-site that can also be used for fast-filling for a few vehicles. The CNG fueling station has two ANGI compressors on-site and no fuel storage, as the vehicles are fueled directly from the compressor. The current natural gas supplier is Center Ice. City Furniture is extremely happy with the quality of gas they have been receiving (very clean and dry). They check filters daily. City Furniture handles routine maintenance of the station/compressors (daily/weekly preventative maintenance) internally and uses an outside company for larger (more complicated) maintenance items.



**Figure B-7. City Furniture CNG station.**

Source: Tampa Bay Clean Cities

City Furniture receives some credits for renewable natural gas, though the fuel is sourced in another state. Renewable natural gas is priced equivalent to CNG.

City Furniture has developed a preparation plan to deal with emergency events and natural disasters. During hurricane events, standard procedures include staging vehicles against the wall (to protect from debris and wind), locking everything down, and zip-tying all CNG station nozzles. All vehicles are stored on-site. The company suspends operation when sustained wind reaches 35 mph, which is a standard threshold for many fleets. The company uses a hotline and the City Furniture app to communicate with employees during emergencies.

The company has 2,000 gallons of gasoline stored for its fleet. The company also has a diesel generator to power the building and a CNG-powered generator to support vehicle fueling, which can fuel CNG vehicles without power. The City Furniture fleet has never experienced issues with flooding, as the facility is located outside of major flood zones. As a contingency plan, City Furniture has an agreement with TruStar to deliver CNG on-site in the event the City Furniture fueling station is completely down. This scenario, though, is highly unlikely and has never happened in the past. During Hurricane Irma, the city of Sunrise asked for CNG, and the company provided CNG fuel for the municipality's priority fleet vehicles. The request for CNG fuel was managed through the local EOC.

City Furniture is researching electric delivery trucks and is interested in fleet electrification. City Furniture representatives have visited several vehicle manufacturers to explore suitable models for City Furniture. The company has eight Teslas on order to be used as company cars. City

Furniture has enough electric power infrastructure to support EVs and is investigating the potential of solar energy.

Key areas to address during hurricanes/disasters:

- Planning, communication, and follow-through.
- Redundancies (e.g., City Furniture operates two compressors at the CNG station to ensure uninterrupted operation).



**Figure B-8. City Furniture CNG delivery fleet.**

Source: Tampa Bay Clean Cities

## **Broward County Transit – Paratransit Division**

Broward County Transit (BCT) serves Broward County and segments of Palm Beach and Miami-Dade Counties through coordination with Palm Tran and Miami-Dade Transit.

The BCT Paratransit Division operates 377 vehicles, of which 277 are propane and the remainder are gasoline-powered. BCT used the company ICOM NA to convert vehicles to propane. BCT uses several types of LPG vehicles: Ford E-450s (12–18-passenger vehicle), Ford Transit cutaways, and Ford Tauruses. The Ford E-450 came with the ROUSH LPG system. They have 41 usable gallons of propane that give an approximate 200-mile range. The newer vehicles have 65 usable gallons and can provide 300+-mile range. ROUSH did not have an LPG conversion system for the smaller Ford transit buses. The LPG Ford transit cutaway buses achieve great mileage (12 mpg). BCT mainly uses bi-fuel propane vehicles (propane and gasoline). It is not clear if drivers are incentivized enough to run mainly on propane rather than on gasoline. Gasoline is more expensive than LPG, so running on gasoline would increase



operating costs. BCT is working with ICOM NA (propane converter) to develop a mono-fuel (LPG-only) system for the buses.

BCT purchases propane from AmeriGas, who also maintains propane fueling infrastructure on-site. The station has two storage tanks with 1,990 gallons of propane each (3,800 gallons of propane total). The dispensers are wired to the internet, so it is easy to monitor usage. All vehicles using the station have fobs that allow for monitoring fuel use. Additionally, those fobs allow for use with other Broward County fleet propane stations.



**Figure B-9. BCT paratransit bus fueling with propane.**

Source: Tampa Bay Clean Cities

BCT uses county fueling stations for gasoline vehicles and does not have gasoline fuel storage on-site.

During previous hurricanes (such as Hurricane Irma in 2018), gasoline and diesel were not available through the port. However, BCT performed all evacuation using LPG vehicles, since propane supply was not interrupted. The county has 60,000 gallons of LPG storage. Additionally, AmeriGas is able to come on-site and “wet-fuel” vehicles if needed. As a result, BCT had no issues with fuel supply during past hurricanes. During hurricanes, BCT often gets requests from city agencies to fuel with propane.



**Figure B-10. BCT propane paratransit buses.**

Source: Tampa Bay Clean Cities

When the county put a bid for propane supply, they put a requirement that the supplier have a local storage of at least 300,000 gallons of fuel in Broward County. With 600,000 gallons of LPG storage, AmeriGas meets that requirement easily. Given an important role of BCT for evacuation and other critical functions, BCT has priority fueling for both gasoline and propane. A new contract with AmeriGas added three additional LPG stations in the county.

Fuel is typically rationed based on the routes the buses run. Buses get 1/4, 1/2, or a full tank of fuel depending on the route and required range. This system is used for everyday operation. The BCT propane station allows for filling up the full tank in 6 minutes, accommodated by a larger pump motor installed.

Broward County is planning to continue expanding its LPG fleet and also plans to replace community shuttles with propane vehicles.

Paratransit service in Broward County is operated by Transportation America (contractor). Fixed-route transit service is handled by Broward County internally. BCT maintains the fleet. There are no issues finding mechanics to work on propane vehicles. ROUSH provided some initial training with LPG vehicles, but there is not much significant difference compared to gasoline/diesel vehicles.

ROUSH is also very responsive with any technical issues. BCT had an issue in the past with buses stalling for no apparent reason. ROUSH helped with finding the problem. The issue turned out to be related to an electric system rather than fuel (LPG). BCT also worked with ROUSH to design a bleeding system used to empty the tanks when maintenance on the vehicles is

performed. As result, LPG is not vented from the vehicle but rather collected into an external tank, resulting in cost savings for the agency.



**Figure B-11. BCT propane fueling facility.**

Source: Tampa Bay Clean Cities

There was an instance when one of the LPG buses caught on fire caused by vehicle electrical issues. Since the bus was propane, the city fire department did not know how to handle it. They decided not to put out the fire and let the bus burn to the ground. BCT propane buses had been involved in several severe accidents, but none of them caused fuel leaks.

The biggest issue with LPG infrastructure is compliance with local ordinances and zoning rules. This is especially relevant for larger-capacity fueling sites. For example, the city of Deerfield only permitted for the installation of one propane fueling station.

Broward County Schools runs approximately 200 buses on propane, so the market for propane in the county is healthy and growing. Additionally, BCT is talking to AmeriGas about getting renewable propane. BCT fixed-route service runs some battery-electric buses (Proterra), but paratransit service does not. For paratransit service, it is possible to use light-duty EV sedans, since not all paratransit vehicles need wheelchairs.

One obstacle for electrification is the need for EV charging infrastructure, which is expensive. Additionally, paratransit service is contracted out with a 5-year contract. That time period may not be enough for the contractor to recoup the investment in infrastructure. This will be challenging to do given a 5-year planning horizon, and the contract may need to be extended beyond 5 years.

Lessons learned from LPG implementation:

- Ensure to carefully plan and prepare for alternative fuels to mitigate surprises. The Propane Education and Resource Council (PERC) was a great resource for BCT. BCT saves approximately \$8.5 million in fuel cost over 5 years with LPG compared to gasoline.
- Account for a range of vehicles. Broward County is primarily urban, which affects duty cycle and fuel usage (fuel usage needed to be estimated while running a bid for AmeriGas).
- The partnership with the fuel provider is very important.
- BCT did not use a lock-in fuel rate. The price of propane is low enough to do so, but at market/sport price. BCT uses a fixed per-gallon administrative cost on top of the regular price. BCT currently pays \$1.5 per gallon of propane.

During past hurricanes, BCT received a request from only one fleet to share LPG. Usually BCT does not advertise that they have propane. In an emergency, fuel availability and sharing is typically handled by the EOC, so requests for fuel would usually come through the EOC. Since Broward County Schools also runs propane buses, BCT can combine efforts with them in emergency situations.

Procedures before the hurricane include topping-off all vehicles with fuel and parking vehicles on the property in a pattern that allows for protecting newer vehicles from being damaged by debris (newer vehicles are parked in the middle, surrounded by older ones). BCT also has a local call-in number for AmeriGas and local support, which is very handy in emergencies. BCT paratransit facility has a diesel generator on-site that is enough to support the building and fueling operations. The BCT fleet did not experienced any problems with standing water.

The BCT paratransit division does not stage buses in different locations before a hurricane. All paratransit buses are stationed at the facility during hurricanes. BCT gets great support from AmeriGas in terms of fueling infrastructure. AmeriGas is located 10 minutes away from the BCT facility and can dispatch techs very fast to troubleshoot problems with the station.

Transportation America (operator of paratransit service) uses an interactive voice response (IVR) system to communicate with employees during emergencies (automated robocalls). Broward County uses a similar system to communicate with its employees.

## **Jacksonville Transportation Authority**

The Jacksonville Transportation Authority (JTA) provides public transit service to the city of Jacksonville, Florida. JTA began converting its fleet to CNG buses in 2015, citing environmental benefits as the primary reason for converting to the alternative fuel. This justification is also spurring the agency's exploration into electric transportation. The agency is also exploring the potential use of renewable natural gas, which is not yet available in the Jacksonville area.

In 2013, JTA commissioned the Alternative Fuel Study to identify alternatives to diesel that would reduce emissions and be cost-effective. That study recommended CNG as the most promising option. JTA also made the decision to use CNG buses for its bus rapid transit (BRT) system (called First Coast Flyer), which launched in late 2015.



JTA currently runs 118 CNG buses, 71 diesel buses, 7 hybrids and 3 Gillig battery-electric buses (BEBs). The agency is also planning to acquire additional CNG buses and a CNG tow truck.

The agency is installing two ChargePoint depot chargers (four outlets) that can charge BEBs in 3 hours.



**Figure B-12. JTA battery-electric bus.**

Source: Tampa Bay Clean Cities

JTA has two CNG stations on property, one private and one public. Stations are built and operated by Clean Energy through a public-private partnership. JTA entered into a fuel purchase agreement with Clean Energy, which specifies that JTA would convert an average of 20 buses per year for 5 years, for a total of 100 buses. The agency has always exceeded the minimum number of CNG buses stipulated in the agreement. The existing CNG stations can accommodate a fleet of 150 CNG buses, with some limited capacity for additional buses. Clean Energy committed to construct and operate CNG fueling stations for a period of 15 years. The station was constructed in 12 months and was completed at the end of 2015. JTA received a \$2.7-million Transportation Regional Incentive Program (TRIP) grant from FDOT to construct the station. One of the provisions of that grant required JTA to make the CNG station open to the public. As a result, Clean Energy essentially constructed two stations: one public and one private.



**Figure B-13. JTA CNG fueling station.**

Source: Tampa Bay Clean Cities

JTA does not store CNG on-site; therefore, fuel supply interruption can cause disruptions, though this has not happened yet. The agency has large storage of both diesel fuel and gasoline on-site (275,000 gallons of diesel).



**Figure B-14. JTA on-site diesel fuel storage.**

Source: Tampa Bay Clean Cities

Many years ago, the CNG station had problems that caused it to be down, raising concerns of reliability. The station has four compressors and can handle one or two of the compressors being down for maintenance or repairs.

While there are plenty of sources for CNG training, there is a lack of robust training for maintenance people to handle BEBs. Original equipment manufacturers may provide some assistance with training, but not much. Gillig provides some training for BEBs, but it is very basic. JTA is looking to find a way to maintain batteries longer, given the high cost of battery replacement.

JTA's current BEBs have 169 miles of range. The agency plans to continue expanding its BEB fleet. In order to install EV chargers for the two buses, JTA had to do electrical upgrades, including adding a transformer. One of the challenges with using BEBs is long routes. JTA covers the entire Duval County, which is a large geographical area. The range of BEBs may not be suitable for all routes.



**Figure B-15. Electric bus charging station installation.**

Source: Tampa Bay Clean Cities

JTA considered using propane for its Connection fleet (JTA's paratransit service), though this turned out to not be cost-effective.

One of JTA's electric buses encountered standing water in operation. When the bus went through standing water, a leak in the wheel well was discovered. Standing water did not cause any issues for electrical components of the bus. The battery is located on top of the bus and was unaffected. The general rule of thumb given to drivers about standing water is: "if you can't see the road, don't go."

One BEB had a balancing problem when charging (would not charge above 80%). The manufacturer (Gillig) addressed this issue with the battery (under warranty).

JTA has outfitted their maintenance shop with fall protection to service the vehicle battery located on top of the bus.

JTA also has five techs trained as CNG tank inspectors. Tanks need to be inspected after every accident of 5 mph or higher, regardless of where the impact was. It is expensive to invite outside inspectors, and they may not come on short notice. JTA decided to invest in its own tank inspectors.

The public CNG station is available to other fleets and accepts credit cards. Refuse haulers and medium-duty city fleets fuel there. The JTA facility has a 300-kW diesel generator that can be used to power the facility (and support fueling) during power interruptions. Additionally, the Clean Energy CNG station has its own 1,200-kW diesel generator. JTA will have to install another generator for EV fueling in case of power interruption. The existing 300-kW generator can only be used for diesel fueling and will not be enough to charge BEBs.

JTA does not store CNG on-site, but instead fills buses directly from the compressor. The fueling system and bus-mounted tanks are monitored for gas leaks (color-coded gas leak system). There was one instance when a CNG bus rolled over and all eight roof-mounted CNG tanks were damaged and vented natural gas. Other than this accident, JTA has never had any serious gas leaks at the facility.

The biggest issue with CNG is the requirement to inspect CNG tanks after every accident at or above 5 mph. JTA expects this requirement to be lifted at some point. 5 mph is really not that much, and there is no need to inspect the tanks if the area of impact did not involve parts of the bus where tanks are located.

JTA has never experienced issues with fuel deliveries or fuel shortages. Petroleum fuel (diesel and gasoline) comes from the Port of Jacksonville. JTA has developed a set of procedures to manage emergencies, including natural disasters. These procedures include accounting for the amount of fuel on hand, fueling all vehicles in preparation for hurricanes, and stationing buses in different locations on high ground (JTA has three locations). All these measures are implemented to make sure buses are available to provide service, evacuation, and emergency response.

In addition to supporting its own fleet, JTA also serves as a backup fuel storage for the city of Jacksonville. The agency goes into lockdown before a hurricane hits. Operations are suspended when sustained winds reach 35 mph. JTA uses several locations around the city to stage buses (e.g., Northdale facility is the secondary staging site).

The EOC coordinates fuel sharing during emergencies. JTA communicates its fuel availability to EOC during disasters. If other government fleets (e.g., fire department, police) need fuel, they will reach out to the EOC, who will direct them to go to JTA to fuel. Fuel availability during emergencies is communicated through a web-based application “WebEOC.” JTA also runs regular evacuation drills with the city of Jacksonville.

Lessons learned from previous hurricane events:



- JTA should have staged bus recall procedures. When operations were suspended at 35 mph, all buses were instructed to return back to the facility. As a result, 200 buses were waiting for vault to deposit fareboxes.
- JTA has a robust remote work capability that worked really well during previous hurricane events.
- Use satellite phones to communicate during emergencies. The phones have wireless priority service (available for government agencies), which allows for pushing the caller to the front of the line when all circuits are busy. This worked very well during emergencies.
- JTA has never had issues with fuel deliveries coming through the Port of Jacksonville. The port operates in a similar way as JTA.
- JTA is independent of Colonial Pipeline, so JTA's fuel deliveries were not impacted by the recent Colonial Pipeline interruptions.
- During previous power interruptions, it was discovered that one building on the property and one rear gate on the facility were not wired to the generator, so the gate becomes inoperable if central power is out. Other than that, the facility is rather resilient to power interruptions. In fact, the bus facility is wired to two utility blocks (if one loses power, only part of campus loses power).

Advice to other agencies:

1. Give enough time to prepare for last-minute issues before a hurricane. Have a plan.
2. Implement previously developed plans.

JTA coordinates with the city and county to update evacuation plans regularly. JTA is the lead agency for the city of Jacksonville transportation evacuation. The agency sends a copy of updated emergency plans to the city. During emergencies, JTA uses two-way communication apps to communicate with the public and employees. They use this app to blast public notifications during emergencies and also have an employee hotline.

## Appendix C. Alternative Fuel Vendors

Last Name	First Name	Title	Organization	Fuel Type	E-mail	Location	Phone	Cell
Magwood	John		American Homegrown Fuel Corporation	Hydrogen, biofuels	<a href="mailto:john@fcbio.com">john@fcbio.com</a>			
Rifenbary	Jared		American Natural Gas	CNG	<a href="mailto:jrifenbary@americanaturalgas.com">jrifenbary@americanaturalgas.com</a>			
Westberg	Joe		AmeriGas	Propane	<a href="mailto:joseph.westberg@AmeriGas.com">joseph.westberg@AmeriGas.com</a>	Jacksonville, FL	904-652-6132	
Franscell	Lance	Sales Manager	AmeriGas Propane	Propane	<a href="mailto:lance.franscell@AmeriGas.com">lance.franscell@AmeriGas.com</a>	Tampa, FL 33610	813-210-4763	
Wheeler	Joe	Senior Account Manager	AmeriGas/Heritage Propane	Propane	<a href="mailto:joe.wheeler@AmeriGas.com">joe.wheeler@AmeriGas.com</a>	Tampa, FL 33610	813-626-9111	727-423-6424
Josephs	Steve	Co-Founder, Director of Engineering	ampCNG	Natural gas	<a href="mailto:sjosephs@ampCNG.com">sjosephs@ampCNG.com</a>	Chicago, IL 60607	630-235-9841	
Johnson	Jeremiah	Dir of Agriculture/Alt Energy Programs	Be-Ev.Com	EVSE infrastructure	<a href="mailto:jeremiah64@gmail.com">jeremiah64@gmail.com</a>		727-463-0020	
De Antonio	Jose	CEO	BioDiesel Las Americas (BDLA)	Biodiesel production	<a href="mailto:jdeantonio@bdlaus.com">jdeantonio@bdlaus.com</a>	Miami, FL	305-851-6974	954-980-9538
Ballesteros	Carlos	Commercial & Procurement Manager	BioDiesel Las Americas (BDLA)	Biodiesel production	<a href="mailto:cballesteros@bdlaus.com">cballesteros@bdlaus.com</a>	Miami, FL	305-851-6974	954-512-7587
Noicely	Adrienne	Executive Sales Manager	Blink	EVSE infrastructure	<a href="mailto:Anoicely@BlinkCharging.com">Anoicely@BlinkCharging.com</a>	Miami, FL	305-521-0200 ext. 200	305-720-0958
Cox	Brandon	NE Florida Business Development Manager	Blossman Gas	Propane	<a href="mailto:bcox@blossmangas.com">bcox@blossmangas.com</a>	Jacksonville, FL 32219		336-963-3939
Giabaldi	Mike	Sales Manager	Brickell Energy	EVSE infrastructure	<a href="mailto:mgibaldi@brickellenergy.com">mgibaldi@brickellenergy.com</a>	Miami, FL	305-389-4615	

Last Name	First Name	Title	Organization	Fuel Type	E-mail	Location	Phone	Cell
Rothe	Jeff	Sales Director, Florida	ChargePoint, Inc.	EVSE infrastructure	<a href="mailto:jeff.rothe@chargepoint.com">jeff.rothe@chargepoint.com</a>			954-644-2944
Dunn	David	Facilities Management	City of Orlando	Electric	<a href="mailto:DAVID.DUNN@orlando.gov">DAVID.DUNN@orlando.gov</a>	Orlando, FL 32802	407-246-3873	321-231-2904
		Clean Energy Customer Service	Clean Energy CNG Station Orlando Airport	CNG		Orlando, FL 32827	866-809-4869	
Torlai	Eme	Account Manager	Clean Energy Fuels	Natural gas	<a href="mailto:eme.torlai@cleanenergyfuels.com">eme.torlai@cleanenergyfuels.com</a>	Dallas, TX 75225	214-572-6591	972-750-6850
Carlos	Andres	National Account Manager	Clean Energy Fuels	Natural gas	<a href="mailto:andres.carlos@cleanenergyfuels.com">andres.carlos@cleanenergyfuels.com</a>		562-370-6695	
Moore	Sherika	Business Development Manager	Clean Energy Fuels	Natural gas	<a href="mailto:sherika.moore@cleanenergyfuels.com">sherika.moore@cleanenergyfuels.com</a>		603-724-6648	404-230-4043
Langille	Brian	Interim Director	Clearwater Gas System	Natural gas	<a href="mailto:brian.langille@clearwatergas.com">brian.langille@clearwatergas.com</a>	Clearwater, FL 33755	727-562-4911	
Tindal	Chris	Assistant Director	Commercial Aviation AF Initiative (CAAFI)	Aviation fuel	<a href="mailto:tindal.caafi.ad@gmail.com">tindal.caafi.ad@gmail.com</a>			
Meyer	Matt	Sales & Business Development	Dannar	Off-road EV/mobile power station	<a href="mailto:mmeyer@dannar.us.com">mmeyer@dannar.us.com</a>	Muncie, IN		574-329-9768
Magalhães	Ricardo	Sales US and Canada	Efacec USA	EVSE infrastructure	<a href="mailto:ricardo.magalhaes@efacec.com">ricardo.magalhaes@efacec.com</a>		(+351) 933 030 928	
Araujo	Ricardo	Sales Manager for Europe and North America	Efacec USA	EVSE infrastructure	<a href="mailto:ricardo.araujo@efacec.com">ricardo.araujo@efacec.com</a>		(+351) 912 302 671	
Sousa	Ivan	Director of Sales	Efacec USA	EVSE infrastructure	<a href="mailto:ivan.sousa@efacec.com">ivan.sousa@efacec.com</a>		(+351) 932 790 032	



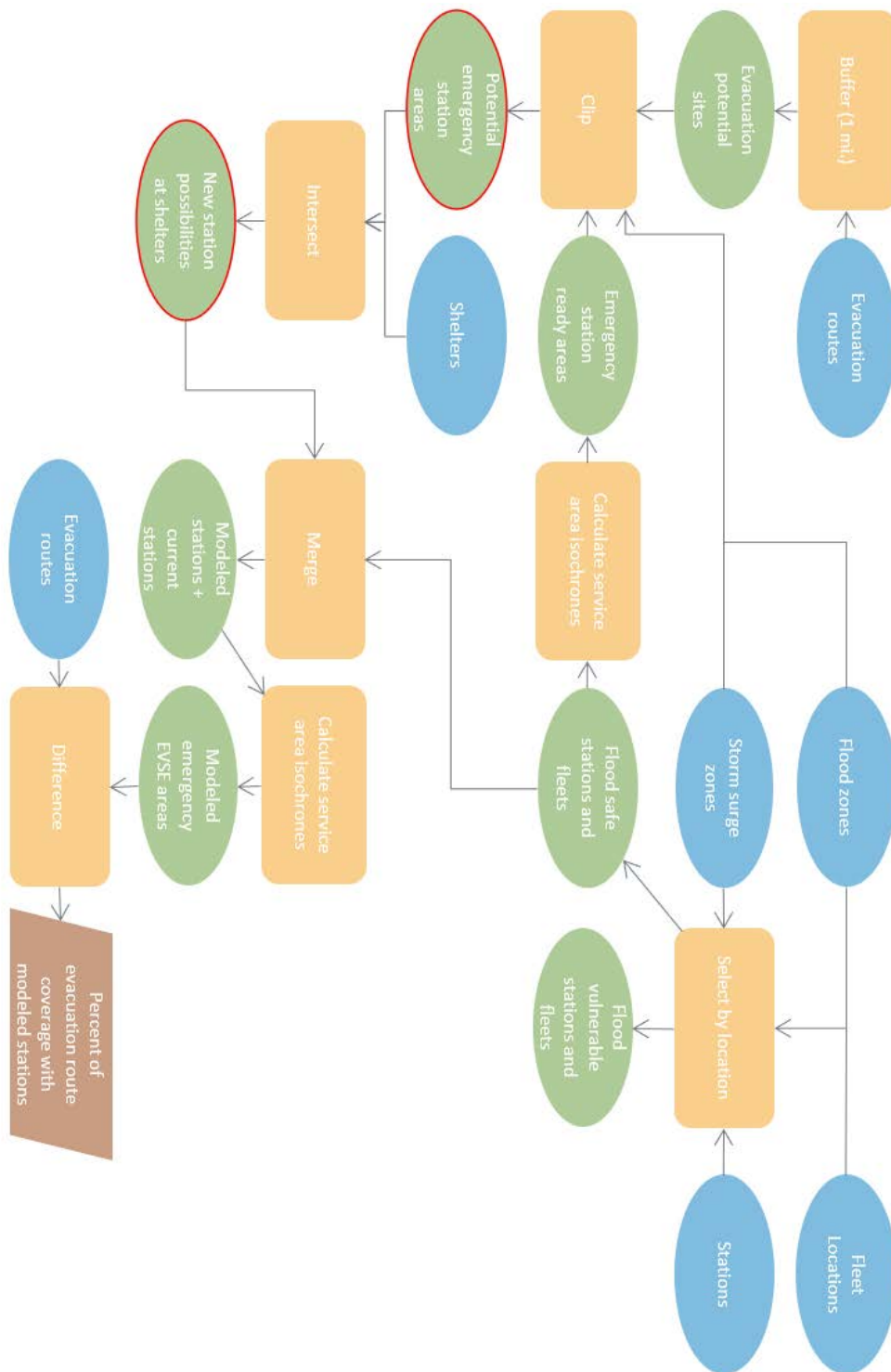
Last Name	First Name	Title	Organization	Fuel Type	E-mail	Location	Phone	Cell
Shapiro	Ben	Business Development Manager	Endera	EVSE infrastructure	<a href="mailto:ben@enderacorp.com">ben@enderacorp.com</a>		307-776-9400	
Dodd	David	Account Manager	Ferrell Gas - Pinellas Park Service Center	Propane	<a href="mailto:daviddodd@ferrellgas.com">daviddodd@ferrellgas.com</a>	Pinellas Park, FL 33782	727-544-1416	
Glander	Richard	Operations Supervisor	Ferrell Gas - Pinellas Park Service Center	Propane	<a href="mailto:richardglander@ferrellgas.com">richardglander@ferrellgas.com</a>	Pinellas Park, FL 33782	727-544-1416	
Wike	Andy	President	Fleetwing Corporation	Biodiesel, ethanol	<a href="mailto:andywike@fleetwingoil.com">andywike@fleetwingoil.com</a>	Lakeland, FL 33802	863-665-7557	
Moyer	Elda	Account Executive	Florida City Gas	CNG	<a href="mailto:Elda.Moyer@nexteraenergy.com">Elda.Moyer@nexteraenergy.com</a>	Doral, FL		786-459-3814
Bowers	Beth	Electric Vehicle Specialist	Florida Power & Light Company	Electric	<a href="mailto:beth.bowers@fpl.com">beth.bowers@fpl.com</a>	Juno Beach, FL 33408	561-304-5670	561-262-6656
Earley	Patti	Fleet Fuel Operations Specialist	Florida Power & Light Company	Electric	<a href="mailto:patti.earley@fpl.com">patti.earley@fpl.com</a>		561-904-3222	
Thompson	Mark	Business Development Manager	Florida Public Utilities	Natural gas, propane, electric	<a href="mailto:mthompson@fpuc.com">mthompson@fpuc.com</a>	DeBary, FL 32713		386-747-6553
McGoldrick	Bill	Key Accounts Manager	Florida Public Utilities	Natural gas, propane, electric	<a href="mailto:bmccgoldrick@fpuc.com">bmccgoldrick@fpuc.com</a>	West Palm Beach, FL 33409	561-202-5131	
Ricre	Romero		Florida Public Utilities	Electric, CNG	<a href="mailto:rsicre@fpuc.com">rsicre@fpuc.com</a>	Fernandina Beach, FL		
	Erik		GAIN Clean Fuel	CNG		Kissimmee, FL 34758	800-438-7912	
Hoover	Buzz		Gate Petroleum	Ethanol, CNG, electric	<a href="mailto:brhoover@gatepetroleum.com">brhoover@gatepetroleum.com</a>	Jacksonville, FL	904-448-2922	
			Glover Oil	Biodiesel 20		Melbourne, FL 32901	321-723-3953	

Last Name	First Name	Title	Organization	Fuel Type	E-mail	Location	Phone	Cell
Swarthout	Cindy		GoSpace	EVSE infrastructure	<a href="mailto:cswarthout@gospa.cego.com">cswarthout@gospa.cego.com</a>			
Henderson	Rock		GoSpace	EVSE infrastructure	<a href="mailto:rhenderson@gospa.cego.com">rhenderson@gospa.cego.com</a>		813-421-5121	813-843-8430
Mills	Andrea	District General Manager	Heritage Propane	Propane	<a href="mailto:andrea.mills@AmeriGas.com">andrea.mills@AmeriGas.com</a>	Tampa, FL 33610	813-626-9111	
Traversa	Xan		Jacksonville Transportation Authority	CNG	<a href="mailto:atraversa@jtafla.com">atraversa@jtafla.com</a>	Jacksonville, FL	904-632-5501	
McKee	Dave	Electrification Program Manager	JEA	Electric	<a href="mailto:mckewd2@jea.com">mckewd2@jea.com</a>	Jacksonville, FL 32202	904-665-4336	
Clemmons	Cynthia	Manager of Legislative & Regulatory Relations	Lakeland Electric	Electric	<a href="mailto:Cindy.Clemmons@LakelandElectric.com">Cindy.Clemmons@LakelandElectric.com</a>		863-834-6595	863-430-1368
Davis	Spencer	NASA Traffic Management Specialist	NASA/KSC	Electric/B20/E85/hydrogen	<a href="mailto:spencer.c.davis@nasa.gov">spencer.c.davis@nasa.gov</a>	Kennedy Space Center, FL 32899	321-861-1633	321-289-7268
Locke	Jack	President & Chief Operating Officer	Nopetro	Natural gas	<a href="mailto:jlocke@nopetro.com">jlocke@nopetro.com</a>	Coral Gables, FL 33134	305-775-9647	
			NoPetro CNG (LYNX)	CNG		Orlando, FL 34804		
Ovitt	David	General Manager	Northside Propane Inc.	Propane	<a href="mailto:dave@northsidepropane.com">dave@northsidepropane.com</a>	Lutz, FL 33549	813-949-4286	
McDevitt	Jody	Sales Director	NovaCharge	EVSE infrastructure	<a href="mailto:jody@novacharge.net">jody@novacharge.net</a>			
Rigsby	Will		NovaCharge	Electric	<a href="mailto:willrigsby@novacharge.net">willrigsby@novacharge.net</a>	Oldsmar	404-229-3603	
Paul	Luis	Managing Director	OBE Power Networks	EVSE infrastructure	<a href="mailto:lpaulk@otepi.com">lpaulk@otepi.com</a>	Miami, FL		832-260-1384
Burgana	Alejandro	Managing Director	OBE Power Networks	EVSE infrastructure	<a href="mailto:aburgana@brickellenergy.com">aburgana@brickellenergy.com</a>	Miami, FL	305-546-5407	

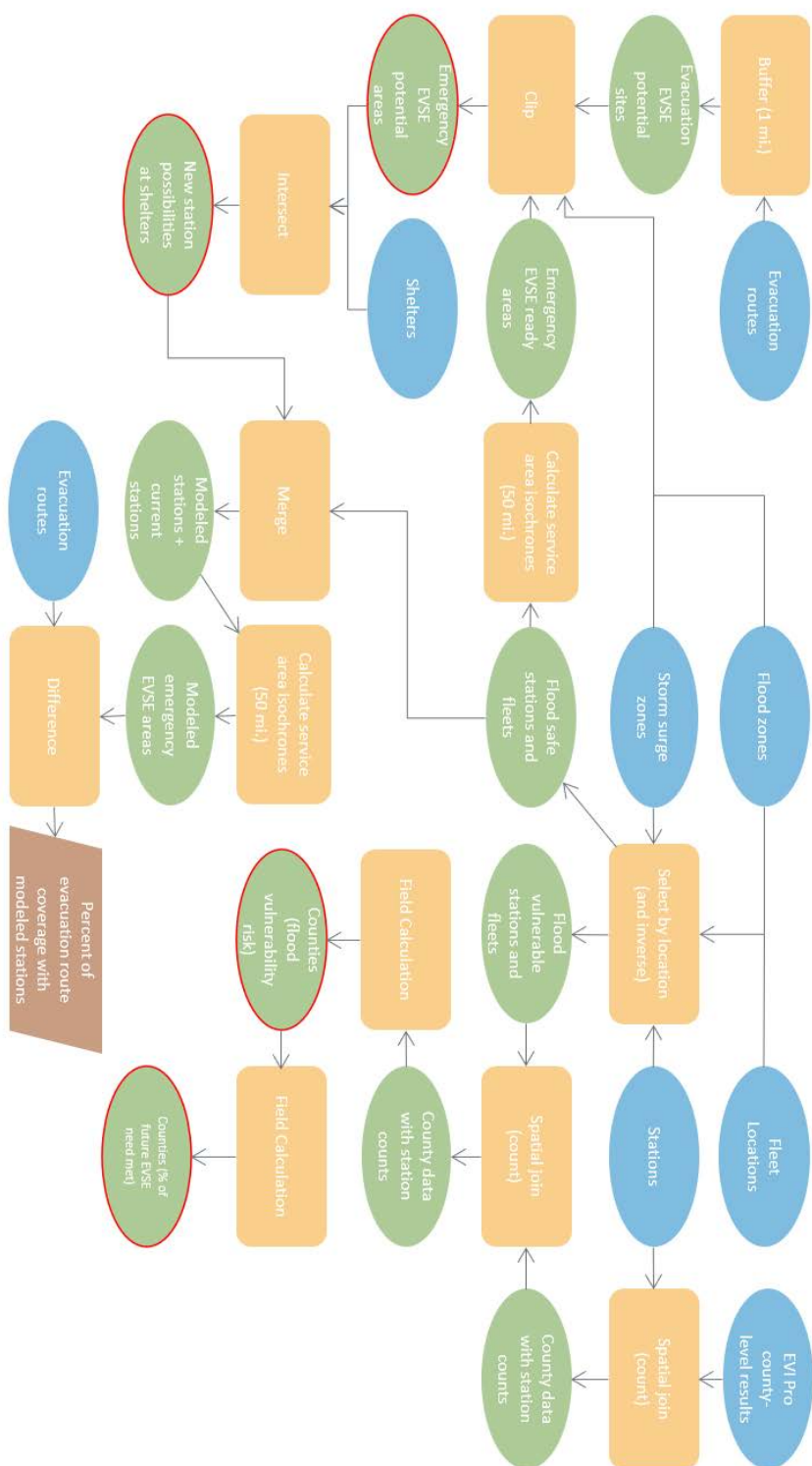
Last Name	First Name	Title	Organization	Fuel Type	E-mail	Location	Phone	Cell
Caceres	Christin	Sustainability Business Support Specialist	Orlando Utilities Commission	Electric	<a href="mailto:ccaceres@ouc.com">ccaceres@ouc.com</a>	Orlando, FL 32802	407-434-2859	
Westlake	Peter	Manager, New Products and Solutions	OUC	Electric	<a href="mailto:pwestlake@ouc.com">pwestlake@ouc.com</a>	Orlando, FL 32801	407-434-2036	407-417-7646
Dennis	Brett		Palatka Gas	CNG	<a href="mailto:bdennis@palatkagas.com">bdennis@palatkagas.com</a>		386-983-4267	
Guerrero	Richard	Equipment Sales & Service Manager	Pioneer Critical Power	Generators/mobile	<a href="mailto:rguerrero@pioneer-criticalpower.com">rguerrero@pioneer-criticalpower.com</a>	Miami, FL	305-599-2045	305-764-4905
Bradley	Scott	Director of Sales	Pioneer Power Mobility	Mobile EVSE/propane	<a href="mailto:Scott@Pioneer-eMobility.com">Scott@Pioneer-eMobility.com</a>	Champlin, MN	617-337-3537	
Kuenzli	Eric		Pivotal LNG	LNG	<a href="mailto:ckuenzli@pivotallng.com">ckuenzli@pivotallng.com</a>			
Carroll	Brian	Fleet Manager	Port Canaveral	Electric/LNG	<a href="mailto:bcarroll@portcanaveral.com">bcarroll@portcanaveral.com</a>	Cape Canaveral	321-783-7831 x 285	
Pearson	Amber	Director of Marketing	Protec Fuel Management LLC	Ethanol	<a href="mailto:amber@protecfuel.com">amber@protecfuel.com</a>	Boca Raton, FL 33487	573-268-6853	
Kaiyalethe	David	Marketing Manager	Protec Fuel Management LLC	Ethanol	<a href="mailto:david@protecfuel.com">david@protecfuel.com</a>	Boca Raton, FL 33487	561-392-3667	
Linn	Jason	Marketing Director	Rack Electric	EVSE infrastructure	<a href="mailto:creative@rackelectric.com">creative@rackelectric.com</a>	Boca Raton, FL	561-391-3550	
	Kayla		Ross Plumbing	CNG		Leesburg, FL 34748	352-728-6053	
Nordsiek	Jeff		St. Johns County	CNG	<a href="mailto:jnordsiek@sicfl.us">jnordsiek@sicfl.us</a>		904-209-0283	
McAllister	Alan	Regional Account Representative	Suburban Propane	Propane	<a href="mailto:amcallister@suburbanpropane.com">amcallister@suburbanpropane.com</a>	Tampa, FL 33610	352-303-4505	
Cole	David		Suburban Propane	Propane	<a href="mailto:dcole@suburbanpropane.com">dcole@suburbanpropane.com</a>			

Last Name	First Name	Title	Organization	Fuel Type	E-mail	Location	Phone	Cell
Fernald	Donald	President	Superior Energy Systems	Propane infrastructure	<a href="mailto:donald@superiornrg.com">donald@superiornrg.com</a>	Columbia Station, OH 44028	440-236-6009	
Cozma	Samy	Biofuels Analyst	Targray	Biodiesel, ethanol	<a href="mailto:scozma@targray.com">scozma@targray.com</a>	Kirkland, Quebec	514-695-8095	438-889-0551
Hernandez	Kenneth	Program Manager, Alt Fuel Vehicles	TECO Energy	Electric	<a href="mailto:kxhernandez@tecoenergy.com">kxhernandez@tecoenergy.com</a>	Tampa, FL 33602	813-228-1392	
Cervantes	Horacio		TECO Peoples Gas	CNG	<a href="mailto:hcervantes@tecoenergy.com">hcervantes@tecoenergy.com</a>	Tampa, FL 33602		
Bahadue	George	Market Lead, Charging Infrastructure	Tesla	Electric	<a href="mailto:gbahadue@tesla.com">gbahadue@tesla.com</a>	Palo Alto, CA 94304	703-992-3698	
Bolger	Shaun	Senior Category Manager - Fuel Pricing	Thorntons Inc.	Ethanol	<a href="mailto:shaun.bolger@mythorntons.com">shaun.bolger@mythorntons.com</a>		502-572-1562	502-727-7886
Duley	Handlin	Senior Category Manager - Retail Fuel	Thorntons Inc.	Ethanol	<a href="mailto:handlin.duley@thorntonsinc.com">handlin.duley@thorntonsinc.com</a>	Louisville, KY		
Flynn	Anthony	Southeast Sales Director	TruStar Energy	Natural gas	<a href="mailto:aflynn@trustarenergyc.com">aflynn@trustarenergyc.com</a>	Rancho Cucamonga, CA 91730		678-215-2762
Watson Colon	Yara	UCF Office of Sustainability	University of Central Florida	Electric/propane	<a href="mailto:Yara.Watson@ucf.edu">Yara.Watson@ucf.edu</a>	Orlando,	407-823-3353	
Butler	Brian	President	VISTRA	Electric, natural gas	<a href="mailto:brian@consultvistra.com">brian@consultvistra.com</a>	Tampa, FL 33613	813-961-1077	
Chadbourne	Harland	Director of Purchasing	Waste Pro	CNG	<a href="mailto:hchadbourne@wasteprousa.com">hchadbourne@wasteprousa.com</a>	2101 West SR 434 Longwood, FL 32779	407-937-2663	305-506-7911
			Withlacoochee Electric Cooperative	Electric		Dade City, FL		

## Appendix D. MCDA Algorithm for Potential New Fuel Station Identification



## Appendix E. Workflow for Future EVSE Needs Mapping



# Appendix F: Literature Review for Vehicles in Standing Water

## Background and Purpose

The purpose of this literature review is to inform Task 5 of the Florida Statewide Alternative Fuel Resilience Plan Funding Opportunity Announcement (FOA) project. Specifically, this literature review assesses information on vehicles and their ability to withstand hurricanes, standing water, and flooding. Critical transportation vehicles such as first-responder fleets, as well as AFV technologies, are focus areas of the literature review. It is important to understand the limitations of vehicles in these scenarios and potential modifications that could be made to improve their durability in order to recommend which vehicles should be added to a fleet for use in emergency response situations.

The literature review was the first step in our standing water assessment (Section 9). It serves as a background for virtual site visits (due to COVID-19) by a mechanic from NREL to fleets that have had a variety of vehicles deal with flooding issues.

## Vehicle Water Damage

This section explores a variety of issues related to vehicles and flooding, including how to help prevent vehicle damage during a hurricane or flood, as well as common vehicle damage and how to assess and repair it.

### Preventing Water Damage

When a hurricane or flooding event is imminent, there are things that vehicle and fleet owners can do proactively to attempt to prevent or minimize damage to their vehicles. According to an article in *Economical Insurance* (Fereiro 2018), there are a handful of actions that can be taken:

- Move vehicles to higher ground. As floodwaters accumulate in low-lying areas first, move and park vehicles on top of a hill or on the top level of an aboveground parking structure. Also ensure vehicles are away from trees or other objects that may damage them during a storm.
- Close all windows and doors. Ensure all openings are sealed to prevent water from getting inside the vehicle during rainfall or rising floodwaters.
- Consider disconnecting the battery. If floodwaters are expected to reach the vehicle, consider disconnecting the battery to prevent electrical shorts and damage to the computer and electronic equipment.

If a vehicle is being driven during a hurricane or flooding event, drivers should be careful not to drive through large puddles or standing water. In many cases, water is deeper than it appears and can therefore get into the vehicle's engine (more detail in the subsequent Engine and Transmission section). Even a small amount of water in an engine can cause irreparable damage. Furthermore, according to the National Weather Service, 12 inches of water can carry away most passenger vehicles, and 2 feet of water can sweep away SUVs and trucks (National Weather Service 2020).



## **Common Vehicle Damage and How To Assess and Repair It**

When a vehicle is involved in a hurricane or flooding event, there are many common issues that could occur. According to an article in *Your Mechanic* (Unrau 2016), it is common for metal surfaces to rust prematurely and for nuts and bolts to seize. In addition, water damage can occur inside the airbag, as the module and other connectors for the airbag controls are often located under the seats of the vehicle.

Other common areas for damage with flooded vehicles are outlined in an article in the *National Automotive Parts Association Know How Blog* (Jerew 2020), including water in the brake fluid, power steering, and coolant reservoirs. If water enters the brake fluid, it can cause it to evaporate, leading to a loss of braking power. In addition, brake pads and shoes can rust and spread the rust to rotors and drums. Therefore, it is important to dry a flooded vehicle thoroughly and work immediately to remove rust from a vehicle as soon as it is identified.

## **Assessing and Repairing Common Damage**

According to an article in *U.S. News & World Report* (Trop 2019), the first thing to do after a vehicle is involved in a flood or standing water (once it is safe to do so) is to evaluate how high the floodwaters came on the vehicle. Look at the depth of the water or for evidence of a water line by mud and debris. Water that didn't rise above the bottom of the doors is unlikely to have caused any significant damage. Water any higher than that could lead to significant damage or even a totaled vehicle. As soon as it is safe to do so, start drying out the vehicle completely to minimize damage and rust. Also pay attention to whether the water was fresh or salt water, as salt water is much more corrosive and damaging than fresh water and is more likely to lead to a totaled vehicle.

According to Unrau (2016), there are several next steps to take to assess initial damage from flooding. First, check any controls that were submerged and ensure the emergency brake is operational and that the pedals move when pressed. Also check that any manual (non-electric) seat adjustments work properly and that the fuel tank, truck, and hood releases work.

Because water can enter brake and power steering fluids, Jerew suggests flushing the brake and power steering systems and potentially draining the fuel tank to eliminate water contamination (depending on the level of flooding). According to Jerew (2020), repairing flood damage is an uncertain venture, and drying out the vehicle as quickly as possible will increase the chances of being able to salvage it. However, according to an article in *Advance Auto Parts* (Jensen 2019), in the worst-case scenario, flood damage can be beyond the repair of even the most skilled mechanic. This is partially because modern vehicles have so many electronics (further discussed in the subsequent Electrical Components section) that are not designed to get wet. Jensen also echoed that the higher the level of the water, and especially if it is salt water, the harder it will be to repair the vehicle and the higher the likelihood of totaling. If a vehicle is repairable, it is likely that there could be hundreds of failure points over the next several years in delayed flood damage and that the car will likely never drive the same again.

An example of a fleet assessing vehicle damage after a flooding event is described in an article in *Government Fleet* (Force 2005). Dan Croft, Fleet Management Director for Collier County, Florida, indicates that after a hurricane has passed, a garage is set up for hood checks for all

operating vehicles. Four employees are used to check the tires, fluid levels, and lights. Vehicles that are used for extended period are given new oil and windshield wiper fluid.

## **Engine and Transmission**

### **Common Damage**

According to an article in *The News & Observer* (Stradling 2018), vehicle owners should not start the engine of a flooded vehicle until it has been fully examined to ensure there is no water in the engine. If water is in the engine or transmission, starting it can do serious damage.

According to an article in *It Still Runs* (Scott 2020), water in an engine can cause not only rust, but also damage to the cylinders if there is water in the engine when it is started. If the cylinders are full of water, the water will not be compressed like air is, and therefore everything connected to the cylinders will bend or break. This phenomenon is called “hydrolocking” and will ruin an engine instantly (Jensen 2019). In addition, water mixed with the transmission fluid or oil will reduce the lubricating qualities, resulting in damage.

Stradling states that even driving through 6 inches of water in a vehicle with limited clearance could allow water to get into the engine. If in doubt, an experienced mechanic should examine the engine (Stradling 2018).

### **Assessing and Repairing Damage**

According to State Farm (2020), the first way to check the engine for water is to check the oil dipstick. On the dipstick, look for water droplets, which likely indicate that there is water in the engine. If water is found, remove the water-damaged cylinders and check for corroded spots. Next, check the fuel tank and line, using a siphon pump to remove some of the fuel to see if water is present. If there is water in the fuel, empty the fuel tank completely.

Jerew (2020) states that the oil level should also be checked. If the oil level seems abnormally high, it is indicative that water likely got into the crankcase (because oil floats on water). The next step is to remove the spark plugs and turn the engine over by hand to get the water out of the cylinders, drain the oil, and replace the oil filter.

Regarding the transmission, Jensen states that it is typically more sensitive to water damage than an engine. To assess and repair it, first change the transmission fluid and filter and monitor it for unusual behavior. Jerew indicates that automatic transmission discs and bands can delaminate in water, and manual transmission synchronizers can be ruined with lack of lubrication. Also change the axle differential fluid either by removing the differential cover or drain bolt or using a fluid pump (Jerew 2020). Jensen (2019) also suggests checking the engine air filter and intake ducting.

Finally, State Farm (2020) suggests changing the oil and transmission fluid right away and doing it again after the car is in good condition and it has been driven for several hundred miles.

## ***Electrical Components***

### ***Common Damage***

According to Stradling (2018), vehicle owners want to know whether the air bags, electronics, and computers were exposed to water, as water exposure to those components will cause damage in the future. Newer vehicles have up to 60 different computer processors in them, and if you submerge a computer in water, it is likely that it will not work the same again. A flooded vehicle may run at first but will likely develop problems later, which can in turn cause vehicle functions to fail. Stradling also echoed earlier statements that the higher the water on the vehicle, the more electronics and parts of the vehicle will be affected.

According to Scott (2020), the electrical system in a vehicle is the part of the car that typically sustains the worst damage from flooding. Scott indicates that electrical damage can take months to appear and can be extremely expensive to repair. Because the electrical and computer system can be thought of as the brain of the car, damage affects a multitude of aspects including electric seat controls, windows, door locks, starter, headlights, anti-lock brakes, airbags, and horn, to name a few.

### ***Assessing and Repairing Damage***

There are a few ways to assess initial damage to the electrical systems in a vehicle, according to Jensen (2019). As previously stated, before turning on the engine to assess, make sure the engine is dried out and safe to start. Turn on the heat and smell for a burning smell that would suggest damaged wires. Also feel the wires under the dashboard and in the engine for brittleness. Listen to the sound system to see if it is not working or sounds bad, which could be signs of water damage (Jensen 2019). In addition, Unrau (2016) suggests checking the dashboard indicators by starting the car and checking for any warning lights or new indicators. In addition, check power windows and door locks. When checking power seat controls, check not only that they work but also that they move the seat in the right direction when the button is pressed.

## ***Interior Considerations***

### ***Assessing and Repairing Damage***

Unrau (2016) states that the interior of a vehicle that has been flooded can develop mold, mildew, and odors from saturated carpet and upholstery. To help prevent this from happening, remove excess water from the vehicle and remove and dry any loose objects. Also hang floor mats and other parts that can be removed to dry. Next, take out the console, seats, and carpets if there was standing water in the vehicle to prevent rust. Finally, wash the carpeting and mats and remove dirt and silt from the interior of the vehicle before replacing all interior items. Replace items with new parts as needed.

## ***Case Study: Virginia Beach Fire and Rescue***

David Wade from the Virginia Beach Fire and Rescue Department (VBFD) wrote a report in 2010 about VBFD's experience with flooding and the damage caused to their fire trucks (Wade 2010). This report is especially relevant because fire trucks are important first responders during natural disasters, and the lessons learned can be transferred to multiple fleets of heavy-duty diesel vehicles. This section provides a summary of their findings.

During several severe weather events around 2009, VBFD responded to calls for service, as it is the duty of the fire department to do so despite weather conditions. During these situations, drivers encountered flooded roadways, which in turn led to VBFD trucks being damaged, some extensively, from being operated on flooded roadways.

Following these events, the department evaluated the damage, cost of repairs, and need for driver education and outlined their findings in a report. They also conducted outreach to national, regional, and local department leaders requesting information on similar problems with flooding and possible solutions. Apparatus manufacturers and private industry were also contacted for information and recommendations. They concluded that flooding is not common, and that many organizations do not know how to address flooding events.

### ***Equipment Used and Damage Found***

VBFD uses several different manufacturers of diesel fire trucks in their fleet: Pierce (primary), American LaFrance, and Boardman. Damage from driving the equipment through flooded roadways was found to be extensive, including:

- Wheel hubs filled with water and had to be serviced, including replacing the seals.
- Brakes were affected by the rapid heating and cooling and had to be replaced before their normal service times.
- Air horns were damaged from water entering their inner working parts.
- Transmissions, rear-end differentials, and pump transfer cases had to be checked, drained, flushed, and refilled with the proper fluids.

While these issues were able to be fixed relatively easily, the following issues were much more serious and costly:

1. Water entered the air intake on the engine of one of the vehicles, and the engine stopped working immediately in the field.
2. Damage to hydraulic lines and the front bumper from driving over unseen objects underwater.
3. Damage to the electrical components. The location of the electrical box allowed it to be submerged in the floodwaters, which caused systems on the truck to stop working that could have ultimately threatened the safety of the first responders in the vehicle.

The air intake for the engine is below and behind the bumper, allowing water to enter the engine and cause major damage, voiding the manufacturer's warranty. VBFD was ultimately able to negotiate the continuance of the warranty but did have to agree to have the engine torn down at a higher cost to allow for water damage to be accurately assessed. It was found during this process that the apparatus systems did their job successfully and shut down the engine before serious damage occurred.

### ***Potential Vehicle Modifications To Avoid Damage***

Through VBFD's research, they came across San Antonio Texas' fire department, who encountered similar issues with water entering the air intake and damage to the electrical box on their Pierce Manufacturing fire trucks. San Antonio worked with Pierce to minimize the risk of these issues happening during future flooding events. They moved the air intake to the side of the truck over the passenger side front wheel and moved the electrical box into a compartment of

choice. These modifications can be done by the manufacturer or done aftermarket via a retrofit kit.

### **Driver Training**

VBFD found that lack of driver training and direction from the department on driving through floodwaters was a contributor to vehicle damage. Young drivers with no flood experience made poor decisions and drove the vehicle directly into the scene through floodwaters rather than walk in and check the situation first, leaving the truck on higher ground. Vehicle drivers were not aware of the repercussions of driving the vehicle through standing water. VBFD offers detailed insight into driver training needs and future improvements in their report.

### **Results**

VBFD found that the major causes of damage to the vehicles were water exposure and the design of the vehicle being conducive to water damage. The most impacted parts were the engine air intake and the electrical systems. They also found that vehicles suffered the costliest damage from striking objects hidden underwater, water entering the engine, and water entering the transmission pump, which pumps transmission fluid throughout the system.

VBFD planned work with the manufacturers to determine how to address the issues of air intake and electrical systems, with the hope of modifying the vehicles similarly to what San Antonio's fire department did. Ultimately, VBFD was able to work with Pierce to obtain vehicles with modified options for the air intake. Pierce also offers an option to relocate the electrical boxes to an area that is less prone to water damage, placing them 5 ft off the ground as opposed to the original position of 18 inches off the ground.

### **Preparing Fleets for Hurricanes and Flooding**

An article in *Fleet Management Weekly* (Kavanagh 2020) provides tips for fleet managers on preparing their fleet for a hurricane or flooding event. To prepare fleet garages and facilities, patch roofs, secure windows, and check for loose items that may blow away. Also check security lighting and that the emergency backup generator is operational. In addition, confirm that communications equipment is in working order and take precautions to protect any vital paper records. For drivers, Kavanagh suggests checking with managers or dispatchers before driving, as well as strategizing routes prior to departing. If drivers hit heavy rain or flooding, exit the road and stay in the vehicle, but do not drive into flooded areas. Finally, avoid electrical equipment that may be submerged in water.

The Federal Transit Administration report *Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation* (Hodges 2011) discusses steps that transit agencies should take prior to flooding events. First, when building major transportation facilities, take caution to not build them in flood zones. In addition, before and during a flooding event, clear debris from drainage systems to prevent flooding. Other actions include implementing green infrastructure stormwater management like stormwater ponds, rain gardens, pervious pavement, and native vegetation buffers to prevent localized flooding and reduce runoff.

An article in *Truckinginfo* (Roberts 2019) suggests making sure drivers are prepared for flooding events by ensuring they have emergency items in their vehicles. This includes bottled water,

nonperishable foods, flashlights, and rain gear. In addition, knowing the path and timeline of the storm and preparing for areas that might be hardest hit is crucial for planning.

Force's (2005) article includes additional thoughts from fleets in Florida. In the article, Dan Croft indicates that prior to a storm, routine vehicle services are put on hold to give priority to repairs and maintenance that may be needed before the storm hits. This includes equipping all emergency vehicles with extra tires, wheels, and 5-gallon cans of tire sealant. Croft also indicates that vehicles that will not be used for post-storm services are pooled together and used for evacuations.

### **Emergency Operating Plans**

NAFA Fleet Management Association's article (Glasheen 2020) discusses preparing fleets for natural disasters. The primary piece of advice is creating a disaster or emergency operations plan to remain operational during a storm and training staff and practicing dry runs to ensure seamless execution. When creating a plan, fleet managers should consider a variety of topics, such as how to operate if employees cannot get to work, determining critical employees and their roles, how to protect vehicles and how to handle the repairs or replacements of damaged vehicles, backup operations location if a facility is damaged, and a communication plan in the event of loss of cell coverage. Finally, capture lessons learned during an emergency event and update the plan accordingly. The Federal Transit Administration report echoes the need for an emergency operating plan or standard operating procedure for extreme weather events considering their increasing frequency.

*Fleet Clean USA's* article "Preparing Your Fleet for Disasters" (Sharone 2018) adds to these recommendations and suggests including a plan for having a power supply should the power go out in an emergency operating plan. It also recommends ensuring extra parts are on hand that may be needed for emergency repairs to vehicles or facilities. Also include emergency routes in case of road closures and evacuation procedures.

Selective Insurance's "Flood Vehicle Management Guidelines" (Selective Insurance 2014) suggests designating an emergency operating plan coordinator, along with a backup, prior to any emergency event. The plan included parameters around when to enact and the order of operations for each step in the plan. Selective echoes the need to identify roles and responsibilities for employees, including who will enact certain aspects of the plan, such as securing facilities and clearing debris, and readying backup communications should the power or cell towers go out. Finally, they recommend developing a plan for alternative vehicle storage locations, which is discussed in more detail in the Vehicle Planning and Repositioning section.

### **Emergency Fuel Plans**

A good emergency operating plan should also include a plan for emergency fuel. Kavanagh (2020) suggests investing in an emergency fuel plan, which functions similar to an insurance plan; paying a monthly fee and signing a contract that ensures access to a set amount of fuel that will be delivered to fleet vehicles even if the normal fuel distribution network is out of commission. He especially recommends this for first responders and other critical fleets like fire fighters and utility companies, as an emergency fuel plan guarantees the fleet can continue to operate during a storm.



Roberts (2019) suggests filling a fleet's tanks ahead of a storm, as fuel can be difficult and expensive to come by in the aftermath. This is another way to ensure fleet vehicles can operate during or after a storm. Glasheen (2020) recommends filling up not only fleet vehicles prior to a storm, but also employees' personal vehicles to ensure they are able to report to work. In addition, ensure the emergency fuel plan includes access to the variety of fuels the fleet uses, as well as generators to prevent power outages for any on-site fueling equipment and fleet facilities. This is also reiterated by Force (2005), who interviewed Doug Brock, Orange County's fleet manager. Brock states that the success of his fleet operations directly correlates to good fuel management, including access to fuel and generator availability. He also states that he plans to buy a new refueling system with more redundancy built in for emergency situations.

The city of Ocala was awarded a grant from the Federal Emergency Management Agency to offset the cost of installing natural gas generators. These natural gas generators will be used to supply the power necessary to charge five electric refuse trucks and the lift site, in addition to lighting the building and powering the city's on-site diesel fueling station.

### **Vehicle Planning and Repositioning**

Another key aspect of preparing a fleet for a storm is planning for how to move vehicles and assets out of harm's way. The Federal Transit Administration states that a standard operating procedure should be planned and implemented to move vehicles and other portable assets out of harm's way to an alternative location or two when flooding is predicted. Determine where assets can be moved prior to the storm and work out an agreement with that facility, if needed. Also ensure that the responsibility for moving vehicles is clear (Hodges 2011).

Selective Insurance also recommends this practice. They suggest identifying alternative storage locations and entering into a contractual agreement to ensure the location will be available when needed. It is suggested for larger fleets that two or more locations are identified, and that drivers who will be responsible for moving the vehicles are aware of their roles. If the fleet is large, consider arranging a contract with a transport service company to move the vehicles (Selective Insurance 2014).

Roberts (2019) suggests parking trailers as closely together as possible when parking truck trailers in an alternate location, with empty trailers tightly placed between the loaded trailers to decrease the chance of being blown away by high winds.

Several examples of fleets moving their vehicles out of harm's way are included in Force's article (Force 2005). Fleet manager Jon Crull states that in the city of Daytona Beach, Florida, vehicles were parked in a stadium about 7 miles inland. Although the area sustained considerable damage, the fleet remained intact. Croft indicated that any vehicles not being used during the storm for evacuations or other purposes are repositioned away from trees and low-lying areas at risk for flooding. Finally, in a phone interview conducted by NREL with the city of Tampa fleet department in June 2020, the department indicated that one of their primary emergency protocols is to move vehicles to higher ground prior to a storm. They have several parking structures in the city, and vehicles are placed at the highest point of the structure.



## Driver Training

As discussed in the Emergency Operating Plans section, drivers in a fleet need to be trained on all aspects of the plan and be clear on what they are responsible for prior to an emergency. In Force's article (Force 2005), Croft echoes the need for driver training, as several police cars lost engines during a flooding event due to city employee errors and lack of judgement in high waters. The importance of driver training is also discussed in the VBFD case study.

For example, the Federal Transit Administration's *Gulf Coast Climate Change Adaptation Pilot Study* (Texas A&M Transportation Institute 2013) describes how the Hillsborough Area Regional Transit (HART) in Tampa has trained their drivers to respond to street flooding encountered en route. When drivers encounter street flooding, they radio into dispatch with the location and description of the flooding, and a HART supervisor is then sent out to examine. A reroute is made accordingly. All drivers are instructed to decrease speed by at least 5 miles per hour during rainfall.

## Other Considerations

One other aspect for fleet operators to consider when preparing for a hurricane and flooding is investing in a GPS, as described in an article in *Rastrac* (Dziuk 2020). GPS tracking can help prepare fleets for an upcoming storm and keep vehicles and drivers safe by tracking the locations of vehicles and their drivers. For example, GPS tracking can assist in locating migrated vehicles after a storm and increases odds of recovering assets. Some GPS tracking devices also provide drivers with panic buttons and emergency alerts. Kavanagh (2020) also suggests the use of a GPS tracking solution to help optimize routing and avoid chokepoints in bad weather.

## Preferred Vehicles for Driving Through Floodwaters

Although no literature was found on preferred vehicles for driving through floodwaters (e.g., vehicles that can typically make it through floodwaters with minimal damage), some information can be gleaned from the phone interview with the Tampa fleet department and the VBFD case study.

Tampa indicates that they do have vehicles in their fleet that were added specifically for their ability to drive through floodwaters of up to 4 feet. Specifically, the HUMVs in their fleet can sustain up to 30 inches of water. However, the best vehicle in the fleet for floods are dump trucks and sewage trucks, as the engines vent on top of the transmission and can sustain up to 4 ft of water. In addition, VBFD indicates that they modified their fire trucks so that instead of being capable of sustaining 18 inches of water, they can now sustain up to 5 feet.

Therefore, it can be concluded that the higher the vehicle, and specifically the higher the engine is off the ground, the better it will fare in floodwaters. However, this is an area with a clear gap in literature that would benefit from additional insights from the fleet managers interviewed as part of this effort.

## Conclusion

This literature review consulted a total of 21 resources, including reports, articles, websites, and notes from one phone interview. Most of the available resources were online articles or websites, as few reports were found on vehicle resilience in hurricanes and floods.

A sufficient amount of information was found regarding common vehicle damage, as well as how to assess and repair it, if possible. All the information identified, except for some information on EVs, was for conventionally fueled vehicles. Therefore, there is a gap in knowledge for how AFVs fare in hurricanes, standing water, and floods.

In addition, the majority of the information available was specific to passenger or light-duty vehicles, with the exception of the VBFD report and the Tampa fleet interview. That said, there is a gap in knowledge around how medium- and heavy-duty vehicles, especially those part of critical fleets such as police, emergency, and utility vehicles, may sustain flooding.

Some information was available on potential vehicle modifications to help prevent floodwater damage, particularly for the VBFD fire trucks. In addition, it can be inferred from the literature that the higher the important vehicle components are off of the ground (e.g., engine air intake and electrical components), the best chance a vehicle has at making it through floodwaters with minimal damage. Another important factor is the placement of the critical vehicle components. As previously stated, there is a knowledge gap here that would benefit from discussions with fleets.

Finally, information on preparing fleets for hurricanes and floods, including emergency operating plans, was readily available. In-depth information was found on best practices and considerations for fleets that may experience extreme weather events.